INJURY RISK-BASED CRITERIA FOR THE APPLICATION OF ADAPTIVE LOGIC TO ADAS SYSTEMS

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ABSTRACT

Performance improvement of advanced driver assistance systems (ADAS) yields two major benefits: an increasingly fast progress towards autonomous driving and a simultaneous advance in vehicle safety. The high safety level provided by ADAS result primarily from the possibility to avoid possible impacts in correspondence of critical road scenarios. Nevertheless, specific obstacles (e.g., stationary vehicles, buildings) can interpose between the opponent vehicles and the working field of the sensors, weakening their functions: in these particular conditions, the impact can be inevitable (inevitable collision state – ICS). The systems currently available on the market are not capable to properly handle an ICS, because its occurrence is not conceived.

In the present work intervention criteria for ADAS are introduced which are based on the vehicle occupants' injury risk (IR), particularly useful in case of ICS. In a critical road scenario, the ADAS must first avoid the impact with maximum margin (maximum clearance between vehicles) and, in case of ICS, minimize impact severity and IR. Referring to a system capable of intervening on braking and steering, the ADAS must monitor the surrounding and act on the degrees of freedom adapting to the possible evolution of the scenario, following an adaptive logic. The sequence of optimal interventions based on such adaptive logic tends toward the best possible outcome.

The context (model-in-the-loop) of the adaptive intervention employing the proposed criteria is first introduced, proposing a solution for testing its actual functioning (software-in-the-loop) with a view to its physical implementation (hardware-in-the-loop). The major criticality of the approach consists in the impact phase reconstruction, because IR is also a function of post-impact parameters (e.g., the velocity change ΔV experienced by the vehicle in the crash).

To highlight the potential benefits offered by an adaptive ADAS and to monitor its behavior, a software has been developed based on the software-in-the-loop solution introduced. The best intervention selection is based on a database filled with results of simulations: the outcomes associated to each braking and steering intervention are summarized in the database, for many critical scenarios; the ADAS retrieves information from the database and, through IR-based criteria, selects the most favorable action. Testing the logic functioning in correspondence of three critical road scenarios in which two vehicles are involved, at each instant it is observed that the developed intervention logic aims at creating eccentrical impact configurations, associated to low ΔV; the low values of resulting impact severity demonstrate how the intervention criteria based on IR represent an important tool for the development of increasingly performing ADAS devices.

INTRODUCTION

The Vision Zero program of the European Community [1] actually represents an important reference for the advance of the automotive industry: the objective is the development of vehicles capable of assuring an increasing level of safety, allowing to reduce road fatalities to zero within 2050. Current design is based on the increase of vehicle's passive safety (e.g., its crashworthiness [2]) and, to a greater extent, in the performance of its active safety equipment. In fact, advanced driver assistance systems (ADAS) allow to primarily reduce the probability for an impact between vehicles to occur [3], by functions as the autonomous emergency braking (AEB [4]). In recent vehicles the integration between many ADAS functions is frequently observed, aimed at providing a higher safety level as a consequence of the higher degree of automation achieved: in the case autonomous vehicles are referred to, this complex ensemble of functions is identified as automated driving system (ADS [5]).

SAE standard [6] expresses the automation level of a vehicle, based on the tasks performed by ADAS functions it is constituted of. While SAE 4-5 prototypes exist, the vehicles used on the road with highest level of automation belong to SAE 3: in case of danger, the driver must be ready to take over control in place of the ADS, which however can manage the entire driving process (handover) [7]. The ADS can intervene primarily on two degrees of freedom of the vehicle:

- longitudinal acceleration – the intervention results in the change of the vehicle running speed; the most typical example of intervention on the vehicle longitudinal acceleration consists in the AEB activation, by which the vehicle decelerates employing the maximum available adherence (100%);
- transversal acceleration – the system action aims at modifying the vehicle degree of steering: systems as the lane keeping assist (LKA [8]) or the more recent autonomous emergency steering system (AESS [9]) allow to respectively correct the vehicle trajectory in case of deviation from the lane center and to avoid impacts with obstacles on the carriageway.

The simultaneous action on the two accelerations are mainly limited by the Kamm circle [10], or analogously by the vehicle limits of longitudinal and transversal adherence (friction ellipse [11]). Due to issues linked to their ethical acceptability [12], the interventions aimed at increasing the speed of the vehicle are usually excluded.

Currently, ADAS devices contribute to fatality reduction insisting on three main factors: a) the number of collisions between vehicles, b) the impact severity and c) the injury entity [13]. First, the number of collisions is reduced by the intervention on steering and braking to avoid the collision, by ADAS devices which are momentarily developed to intervene on a straight road; nevertheless, collisions in correspondence of intersections often occur, are much more complex and result in more critical scenarios in respect to straight roads. In these circumstances, the ADAS cannot prevent many accidents from occurring, but it can intervene to minimize the impact severity. An ADAS intervention aimed at reducing the closing velocity at collision V_r is intuitively the best option to minimize the impact severity; however, V_r only partially affects the severity and injury associated to the collision, which mainly depend on the acceleration experienced by the occupants [14]. An alternative parameter to the occupants' acceleration is the velocity change ΔV sustained by the vehicle in the impact: ΔV associated to real accidents can be more easily retrieved from in-depth accident databases, and is strongly correlated to injury risk (IR) [15].

The ADAS devices currently available on the market perform no evaluation on severity of an impending impact; therefore, they do not allow for road safety optimization acting on all the three factors cited above. Inevitable collision states (ICS [16]) correspond to conditions in which any action by the ADAS or the driver does not allow to avoid the impact, as a consequence of low time to collision (TTC). Different reasons contribute in making ICS a reality in the current road environment. First, a circulating fleet with average age of 11 years is observed on European roads [17], with co-existence of vehicles with different SAE levels of automation: in such context, communication between vehicles (V2V [18]) will be limited also in the near future, and recognition of the opponents will totally depend on the sensors efficiency. In contrast, obstacles such as stationary vehicles or buildings concur in limiting the effectiveness of ADAS sensors, in terms of depth of field [19]: this can result in a retarded identification of approaching vehicles, with consequent TTC not compatible with collision evitability.

