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Analysis of Driver Risk Perception at Intersections Across Various Road Contexts: A Driving Simulator Study

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ABSTRACT

Road safety is directly tied to how drivers perceive risk. Recognizing and reacting to potential hazards allows drivers to take necessary preventive measures to avoid accidents. To support this, contemporary safety methodologies rely on the 'Self-Explaining Road' principle, designed to help drivers automatically adapt their behavior by clearly understanding the road layout. This study aims to measure driver reactions close intersections, a singular point on the road, through indicators recorded by a virtual reality driving simulator. Specifically, the study compared risk perception across three different configurations of at-grade intersections: a rural road and two suburban roads. The two suburban configurations differed by the presence of a pedestrian crossing in the second one. The risk factors considered in the study include approach speed, deceleration, brake reaction time, and time to collision. Deceleration was also measured by comparing the friction demand during braking with the friction available from the pavement, considering the latter as the threshold value beyond which loss of control phenomena can occur, perceived by the driver as a safety alarm. The validity of the indicators and the statistical significance of the sample were verified using dedicated statistical models. The data derived from the processing offer the necessary tools to verify the effectiveness of road design and management. The analysis highlights the need to adopt a systemic approach that integrates the surrounding environment; indeed, it emerges that the criticality of a scenario is closely correlated with the surprise factor, rather than an absolute intrinsic risk.

Keywords: Driver risk perceptron, Risk factors, Intersections, Driving simulator

INTRODUCTION

In line with the most recent European methodologies for road risk assessment, In-Built Safety correlates design choices with user behavior. This approach can be defined as "intrinsic safety," as infrastructure design standards should integrate the expected behavior of drivers to reduce the likelihood of crashes and mitigate their consequences if they occur. The principle of In-Built Safety is synthesized by two road concepts: Self-Explaining Roads and Forgiving Roads. Therefore, ensuring alignment design legibility and consistency between all road elements and the surrounding environment is essential. This consistency induces users to adopt homogeneous, safe behaviors that match design expectations.

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Furthermore, it should not be overlooked that driver behavior varies significantly both among different individuals and within the same person, as performance is linked to their own psycho-physical condition and/or influenced by external factors. Consequently, the study of risk perception spans multiple disciplines, requiring a systematic approach to analyze the many factors that influence the ability to recognize potential hazards and, consequently, to make the right decisions to avoid or reduce traffic accidents.

Kundair et al. (2023) examined the effects of sleep-deprived fatigue through driving tasks in a driving simulator comparing age and gender factors. The analysis revealed a greater ability to maintain attention levels both in drivers under 40 years of age and in the male sample. Sun et al. (2023) also examined the effects of sleep deprivation on a sample of taxi drivers, measuring their driving performance via reaction times and gaze fixation. The results revealed a general slowing of response times and eye movements, with the effect being more pronounced for "covert" hazards compared to "overt" ones. Regarding gender differences, Ferrante et al. (2020) conducted a study using simulated driving tests to measure stopping behavior at an urban intersection based on three risk perception indicators: Time-to-Collision (TTC), brake pressure, and slip ratio. The results revealed lower risk perception and less cautious driving behavior among the male sample. D'Anna et al. (2016) evaluated driver risk perception by measuring a parameter of attention that is the Alertness Indicator (AI) extracted from the brain activity (EEG measurements), in two typical road conditions, that are urban and sub urban areas. These values were subsequently validated by comparison with surrogate safety measures based on kinematic parameters, recorded in road environments characterized by different hazard levels.

Among the various aspects to consider in a safety analysis, a fundamental role is played by the surrounding environment. Indeed, given the same geometric configuration, user expectations vary significantly between a rural and an urban context. In this regard, Cox et al. (2017) highlights how the urban scenario is riskier than its rural counterpart, due to the greater complexity of the elements involved. This assumption was demonstrated through a study that, in addition to the environmental context, examined the driver's age, experience, and risk sensitivity.

