Available online at www.sciencedirect.com

ScienceDirect

Transportation Research Procedia 69 (2023) 53–60

Transportation Research Procedia

www.elsevier.com/locate/procedia

AIIT 3rd International Conference on Transport Infrastructure and Systems (TIS ROMA 2022), 15th-16th September 2022, Rome, Italy

Evaluating the Effectiveness of Countermeasures in Improving the Safety of Highway Merging Zones

A. Calvi*, F. D'Amico, C. Ferrante

Department of Engineering, Roma Tre University, Via Vito Volterra 62, 00146, Rome, Italy

Abstract

The merging process from an acceleration lane to the through lane of a motorway is an important aspect at interchanges, both in terms of safety and operating conditions. Several studies have demonstrated that the merging zones of interchanges are the main sources of interference between through and entering vehicles. In this context, incorrectly assessed gaps and headways can lead to severe crashes and traffic delays at interchanges. This study investigates the effectiveness of different countermeasures to improve the safety of merging zones and the ability of through drivers to adopt safe headways to vehicles entering from the motorway on-ramp. Four different countermeasures were tested in a driving simulator study: i) a gap metering signalization, consisting of a Variable Message Sign (VMS) and new pavement markings; ii) a static symbol projected on the vehicle's windshield by means of a Head-Up Display (HUD) that informed the driver to maintain safe headways to the entering vehicle; iii) a dynamic symbol based on Augmented Reality (AR) technology, built into connected vehicle technology, that provided additional visual information to the driver about his current headway to the entering vehicle; iv) the AR system was also tested with an additional audio warning. The driving behavior of forty-four drivers under the four different configurations based on the tested countermeasures was then compared to the driving behavior recorded under a configuration without any countermeasures (baseline condition). The results revealed significant positive effects of all the countermeasures, especially of the AR systems that helped through drivers to adjust their headway to the entering vehicle and thus the most effective solution for improving the safety of the merging zone. This study confirmed the great potential of AR and connected vehicle technologies to improve general safety conditions on the road network, especially in risky situations and difficult maneuvers.

Keywords: Driving simulator; Time Headway; Road safety; Merging zone; Safety countermeasures; Augmented Reality; Connected Vehicles

* Corresponding author. Tel.: +39 0657333451.
E-mail address: alessandro.calvi@uniroma3.it

2352-1465
10.1016/j.trpro.2023.02.144

1. Introduction

The merging process from an acceleration lane to the through lane of a motorway is an important aspect of safety and operating conditions at interchanges. Several studies have demonstrated that motorway interchanges, and specifically entrance ramps, are one of the most critical conditions for the highway network in terms of vehicular interferences and conflicts. Moreover, interchanges have been identified as the most likely areas for motorway collisions to occur (e.g., Calvi and De Blasiis, 2011; Yang and Ozbay, 2011; Kononov et al., 2012), as they are in the merging zones where drivers travel at different speeds with consequent potential interferences. In this regard, a French study found speed differences of up to 30 km/h between vehicles in transit and those entering the right lane of the motorway (Louah et al., 2011). A driving simulator study by Calvi and De Blasiis (2011) found that drivers on the right lane of the motorway are often not ready to respond in time to merging vehicles. This can lead to sudden decelerations and lane changes, which can cause congestion and conflicts.

