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Adapting V-ISA Technology: Driver Behaviour along Interchange Ramp and Merging/Diverging Terminals

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Abstract

An original in-vehicle Intelligent Speed Adaptation System for Visibility (V-ISA) was designed to promote compliance with real-time speed management. The functionality of V-ISA is based on the prevailing sight conditions along the road, and operates in two variants: (i) providing visual information, and (ii) vehicle speed intervention. A road scenario with the driver performing merging and diverging manoeuvres in a motorway section was designed. A within-subject experiment involved 32 participants and a vehicle equipped with the two variants and the system off (baseline condition) under two traffic flow conditions. V-ISA had a significant positive effect on the drivers' longitudinal performance along ramps. This change in behaviour along ramps had no effect on merging and diverging manoeuvres. V-ISA had a positive impact on driver speed behaviour in such complex road environment and assisted drivers to modulate the operating speed towards the safe dynamic limits.

Keywords: Intelligent Speed Adaptation; Driver Behaviour; Driving Simulation; Road Safety; Sight Distance; Merging; Diverging.

1. Introduction

The driver's choice of speed has been found one of the essential factors in road safety. There is a growing body of literature that recognises the influence of human factors like age, gender, driving style or experience on speeds (Karthaus *et al.*, 2020; Shinar *et al.*, 2001). Moreover, perception related to road environment such as road geometry, roadside furniture, visibility and traffic flow conditions also impacts on speed (Elliott *et al.*, 2003; Jamson *et al.*, 2012; Assum *et al.*, 1999). The speed choice is the result of driver

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adaptation to the perceived level of risk (Wilde, 1998). It is possible for drivers to misjudge or intentionally exceed the speed limit, which exposes them to a higher risk of crash (Bassani *et al*., 2019).

Conventional speed control measures such as horizontal marking, vertical signs, rumble strips, speed bumps or speed detection cameras have shown partial or complete effectiveness in a limited area of control (Li *et al.*, 2020). These safety measures become responsible for the migration effect as drivers attempt to compensate for speed reduction with higher operating speed after passing control sections/areas (Smiley & Rudin-Brown, 2020). In contrast, in-vehicle Intelligent Speed Adaptation systems (ISA) improves the driver's speed choice with continuous driver assistance (Young *et al*., 2010). The functionality of current ISA systems is solely based on road sign recognition and/or navigation system (GPS) cooperating with speed databases (Fleyeh and Davami, 2011; Karthikeyan and Tamileniyan, 2010). However, the effectiveness of the current ISA systems might be influenced due to the absence of speed limit signs or unreliable databases (Young *et al*., 2010). Moreover, permanent, or temporary changes in the roadside conditions may also alter the safe speed thresholds, particularly on road curves where the sight distance is limited (Bassani *et al*., 2019; Lioi *et al*., 2022).

Hazoor *et al*., (2021), designed an innovative ISA system, called V-ISA (Intelligent Speed Adaptation for Visibility) to assist drivers in the adoption of the most appropriate speed consistent with prevailing sight conditions. The system defines the speed limits by estimating in real-time the distance from the driver's point of view to the farthest visible point, i.e., the so-called available sight distance (ASD), and by comparing *ASD* with stopping distance (*SD*) required by the vehicle in case of emergency braking (Figure 1). To ensure safe driving operations, the algorithm and functionality of the V-ISA system are designed in accordance with the current road geometric design standards (MIT, 2001; AASHTO, 2018).

