AUTOMATIC OPENING OF EMERGENCY WINDOW BY MAGNETIC RELEASE MECHANISM

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ABSTRACT
The main objective is to facilitate quicker and safer evacuation of passengers in case of frontal and rear impact of bus by automatic opening of emergency windows. The integrated magnetic release mechanism controlled by various sensors like piezo sensor, accelerometer sensor, temperature sensor and poison gas sensor installed at various locations inside the bus, helps in releasing the emergency windows during an impact. This reduces the time the passenger takes to exile the bus as the need for break opening of the windows is avoided. This system also facilitates increased number of exit points for the passengers by changing all windows into exit windows. At normal situations, the metal beaded windows are held firmly in position by the magnet, whereas during impact it releases the windows without damaging them which increases the longevity of the system.

INTRODUCTION
The present system of emergency exit consists of a breakable window with a provision of a hammer. However during impact the because of sudden G-force change and Post-Traumatic Stress Disorder, the normal human response time increases. This delay increases the time taken to come out of the bus which can dangerous in case of accidents involving fire or those involving spreading of poisonous gases. This can be reduced by using the proposed system

Figure 1: emergency window with hammer to break open

The proposed system consists of metal beaded windows, Piezo sensors, accelerometer sensor, poison gas detector and temperature sensor. These sensors when activated, sends signal which is used to drive the servo motor. The servo motor turns the diametrically magnetized cylindrical permanent magnet. This changes the magnetic field, causing the emergency windows to open. This is advantageous because in case of minor incident, then we can override the system and close the windows and operate the bus.

BACKGROUND

Magnetic Setup consists of a permanent cylindrical diametrically magnetized neodymium magnet. It is installed similar to a magnetic V- block (shown in *fig 2).*

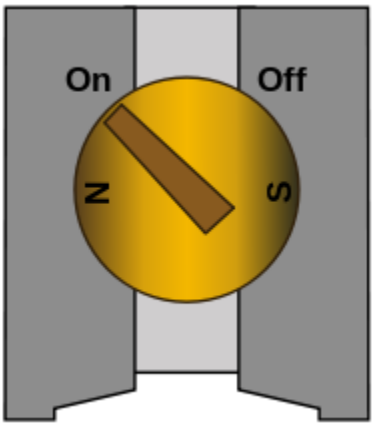

Figure 2: Magnetic V-block

The center permanent magnet, due to its field strength holds the metal piece firmly in its position. The magnetic strength of the permanent magnet on the metal strip at a distance is given by

$B_r (r, Ø) = \mu_o * M * a^2 * \cos (Ø) / 2 * r^2$
$B_Ø (r, Ø) = \mu_o * M * a^2 * \sin (Ø) / 2 * r^2$

Where,
M= magnetization of the magnet
r and Ø are cylindrical coordinates of the metal strip from poles of the magnet

From above equations, the magnetic strength is inversely proportional to the square of distance of the magnet, when the magnet is turned away using a servo motor, the distance of the poles from metal strip increases therefore causing the strength to decrease, thus resulting in opening of the windows.

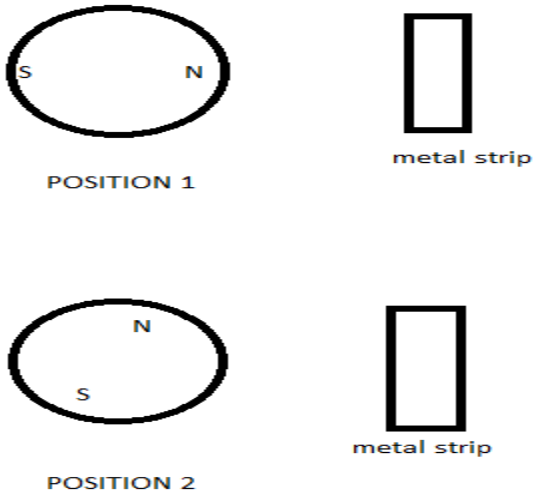

Figure 3: Positions of the magnet

The position 1 (in figure 3) shows the position of the magnet during normal working conditions of the bus. Position 2 shows the magnet being displaced by a motor which results in opening of the windows.

The Poison Gas Detector is installed inside the bus and it send signal to the central ECU when the gas concentration crosses the maximum ppm range tolerable by humans.

Accelerometer sensor detects the vibration level of the bus structure. During an event of accident where the structure undergoes vibration above the particular the standard WBV (whole Body Vibration), Then it send signal to the ECU. Also the Piezo sensors installed at various locations on the bus when impacted will send signal to the ECU.

Temperature Sensor monitors the temperature inside the bus and when it detects a sudden rise in temperature above the desirable limits, it send signal to the ECU.

Electronic Control Unit receives signal from sensors installed at different locations on the bus. When signal comes from the sensors, it activates the warning indicator present in the display unit present near to the driver and it also controls the servo motor to rotate the cylindrical magnet away from the metal strip (90°).

The overall schemtic layout of the emergency system is shown in *figur 4*

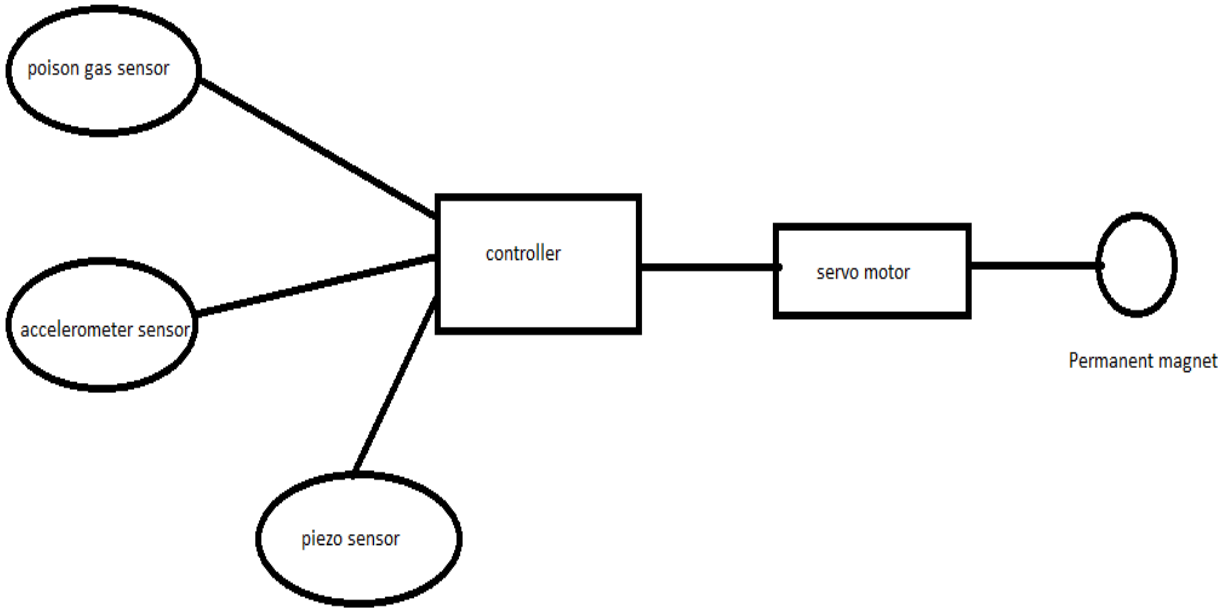

Figure 4: Schematic Representation of the system

CONCLUSION AND RECOMMENDATION

The proposed system can help in quicker evacuation of the passengers because of reducing the time required to open the emergency windows, in case of frontal impact, rear impact and fire accidents. Due to the increasing the number of accidents[1] involving buses, the need to improve the safety features of the existing buses is an ultimate requirement.
However the proposed system doesn't provide any advantage over the current system in case of rollovers.