Despite significant advancements in automotive technology and vehicle design, such safety issues on interchanges in general, and specifically on acceleration lanes and merging zones, have not been resolved, as evidenced by more recent crash analyses developed on such areas (e.g., McCartt et al., 2004). Scientific literature proposes several studies and analyses that relate crash frequencies at interchanges to different explanatory variables such as traffic volumes and geometric design standards. However, there are no guidelines and few research outcomes to provide designers with clear and updated criteria for improving the safety of the acceleration lanes and, more specifically, of the merging maneuvers of entering vehicles based on actual driver behavior. In fact, entering vehicles from motorway on-ramps could represent a significant risk for drivers travelling in the right lane of a motorway, as they have to manage speed and headway adjustments to restore a safe headway to the entering vehicle (Garber and Hoel, 2009). Moreover, short headways leave drivers with little time and space to take evasive actions if an on-ramp vehicle forces a merge maneuver into the outer motorway lane, creating a competition with the through drivers for the same space on the motorway (e.g., Kondyli and Elefteriadou, 2012; Riener et al., 2013). To reduce conflicts with merging vehicles from on-ramps into the right lane of a motorway, drivers in the right lane of the motorway must maintain a safe headway to the merging vehicle. However, several studies have highlighted that drivers have difficulties estimating their headway while driving (e.g., Taieb-Maimon and Shinar, 2001; Taieb-Maimon, 2007), and a lot of different results have been obtained when drivers had to figure out a specific time headway (Michael et al., 2000; Risto and Martens, 2013).

This is why many researchers around the world have proposed and tested various merge control approaches over the years. A traditional merge control strategy is ramp flow control (also known as ramp metering) that uses specialized traffic signals to release vehicles onto a motorway to minimize the interference between the entering vehicles and the through vehicles on the motorway (Jin et al., 2017). However, prevailing gap metering systems fail to indicate the minimum required gap and leave it to the drivers' judgment to adjust their headway (Kondyli, 2009; Kondyli and Elefteriadou, 2012). Other strategies for Active Traffic Management (ATM) at merge sections have been tested based on Variable Speed Limits (VSL) to control the traffic flow at merging zones and warn drivers of downstream congestion to allow smoother approaching speeds to the merging zone (Carlson et al., 2010). However, these systems do not directly control the spacing of vehicle gaps on the merge target lane and do not take into account different drivers' attitudes and perceptions of the safety distance that are crucial for improving safety and operation of merging zones (Kondyli and Elefteriadou, 2012). Reinolsmann et al. (2019) tested the impact of a number of dynamic merge control strategies, such as lane control signalization (eventually combined with variable speed limits) and static merge control (e.g. merge warning signs or road marking treatment) to measure the behavioral responses of drivers being directly exposed to platoon merging from on-ramps of a 4-lane urban and rural expressway. The results of their driving simulator study revealed that dynamic merge control was more effective for rural expressways considering the higher traffic speeds, while on urban expressways, dynamic merge control did not provide additional safety benefits and could be substituted by a low-cost static merge control approach. Later, the same authors (Reinolsmann et al., 2021) proposed another measure to assist drivers in the right lane of a highway in correctly evaluating the headways to merging vehicles from the on-ramp of an interchange. The authors developed a driving simulator study where they tested a new Active Gap Metering (AGM) signalization consisting of a combination of pavement markings and an innovative Variable Message Sign (VMS). Overall, the results showed that the proposed system works well: drivers gradually increased their distance from the lead vehicle, which led to longer headways to merging on-ramp vehicles and better safety conditions.

Recently, several innovative systems based on Augmented Reality (AR) technology integrated with connected vehicle technology have demonstrated their effectiveness in providing warnings in the driving environment through symbols and signaling systems. Such in-vehicle applications can optimize the driver's visual awareness and provide new and additional visual feedback to enhance the driving experience. It is strongly recommended to develop a detailed analysis of behavioral data in order to assess the impact of these technologies on driving behavior and performance. In fact, while some previous driving simulator studies have demonstrated the effectiveness of the connected environment and the ability of AR technologies to improve driving behavior and road safety in several critical driving situations (Calvi et al., 2020b; 2020c; 2020d; 2021), there are still no contributions that have assessed that AR warnings can assist drivers during merging maneuvers and in their estimation of safe headways to entering vehicles. Accordingly, the study presented in this paper investigates the effectiveness of different countermeasures, also based on AR and connected vehicle technology, to improve the safety of merging zones and the ability of through drivers to adopt safe headways to entering vehicles from the motorway on-ramp.