Hjelkrem et al. (2016) proposed the Chosen Risk Index (CRI) to measure the levels of risk perceived by car and truck drivers during car-following maneuvers, relating them to parameters describing precipitation, light conditions, and road surface conditions. Chen et al. (2019) proposed a model based on risk homeostasis theory to measure drivers' risk perception during overtaking maneuvers by analyzing kinematic parameters under various weather conditions. The study found that light rain or fog had a minimal impact on drivers' perceived risk, which increased only when visibility was significantly reduced. In contrast, risk perception remained consistently high in snowy conditions.

Intersections are among the critical scenario requiring a higher level of attention from both designers and road users. In addition to perceiving visual stimuli while driving, it is equally crucial to promptly assess their relevance to safety. This process becomes more demanding in complex environments,

such as road intersections of varying complexity, where the increased number of conflicts arising from the interaction of different traffic flows raises the likelihood of risky maneuvers being performed. The increased number of conflicts arising from the interaction of different traffic flows raises the likelihood of risky maneuvers being performed. A study conducted by Basu et al. (2022) evaluates the effects of intersection density in rural areas. The use of a driving simulator made it possible to measure driving performance as the distance between intersections varied analyzing speed data and associated fluctuations and to highlight the difference between easing off the throttle and using the brakes in relation to perceived risk. The results confirm the varying levels of complexity and the resulting risk conditions previously discussed for urban versus rural areas. Furthermore, the higher concentration of vulnerable road users further increases driving risk. While several studies have examined the impacts of risk by focusing on individual factors, others have utilized systemic analyses. This latter approach was adopted by Yang et al., who proposed a multidimensional road risk assessment method at intersections that combines intersection geometry, vehicle trajectories, and turning manoeuvres.

The aim of this study is assessing the risk levels perceived by users approaching an intersection through the analysis of 4 indicators: the difference between the speed upon approach to the intersection and the speed at the end of the maneuver, deceleration, brake reaction time, and the conventional time-to-collision. With this aim, three typical road environments, rural, suburban, and suburban with pedestrian crossing, in a driving simulator were implemented and the driver's behaviour were analysed using kinematic parameters.

MATERIAL AND METHOD

Participants

The test initially involved 35 volunteers; three of them discontinued the test due to simulator sickness. Therefore, the data of 32 participants (17 women and 15 men, aged between 20 and 33) were deemed valid. After receiving instructions on the test procedures, each user completed two questionnaires: a preliminary one, aimed at collecting demographic data and driving experience, and a post-simulation one, to evaluate their feelings and impressions. Furthermore, the statistical homogeneity of driving behavior was validated using Chauvenet's criterion, which excludes any outliers relative to the mean observed in the simulation outputs. In this study, the criterion was applied to the speed parameter. Before the test, to familiarize themselves with the driving simulator, they drove for approximately 10 minutes in a generic scenario.

Driving Simulator and Scenario

The driving tests were conducted in the LASS3 laboratory at the DICITA Department of the University of Roma TRE, utilizing a driving simulator integrated into a real vehicle. This setup was connected to a workstation

equipped with STISIM Drive® software. The driving scenarios were projected across a 180° field of view onto a wide screen using three projectors (see Figure 1). During the simulation tests, 45 parameters were sampled at a frequency of 4 Hz. The test is conducted along a single road section that includes two environments: rural and suburban. The overall route, with a total length of approximately 36 km, features a predominantly rural road configuration. Within this alignment, six 4-km segments were integrated, designed to simulate suburban environments. These sections are characterized by the presence of specific typical buildings and road signs, varying roadside vegetation and, most notably, intersection density. Furthermore, within the context of suburban road intersections, those with pedestrian crossings were included to estimate the impact of a more complex scenario on users' risk perception. Therefore, three intersection scenarios were implemented: rural road (Scenario 1), suburban road (Scenario 2), and suburban road with a pedestrian crossing (Scenario 3).



Figure 1: Driving simulator of LASS – rural and suburban scenarios.