The present work discusses an ADAS activation logic based on intervention criteria which minimize IR for the occupants. Specifically, a system constituted by autonomous steering and braking functions is referred to, which are capable of jointly intervening to avoid the impact as a priority and, in case of ICS, to minimize IR. The choice of optimal maneuvers is adaptively carried out, i.e., the choice is evaluated at each time step monitoring the environment by sensors. The choice of optimal maneuvers varies with the external scenario, considering for instance the possible maneuvers of the opponent vehicle or additional changes in the road environment (e.g., due to vulnerable road users). In the manuscript the main technical solutions for the application of IR-based criteria to ADAS are highlighted, showing the main implications from the software and hardware point of view resulting from such integration. Through a simulation program specifically developed, the behavior of an ADAS implementing these criteria is exemplified in some cases of ICS between vehicles.

MATERIALS AND METHODS

Referring to well-established practices in the design of ADAS devices [20], in the present Section the elements necessary for the implementation of IR-based criteria are evidenced: first, the context of ADAS intervention is defined (model-in-the-loop); then a technical solution for the simulation of such intervention is proposed (software-in-the-loop), with a view to its eventual physical implementation (hardware-in-the-loop). For convenience, in the following the term "adaptive ADAS" is employed to indicate a device capable of adapting in real time to changes in the external conditions, employing IR-based criteria to intervene by braking and steering.

Model-in-the-loop definition

Model-in-the-loop (MiL) is a representation of the context in which the ADAS operates, fundamental to efficiently establish the ADAS functional requirements in software and hardware terms. ADAS interfaces with the external environment by sensors, scanning the key elements by different technologies (typically LIDAR and RADAR [21]); the most recent vehicles are equipped with scanning systems with an aperture angle higher than 300°, with more than 170° in the sole portion in front of the vehicle [19]. If combined with an appropriate depth of field (field of view), an angle of 170° allows to identify all road criticalities.

Detection of a critical scenario mainly depends on the algorithm employed by the ADAS manufacturer. Generally the TTC, which tends to non-linearly shorten while the vehicle approaches [22], is an efficient danger indicator of the specific road situation: for instance, the decision logic for the intervention by forward collision warning (FCW) and AEB is generally based on TTC evaluation. The ADAS activates its functions only at specific values of TTC, and in particular when the reaction time of the driver is no more compatible with the impact avoidance [10]. The key elements for the correct functioning of an adaptive ADAS (functional requirements) can be summarized by the scheme in Fig. 1.

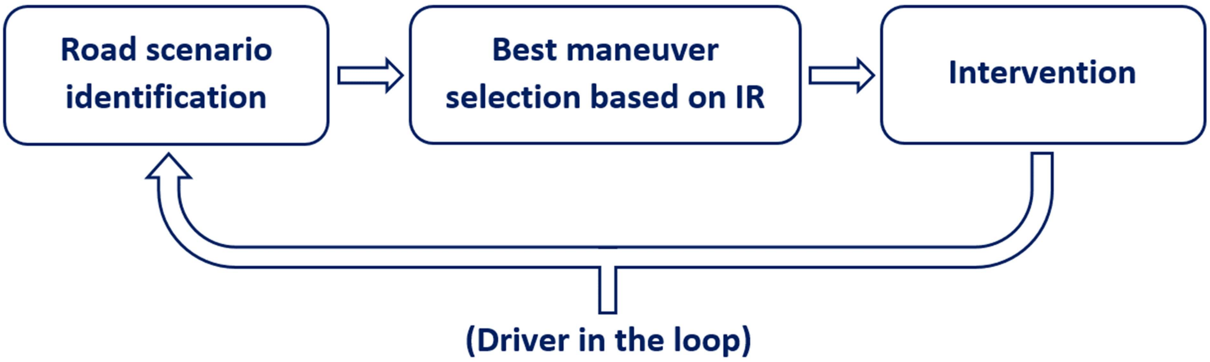


Fig. 1. MiL functioning scheme of an adaptive ADAS.

The system, through sensors, must define the road environment identifying the boundary conditions. Let us consider a planar visualization of the road environment as the one in Fig. 2, in which y corresponds to the longitudinal direction of motion for vehicle A (on which the ADAS is implemented) and x its perpendicular. At a specific TTC, the main parameters of the surrounding environment which can be extracted by sensors attain coordinates x,y and the heading h of an opponent vehicle B, as well as the components of B velocity along the axis (V_x e V_y); these velocities are to be intended in relative terms: since vehicle A velocity is known for the ADAS system, the absolute velocity of vehicle B can be directly obtained. Information regarding the dimensions can be employed to establish the type of vehicle, its class and eventually to derive a plausible mass [23].

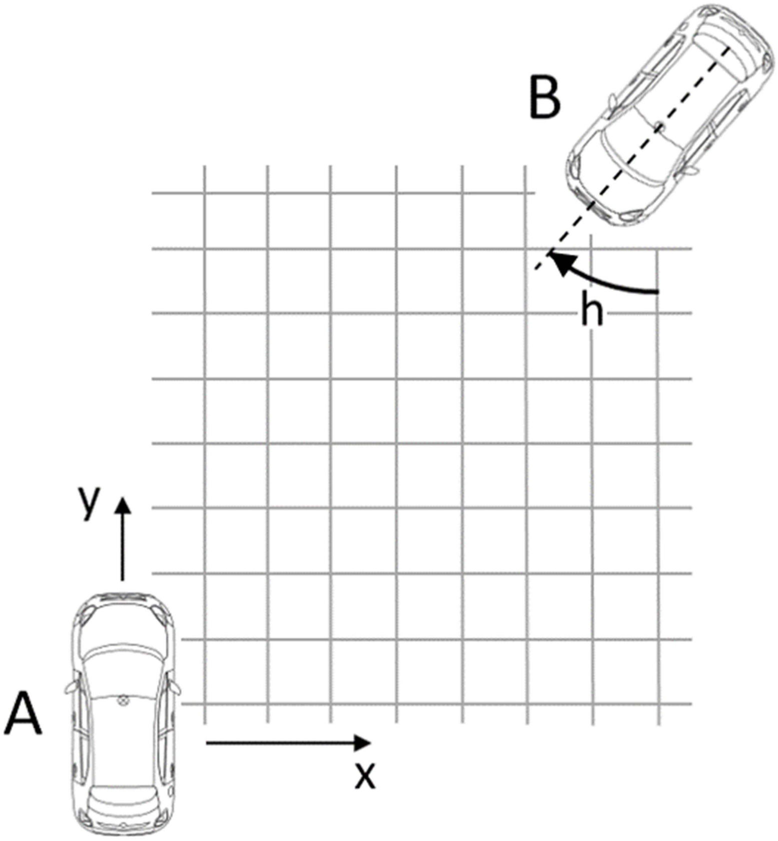


Fig. 2. Planar scheme of the road environment: the ADAS sensors of vehicle A allow to determine *x,y* coordinates, heading *h* and velocity components of the generical opponent vehicle B.