1: Asia-Pacific road accident statistics

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OCCUPANT PROTECTION PERFORMANCE IN SIDE IMPACT COLLISIONS PRECEDED BY PRE-CRASH DEPLOYMENT OF ON-BOARD SAFETY SYSTEMS

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ABSTRACT

This paper presents a simulation methodology for developing new automotive safety systems in an integrated manner that ensures optimal exploitation of benefits of predictive sensing and occupant restraints.
The investigation was performed using the combination of available simulation techniques for modeling Advance Driver Assistance Systems (PreScan software) and simulating the behavior of dummies and real humans under certain load conditions (MADYMO software and Active Human Model (AHM)).
The methodology was applied to investigate the occupant protection in side impact collisions making use of pre-crash deployed safety systems, such as pre-crash thorax airbag, inflatable seat bolsters, movable seat and a combination of them. The impact load on the dummy was derived from the simulation of the full FE vehicle under Euro NCAP Side Impact Testing protocol conditions.
The results obtained showed the clear potential of adopting an integrated safety system for side impact protection applications. When the collision is detected in advance the time gained can be exploited to increase the overall occupant protection by deploying safety countermeasures prior to the crash. Keeping the occupant further from the intrusion zone, reducing the relative impact velocity and controlling the occupant motion when entering the in-crash phase were key to significantly reduce the injury risk.
To realize the above phenomena, different pre-crash concept occupant motion solutions were defined and investigated: pre-crash deployed thoracic airbag, pre-crash deployed side-bolsters and pre-crash deployed laterally moving seat. Additionally combinations of each solution were investigated. The simulation analysis showed the best protection is ensured by the system combined of side-bolsters and moving seat deployed before the collision, in which case the overall injury risk was lowered from 130% to 44%, when expressed as values normalized with respect to high performance Euro NCAP limits.

INTRODUCTION

Worldwide, the number of people killed in road traffic crashes each year is estimated at almost 1.2 million, while the number of people injured could be as high as 50 million [1, 2, 3]. Without increased efforts and new initiatives, the total number of road traffic deaths worldwide and injuries is forecast to rise by some 65% between 2004 and 2030 becoming the fifth most likely cause of death [4].
Improving vehicle safety is a key strategy used in addressing international and national road casualty reduction targets and in leading to a safer road traffic system. It is also one of the major research areas in automotive engineering [5]. The safety of vehicle occupants has evolved recently due to the market implementation of new sensing technologies that enable to predict and identify hazardous road traffic situations and thus actively prevent or mitigate collisions. The upcoming safety developments lead to the potential future integration of these technologies with the conventional passive safety, where the safety systems are deployed based on crash sensing.
The integrated safety system proposed for the future focuses on managing the information from the predictive sensing about the imminent collision and communicating it to the on-board restraint systems to optimally protect the occupants and thus further reduce the injury risk in case of a collision. Developing an integrated safety system doesn't mean only to fuse together the active and passive systems. The work behind the fusion concerns the necessity of first developing the system in an integral manner and then studying and assessing what is its global effect on the injury mitigation.

Being at the beginning of the development of this new family of safety systems, at the moment there's lack of literature reference regarding this topic. New experimental methods and simulation tools for evaluating the efforts of pre-crash dynamics on the occupant injury risk during the crash phase are needed.
The present paper shows and proposes a simulation methodology created to support an integrated safety system development process for side collision application. Analyzing traffic accident statistics, it comes out that side impact is one of the car accident typologies and also one of the most critical sources of fatalities. According to the American Insurance Institute for Highway Safety (IIHS), side impact crashes accounted for 27 percent of passenger vehicle occupant deaths in the United States in 2009 [6].
The higher level of danger related to the side impact, if compared to the one caused by frontal crashes, lies in the considerably lower energy absorption capabilities of side structures and consequently larger intrusion and higher risk of injuries resulting from the contact with them [7]. The limitations of further improvements to vehicle safety for the side impact collisions motivate the development of innovative methods to lower the injuries and make the vehicle safer.
This paper presents the methodology for developing and testing the integrated safety system for side collision application and provides a safety performance overview of different pre-crash occupant protection countermeasures compared to a regular in-crash protection system used as a performance reference.

METHODOLOGY

Tools

The methodology used in the study follows the one illustrated in the paper published at SAE International in 2013 by M. Velardocchia at al. [8] in which a virtual integrated safety development platform was created and assessed. The methodology consists of the coupled and complementary use of two software packages: PreScan and Madymo [8]. PreScan was used for accident scenarios modeling and for designing the sensing and control systems for the side collision recognition, whereas Madymo was utilized for assessing the effects of pre-crash deployment of the thorax airbag.
In the Figure 1 the schematic illustration of the methodology and its tools derived from the previously published investigations [8] is presented. The analysis starts from the real world scenario that determines input boundary conditions for PreScan in which the vehicle maneuvering is being simulated. The results produced by PreScan simulation are then fed to MADYMO in order to simulate pre- and in-crash crash actions on the occupant motion. The consequent effects on the in-crash phase determine the injury values, thus the occupant response.

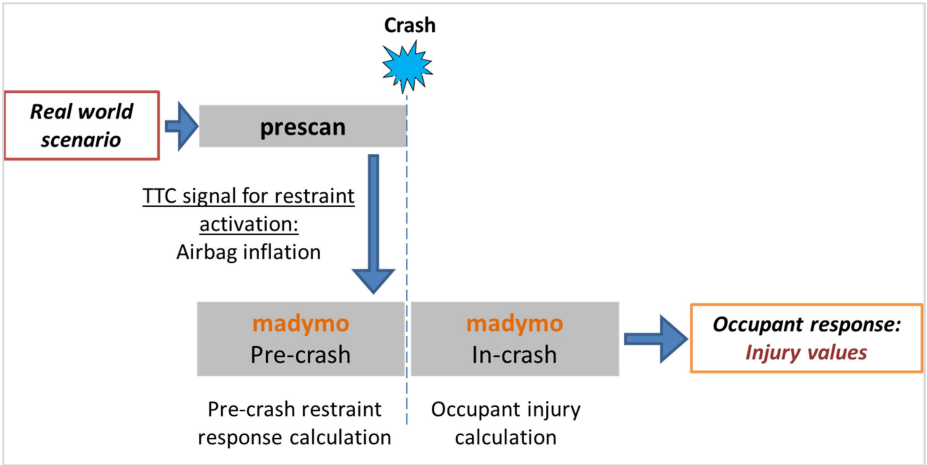


Figure1. The methodology: combined usage of PreScan and Madymo.

The parameters used to give a quantification of the injuries on the occupant in the EuroNCAP side impact test protocol refer to head, chest, abdomen and pelvis; more details about injuries parameters are available in the Appendix section. Since the Head Protection Criteria (HPC) is typically not significant in these crash conditions and has a low value when compared to the low performance limits, this was not used in the present study as protection performance parameter.