Indicators

Through the processing of the parameters recorded during the test, including both those relating to the driver's actions and those referring to interactions with pedestrians and other vehicles, risk perception was estimated based on four indicators: the speed variation when approaching the intersection, deceleration values and parameters useful for understanding how drivers carried out the stages of stopping maneuvers, the brake reaction time to measure the actual braking time, excluding the processing and decision-making phases and the time-to-collision which indicates the temporal distance at which the user perceived the risk.

Regarding the first two indicators, a few clarifications are necessary. Specifically, the first indicator is chosen to highlight the evolution of the maneuver. Consequently, to accurately measure risk perception, it is insufficient to consider speed at single moments or its absolute variation; rather, this variation must be related to the initial speed of the maneuver. It is indeed essential to evaluate how the driving style adapts to specific circumstances, modulating the speed based on factors such as weather conditions or vehicular interference.

The results were analyzed by comparing each scenario with a 'control condition', defined as a baseline level where the road environment presents no constraints or disturbing elements. In addition to the absolute value of the second indicator, the deceleration behavior of each user was evaluated

by measuring the portion of skid resistance employed relative to that provided by the pavement. The ratio between utilized and available friction offers an objective measure of a low-risk perception: failing to assess the hazard correctly or in a timely manner, the user is forced to brake sharply, depleting the available skid resistance at the tire-pavement interface.

Statistical Validation

In order to verify the validity of the identified indicators, the ANOVA (Analysis of Variance) statistical method was applied. As highlighted by the results reported in the table, the variations in driving behavior across the three scenarios are systematically significant (p-value < 0.05) in terms of speed, deceleration, brake reaction time, and Time to Collision (see Table 1).

Table 1: ANOVA results.

Speed Variation [m/s]	Deceleration [m/s^2]	Brake Reaction Time [s]	Time to Collision [s]
$F_{(3,120)}$	$F_{(3,120)}$	$F_{(3,120)}$	$F_{(3,120)}$
6.70	3.92	8.58	6.33
P = 0.012	P = 0.032	P = 0.002	P = 0.015

With reference to the sample homogeneity verification using Chauvenet's criterion, the recorded velocity values in all trials showed no anomalies with respect to the mean and standard deviation of each test; therefore, no trials were excluded.

RESULTS AND DISCUSSION

Based on the results obtained, some differences can be observed across the three analyzed scenarios.

Speed Variation

Regarding approach speeds at intersections, average values in all three environments were consistently lower than in the baseline condition, defined as a straight highway section in a rural area with traffic low enough to prevent interference. Specifically, drivers exhibited the least cautious behavior and a lower perception of risk in the suburban environment, where the sample showed a mean speed reduction of only 9%. The reduction in average speed among the sample of users was more pronounced in the rural setting (–17%), reaching 27% in the scenario involving an intersection with a pedestrian crossing (fig.2a). Furthermore, an examination of the speed variation in the section approaching the intersection reveals that this scenario exhibited the highest values and the most significant shifts in behavior compared to the other two scenarios, which proved to be more homogeneous (fig.2b). These elements suggest that the third scenario represents the configuration where the highest perception of risk was recorded.

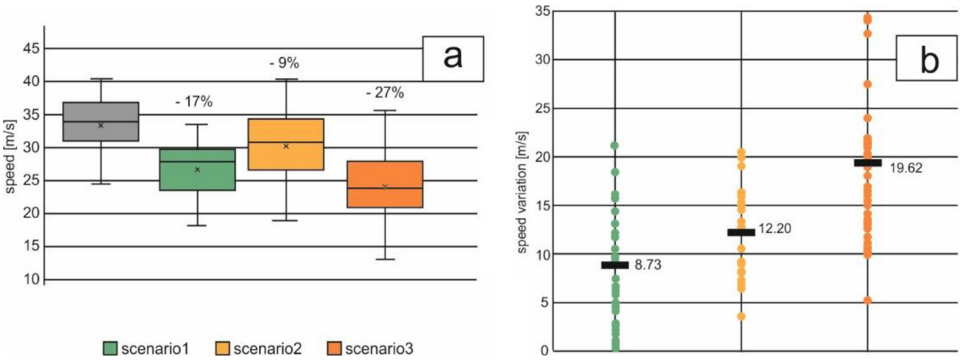


Figure 2: The intersection approach speed (a) and speed variations (b).