The maneuver to undertake must be selected as a function of predefined criteria: in such context, activation must primarily avoid the collision, with a value of clearance (minimum distance reached between the vehicles during their free motion) as high as possible; in case this is not possible (ICS), the system must minimize IR for the occupants. The autonomous application of the maneuver chosen in terms of braking and steering is carried out by the electro-mechanical components of the vehicle, by systems as brake-by-wire or steer-by-wire [24]. Once these phases have been accomplished, the ADAS scans once more the surrounding to monitor its evolution and adapt consequently, considering also the eventual actions undertaken by the drivers of both vehicles (driver-in-the-loop [25]). If the time step between two scans is sufficiently low (e.g., 0.1 s) changes to the surrounding are already comprehensive of drivers' intervention: in this case, it is not necessary to foresee the scenario evolution making use of complex driver models [26].

Software-in-the-loop solution

Once defined the functional requirements of the adaptive ADAS by MiL, a software-in-the-loop (SiL) is necessary to transpose them in a virtual environment and test the ADAS functioning. The SiL must allow to simulate the ADAS functioning according to the concepts reported in the V-model [27] of Fig. 3. First, the ADAS derives information regarding the environment by sensors, thus defining the scenario by position, velocity and dimensions of the vehicles. Then, for the specific scenario the ADAS must be capable of simulating each possible intervention, deriving the related outcome and identifying the best maneuver (maximum clearance or minimum IR). The best maneuver is subsequently undertaken and the vehicles are subject to a motion which is dependent on the time step selected for the analysis, as well as the degree of braking and steering for each vehicle; the response of braking and steering system is not instantaneous, and a setting time to the desired value should be accounted for: for instance, for tyre steering actuators, typical values are 45°/s [28]. The iterative cycle starts once more, with the identification by sensors of new position and velocity of the opponent.

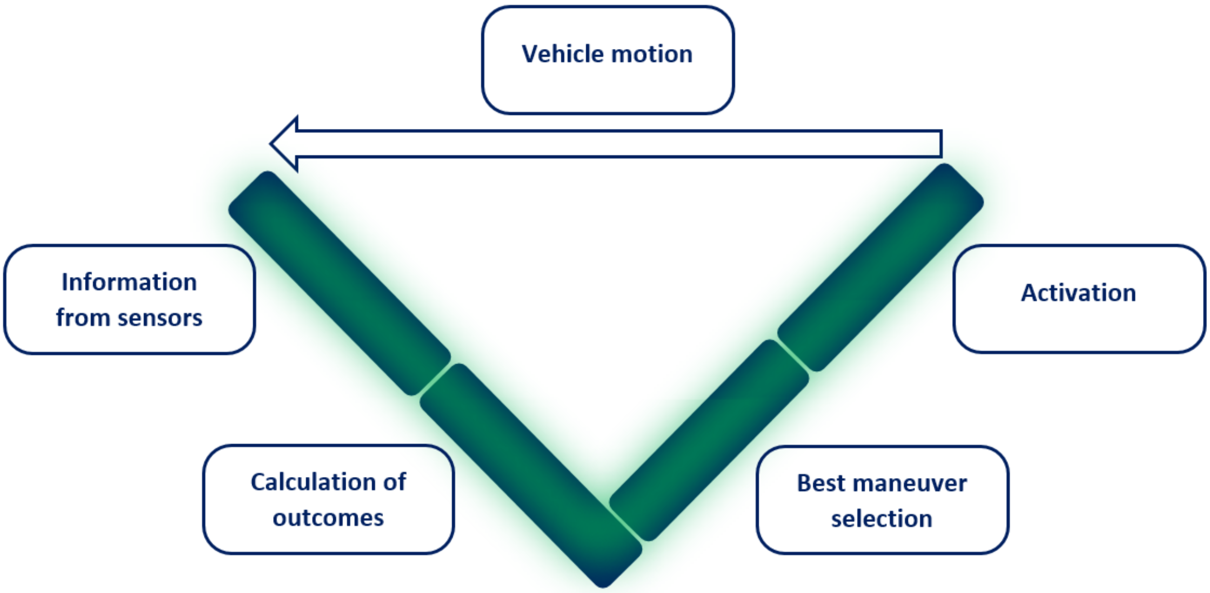


Fig. 3. SiL functioning scheme of an adaptive ADAS.

For calculation of outcomes associated to each maneuver, starting from a specific scenario, it is necessary to simulate each possible braking and steering intervention. The simulation of kinematics (free motion of vehicles) is primarily significant: if no impact between vehicles occurs, the system must identify the resulting clearance. If the maneuver results in an impact, IR derivation is obtained simulating also the impact phase: as visible in Fig. 4, IR depends in fact on the impact type, on occupant's position and on ΔV [29], which is a typical post-impact parameter; the logistic regression curves are referred to a values of Maximum Abbreviated Injury Scale equal to or higher than 3 (MAIS 3+). Even if approximated methods [30] exist for the calculation of impact severity starting from sole pre-impact parameters (as V_r in rear-end collisions [31]), simulation of the impact phase remains the most accurate solution for a correct estimate of ΔV.