The focus of this study was then on the rib deflection, on the viscous criterion, on the abdomen peak force and on the pubic symphysis peak force. In particular, the protection system performance was based on the comparison with respect to the high performance limits (see Figure 2) of the EuroNCAP "Side Impact Test Protocol", version 5.2, from November 2011.

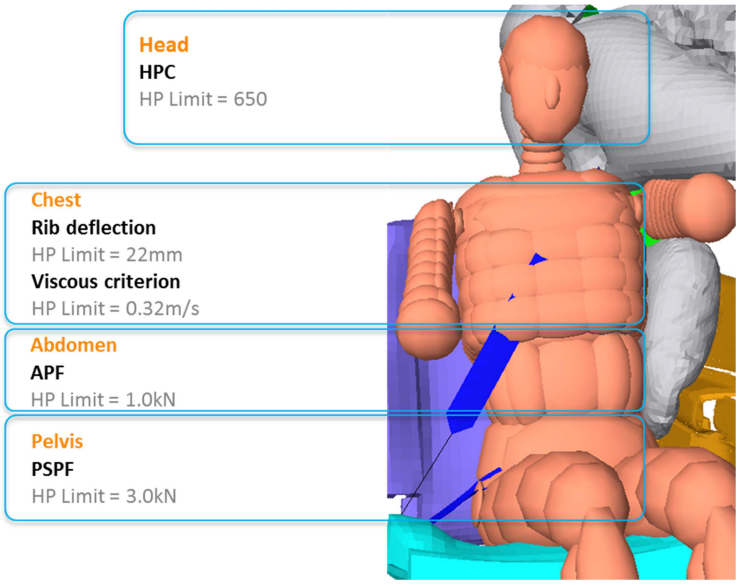


Figure2. EuroNCAP high performance protection criteria in side impact.

Case study scenario

The present study was carried out with the aim of modeling a side impact scenario which represents real accident data gathered by surveys. M. Velardocchia et al. [8] points out that typical side impacts occur in urban areas, when one of the two vehicles involved runs a red traffic light, other traffic control such as a stop or yield sign, or tries to perform an incorrect maneuver for turning and driving into another road.
Resting upon this information a representative scenario was selected as object of the investigation and modeled with PreScan. The scenario represents an urban intersection in daylight conditions, where a couple of generic compact cars are involved in a side impact (Figure 3).

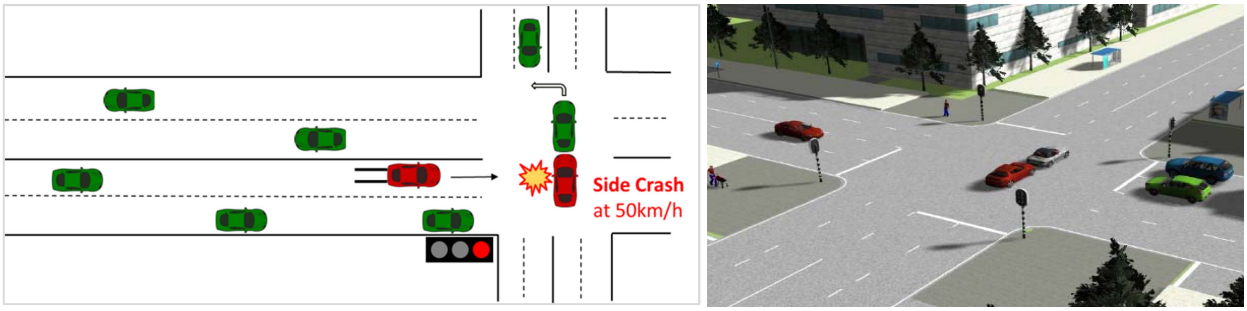


Figure3. Studied side impact scenario.

At the moment of impact the struck car (hosting the side impact pre-crash system) is stationary on the road crossing, queuing for a left turn. It is blocking the lane for the upcoming traffic from perpendicular direction. The striking car on the perpendicular lane is initially travelling at 60 km/h, fails to notice the red traffic light, and collides with the struck car at a velocity of 50 km/h, after an emergency braking performed by the driver.
The scenario represents the layout of a real life side impact and the resulting accident dynamics is in line with the one required by European regulatory [9] and consumer [10] side test protocols, where the car under examination is struck by a mobile deformable barrier (MDB) moving at 50 km/h and colliding at an angle of 90 degrees with respect to the tested vehicle.

The test condition parameters are as follows:
1. Impacted car speed: 0 km/h (stationary);
2. Impacting car speed: 50 km/h;
3. Angle of impact: 90 degrees;
4. Side of impact: driver side.

Pre-Crash Detection System

The vehicle that undergoes the side impact is equipped with two idealized surrounding sensors located on the impact side of the vehicle and at the same location in the vehicle longitudinal direction. The two sensors are:
    1. Short Range Radar (SRR) with a single detecting beam;
    2. SRR with 20 scanning beams.

Besides the different number of scanning beams, the other scan parameters are the same for both radars:
1. Horizontal scan;
2. Maximum range: 30[m];
3. Field of View (FoV) in Azimuth: 80[°];
4. Field of View in Elevation: 3.5[°];
5. Heading angle: 70[°];
6. Total scanning frequency: 100[Hz].

The two radars work constantly together although each one is assigned a specific task: the single beam radar detects the objects inside the field of view, pre-selects collidable ones and calculates the time to collision (TTC); in parallel the multiple beam radar is in charge of identifying vehicles among the collidable objects. Making use of the data from the two radars and fusing them, the detection algorithm is able to identify the presence of a collidable vehicle. When the TTC of a collidable vehicle is less than 0.6s, then the necessary condition to activate the desired on-board pre-crash device is satisfied.
A detection performance assessment of the algorithm was executed in [8]: results showed that the system could detect an impending side collision 150ms before this actually took place, in the worst case. Starting from this assumption and considering an additional margin of risk, all the studied pre-crash countermeasures that will be showed in the following paragraph were always triggered not more than100ms before the crash.

Vehicle Model And Restraint Systems

The side impact dynamics and the consequent injuries on a hypothetical occupant sitting in a vehicle equipped with collision detection system and pre-crash restraint systems were studied by building and using a virtual vehicle model with the tool MADYMO.
The side impact load on the driver was obtained by giving the side structure (B-pillar and door) and the seat a prescribed motion as obtained from the simulation of a Finite Element (FE) full vehicle system impacted by a Mobile Deformable Barrier (MDB) at the speed of 50 [km/h].
The vehicle model representation is simplified, as limited to the components relevant for the interaction with the occupant in the side impact collision load case: the seat, door and B-pillar. The door model is built using Multibody techniques and consists of several parts representing the elements of door structure and door trim. The external geometry of each element is represented by rigid FE models that are assigned to the corresponding door part and form together the entire door. The deformation of the door during the collision (door intrusion) is represented by prescribed motion of the bodies of appropriate door parts. The local deformability of the door trim that results from the interaction with the occupant is represented in a simplified manner using translational joints between the external trim geometry and underlying moving bodies. The compliance of the joints is restrained using distance-force characteristics that were tuned to represent the local deformability of each part of the door including the crushable and energy absorbing structures. The seat and the B-pillar motion resulting from the collision deformations is prescribed in a similar manner as for the door. The contact characteristics and material properties of the seat cushion were tuned in order to simulate accurate interactions with the dummy during its relative motion.
The base Madymo model also contains: a 3-point seat belt, a curtain airbag and a seat mounted thorax airbag.
The seat belt insertion points are attached to the B-pillar and the seat. The seat belt is equipped with a retractor and a pretensioner. The pretensioner was triggered at the time of 8ms after the crash in all considered cases; the curtain and the thorax airbags are also triggered 8ms after the crash.
The curtain airbag is a cushion of about 35liter in size. This is attached to nodes moving according to the deforming structure simulated in the full FE vehicle crash mentioned above.