Deceleration

A further analysis examined the distance between the point of deceleration onset and the intersection, which was considered a proxy indicator of the driver's level of attention. At equal approach speeds, this parameter was found to be greater in the rural scenario, highlighting an inversely proportional correlation with the subject's initial deceleration speed. In contrast, a specular behavior was observed in the other two scenarios, thereby denoting a lower overall level of attention (see Figure 3).

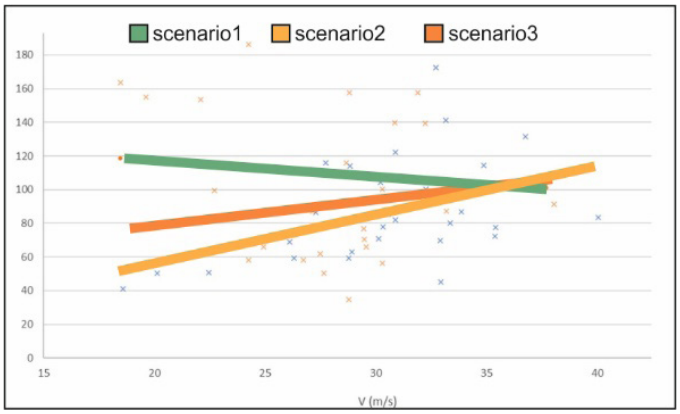


Figure 3: Residual braking distance vs. speed.

With the rise of proactive methodologies, the analysis of road safety conditions has extended from the vehicle and infrastructure to the user, monitoring their psychophysical state through instruments mainly derived from the medical field. More simply, the study estimated the perceived dangerousness of a specific maneuver by calculating the share of friction utilized during braking, derived from processing the simulator's outputs. Specifically, a friction value of 0.8 was set in the simulation; this implies that accelerations or decelerations exceedingly approximately 8 m/s² trigger

skidding processes, which are perceivable by the user during the test. The Figure 4 shows that in no case was a friction coefficient greater than 1 demanded, a value that would have resulted in a loss of vehicle control. Finally, at the extra-urban intersection, both the average value of utilized friction and the number of users who exceeded the threshold limit (0.8) are significantly lower compared to the other two scenarios.

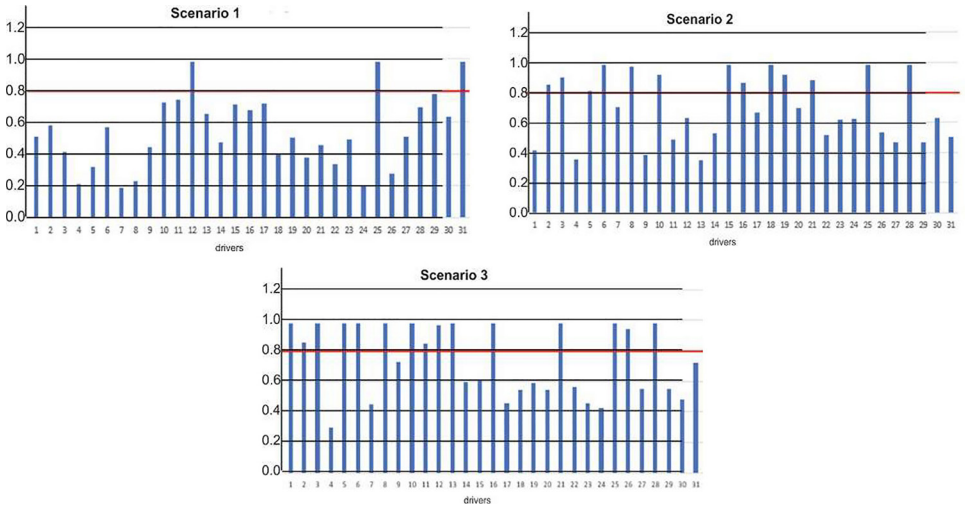


Figure 4: Share of friction for the three scenarios.