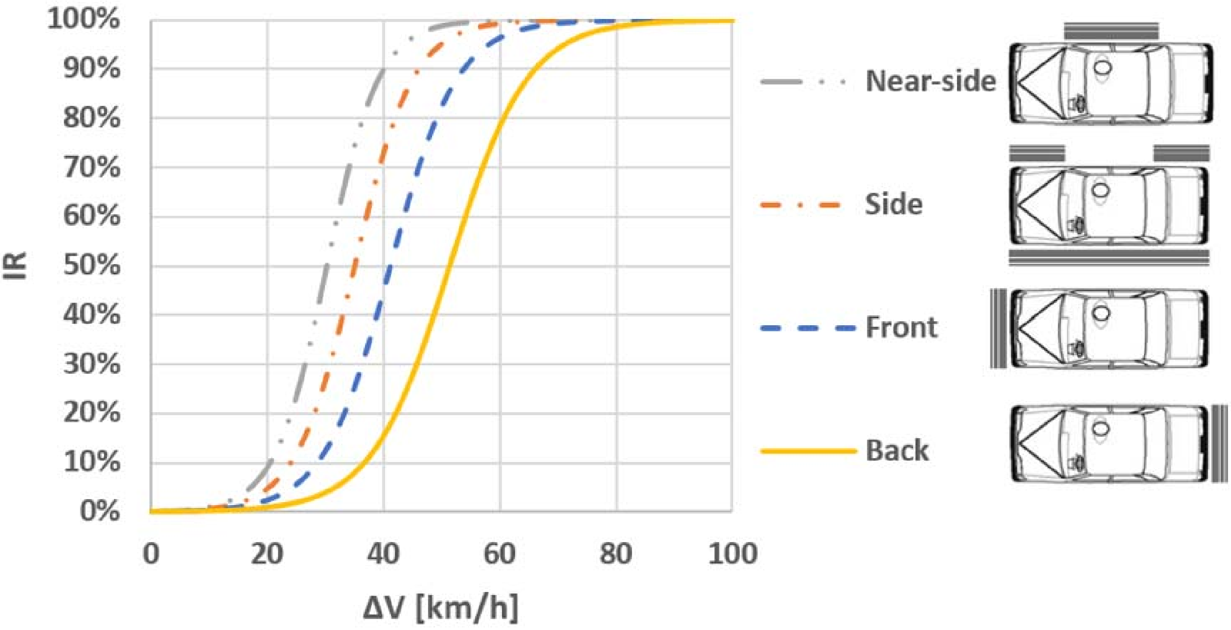


Fig. 4. IR curves as a function of ΔV, impact area and position of the occupant (modified from [29]).

The impact phase between vehicles can be simulated through different calculation methodologies, i.e., through analytical models, finite element method (FEM), multi-body systems (MBS) and reduced order dynamic models. Analytical methods are typically based on impulse-momentum models and allow to solve the problem analytically at the cost of strong approximations, mainly deriving from the choice of a plane and a center of impact [32]. FEM and

MBS are employed in the accurate reconstruction of impacts, for instance in vehicle crashworthiness analysis [33]: calculation time for the single impact configuration between vehicles is in this case high, typically variable between an hour and a day with modern calculators. In such a context, the use of special-purpose RODM is justified, featuring intermediate characteristics of calculation time and accuracy in respect to analytical methods and FEM/MBS [34]. For the simulation of the event, vehicles of equal mass can be considered; through appropriate corrective coefficients, it is possible to calculate the outcomes of impacts between vehicles of different categories (e.g., sport-utility vehicles, vans, etc.).

Once the results of simulations for the possible maneuvers are available for the specific critical scenario, the activation logic is capable of associating a specific value of clearance (collision avoided) or IR (collision not avoided) to each braking and steering intervention. Such capability is summarized in an intelligible way by the map of outcomes reported in Fig. 5, whose analysis allow the ADAS to select the best intervention in the specific critical scenario. In case the the clearance is defined by negative values of IR, the problem of finding the best intervention simplifies to the identification of minimum IR. At a graphical level, if in the map of Fig. 5 green colored areas are present (impact evitability), the system will activate preferring interventions corresponding to dark green; in case only red colored areas are present (ICS), the system will intervene selecting light red areas (low IR).

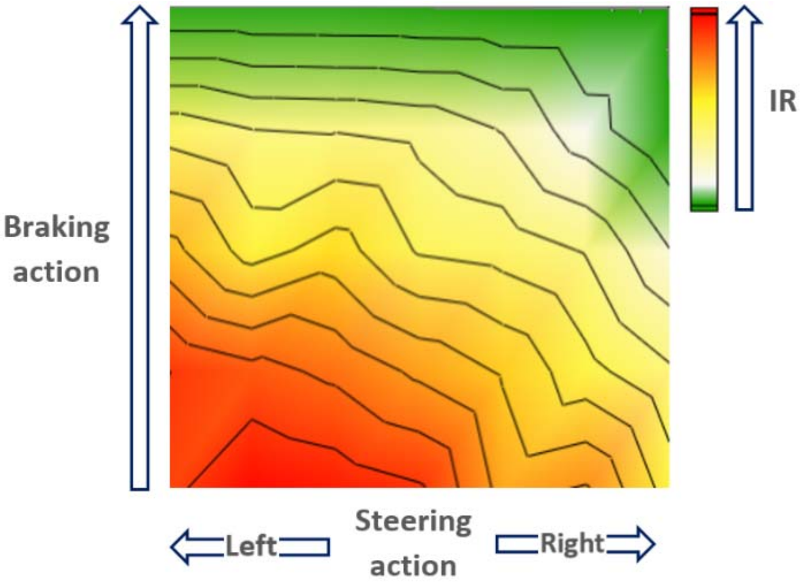


Fig. 5. Map of outcomes for a generic critical scenario, which summarizes the values of IR associated to each braking and steering intervention by an adaptive ADAS.

Hardware-in-the-loop proposals

SiL functions can be converted in two different forms of hardware-in-the-loop (HiL), as a function of the final use: an instrument to evaluate different ADAS logics (e.g., AEB, AESS or their combination) or an actual ADAS to be implemented on-board the vehicle. In the first case, in which the objective is to compare the performances of different ADAS functions by simulation, calculation time has low relevance; on the other hand, in the second case the adaptive ADAS must determine the outcomes associated to all possible interventions in a time which is compatible with the scanning time ofthe scenario. This requirement cannot currently be satisfied even employing RODM: the impact phase reconstruction process is highly time consuming, while the scanning of the scenario occurs in a time close to 0.1 s. The time for scanning mainly depends from the type of sensors and how they are mutually integrated (sensor fusion [35]). For such reason, in the view of an on-board implementation, it can be convenient to refer to a database filled with the results of simulations, from which the adaptive ADAS can easily extract the best maneuver associated to a critical scenario. In this case, the time required to identify the best maneuver corresponds to the sole time of access to the database (some milliseconds).