2. Methodology

2.1. Driving simulator

The study took place in a medium-fidelity, fixed-based driving simulator (Figure 1) at the Department of Engineering at Roma Tre University. The simulator comprises a left-hand-drive Toyota Auris car positioned within a curved screen, affording a 180-degree forward and contiguous side image of the driving scene via three overhead HD projectors, together with rear and side mirror displays. A force feedback steering wheel and pedal set are integrated faithfully with the existing Toyota primary controls. The simulated driving environment was created using STISIM software that allows the collection of several driving parameters with a frequency up to 60Hz by means of a performance measurement system. There have been previous studies that validated the driving simulator (Calvi, 2018; Calvi et al., 2020a), therefore allowing researchers to study complex behaviors that would be difficult, dangerous, or unethical to investigate in the real world.

Fig. 1. Driving simulator

2.2. Scenario and Countermeasures

A motorway scenario was implemented in the driving simulation. The cross-section of the motorway consisted of three lanes in each direction (each lane was 3.75 m wide), a hard shoulder of 3.00 m wide and a median of 4.00 m wide. Various elements, such as vertical signs and markings, vegetation, buildings, barriers, and other vehicles, have been included to make driving more realistic. There was a speed limit of 130 km/h. The total length of the motorway scenario was 40 km, along which seven interchanges were implemented; they included firstly a deceleration lane with an exit ramp (that was simulated just to improve the realism of the driving), and just after an acceleration lane with vehicles entering the motorway from the entrance ramp to the right through lane of the motorway; this determined a merging zone and a potential interaction with the driver's vehicle that was driving in the right lane, as, along the interchanges, a platoon of vehicles with a higher speed and a short headway was simulated in the middle lane of the motorway to prompt the driver to avoid overtaking the entering vehicle in front. More specifically, five interchanges were used for testing the driver's behavior while approaching the merging zone and during the interference with the vehicle entering from the on-ramp of the acceleration lane; in the other two interchanges, no vehicles were entering the motorway and were included in order to prevent the drivers from expecting an entering vehicle at each interchange that could condition their behavior and consequently bias the results. In the scenario, the seven interchanges were located in different positions to avoid having the results be influenced by the order in which the drivers face the various interchanges and the correspondent countermeasures. In fact, each of the five interchanges used to test driving behavior was characterized by a different countermeasure tested in the study to evaluate their effectiveness in improving the safety of vehicular interactions along merging zones and, more specifically, in assisting drivers in maintaining a safe distance to the entering vehicle. The countermeasures are illustrated in Figure 2 and described as follows:

1. a baseline condition (namely B, Figure 2a), with no countermeasures; the motorway signs informing the driver of the next interchange were implemented in the simulation (the signs were included for all the interchanges);
2. a gap metering signalization (namely countermeasure C_1, Figure 2b), consisting of a gantry-mounted Variable Message Sign (VMS) installed 400 m before the on-ramp and several chevron markings (auxiliary markings) that were paved on the right lane (Figure 3); the distance between the chevrons counts as 50 m; the driver was previously informed and trained about the use and operation of the symbol;
3. a static symbol (namely countermeasure C_2, Figure 2c) projected on the vehicle's windshield since 400 m before the on-ramp by means of a Head-Up Display (HUD) that informed the driver to maintain safe headways to the entering vehicle; the meaning and the aim of the symbol displayed were explained to the drivers before the test;
4. a dynamic symbol (namely countermeasure C_3, Figure 2d) based on Augmented Reality (AR) technology, built into connected vehicle technology, that provided additional visual virtual information to the driver about his current headway to the entering vehicle and the safe headway to maintain; the symbol was similar to the previous one and consists of a series of horizontal and colored lines, from red to green, aimed at indicating the driver the safe distance to maintain from the entering vehicle. If the entering vehicle was located after the last green line, then the driving condition was safe; otherwise, it was unsafe, and the correspondent color provides the risk level of the car-following condition; the total length of the symbol, from the first red line to the green one was 100m, assumed as the safe distance when driver adopted a speed of 100km/h;
5. the AR system was also tested with an additional audio warning (namely countermeasure C_4).