Brake Reaction Time

The Reaction Time (RT) indicator, used as a reference in determining road design standards, encompasses the actual time required to perform an action, as well as perception, comprehension, and decision times. Furthermore, the determination of this parameter is influenced by a safety margin, mostly subjective, that accounts for variables such as fatigue levels and age. Thanks to the driving simulator's logging software, it is possible to isolate and calculate only the time needed to execute the action; this metric not only indicates reflex sharpness but also measures the driver's level of alertness in a hazardous situation. Experimental literature agrees on estimating the brake reaction time value at around 1 second, compared to the 2–2.5 seconds required for the full perception-reaction time.

The test results highlight the heterogeneity of behaviors at rural road intersections. Approximately 25% of the sample recorded a braking time that exceeds both the action time (1 second) and the reaction time value suggested by international guidelines. In scenario 3, in addition to a reduction in heterogeneity, approximately one-third of the sample falls between 1 and 2 seconds, never exceeding this threshold. Scenario 2 results, on the other hand, are fully compliant with the literature values, the majority of users showed significantly low reaction times, under the 1-second threshold, indicating that the drivers perceived a very high level of risk associated with this type of interference (see Figure 5).

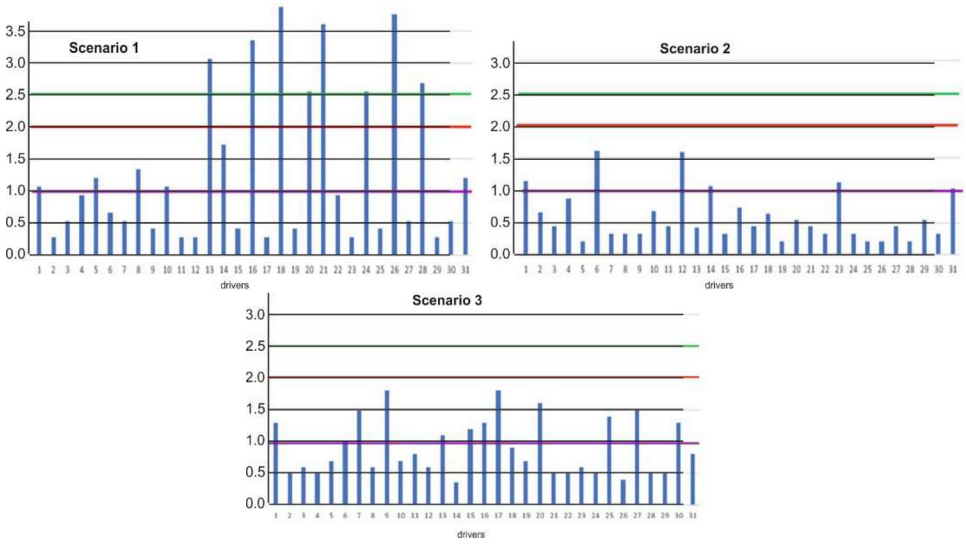


Figure 5: Brake reaction time for the three scenarios.

Time to Collision

A clear consistency with the brake reaction time results emerged from the analysis of the drivers' Time to Collision. Specifically, for both the rural intersection and the suburban intersection with a pedestrian crosswalk, the TTC values showed a decreasing trend as the approach speed increased. In both cases, the variation range remained between 2.5 and 5 seconds; conversely, Scenario 2 exhibits a significantly lower variability (see Figure 6).

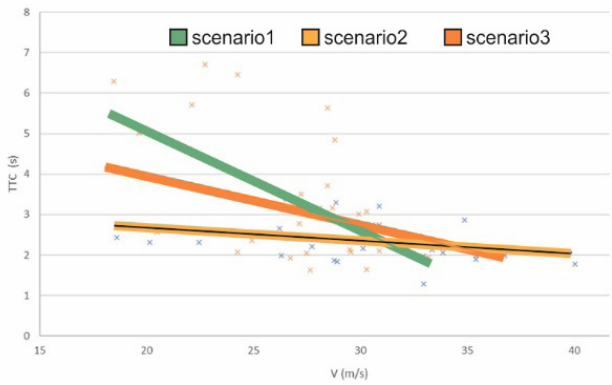


Figure 6: Trend of TTC vs. speed.