The thorax airbag has a volume of about 10.5liter; the inflator used reaches 223kPa when inflated in a 10liter closed tank. Its permeability is set to 0.5% and vent hole diameter is 6.2mm.
The reference model so far described was then modified so that pre-crash protection systems could be implemented and studied. The three investigated restraint systems presented in this paper are:

1. Pre-crash thorax airbag

The pre-crash thorax airbag was already investigated and assessed in [8]. In the current study it is again mentioned for comparison with the other proposed solutions. The optimization study performed previously brought as result a thorax airbag model with the same cushion shape and material as in the reference model, which is deployed 100ms earlier than the reference thorax airbag (effectively 92ms before the crash). Furthermore, when the airbag deploys the vent hole (whose equivalent diameter is in this case 8.3mm) is still closed; only later, 15ms after the crash, the vent hole is opened.

2. Pre-crash inflatable seat bolsters

The solution with the inflatable seat bolsters was studied by Daimler-Benz AG for the Experimental Safety Vehicle program in 2009, called ESF 2009 [11, 12]. Following the information available about this study, two inflating bolsters located respectively in the seat cushion and in the seat back cushion (only on the impact side) were implemented in the base Madymo model. They have been modeled as two ellipsoids attached to their own translational joint. The countermeasure is triggered 92ms before the crash; when the system is deployed, the ellipsoids move 40mm towards the dummy, pushing it towards the center of the vehicle. In particular, one ellipsoid acts on the thorax and the abdomen of the dummy, whereas the other ellipsoid pushes its pelvis and its outer leg. The bolsters can move back to their initial position according to a load characteristic specifically tuned to minimize the chest deflection of the dummy in the phase preceding the contact with the thorax airbag. The thorax airbag is the same as in the reference model, therefore is deployed 8ms after the crash.

3. Pre-crash moving seat

Similar to the inflatable seat bolsters also the pre-crash moving seat was part of the ESF 2009 program [13]. The driver seat in the reference model is already attached to a joint and is moving with a prescribed motion during the in-crash phase. In the pre-crash phase it has been given an additional displacement of 50mm towards the center. The seat starts moving 92ms before the crash and stops at time t=0ms, whereas the thorax airbag is the same as in the reference model, therefore is deployed 8ms after the crash. The pre-crash seat travel was represented as prescribed motion following the S-shape displacement in time (see Figure 4). The resulting acceleration transmitted to the seat to execute the prescribed motion accordingly to the assumed seat motion, requires application of external force of 4.7kN, with the assumption that the total weight of the moving system (occupant and seat) amounts to 100kg. The plots illustrating the mechanics of the pre-crash seat motion are presented in the Figure 4.

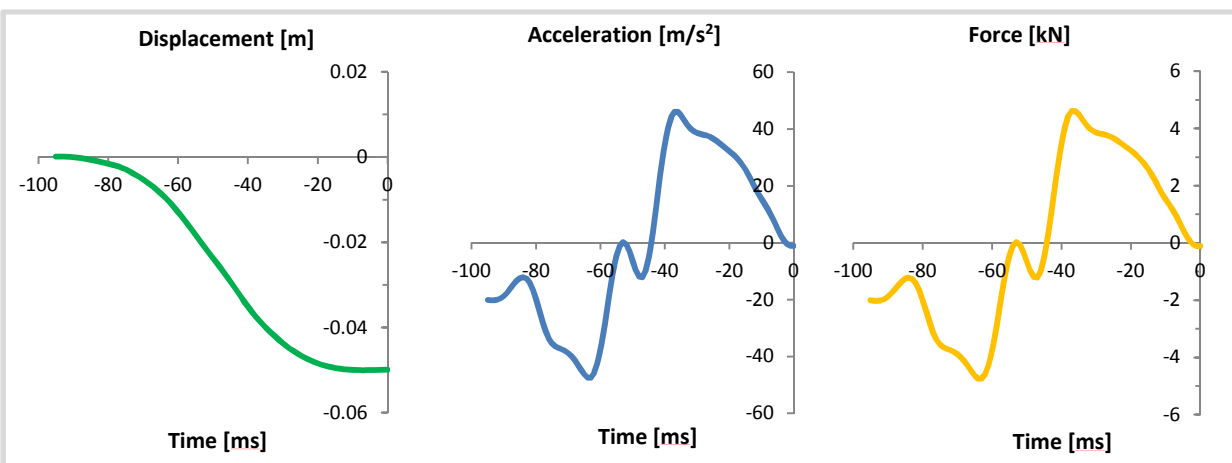


Figure4. Pre-crash moving seat displacement, acceleration and force plots.

An overview of the above-mentioned pre-crash safety systems is presented in Figure 5.

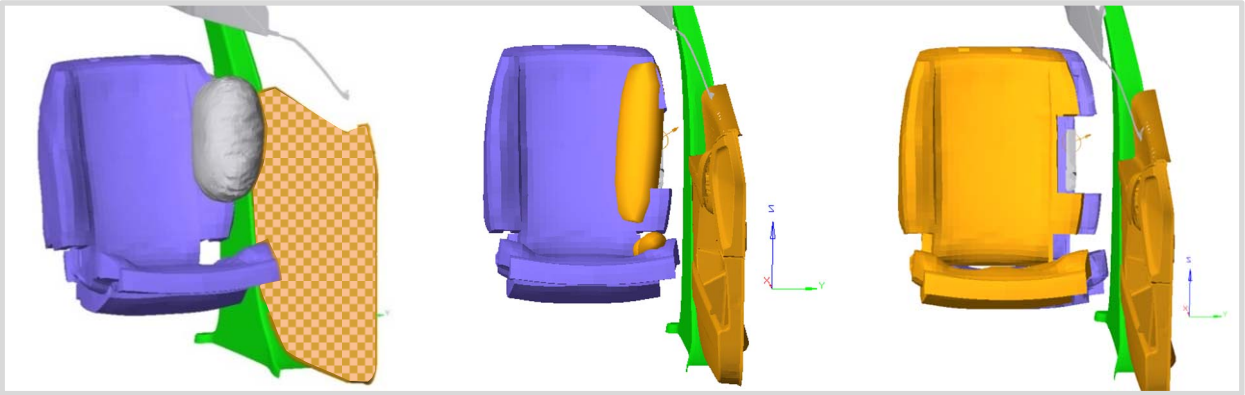


Figure5. Pre-crash safety systems; from left: thorax airbag, inflatable seat bolsters and movable seat.

The occupant dummy used throughout the complete investigation is the ES-2re Q Madymo ellipsoid dummy model.