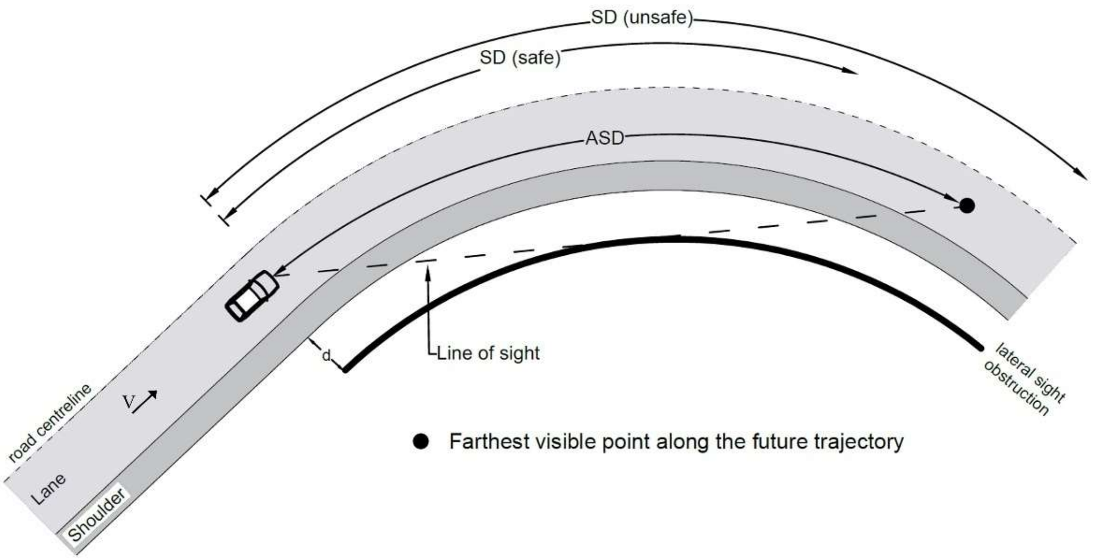

Figure 1: Example of available sight distance (ASD) from driver point of view and comparison with safe and unsafe stopping distance (SD). Note: d = lateral distance between road edge and lateral sight obstruction; V = traffic flow direction.

In our previous study, the V-ISA system was validated for *ASD* estimation with the help of onboard virtual sensors and a robust feedback algorithm (Hazoor *et al*., 2021). Further, the feedback modalities (i.e., Human-Machine Interaction, HMI) implemented for the V-ISA and its effectiveness on drivers' speed choices to mitigate the risk associated with speeding were assessed (Hazoor *et al*., 2022). Finding from studies indicates that V-ISA supports drivers to adopt a behaviour that is more consistent with the real conditions while manoeuvrings road curves, consequently creating safer driving conditions (Hazoor *et al*., 2022). However, the impact of V-ISA on driving performance was assessed under certain limitations, such as simple road scenarios having homogeneous road section and under free-flow traffic conditions (no interaction with traffic). As of yet, there is still uncertainty about the use of V-ISA in vehicles under complex road configurations where drivers have to deal with significant changes in speed and trajectory, and how it will affect driver behaviour and performance.

In this study, we investigated the effect of two V-ISA variants (information and intervening) on driving speed along interchange ramps and how the presence of V-ISA variants might affect merging and diverging manoeuvres along acceleration and deceleration lanes/terminals. Further, driver behaviour and attitude towards speeding were investigated under two different traffic flows conditions, and the possible link between driver behaviour and use of the V-ISA variants is here discussed.

2. Method

2.1 V-ISA operations

The implementation of the innovative V-ISA technology was achieved with the co-simulation between SCANeRStudio™ driving simulated environment and MATLAB Simulink. The data collected using the on-board virtual sensors were treated and analysed in the Simulink model to estimate the *ASD* as per prevailing road sight condition from the driver point of view. Additionally, real-time ego vehicle, traffic (other vehicles) and road configuration data were used in the Simulink model to define the operating conditions in accordance with the V-ISA variants (Hazoor *et al*., 2021; Hazoor *et al*., 2022). Two variants of the V-ISA were modelled in the current study:

(1) **V-ISA information,** assist the drivers throughout the drive with a virtual LED (light emitting diode) bar at bottom of the display (represents front windscreen of the vehicle). The LED bar was provided with three colours: green, when a driver operates in the safe condition (i.e., $ASD > SD$); yellow, to inform that he/she approaches to unsafe condition (pre-alert); and the red bar that communicate the driver the unsafe condition (i.e., $ASD < SD$) as illustrated in Figure 2.

(2) **V-ISA intervening,** limit the vehicle speed by acting on the throttle and/or brake commands when the driver approaches the unsafe condition ($ASD < SD$). Similarly, if the driver enters the unsafe condition with a speed higher than the limit, the system smoothly decreases the speed to the prevailing limit. To inform the driver about the intervening operation, the colour of the LED bar changes from green to blue like in Figure 3 (Hazoor *et al*., 2022).