The functioning of the hardware system which includes the IR-based criteria can be outlined as in Fig. 6. In a specific instant, the ADAS determines by sensors the position and heading of the opponent vehicle, its velocity and its dimensions. The ADAS identifies the outcomes corresponding to different possible maneuvers, calculating IR for the occupants (or retrieving it from the database) and identifying the best intervention. By electronic systems, the information is converted in a steering angle and a braking level to be applied. Then, the system reiterates the process:

the position of the opponent and its velocity identified by sensors differ from the ones at the previous time step, defining thus a new critical scenario that the system should optimally handle.

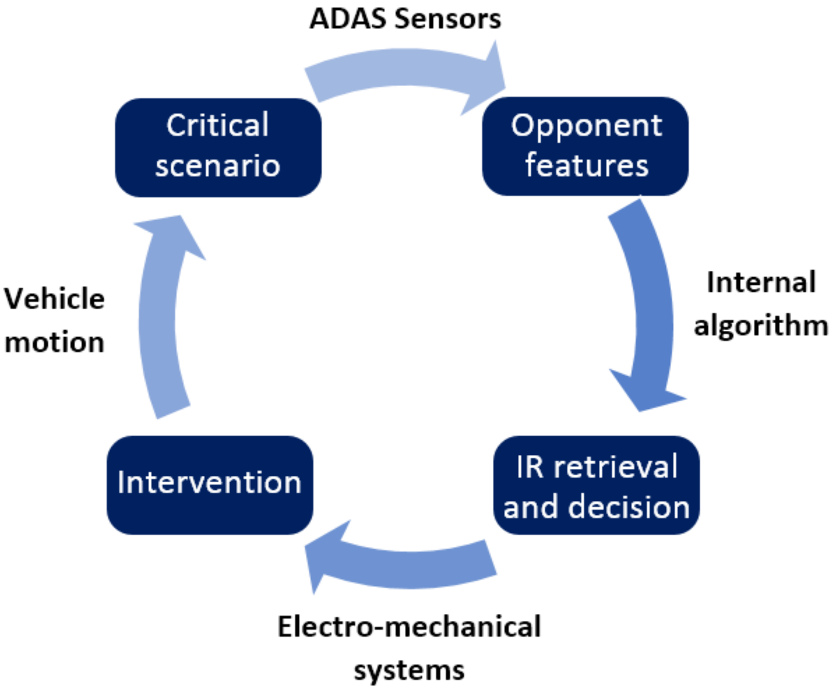


Fig. 6. HiL functioning scheme of an adaptive ADAS.

RESULTS

To highlight the potential of an adaptive logic of intervention in terms of road safety enhancement, the development of an appropriate virtual environment for the SiL implementation is required, allowing to simulate the process in Fig. 3. As reported in the previous Section, the fundamental part of such cycle is the outcome retrieval associated to the single activation: with a view to an HiL implementation on-board the vehicle, by a RODM software [36] a database including the outcomes associated to each braking and steering maneuver has been compiled, for many critical scenarios. The RODM simulation software, implemented in a LabVIEW™ environment, is based on the discretization of the sole vehicle perimeter through 2D beam elements, with constitutive equations similar to the ones employed in FEM models. For an in-depth description about the functioning of the RODM, refer to a previous work [37].

To comprehend which scenarios are included the database, let us refer to Fig. 2: hypothesizing the position of vehicle A always coincident with the origin of the axes, in Tab. 1 is reported the discretization of velocity for A and B, position and heading of B, intervention on steering and braking of A. The maximum distance between the vehicles is considered equal to 14 m: considering vehicles moving at 50 km/h, a maximum TTC equal to 1.0 s can be deduced for the scenarios making up the database; the number of simulated scenarios totals more than 50,000. The model for vehicle A and B is the same: the vehicle belongs to the C segment, with a length equal to 4.2 m, width 1.8 m, wheelbase 3.5 m and mass 1300 kg. The road-tire coefficient of friction is assumed equal to 0.8, and a complete braking corresponds thus to a deceleration of 8 m/s^2. Calculation time for the single simulation with the RODM software is about 1.5 s. For the single simulation, the velocity and the heading of the opponent vehicle are considered constant.

Tab. 1. Parameters which define the space of critical scenarios and interventions, making up the database.

Parameter	Vehicle	Minimum Value	Maximum Value	Step
X coordinate (m)	B	0	14	2
Y coordinate (m)	B	0	14	2
Longitudinal velocity (km/h)	A	10	70	5
Longitudinal velocity (km/h)	B	10	70	5
Heading (°)	B	70	110	10
Steering angle (°)	A	-9 (left)	+9 (right)	3
Braking level (%)	A	0	100	25

To monitor the behavior of the adaptive ADAS and the actual employment of the criteria, three case studies regarding critical scenarios in correspondence of intersections are referred to: for each case study, the parameters related to the velocity of the two vehicles and to the position and heading of the opponent are summarized in Tab. 2; from accident database analysis, it is estimated that those case study represent approximately 30% of the real accident scenarios. In the three case studies, the scenario evolves due to the intervention of the driver in vehicle B. Vehicle B initially moves perpendicularly to A in all three cases; vehicle A heading is null by definition. It is assumed that the input provided by the ADAS reaches instantaneously the electro-mechanical component. The time elapsed between two successive scans of the scenario by sensors is assumed equal to 0.1 s.

Tab. 2. Parameters which define the analyzed case studies.

Parameter	Case study 1		Case study 2		Case study 3	
	Vehicle A	Vehicle B	Vehicle A	Vehicle B	Vehicle A	Vehicle B
X coordinate (m)	0	13	0	10	0	12
Y coordinate (m)	0	11	0	8	0	9
Longitudinal velocity (km/h)	50	50	50	50	50	50
Heading (°)	0	90	0	90	0	90

Case study 1

It is considered that vehicle B driver does not notice the presence of A while performing a left steering maneuver. In 0.2 s, the steering action on vehicle B tires changes from 0° to -9° (adherence limit). The history of steering and braking actions for A according to IR-based criteria is reported in Fig. 7. Between 0.1 s and 0.3 s the outcome map indicates that there is the possibility to avoid the impact by left steering, and the system acts accordingly. Because of the motion of B towards A, between 0.3 s and 0.4 s the ADAS detects that the scenario corresponds to an ICS: the system adapts with a 100% braking, to reduce the collision velocity. In the subsequent instants, the system determines that a 100% braking action would imply an impact at lower velocity, but with low eccentricity: in this case high ΔV would result, because most of the energy would be converted in translation rather than rotation. The brake is thus released to create an eccentrical impact configuration, moving the impact point towards the rear extremity of vehicle A.