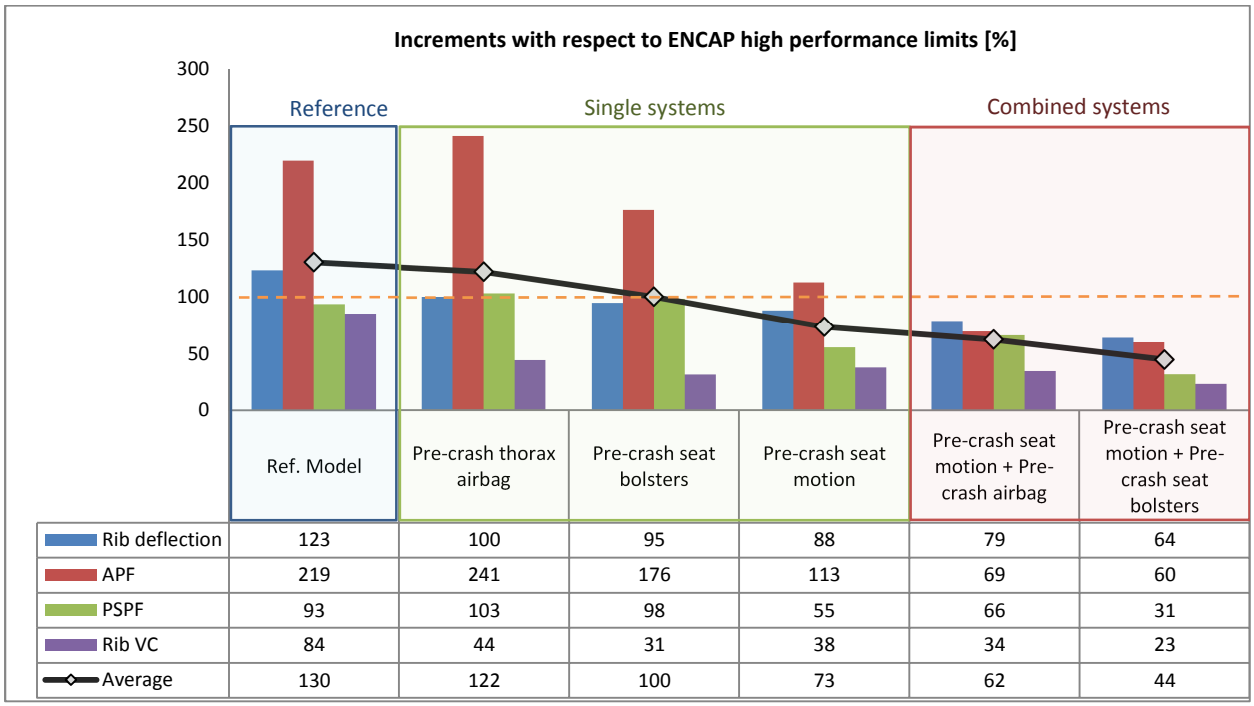
INVESTIGATION APPROACH

The need for the assessment of the potential of pre-crash activated protection systems arose directly from the results of the study [8] about the integrated safety potential in a side impact load case.
When using a pre-crash thorax airbag (with the specifics as described in the paragraph above), the chest deflection could be significantly improved. This confirmed the assumption that by pushing away the driver from the intrusion zone towards the center of the vehicle, it could be possible to significantly reduce the chest injuries. For rib deflection and rib VC parameters, the explained strategy led to reductions of about 20% and 50% respectively. Unfortunately a side effect was also observed, because APF and PSPF injury parameters showed a degradation of about 10 percent. The significance of the problem was related not only to the degradation of APF and PSPF injury parameters, but also to the fact that the APF, came dangerously close to the EuroNCAP protocol low performance limit, and thus could be considered as a significant limitation of the investigated system.
The analysis showed that the airbag, when deployed, interacts directly only with the thoracic and abdominal dummy regions, while the pelvic region is not loaded. This interaction generates the torque that causes lateral rotation of the dummy before the in-crash loading occurs. As a consequence, the pelvis and abdomen are not optimally restrained by the seat and by the thorax airbag respectively. In order to address the unwanted dummy rotation, and APF and PSPF deterioration, the dummy would need a more homogeneous push along the entire upper body region in the pre-crash phase.
Starting from these considerations, the first objective of the study was to find alternative solutions to the pre-crash thorax airbag which allow intervening more effectively on the occupant motion. The second objective was to quantify their potential as well as to make a comparison between the systems and with respect to the base model.
The reference protection system together with the investigated pre-crash occupant protection systems whose results are presented in the following paragraph, are listed below:

1. In-crash thorax airbag
2. Pre-crash thorax airbag
3. Pre-crash inflatable seat bolsters
4. Pre-crash moving seat
5. Pre-crash moving seat together with pre-crash thorax airbag
6. Pre-crash moving seat together with pre-crash inflatable seat bolsters

RESULTS

The injury values produced by the ES2-re dummy in the simulations are presented in Figure 6. Each value represents the ratio (expressed in percentage) between the calculated dummy injury value and the related high performance limit according to the EuroNCAP protocol (see Figure 2).



	Ref. Model	Pre-crash thorax airbag	Pre-crash seat bolsters	Pre-crash seat motion	Pre-crash seat motion + Pre-crash airbag	Pre-crash seat motion + Pre-crash seat bolsters
Rib deflection	123	100	95	88	79	64
APF	219	241	176	113	69	60
PSPF	93	103	98	55	66	31
Rib VC	84	44	31	38	34	23
Average	130	122	100	73	62	44

Figure6. Result overview: protection performance comparison among the different investigated solutions.

The safety performance of the reference model and of the pre-crash thorax airbag is the same as the one mentioned in the [8] and is here reported for a wider and more complete results analysis and discussion. As already mentioned in the Investigation Approach section, the most critical parameter for the dummy in the reference model is the APF, which is only 300N below the low performance limits and no less than 1.2kN above the high performance limits. Whereas the pre-crash thorax airbag showed good potential in the reduction of the chest related injuries, with no possibility to decrease the problematic APF, all the other investigated countermeasures provided an overall increased protection to the dummy, as this was observed for the chest, for the abdomen and for the pelvis.
The two single system solutions, namely the pre-crash inflatable seat bolsters and the pre-crash moving seat decreased the averaged injuries of the dummy from 130% to 100% and 73% respectively, with respect to the EuroNCAP high performance limits. Although the better protection of the chest area is comparable between the two systems, the main difference was encountered at the level of the abdomen and of the pelvis: the inflatable seat bolsters did not decrease the PSPF and could only reduce the APF by about 20%, whereas the moving seat could almost half both APF and PSPF. Therefore the overall protection performance of the moving seat was the best among the single system solutions.
Combining the pre-crash seat motion with the pre-crash airbag or pre-crash seat bolsters shows an increased potential in the dummy injury reduction when compared to both the reference model and the moving seat solution. The most important achievement is that all the injury peak values fall below the high performance threshold including APF. The model in which the pre-crash moving seat is combined with the inflatable seat bolsters could achieve an APF reduction of 73% with respect to the reference system, meaning about 1.6kN of less force acting on the abdominal area; the APF reduction for the other combined solution equals 68%. These results indicated that in case of fusion of two protection systems, no degradation of the overall injury performance occurred; rather there is potential for further improvements of injury levels. Only the PSPF peak value measured in the moving seat and pre-crash airbag combination increased slightly, although it remained safely below its reference value and below the high performance limits.

Besides the injury values, the simulations provided also other useful information necessary for the comprehension and the analysis of the results. Each system, as already highlighted in this paper, intends to give the dummy an initial impetus towards the center of the vehicle. The animation output shows the differences between how each investigated solution had acted on the dummy pre-crash motion and is presented in the Figure 7.