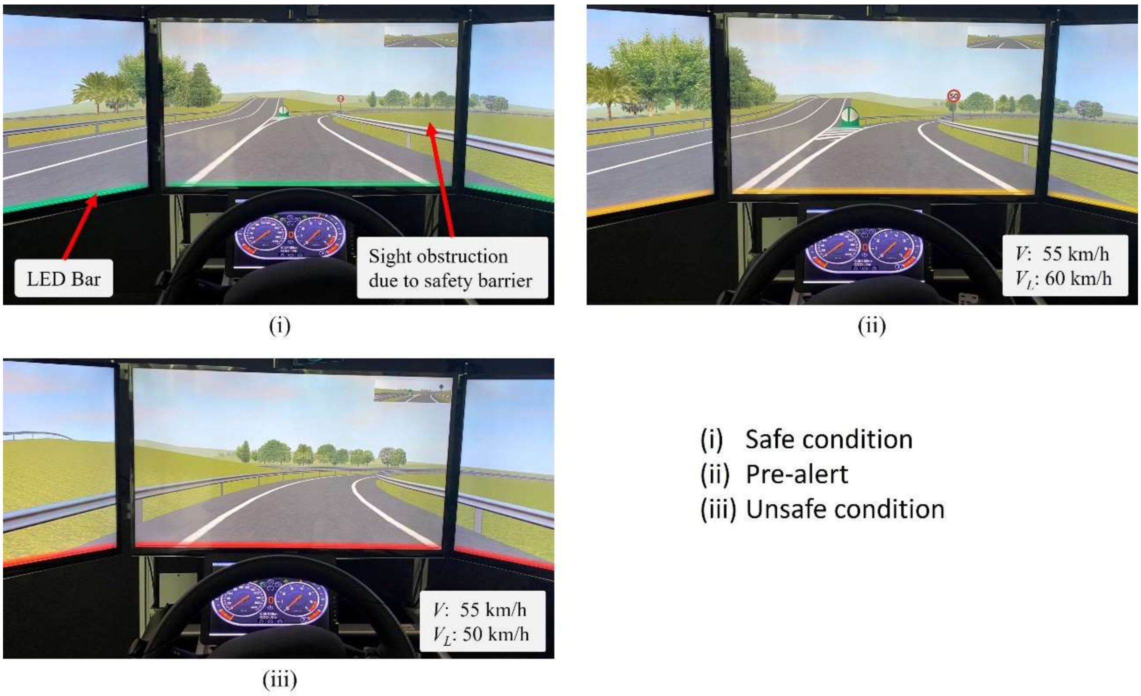

Figure 2: A) Example of the V-ISA information LED bar on the screen display in the driving simulator (Note: V = current speed and V_L = limit speed).

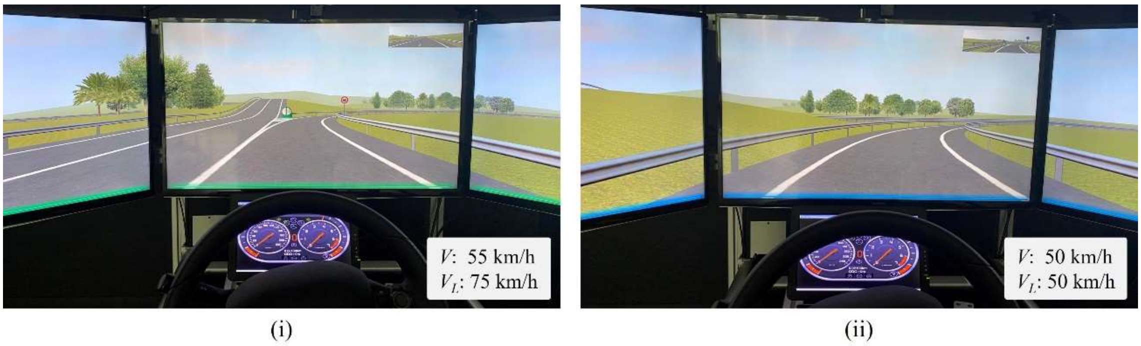

Figure 3: Example of the V-ISA intervening LED bar in (i) safe condition and (ii) intervening operation. (Note: V = current speed and V_L = limit speed).