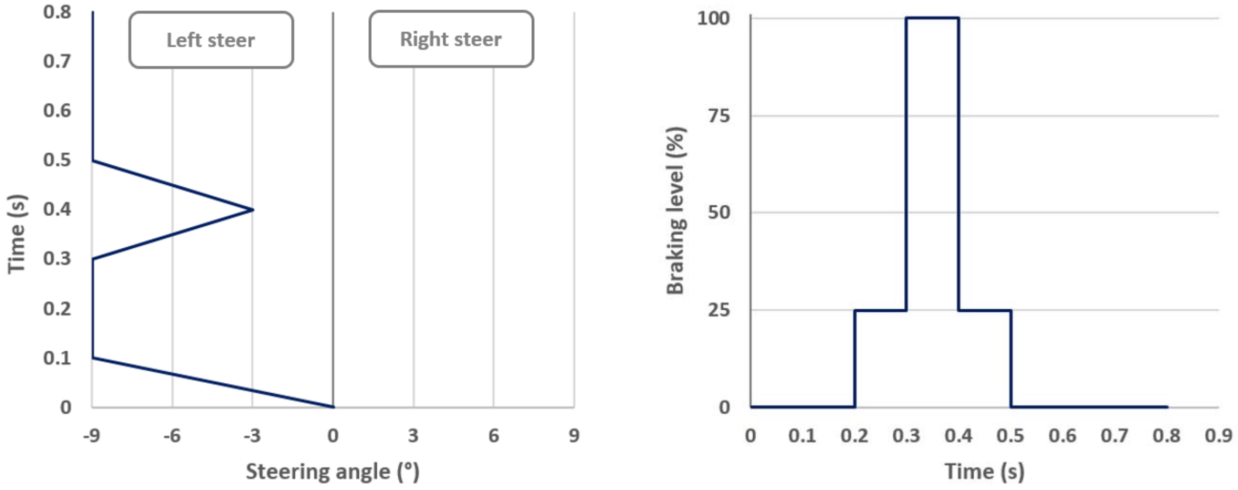


Fig. 7. Case study 1: history of the adaptive ADAS actions on braking and steering.

Case study 2

It is assumed that vehicle B applies a right steering evasive maneuver, according to the typical behavior of a driver [38]; in a time interval of 0.2 s, the steering action on vehicle B tires changes from 0° to +9° (adherence limit). The impact is inevitable from the beginning and the system, as a priority, tries to increase the impact eccentricity by steering and braking. Then (from 0.2 s to 0.4 s), the ADAS detects that vehicle B tries to avoid the collision, and that the release of brake creates an eccentrical impact configuration. Lastly (from 0.4 s to 0.6 s), the system acts with 100% brake to reduce V_r.

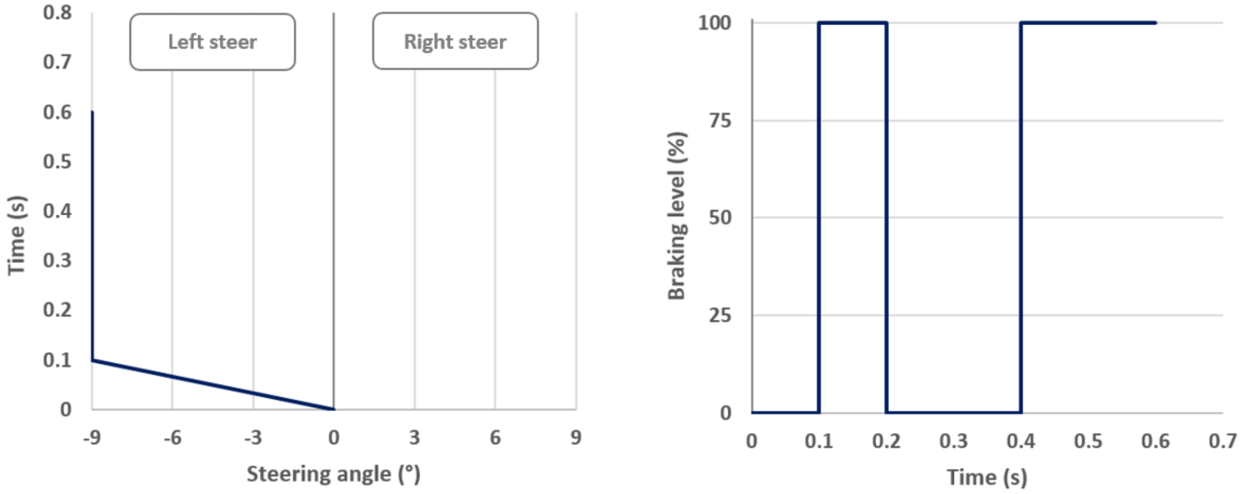


Fig. 8. Case study 2: history of the adaptive ADAS actions on braking and steering.

Case study 3

It is assumed that vehicle B brakes as soon as vehicle A has been identified: in 0.2 s, the braking action of vehicle B changes from 0% to 75% (typical braking action of a driver, with deceleration equal to 6 m/s^2 [38]). The scenario corresponds from the beginning to an ICS, and the system, as a priority, tries to get around vehicle B by left steering (from 0.1 s to 0-4 s in Fig. 9); the system reduces V_r by a 100% braking action only when vehicle A position is compatible with an eccentrical impact (from 0.4s to 0.7 s).