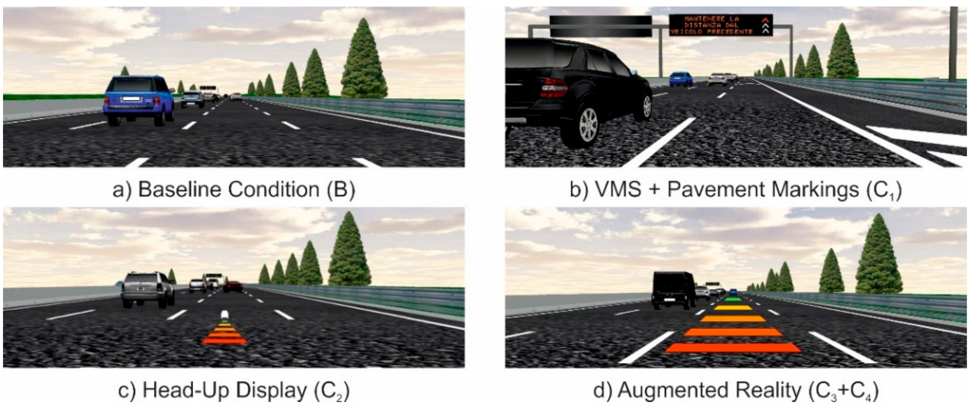

Fig. 2. Scenario and countermeasures

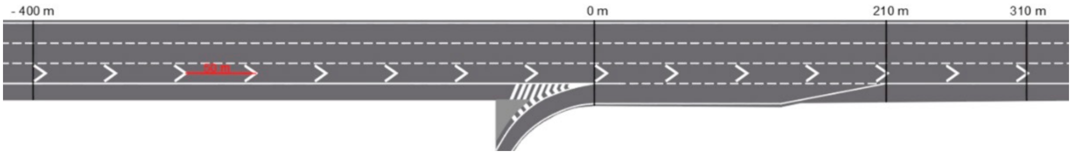

Fig. 3. Countermeasures C_1: design of the chevrons auxiliary markings

2.3. Participants and Procedures

In the experiment, 21 males and 23 females participated, with an average age of 30.1 years old (SD = 5.3) and 10.4 years of driving experience on average (SD = 3.6). All participants were students and professors from the Department of Engineering at Roma Tre University. One participant did not finish the experiment due to simulator sickness, and two were excluded since they drove at extreme driving speeds. Therefore, the final sample consisted of 41 participants, 19 males and 22 females. The sample age ranged from 22.8 to 59.3 years old (average age = 29.7, SD = 5.1).

The same experimental protocol was applied to each participant. First, the participants were introduced to the overall objective of the study (without revealing the exact purpose and details to avoid biased results) and then trained with explanations of the designed countermeasures and their operation and use. They were then asked to give informed consent and to fill out a short questionnaire providing their gender, date of birth, date of obtaining the driver's license, assessment of their driving ability, and frequency of driving. Second, the participants familiarized themselves with the operation of the driving simulator during a training scenario before driving the test scenario. The participants were asked to drive as they normally would and as they considered appropriate for the situation. Third, after the training, each participant drove the test scenario, including the four countermeasures and the baseline condition. The sequence of the different merging zones was diversified by groups of drivers to avoid any conditioning of the results relating to the order in which the countermeasures were proposed and tested. Finally, after the test, the participants had to fill out another questionnaire to see if they had simulation sickness and how bad it was.