2.2 Road Scenario and Equipment

For this study, the road environment was design in such a way that participants were compelled to transit along interchanges, performing merging and diverging manoeuvres along a motorway section through curved interchange ramps as shown in Figure 4. Both the continue and the reverse design for ramps was adopted. With respect to linear terminals, such designs create important sight limitation that can compromise the performance. A 9 km long, road alignment was composed of two motorway segments and two two-lane highway segments, and participants were asked to drive along all the segments to complete one experimental drive. The road elements were design as per Italian geometric design standards for highways and streets (MIT, 2001; MIT, 2006). The motorway cross-section offered two lanes per direction, having lane width of 3.75 m and a right shoulder width of 3.00 m (for more details, please see Portera and Bassani, 2021). Safety barriers were placed along both edges of the road section throughout the alignment (i.e., interchange ramps, motorway, and two-lane highway) which provides the specific *ASD* values while negotiating curves (Lioi *et al*., 2022). A traffic flow of passenger cars (pc) was generated along the motorway sections with volumes (V) of 1000 pc/h (low flow condition) and 4000 pc/h (high flow condition). In case of two-lane highway 500 pc/h and 1800 pc/h were adopted for low and high traffic flow conditions respectively. The study was performed in conformity with the Code of Ethics of the World Medical Association (Declaration of Helsinki) (World Medical Association, 2018).

The equipment used for the experiments consists of a fixed-base driving simulator (AV Simulation, France) at the Road Safety and Driving Simulation Laboratory of Politecnico di Torino, Italy. The simulator was previously validated for driver speed decisions, lateral manoeuvres, and operations (Catani, 2019; Bassani *et al*., 2018; Catani and Bassani, 2019; Karimi *et al*., 2020). Moreover, the V-ISA model (algorithm) had previously been validated for *ASD* and *SD* estimation with variants feedback modalities (Hazoor *et al*., 2021; Hazoor *et al*., 2022).