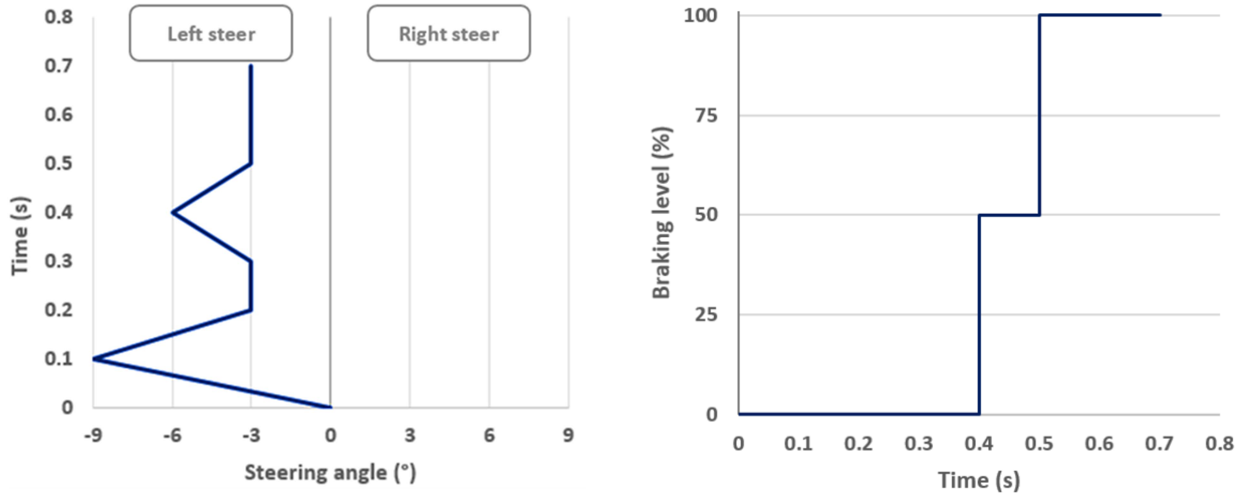


Fig. 9. Case study 3: history of the adaptive ADAS actions on braking and steering.

DISCUSSION

In Fig. 10 the impact configurations for the three case studies are reported, in case the system does not intervene (a), intervenes by 100% braking (b), intervenes by adaptive logic (c). In case study 1-2 the adaptive logic leads to impact configurations similar to the ones associated to the lack of intervention. The use of the adaptive logic implies the involvement of the compartment in the impact: employing the convention in Fig. 4, assuming occupants' presence on the right side of the vehicle, the impact belongs to the "near-side" type with highest potential severity. In reality, activation of the system converges toward impact configuration with higher eccentricity (lower Δ*V*) in respect to a 100% braking action. In case study 3, besides a higher Δ*V*, a different type of impact will result, passing from "side" in case of adaptive logic to "near-side" in case of 100% braking action. Overall, the combined intervention on braking and steering according to IR-based criteria efficiently contributes to the impact severity decrease.

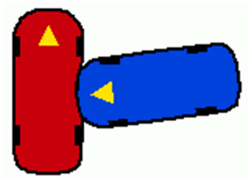
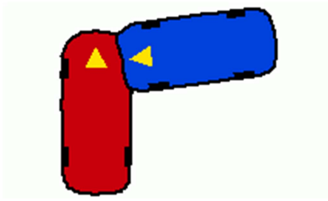
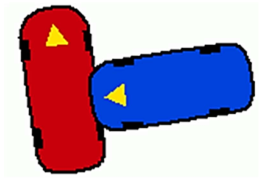
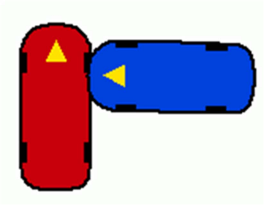
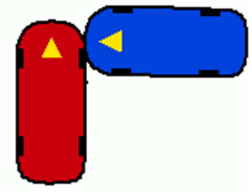
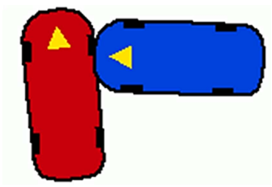
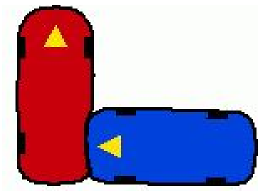
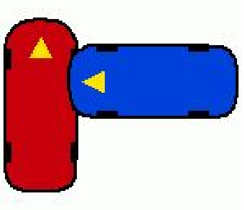
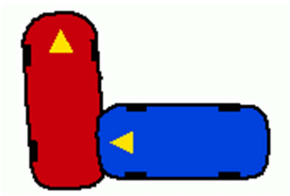
	(a) No intervention	**(b) 100% braking**	**(c) Adaptive logic**
Case study 1			
Case study 2			
Case study 3			

Fig. 10. Impact configurations for case study 1-3, as a function of the intervention logic employed.

Information related to impact configuration can be analogously expressed by means of the crash-momentum index (CMI) [39]. CMI represents the impact eccentricity: the lower the CMI, the more eccentrical the impact. Based on post-impact parameters [40], it can be expressed as CMI=$\Delta V/V_{r\_PDOF}$, where V_{r_PDOF} represents the V_r component along the principal direction of force (PDOF) at the collision instant: Δ*V* is thus the combination of impact eccentricity and closing velocity. From the definition of CMI derives that a decrease in V_r (e.g., by AEB) can result in no substantial benefit in terms of impact severity: if V_r decreases but its component along the PDOF does not (or CMI increases), a 100% braking action can be not effective in lowering Δ*V*. It is possible to represent the impacts of Fig. 10 in the CMI-V_{r_PDOF} plane [40], resulting in the situation shown in Fig. 11. Distinguishing between the possible ADAS interventions following Fig. 10 convention, it is evidenced that the adaptive logic (c) involves Δ*V* always lower in respect to the 100% braking condition (b), because of the lower CMI; in such cases, the "No intervention" logic (a) is preferable to a 100% braking action.