2.4. Data Collection

In order to analyze the behavior of the drivers approaching each merging zone, characterized by a different countermeasure, in relation to the entering vehicle, the following variables were collected: longitudinal speed (S), distance of the driver's vehicle to the entering vehicle (d), and time headway (TH) of the driver's vehicle to the entering vehicle. Those variables were identified in the literature as some of the most common measures for describing driver behavior in merging zones when the overall aim is to analyze the interactions between through vehicles and entering vehicles. Time headway is the time difference between the front of the leading vehicle passing a point on the lane and the front of the following vehicle passing the same point; it is without a doubt one of the most commonly used indicators to estimate the severity of a traffic situation. Some countries recommend it as an indicator for detecting critical safety distance. For example, in the Netherlands and France, drivers are advised to limit their TH to more than 2 seconds (Risto and Martens, 2013). Similarly, in the US, several training programs (Michael et al., 2000) for drivers state that TH must be more than 2 seconds. Moreover, in the literature, it is commonly accepted that 2 s is the minimum time headway for safe car-following conditions (e.g., the "two-second rule") (Shinar, 2007). Accordingly, TH less than 2 seconds was considered a risky condition in this study.

Specifically, each variable described above was analyzed into five subsequent points (d and TH in points 3, 4 and 5):

1. when the countermeasure firstly appeared to the driver (400 meters before the on-ramp);
2. when the driver first noticed the entering vehicle along the on-ramp;
3. when the entering vehicle started the merging maneuver;
4. when the merging vehicle ended the merging maneuver;
5. at the end of the investigation site (100 meters after the end of the acceleration lane).

Moreover, the average values of the distance and time headway between point 3 and point 5 ($d_{3\text{-}5}$ and $TH_{3\text{-}5}$, respectively) were also calculated for each driver. Finally, the number of drivers who showed a distance to the entering vehicle shorter than the stopping distance, as well as the number of drivers who drove behind the entering vehicle with a TH of less than 2 seconds were calculated for each one of the four countermeasures and for the baseline condition.

3. Results

Statistical tests were used to examine the effectiveness of the countermeasures on driving parameters in improving the efficiency and safety of the motorway merging zones. For this purpose, one-way ANOVA (analysis of variance) with repeated measures and non-parametric tests was applied. Specifically, a one-way ANOVA (5x1) was carried out for each collected variable, with the different countermeasures (B, C_1, C_2, C_3, and C_4) being considered as independent variables. The effects of the countermeasures on each dependent variable described above (speed, distance and time headway) were evaluated. A level of 0.05 was adopted for the significance test. If the distribution did not meet the ANOVA assumptions, non-parametric tests were used.

3.1. Speed

The driver's speed profile approaching the interchanges and during the merging maneuver of the entering vehicle was collected and compared among the different configurations (B, C_1, C_2, C_3, and C_4). Table 1 summarizes the statistical test findings and contains descriptive data, namely average values and standard deviations (in brackets). The analysis of variance shows significant differences in driving speed for all the measurement points, except for S_1, which conversely resulted in similar values for all the configurations ($p = 0.146$). This result was expected as "point 1" was located where the countermeasures first appeared to the driver (400 m before the on-ramp) and, consequently, the driving speed could not be influenced by the different configurations. For all the other points of measurement, it can be noted that the highest speeds are recorded in the baseline condition where no countermeasures were implemented, with potential greater interferences with the vehicle entering from the on-ramp that adopted lower speeds than the vehicles on the motorway right lane (Calvi and De Blasiis, 2011). Accordingly, the effects on the driver's speed of all the tested countermeasures are related to a reduction in speed due to the warnings and suggestions provided in advance to the driver about the entering vehicle as well as the safe distance to adopt. At the end of the merging zone, it is also interesting to note that the speeds of drivers increased more when using AR countermeasures (C_3 and C_4), which, conversely, resulted in the lowest speeds during the merging maneuver.

Table 1. Speed average values, standard deviations (in brackets) and statistical analysis results.