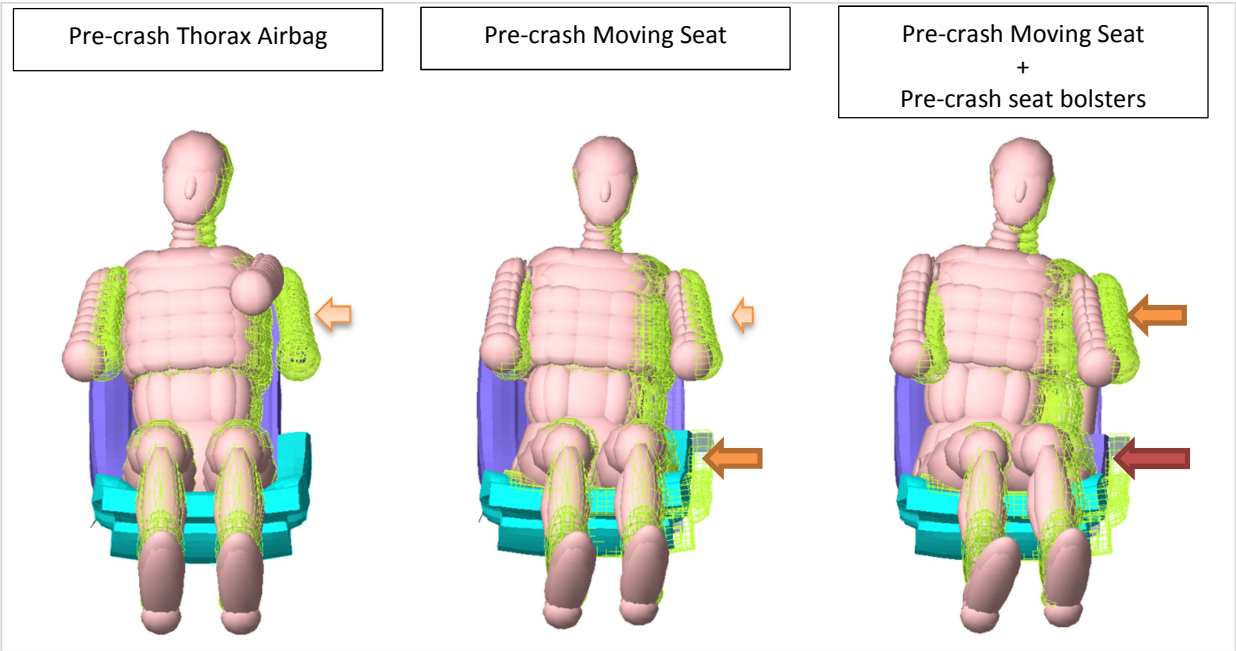


Figure7. Dummy position at the crash time t = 0ms in three different models. Green coloring is used for reference dummy model position.

The first investigated solution, the pre-crash thorax airbag, pushes the dummy directly on the rib cage, resulting in a rotation of the upper body around the pelvis which itself does not move significantly (see Figure 7). When the side structures start intruding into the vehicle, the first contacts occur with the pelvis and with the abdomen which are not protected by the airbag, causing a worsening of APF and PSPF. Only the thorax, which is already supported by the cushion, can be efficiently protected.
The direction of the upper body rotation observed for the other four studied solutions was different; two of them are taken as example and presented in Figure 7, in order to show and explain this different behavior.
In the pre-crash moving seat solution, the seat pushes the dummy mostly from the pelvis. Because of the inertia the upper part of the body tends to remain in the original position; the contact of shoulder and chest with the seat back cushion gives some additional support to the dummy during the desired pre-crash motion, although the dummy is clearly rotated outwards. Despite this, the effective relative distance of chest, abdomen and pelvis from the door is increased, whereas the head stays almost in the initial position.
Similar considerations can be made on the last pictured solution (see Figure 7), the combination of the moving seat and the inflatable seat bolsters. Also in this case the upper body is rotated outward as a result of the direct push of the seat cushion on the pelvis. There is however a difference, which consists in the higher overall force applied to the dummy and which is directly depending on the fact that during the pre-crash seat motion also the inflatable seat bolsters are deployed.
Each system performed differently from the other but the common factor was that, in all the cases, the effect of acting on the occupant motion before the crash was always beneficial. The injury curves showed a close and direct link between the injury peak values and the time when these were measured: the more significant push on the dummy, the faster it moved away and the bigger the gap from the intrusion zone. As a consequence the loads on the dummy body regions started later and less and less intensely, as the intrusion velocity and the related effect on the dummy decreases during the crash from the peak value (at crash time t=0ms) to zero, when the maximum intrusion is measured.
Besides the importance of giving the dummy more space and initial velocity at the moment of the crash, the results showed the importance of the upper body orientation. In particular, having the dummy upper body orientated outward was found to be consistently effective in the reduction of all the injury values, throughout all the

investigated solutions. The described position shows to work effectively in the distribution of the load on the dummy as it enters the in-crash phase with an angle which is very similar to the one that it will get throughout the loading phase: this prevents the 'pendulum' effect observed when using the pre-crash thorax airbag, thus allowing a more evenly distributed load on the dummy.

CONCLUSIONS

The paper intends to present a methodology based on the coupled use of two software packages to simulate road accident scenarios by designing a side collision detection system (PreScan) and assessing the effects of pre-crash strategies on injury parameters on a virtual dummy model (Madymo).
The investigation into different pre-crash deployed injury conceptual countermeasures showed that the most effective occupant motion control system is the one in which the pre-crash inflatable seat bolsters system is coupled with the pre-crash moving seat solution. The two countermeasures are triggered simultaneously 92ms before the crash, while the thorax airbag and the seat belt pretensioner are trigger 8ms after the crash as in the reference model. With this proposed occupant protection it was possible to bring the peak values of rib deflection, APF, PSPF and VC, below the EuroNCAP high performance limits.
The most significant improvement were obtained on the APF, as this was lowered by 73% with respect to the reference system, meaning about 1.6kN of less force acting on the abdominal area. The rib deflection that in the reference model was above the high performance limits could be decreased by 48%. The average of the four injury parameters peak values dropped by about 65%.
The other investigated solutions showed also a significant potential in reducing injury values in all body regions and outlined the real potential of the integrated safety systems for side impact scenarios and which of the occupant motion control strategies are the most effective for injury risk reduction. It can be summarized that the key biomechanical phenomena that contribute most to the occupant protection for side impact loadings are:

a) increased distance between the occupant and parts of the vehicle that intrude during the side impact, that results in decreased contact speed between occupant and intruding parts
b) initial occupant velocity in the same direction as the impact direction, that additionally reduced the contact velocity between occuapnt and intruding parts
c) initial outward rotation of the lower body that results in a more equal distribution of the contact interaction between occupant nad intruding parts

Similar, conceptual level observations were previously published in [11].
Introduction of predictive sensing to the side collision protection and utilizing the information about the upcoming collision to take actions on the occupant pre-crash kinematics, results in the global occupant injury risk reduction. The aim was to demonstrate the potential of the new design concepts which are still not possible to implement in series production and/or are currently only mentioned in the literature, so as to stimulate discussion of the necessary technological developments.
The investigation was limited to the specific crash conditions and does not show the sensitivity of the proposed solutions to different load cases. In order to assess the total potential of predictive sensing for side impact collision application, future studies are needed to prove the usefulness of the proposed approach for other load cases, different occupant sizes and different vehicle types and sizes.
Integrated Safety is a new region of automotive safety and does not have established simulation methods in place. The combined use of PreScan and Madymo for side pre-crash study is one of the first applications of both software packages together for the Integrated Safety purposes. The use of this method requires expertise in both active and passive safety areas and additional effort from the user in terms of interface handling throughout the use of both software suits. It should be also noted that Madymo was originally designed for in-crash simulations, and its functionalities are not yet fully optimized for pre-crash problem analysis. One Madymo limitation is the lack of validated side impact dummy models for low-g loadings that occur during the pre-crash phase.
In conclusion, given the significant injury damage, typically accompanying side impact collisions and the yet limited understanding of the potential for integrated safety to address this issue, this paper intends to initiate the interest in further research that can exploit new predictive technologies to reduce the harm caused by side impact.