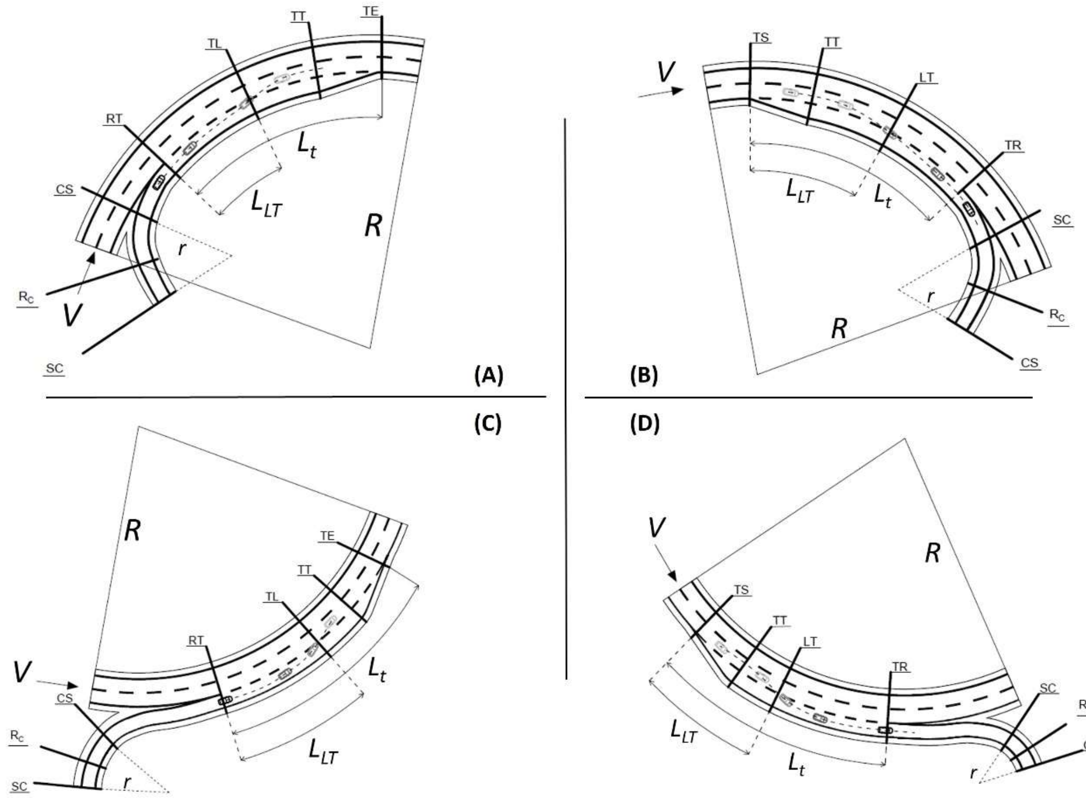

Figure 4: Data collection points according to ramp – terminal connections design (CS – RT): (A) merging with continuous connection, (B) diverging with continuous connection, (C) merging with reverse connection, (D) diverging with reverse connection. (Note: SC = Spiral to Curve; R_c = ramp centre point; CS = Curve to Spiral; RT = ramp to terminal; TL = terminal to lane; TT = terminal to taper; TE = terminal end; L_t = length of terminal (360 m and 200 m for acceleration and deceleration lane respectively); L_{LT} = merging/diverging distance; V = traffic flow).

2.3 Participants and Experimental Design

In present study, thirty-two licensed drivers (18 males and 14 females) took part in the experiments on a volunteer basis. The participant's ages ranged from 20 to 58 years, (mean age = 38.1 years) as listed in Table 1. An effort was made to ensure that the group of participants reflect the characteristics of Italian driving population (MIT, 2016).

The experiment followed a within-subject (repeated measure) design with three levels, including two V-ISA variants (information and intervening) and a baseline condition (system off), two level of traffic flow conditions (low and high traffic flow), and two level of gender (male and female). The dependent variables were average speed (s), lateral position(l_p) and standard deviation of lateral position (SDLP) while performing merging/diverging manoeuvres along the motorway section and in the ramp. Moreover, merging/diverging distance in the entry and exit lane were also considered in the analysis.

Table 1: Participants demographic characteristics (Note: Min = minimum; Max = maximum; SD = standard deviation.

Gender	*Age [years]*			*Driving Experience [Years]*	*Annual mileage [km]*	*No. of accidents involved in [-]*
	Min	Mean	Max	Mean (SD)	Mean (SD)	Mean (SD)
Males	20	38.4	58	19.11 (11.39)	10674 (6450)	0.88(1.37)
Females	24	37.4	57	19.14 (11.13)	9764 (6555)	0.71 (0.88)

2.4 Protocol/Procedure

As per the repeated measure design, each participant (test driver) drove in six scenarios with the combination of three V-ISA levels (information, intervening and baseline condition) and two levels of traffic flow condition (high and low). The experiments were conducted in two sessions on different days to avoid any sickness related effects on drivers (Philip *et al*., 2003). In each session, participants drove on three pre-selected scenarios and the order of the scenarios was randomly chosen. During each scenario, only one V-ISA was presented with the respective traffic flow condition (high or low).

At the start of experimental session, participants were invited to fill-out the pre-drive questionnaire to ascertain that they were in good health and not taking any medication that could influence their driving behaviour. Before experimental drive, the functionality of V-ISA variant and the description of pre-selected scenario were described to participants. Further on, participants were also invited to drive on a trial track for 5 min to familiarize themselves at the driving simulator.

2.5 Observed variables and Statistical Analysis

The following parameters at specific locations/points along the road alignment were recorded to evaluate the influence of V-ISA variants on the driver behaviour and performance (Figure 4):

- speed (S_{RC}) at the middle point (R_c section) of the ramp (i.e., along the circular arc);
- standard deviation of lateral position (SDLP) along the ramp arc (from SC to CS termini);

- speed (S_{TL}) at T_L (terminal to lane) for merging manoeuvres in the motorway;
- speed (S_{LT}) at L_T (lane to terminal) for diverging manoeuvres from the motorway;
- merging and diverging distance (L_{LT} & L_{TL}), point where vehicle centre of gravity (CoG) shifts from terminal to motorway lane (TL) or vice versa (LT), respectively.