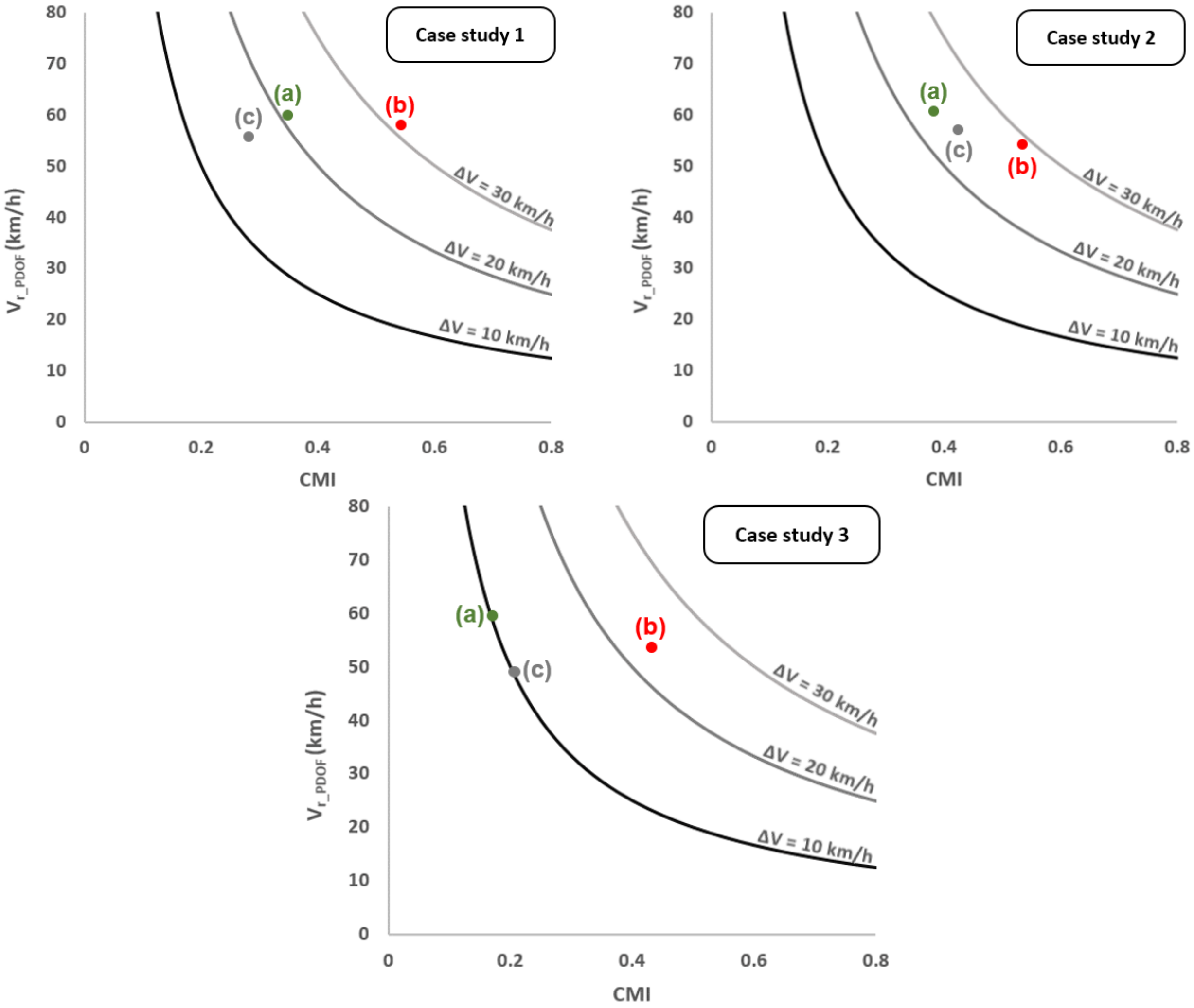


Fig. 11. Representation of the impacts on the CMI-V_{r_PDOF} plane for case study 1-3, in case of no intervention (a), 100% braking action (b) and adaptive logic (c).

In Tab. 3 the outcomes in terms of IR for each case study are reported, based on the logic selected for activation. Coherently with the above expressed concepts, the adaptive logic implies a lower IR value in comparison to the other intervention logics. The maximum benefit deriving from the use of the criteria is evidenced in case study 1: IR deriving from the use of the adaptive logic is equal to 4% (ΔV=16 km/h), instead of 34% obtained by the 100% braking action intervention (ΔV=32 km/h).

Tab. 3. Outcomes in terms of IR associated to each case study, based on the ADAS logic selected for activation.

Case study	Intervention	IR
1	No intervention	9%
	100% braking	34%
	Adaptive logic	4%
2	No intervention	20%
	100% braking	41%
	Adaptive logic	19%
3	No intervention	1%
	100% braking	16%
	Adaptive logic	1%

CONCLUSIONS

The present work analyses solutions for ADAS activation based on criteria for the minimization of injury risk (IR) and clearance. In this work are shown the characteristics and tools required for the application of such criteria to adaptive logics, allowing the ADAS to adapt to the scenario evolution. Three case studies are examined to demonstrate the criteria effectiveness, comparing the solutions with current ADAS activation logics.

A special developed software is firstly introduced, set up to analyze the behavior of an ADAS device implementing the IR-based criteria: the software is based on a database filled with outcomes associated to combined interventions on braking and steering, in many critical scenarios; since the injury outcome (i.e., IR) depends on the velocity change ΔV experienced by the vehicle in the eventual impact, the database has been compiled using a reduced order dynamic model to simulate the impact phase between the vehicles. The use of a database allows to identify the best intervention in a short time, i.e., the time necessary to access to the database (some milliseconds): this solution is to be preferred with a view of an on-board vehicle implementation of the criteria. Referring to some case studies, it has been proven that the IR-based criteria for ADAS activation allow the vehicle to optimally handle highly critical road scenarios, and in particular ICS: adapting to the scenario evolution resulting from the opponent vehicle's driver actions, the system leads to eccentrical impact configurations; this is compatible with low values of ΔV, and IR as a consequence.

Even though explorative, the present work evidences the advantages deriving from the use of the proposed criteria and how the ADAS implementing such criteria can be further optimized. Currently, as a priority, the simulated intervention minimizes IR for the vehicle on which the ADAS is implemented: minimization of IR for the opponent vehicle is also possible, as well as the average IR between the two vehicles. Including IR for the opponent among the intervention criteria, their application field could be further expanded, considering that IR curves for different types of vehicles (e.g., motorcycles) or vulnerable road users can be found in literature. Furtherly, the discussion can also be expanded to IR curves associated to MAIS lower than 3 (e.g., MAIS 2+), thus including lower degrees of injury: this would allow to limit the number of serious injuries and also moderate injuries, allowing to amplify the overall effects on road safety.

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