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APPENDIX

1. APF

The Abdominal Peak Force is a measure of injury to the abdomen: APF is the maximum side abdominal strain criterion and is expressed as the highest value of the sum of the three forces [N] measured at each abdominal load cell (front, middle and rear) on the impact side.

2. HPC

The Head Protection Criteria is the standardized maximum integral value of the head acceleration.

3. PSPF

PSPF is the criterion for pelvis strain during side impact and is determined by the maximum strain on the pubic symphysis, expressed in [kN].

4. RDC

The Rib Deflection Criteria is the criterion for the deflection of the ribs, expressed in millimeters [mm], in a side impact collision.

5. VC

Also called as Viscous Injury Response, VC is an injury criterion for the chest area. The VC value [m/s] is the maximum crush of the momentary product of the thorax deformation speed and the thorax deformation. Both quantities are determined by measuring the rib deflection.

A METHODOLOGY AND TOOL CHAIN TO DEVELOP INTEGRATED SAFETY SYSTEMS

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ABSTRACT

This paper presents a methodology that enables designing integrated safety systems. The advantages of the methodology are demonstrated by applying it to a passive safety system that is supplemented by an AEB active safety system. The passive and integrated safety systems are compared through simulations with a set of vehicles and occupants subjected to load cases obtained from regulations. The methodology reveals changes in injury mechanisms and advantages of the addition of AEB.

INTRODUCTION

Road vehicles are increasingly equipped with active safety systems that aid the driver in preventing frontal collisions (for example collision imminent braking (CIB), autonomous emergency braking (AEB) systems) as well as lateral collisions (for example lane departure warning (LDW) and lane keeping assistance (LKA) systems). These systems use sensing technologies like radar, lidar and cameras and are designed and introduced as safety systems that help avoid crashes or mitigate injuries when crashes are unavoidable.
Previous investigations on the effect of autonomous braking and evasive steering on the occupant's position have shown, that the occupant being out of position may result in an altered injury mechanism during the crash [1,2]. Furthermore, countermeasures like PRE-SAFE ® [3] or predictive pre-pretensioning are effective in reducing the occupant's out-of-position situation provided that the timing of the pre-tensioning of the belt is well-chosen.
In order to develop innovative restraint systems that provide an increased occupant protection, it is important that engineers are able to analyse the effects on the occupants of active systems that take over the control over the vehicle from the driver and understand why and how injury mechanism are altered.
This paper presents a methodology that enables an engineer to simulate various accident scenarios and to develop countermeasures to avoid adverse effects of increased injuries due to active safety system deployment. The methodology is demonstrated in the example case study of a frontal collision preceded by the activation of the AEB.

METHODOLOGY

The Integrated Safety System is a holistic vehicle safety system in which active safety systems and passive safety systems continuously exchange information regarding occupant state and vehicle state to provide the maximum protection to the occupants. Integrated Safety is a relatively new domain in the automotive safety landscape and production-level design processes are starting to be adapted to account for a further integration of passive and active safety system design. The methodology is illustrated in Figure 1.

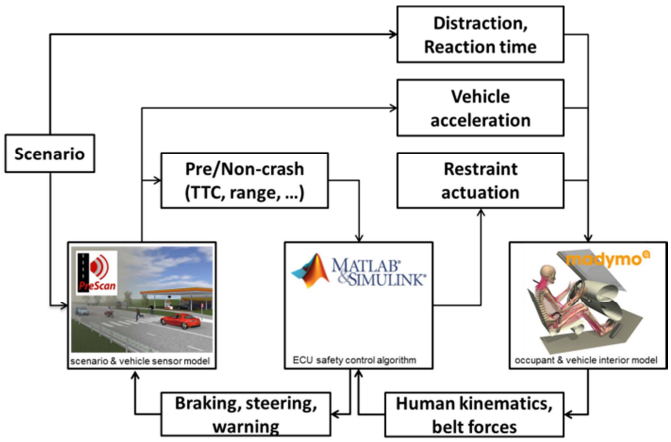

Figure 1. Integrated Safety Methodology

The accident scenario prescribes all boundary and initial conditions with respect to the participating vehicles and the human actors. Traditionally, when active safety system development and passive occupant restraint system development are separated, the scenario delivers information to both designs separately. In Figure 1 this is illustrated with the scenario that is described in an ADA development tool which feeds pre/non-crash information like time to collision, distance to preceding vehicle, etc. into the ECU safety control algorithm. In turn this algorithm provides modifications to the scenario like warnings to be given to the driver or interventions like braking or steering. Separately from this, the scenario provides occupant information like distraction and reaction time as well as vehicle information like its acceleration to enable an in-crash simulation to evaluate occupant safety.
When the ADA system influences the vehicle motion, be it pre- or in-crash, the vehicle motion no longer comes directly from a predefined scenario, but is to be communicated from the evolving scenario in the ADA tool to the occupant simulation to allow the simulation of pre-crash motion of the occupants as well as to determine initial conditions for the in-crash phase. Similarly, when the ADA system influences the restraint actuation, the conditions of the restraint system are to be communicated to the occupant safety simulation to start the in-crash simulation with the proper initial conditions.
Finally, the influence of the occupant restraint system on the occupant and visa versa is to be communicated back to the ECU safety control algorithm to allow for a feedback loop on the restraint actuation. This information can also be used to allow for a feedback loop on the vehicle parameters, i.e. the occupant state influences the strategy chosen to avoid or mitigate the collision.
The following simulation tools are used in this methodology [4]:

- PreScan: This tool allows to build scenarios, to design active safety systems using the tool's sensor models or by using users' own sensor data to develop and test algorithms of the ECUs. The tool also produces the vehicle's linear and angular velocity and acceleration data when the tool's or third-party vehicle dynamics models are used.
- Active Human Model (AHM): This tool allows to represent real human motion during pre-crash maneuvers with low acceleration levels [5,6,7]. Volunteer testing confirmed that the actual human being (50th %ile male volunteer) behaves differently compared to the Hybrid-III dummy during pre-crash manouvers with low acceleration levels. Hybrid-III dummies were mainly developed for high speed crashes and for in-position crash tests. Therefore Hybrid-III dummies are not adequate to predict human behavior during the pre-crash braking phase.
- MADYMO: MADYMO is a simulation tool to help analyze occupant behavior and calculate injuries during the crash.