A series of repeated measures analysis of variance (RM-ANOVA) were modelled to estimate the contributions of the experimental factors on driver longitudinal and transversal behaviour. We calibrated separate RM-ANOVA for each dependent variable considering the data collection points. As per the within-subject design, data were analysed by comparing each driver to him/herself across the levels of experimental factors. Hence, the variance between drivers remains as part of the error term. We used Bonferroni correction for multiple comparison with significance level set at $p < .05$. In the case sphericity assumptions violations, Greenhouse-Geisser corrections were adopted. In terms of data collection points/locations, they were comparable to those in (Portera and Bassani, 2021; Portera and Bassani, 2020; Calvi *et al.*, 2012).

3. Results and Discussions

3.1 Ramps

When considering the speed along the ramps for both entering (on-ramp) and exiting (off-ramp) the motorway section, we found a significant effect of V-ISA variants [$F(2,62) = 13.48$; $F(2,62) = 17.54$; all p-values < .001]. Furthermore, post-hoc analysis revealed that the use of V-ISA (information and intervening) significantly reduces the speed when compared with the baseline condition (all Bonferroni corrected p-values < .001). The post-hoc comparison between V-ISA variants (information and intervening) did not reveal any significant difference with the lowest average speed in the case of V-ISA intervening as illustrated in Figure 5. Connection type design (continuous and reverse) also have a significant effect on the drivers' choice of speed along the ramp arc [$F(1,31) = 22.0$; p value < .001]. However, this effect was not observed when drivers were exiting the motorway section (Figure 5B). Traffic flow conditions have no significant impact on speed, and these results should have been expected since drivers had no interaction with the traffic on the ramps. All two-way, first order interactions (i.e., V-ISA variants × Connection type; V-ISA variants × Traffic flow condition; Connection type × Traffic flow condition) and three-way interactions (i.e., V-ISA variants × Connection type × Traffic flow condition) did not reveal any significant differences.

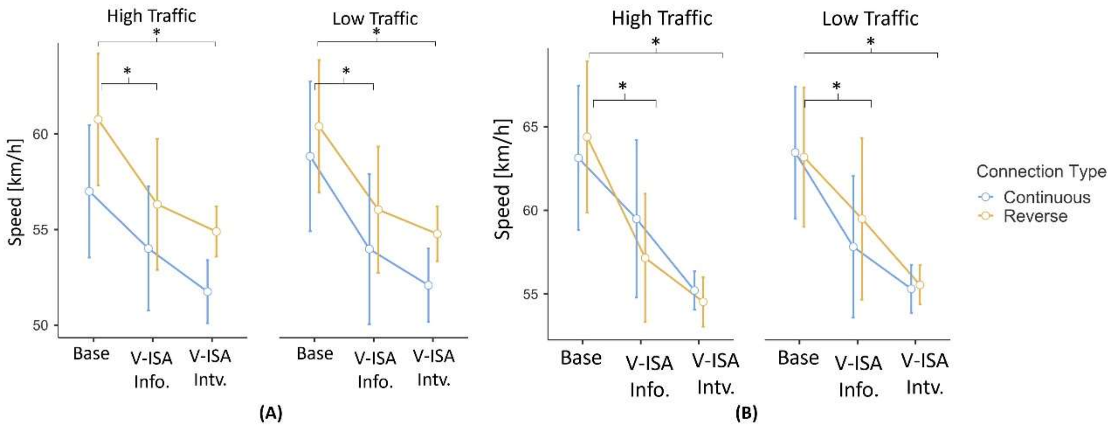

Figure 5: Effect of V-ISA variants, connection type, and traffic flow condition on the speed along (A) entry ramps (B) exiting ramps. Note: "*" symbol represents the significant differences $p < .001$); Info = Information; and Intv. = Intervening.