Variable		Configuration					Statistical Results	
		Baseline (B)	VMS (C_1)	HUD (C_2)	AR (C_3)	AR+audio (C_4)	*F*	*p*
Speed [km/h]	S_1	128.02 (13.30)	130.94 (12.98)	130.34 (12.02)	124.76 (12.01)	126.46 (13.11)	1.726	0.146
	S_2	127.69 (13.06)	112.91 (16.64)	120.29 (11.87)	126.77 (10.07)	118.48 (16.18)	7.723	<0.001
	S_3	105.58 (13.63)	98.80 (12.39)	96.69 (10.26)	91.58 (12.03)	91.97 (12.06)	9.180	<0.001
	S_4	98.39 (11.87)	93.77 (11.83)	93.66 (9.77)	89.79 (11.39)	90.50 (11.66)	3.708	<0.025
	S_5	109.25 (11.24)	104.05 (12.60)	108.93 (12.47)	111.97 (8.58)	114.21 (9.54)	4.996	<0.011

3.2. Distance

Table 2 summarizes the statistical test findings on the longitudinal distance between the driver and the entering vehicle and contains descriptive data, namely average values and standard deviations (in brackets). A significant difference between configurations has been observed for all the measurement points, as well as for the average distance along with the car-following condition (from point 3 to point 5). Specifically, when using countermeasures, the drivers adopted a longer distance to the entering vehicle (up to +60m) than that recorded in the baseline condition, with a significant improvement in terms of the safety condition of the merging zone. In fact, it is interesting to highlight that the number of drivers who adopted a distance to the entering vehicle during the car-following condition shorter than the stopping distance was significantly different among the configurations. In fact, the number of such drivers was 25

(61%), 9 (22%), 11 (27%), 3 (7%), and 7 (17%) for B, C_1, C_2, C_3, and C_4, respectively, demonstrating the effectiveness of the countermeasures in improving the safety condition of the interaction between the driver and the entering vehicle, especially for those based on AR and connected vehicle technology (C_3, and C_4).

Table 2. Distance average values, standard deviations (in brackets) and statistical analysis results.

Variable		Configuration					Statistical Results	
		Baseline (B)	VMS (C_1)	HUD (C_2)	AR (C_3)	AR+audio (C_4)	*F*	*p*
Distance [m]	d_3	101.05 (22.68)	129.44 (32.31)	126.14 (23.11)	148.14 (23.58)	137.88 (33.40)	16.796	<0.001
	d_4	93.04 (24.77)	123.23 (35.28)	120.50 (24.77)	143.38 (26.18)	133.29 (35.93)	16.415	<0.001
	d_5	97.38 (34.17)	157.49 (54.23)	128.03 (49.26)	152.36 (45.32)	139.93 (65.27)	25.484	<0.001
	d_{3-5}	92.09 (27.41)	136.87 (45.64)	121.53 (35.67)	145.55 (33.82)	136.03 (51.32)	43.045	<0.001

3.3. Time Headway

Table 3 summarizes the statistical test findings on the Time Headway of the drivers to the entering vehicle and contains descriptive data, namely average values and standard deviations (in brackets). The results demonstrated once more that the countermeasures improved the safety condition during the merging maneuver of the entering vehicle and the consequent car-following condition. The lowest values have been recorded in the baseline condition, while in all the other configurations with the countermeasures and for all the measurement points, the Time Headway was significantly higher (up to + 2.5s). Moreover, it is interesting to highlight that the number of drivers who adopted Time Headways to the entering vehicle of less than 2 seconds (considered an unsafe driving condition) was significantly different among the configurations. In fact, it was 5 (12%), 2 (5%), 2 (5%), 0 (0%), and 0 (0%) for B, C_1, C_2, C_3, and C_4, respectively. As already discussed for the longitudinal distance, it demonstrates again the effectiveness of all the countermeasures in improving the safety condition of the interaction between the driver and the entering vehicle, especially for those based on AR and connected vehicle technology, for which no drivers adopted TH lower than the risk threshold (2 seconds).

Table 3. Time Headway average values, standard deviations (in brackets) and statistical analysis results.