CONCLUSIONS

The comparative framework of individual indicators aims to optimize resources and decision-making processes, promoting a proactive intervention strategy that considers the systemic nature of effects.

Each indicator confirms that, on average, users had a higher perception of risk when a vehicle entered the rural road intersection. Only for the TTC is the mean value of Scenario 3 slightly higher (~ 0.6 s) than that of Scenario 1. It can be observed that the presence of the pedestrian crossing influences driver behavior. Indeed, a comparison of the average indicator values recorded in Scenario 3 reveals a risk assessment similar to that of Scenario 1, rather than Scenario 2 (which is theoretically more similar). This suggests that the presence of a pedestrian crossing at an intersection on a rural road reduces the propensity for risk.

Regarding the standard deviation, the highest dispersion is almost always observed at the rural road intersection. This is presumably because a high perception of risk tends to amplify the variability of subjective assessments.

Table 2: Statistical parameters of the indicators.

	Speed Variation [m/s]		Deceleration	
	Mean	**St. Dev.**	**Mean**	**St. Dev.**
Scenario 1	8.73	5.79	–2.57	1.69
Scenario2	12.20	4.69	–3.41	1.67
Scenario 3	19.62	7.03	–3.90	1.36
	Brake Reaction Time [s]		**TTC [s]**	
	Mean	**St. Dev.**	**Mean**	**St. Dev.**
Scenario 1	1.32	1.20	3.16	1.61
Scenario2	0.59	0.39	2.39	0.51
Scenario 3	0.90	0.44	3.75	0.79

The study confirmed that, in order to properly drivers risk assess and their resulting behaviors, it is necessary to examine the effects of each road element through a systemic environmental approach, rather than considering the absolute intrinsic risk of each one.

REFERENCES

Basu, S.; Ferrante, C.; De Blasiis, M.R. (2022) Influence of Intersection Density on Risk Perception of Drivers in Rural Roadways: A Driving Simulator Study. Sustainability 2022, 14, 7750. https://doi.org/10.3390/su14137750

Chen C., Zhao X., Liu H., Ren G, Liu X (2019) Influence of adverse weather on drivers' perceived risk during car following based on driving simulations. J. Mod. Transport. 27(4):282–292 doi.org/10.1007/s40534-019-00197-4

Cox, J. A., Beanland, V., & Filtness, A. J. (2017). Risk and safety perception on urban and rural roads: Effects of environmental features, driver age and risk sensitivity. Traffic Injury Prevention, 18(7), 703–710. https://doi.org/10.1080/15389588.2017.1296956

D'Anna C., Bibbo D., Bertollo M., di Fronso S., Comani S., De Blasiis M.R., Veraldi V., Goffredo M., Conforto S. (2016) State of alertness during simulated driving tasks, In XIV Mediterranean Conference on Medical and Biological Engineering and Computing (Vol. 57, pp. 907–912). Springer.

Ferrante C., Veraldi V., De Blasiis MR. (2020) Gender Differences Measured on Driving Performances in an Urban Simulated Environment. Advances in Human Factors and Simulation, Springer, 2020, pp. 135–143.

Hjelkrem OA, Ryeng EO (2016) Chosen risk level during car following in adverse weather conditions. Accident Analysis and Prevention 95:227–235. Doi. org/10.1016/j.aap.2016.07.006

Khudair A, Subhi A , Jabbar A, Al-Dahawi A.M. (2023) Studying the effect of fatigue on driving speed: A simulation study. Conf. Proc. 2834, 060001.

Sun, L.; Zhang, M.; Qiu, Y.; Zhang, C. (2023) Effects of Sleep Deprivation and Hazard Types on the Visual Search Patterns and Hazard Response Times of Taxi Drivers. Behav. Sci. 2023, 13, 1005. https://doi.org/10.3390/bs13121005