In line with our previous study (Hazoor *et al.*, 2022), along the road sections where sight distance was limited (i.e., curves, ramps), V-ISA variants were in operation and assist drivers to maintain a speed that was consistent with the safe visibility conditions. The reduction in the mean speed along the ramps was a direct influence of the V-ISA variants (Figure *5*). The effectiveness of the V-ISA variants remains the same irrespective of the interchange geometry (continuous and reverse design), having a higher mean speed value in the case of baseline condition (system off) and the intervening variant was successful to maintain the operating speed distribution under the threshold speed limit in accordance with the available sight distance. RM-ANOVA revealed that V-ISA variants have no significant effect on the standard deviation of lateral position (SDLP) values compared to the baseline condition (system off), which indicates that the lateral control of the vehicle was not affected by activation of the V-ISA variant. Significant difference in SDLP values were observed only for connection type (i.e., Continuous × Reverse) with higher values for reverse design when exiting from the motorway section [$F(1,31) = 30.85$; p-value $< .001$]. A possible explanation for this might be that when the driver entered the motorway section, he/she did not interact with the connection, while he/she already interacted when exited from the motorway section.

3.2 Acceleration and Deceleration Terminals

The results of RM-ANOVA revealed that the driver's choice of speed to enter the motorway section (i.e., from terminal to lane, S_{TL}) was not affected by the presence of V-ISA variants [$F(2,62) = 1.593$; *p*-value = .211]. It was also found that connection type remain insignificant in terms of merging speed (S_{TL}) [$F(1,31) = 2.747$; p value = .108]. The estimated marginal means for speed at the terminal to lane point (S_{TL}) are presented in Figure 6A. However, a significant difference was observed for the merging distance (L_{TL}) for the connection type [$F(1,31) = 20.88$; p value = .001]. Drivers adopted lower distances in the case of reverse connection type to perform merging manoeuvre, and results remain consistent without any significant influence of V-ISA variants [$F(2,62) = 2.94$; p value = .06] as shown in Figure 6B. Moreover, the merging speed was not significantly influenced by traffic flow (high or low level) [$F(1,31) = 0.113$; p-value = .739].

The effect of road geometry (ramp – terminal connection type) on the speed and merging distances are coherent with those obtained by (Portera and Bassani, 2020), who suggest that the effect of connection type remains substantial at the beginning of the terminal (point RT in Figure 4) and lessens with the terminal length. All two-way, first order interactions (i.e., V-ISA variants × Connection type; V-ISA variants × Traffic flow condition; Connection type × Traffic flow condition) and three-way interactions (i.e., V-ISA variants × Connection type × Traffic flow condition) did not exhibit any significant differences.

When considering the diverging manoeuvre to exit the motorway section (i.e., from lane to terminal, LT), traffic flow conditions affected the drivers' speed choice [$F(1,31) = 5.636$; p-value = .024]. In the case of low traffic flow, the driver operated at a higher average speed (S_{LT}) at diverging point (lane to terminal) as shown in Figure 7A. These results reflect those of (Calvi *et al.*, 2012) who also found that while approaching an exit drivers' behaviour are highly influenced by the traffic flow. The connection type (continuous/reverse) had no effect on the speed (S_{LT}), but it significantly influenced the diverging distance (L_{LT}) with lower values for the reverse design [$F(1,31) = 66.56$; p-value < .001] as presented in Figure 7B. Moreover, the V-ISA variants had no significant effect on the speed (S_{LT}) and diverging distance (L_{TL}) compared to the baseline condition. First order, two way interaction between traffic flow condition and connection type was also significant [$F(1,31) = 5.23$; p value = .029]. Other two-way and three-way interactions were not statistically significant.