Variable		Configuration					Statistical Results	
		Baseline (B)	VMS (C_1)	HUD (C_2)	AR (C_3)	AR+audio (C_4)	*F*	*p*
TH [s]	TH_3	3.57 (1.15)	4.92 (1.83)	4.80 (1.24)	6.02 (1.70)	5.63 (2.14)	49.719	<0.001
	TH_4	3.52 (1.27)	4.94 (1.99)	4.74 (1.33)	5.95 (1.80)	5.54 (2.27)	44.990	<0.001
	TH_5	3.28 (1.36)	5.56 (2.16)	4.40 (2.05)	4.98 (1.71)	4.53 (2.55)	33.169	<0.001
	TH_{3-5}	3.39 (1.17)	5.40 (2.01)	4.52 (1.61)	5.47 (1.60)	5.03 (2.41)	43.045	<0.001

4. Conclusions

This driving simulator study has highlighted the great benefits that Augmented Reality cues and connected vehicle technologies could bring to managing potential conflict between vehicles within the merging zone of motorway interchanges. In fact, significant positive effects of the tested AR warnings (countermeasures C_3 and C_4) on driving performance and road safety during the merging maneuver of a vehicle entering from a motorway on-ramp into the main traffic just in front of the driver were observed: reduced drivers' speeds to accommodate the merging maneuver of the entering vehicle, an increase in the longitudinal distance between the driver and the entering vehicle during the car-following condition, and an increase in the Time Headway between the same vehicles. Moreover, the number of drivers who travelled within the merging zones in unsafe conditions significantly decreased compared to the baseline condition. Also the other countermeasures that were tested in this study (countermeasures C_1 and C_2) had positive effects on the safety of the merging zone. When using both a Variable Message Sign (VMS) with chevron markings (C_1) and a static symbol projected on the vehicle's windshield by means of a Head-Up Display (HUD) (C_2), longer distances and Time Headways between the driver and the entering vehicle were found than in the baseline condition.

Moreover, this study demonstrated the high potential and effectiveness of driving simulation in the analysis and evaluation of the effects of AR technologies on driving performance and road safety. The results should be taken very seriously when developing driver warning systems. They could help the automotive industry figure out how to make more efficient in-vehicle crash prevention systems.

References

Calvi, A., De Blasiis, M.R., 2011. Driver Behavior on Acceleration Lanes: Driving Simulator Study. Transportation Research Record: Journal of the Transportation Research Board 2248, 96-103.

Calvi, A., 2018. Investigating the Effectiveness of Perceptual Treatments on a Crest Vertical Curve: A Driving Simulator Study. Transportation Research Part F: Traffic Psychology and Behaviour 58, 1074-1086.

Calvi, A., D'Amico, F., Ferrante, C., Bianchini Ciampoli, L., 2020a. A Driving Simulator Validation Study for Evaluating the Driving Performance on Deceleration and Acceleration Lanes. Advances in Transportation Studies 50, 67-80.

Calvi, A., F. D'Amico, C. Ferrante, Bianchini Ciampoli, L., 2020b. Evaluation of Augmented Reality Cues to Improve the Safety of Left-Turn Maneuvers in a Connected Environment: a Driving Simulator Study. Accident Analysis & Prevention 148, 105793.

Calvi, A., D'Amico, F., Ferrante, C., Bianchini Ciampoli, L., 2020c. Effectiveness of Augmented Reality Warnings on Driving Behavior While Approaching Pedestrian Crossings: a Driving Simulator Study. Accident Analysis & Prevention 147, 105760.

Calvi, A., F. D'Amico, C. Ferrante, Bianchini Ciampoli, L., 2020d. Assessing the effectiveness of Augmented Reality cues in preventing rear-end collisions: a driving simulator study. Advances in Intelligent Systems and Computing 1212, 229-236.