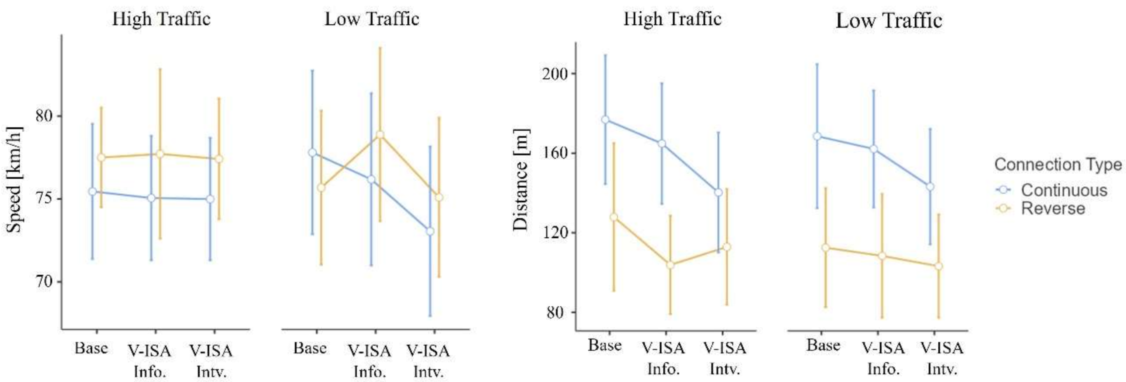

Figure 6: Effect of V-ISA variants, connection type, and traffic flow condition on the (A) merging speed, and (B) merging abscissa. Note: Info. = Information; Intv. = Intervening.

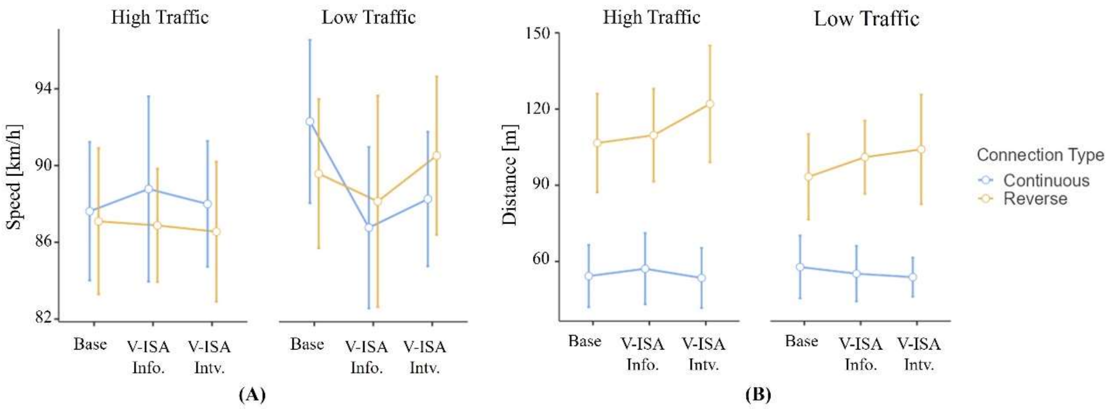

Figure 7: Effect of V-ISA variants, connection type, and traffic flow condition on the (A) diverging speed, and (B) diverging abscissa. Note: Info. = Information; Intv. = Intervening.

4. Conclusions

The study set out to examine the driver performance in the complex road and traffic environments with in-vehicle V-ISA technology. We studied the influence of the V-ISA variants (information and intervening) on the speed choice along the ramps and how the presence of V-ISA variants affects the merging and diverging manoeuvres.

We observed that along the ramps with limited sight distance, the V-ISA variants effectively assist the driver to modulate the operating speed as per prevailing sight conditions. In particular, we found that the average speed in the ramps was significantly reduced when using the V-ISA information variant in comparison to the baseline condition (system off). We believe that the continuous in-vehicle feedback or information encouraged drivers to operate prudently. In contrast, the V-ISA intervening variant enforced drivers to operate always under the safe speed limit, which results in a significant reduction in the speed along those road sections with limited sight distance available. Further on, the study has also shown that the change in the longitudinal behaviour when using the V-ISA variants along ramps has no severe influence on the merging and diverging manoeuvres where drivers had sufficient front sight distance. However, it cannot be neglected that other factors including road geometry and traffic flow influences the driver's decisions for merging/diverging in terms of speed and distance.

The current study is the first attempt to test the functionality of the V-ISA algorithm in complex road geometry and interaction with traffic. Overall, the study strengthens the idea that the V-ISA is fully capable to function in complex environments. The present study lays the groundwork for future research to further assess the functionality of the V-ISA technology and its influence on driver behaviour and performance. However, the effects of geometrical factors including the type of interchange, the radius of the ramp, and the length of the acceleration/deceleration ramp terminal would be a fruitful area for future investigations.

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