Calvi, A., F. D'Amico, C. Ferrante, Bianchini Ciampoli, L., 2021. Driving Simulator Study for Evaluating the Effectiveness of Virtual Warnings to Improve the Safety of Interaction between Cyclists and Vehicles. Transportation Research Record: Journal of the Transportation Research Board, doi: 10.1177/03611981211061351.

Carlson, R.C., Papamichail, I., Papageorgiou, M., Messmer, A., 2010. Optimal Motorway Traffic Flow Control Involving Variable Speed Limits and Ramp Metering. Transportation Science 44(2), 238-253.

Garber, N.J., Hoel, L., 2009. Traffic and Highway Engineering. Fourth Edition.

Jin, P.J., Fang, J., Jiang, X., DeGaspari, M., Walton, C.M., 2017. Gap metering for active traffic control at freeway merging sections. Journal of Intelligent Transportation Systems: Technology, Planning, and Operations 21(1), 1-11.

Kondyli, A., 2009. Driver Behavior At Freeway-Ramp Merging Areas: Focus Group Findings. Transportation Research Record: Journal of the Transportation Research Board 2124, 1-22.

Kondyli, A., Elefteriadou, L., 2012. Driver behavior at freeway-ramp merging areas based on instrumented vehicle observations. Transportation Letters, The International Journal of Transportation Research 4(3), 129-142.

Kononov, J., Durso, C., Reeves, D., Allery, B.K., 2012. Relationship between Traffic Density, Speed, and Safety and Its Implications for Setting Variable Speed Limits on Freeways. Transportation Research Record: Journal of the Transportation Research Board 2280, 1-9.

Louah, G., Daucher, D., Conde-Céspedes, P., Bosc, F., Lhuillier, J.P., 2011. Traffic operations at an entrance ramp of a suburban freeway first results. Procedia - Social and Behavioral Sciences 16, 162-171.

McCartt, A.T., Northrup, V.S., Retting, R.A., 2004. Types and characteristics of ramp-related motor vehicle crashes on urban interstate roadways in Northern Virginia. Journal of Safety Research 35(1), 107-114.

Michael, P.G., Leeming, F.C., Dwyer, W.O., 2000. Headway on urban streets: observational data and an intervention to decrease tailgating. Transportation Research Part F: Traffic Psychology and Behaviour 3(2), 55-64.

Reinolsmann, N., Alhajyaseen, W., Brijs, T., Pirdavani, A., Hussain, Q., Brijs, K., 2019. Investigating the impact of dynamic merge control strategies on driving behavior on rural and urban expressways – A driving simulator study. Transportation Research Part F: Traffic psychology and behaviour 65, 469-484.

Reinolsmann, N., Alhajyaseen, W., Brijs, T., Pirdavani, A., Hussain, Q., Brijs, K., 2021. Investigating the impact of a novel active gap metering signalization strategy on driver behavior at highway merging sections. Transportation Research Part F: Traffic psychology and behaviour 78, 42-57.

Riener, A., Zia, K., Ferscha, A., Ruiz Beltran, C., Minguez Rubio, J.J., 2013. Traffic flow harmonization in expressway merging. Personal and Ubiquitous Computing 17(3), 519-532.

Risto, M., Martens, M.H., 2013. Time and space: The difference between following time headway and distance headway instructions. Transportation Research Part F: Traffic Psychology and Behaviour 17, 45-51.

Shinar, D., 2007. Traffic safety and human behavior. Elsevier Ltd.

Taieb-Maimon, M., 2007. Learning headway estimation in driving. Human Factors: The Journal of the Human Factors and Ergonomics Society 49(4), 734-744.

Taieb-Maimon, M., Shinar, D., 2001. Minimum and comfortable driving headways: Reality versus perception. Human Factors 43(1), 159-172.

Yang, H., Ozbay, K., 2011. Estimation of Traffic Conflict Risk for Merging Vehicles on Highway Merge Section. Transportation Research Record: Journal of the Transportation Research Board 2236, 58-65.