APPLICATION

Here the strength of the methodology is illustrated by focussing on a pre-defined frontal collision accident in which an existing passive safety design is supplemented with an AEB system. It is analysed how this modification affects the occupant's safety by focussing on the human kinematics and the resulting changes in injury mechanisms.

Accident sequence

The frontal crash is divided in several phases, illustrated in Figure 2.

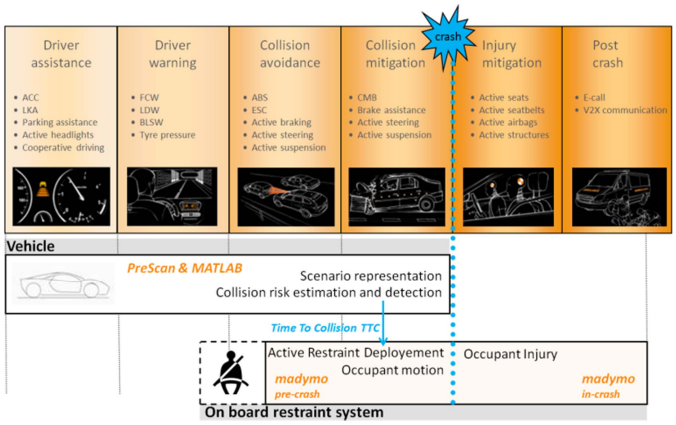

Figure 2. Sequence of the pre-collision and post-collision events

1. Driver warning phase: the radar / camera system detects an object in the path of the vehicle and sends a warning to the driver.
2. Collision avoidance phase: the ECU safety control algorithm determines that under the given circumstances a collision is likely and decides that the AEB system must be activated. The vehicle starts to decelerate with a given moderate deceleration level.
3. Collision mitigation phase: the ECU safety control algorithm determines that a collision can no longer be avoided and decides to apply a more aggressive decelleration strategy as well as to prepare the occupant restraint system for the imminent collision.
4. Injury mitigation phase: the AEB system does not stop the vehicle completely and the vehicle collides, the (activated) restraint system (seatbelts, airbags, etc.) provides protection to mitigate occupant injuries.

Assumptions and limitations

In this study we start from a traditional passive safety restraint system (containing dual stage inflated airbags, belts, belt load-limiters and belt pre-tensioners), used in the injury mitigation phase and wish to extend the safety system into the collision avoidance phase. Validated models for motorized seatbelt pretensioners or other types of OOP countermeasures were not available therefore not used in the analysis.
Furthermore, it is assumed that the crash speed is higher than the airbag deployment threshold speed and consequently the airbags still deploy.
This study is limited to one idealized braking profile, having moderate decelleration in the collision avoidance phase and aggressive decelleration in the collision mitigation phase, illustrated in Figure 3.

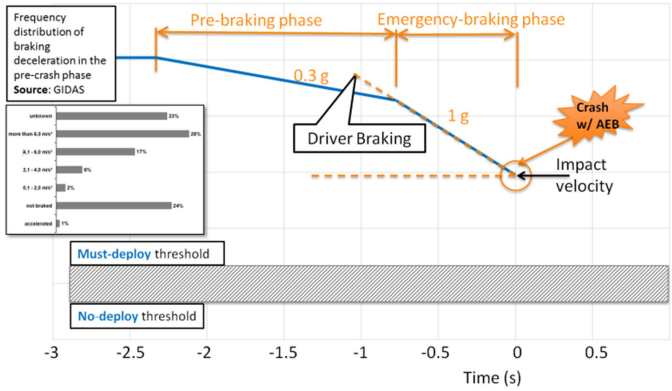

Figure 3. Pre-crash velocity profile

The braking profile contains two distinct phases, i.e. 0.3 g for 1 sec followed by 1 g's for 0.6 seconds. Many automakers use different braking strategies therefore produce different braking profiles. Although the profile is based on those considered by some of our customers, we realize it may not represent real-life braking performance of actual AEB systems currently in production.
In the study 3 MADYMO models are used that represent various vehicle types, i.e. a sports car (vehicle 1), a A/B-class vehicle (vehicle 5) and a C-class vehicle (vehicle 4). All vehicle models were fully validated against actual crash tests. Special attention was given to the models to make sure all occupants remain in an exact equilibrium when no load was applied to make them suitable for use in pre-crash simulations.
Three impact speeds were used in the analysis, i.e. protocol speeds from FMVSS 208 (25 mph, unbelted), US NCAP (35 mph) and Euro NCAP (64 km/h). To ensure that the impact simulations are all done at crash speeds for which the MADYMO models are validated and to exclude any effects on the injury levels from the reduced impact speed, the initial speeds for the AEB simulations were chosen to be 31.8 km/h (19.7 mph) higher as the non-AEB simulations which corresponds to the total reduction of speed of the chosen braking profile.
Besides this technical limitation of our analysis, we believe that although the goal of AEB is to reduce the impact speed, future accident statistics still have to confirm that impact speeds have indeed reduced due to the introduction of AEB. Until then, it seems wise to continue to adopt the accepted protocol speeds for the in-crash scenarios.

Simulation set-up

For each vehicle, 3 occupant models are used, i.e. the Hybrid-III 5%ile ATD, Hybrid-III 50%ile ATD and the Active Human Model 50%. All occupant models were used in both the driver as well as the passenger configuration and each was subjected to three impact configurations, i.e. a rigid wall belted, a rigid wall unbelted and an ODB condition, conforming to the choice of impact speeds. The simulation matrix is illustrated in Figure 4.
For all these 54 combinations a standard impact scenario as well as an impact scenario preceded by AEB was analysed. Note that for vehicle 1 the ODB validation of the model was not available, i.e. in the end 48 different load cases were analysed.

			Impact speeds [km/h]					
			RW -B		RW - UB		ODB	
			std	AEB	std	AEB	std	AEB
Driver	5 % Hybrid-III	Vehicle 01	56	56	40	40	*na*	*na*
		Vehicle 04	56	56	40	40	64	64
		Vehicle 05	56	56	40	40	64	64
	50 % Hybrid-III	Vehicle 01	56	56	40	40	*na*	*na*
		Vehicle 04	56	56	40	40	64	64
		Vehicle 05	56	56	40	40	64	64
	50 % AHM	Vehicle 01	56	56	40	40	*na*	*na*
		Vehicle 04	56	56	40	40	64	64
		Vehicle 05	56	56	40	40	64	64
Passenger	5 % Hybrid-III	Vehicle 01	56	56	40	40	*na*	*na*
		Vehicle 04	56	56	40	40	64	64
		Vehicle 05	56	56	40	40	64	64
	50 % Hybrid-III	Vehicle 01	56	56	40	40	*na*	*na*
		Vehicle 04	56	56	40	40	64	64
		Vehicle 05	56	56	40	40	64	64
	50 % AHM	Vehicle 01	56	56	40	40	*na*	*na*
		Vehicle 04	56	56	40	40	64	64
		Vehicle 05	56	56	40	40	64	64

64	Impact speed of model used for study [km/h]
na	No material available for study
std	Standard Loadcase as defined per protocol
AEB	With braking, scenario (impact speed = protocol impact speed)
RW - B	Rigid Wall Belted - FMVSS208/USNCAP 35 mph test
RW - UB	Rigid Wall Un-Belted - USNCAP 25 mph test
ODB	Offset Deformable Barrier - EuroNCAP 64 km/h

Figure 4. Simulation Matrix 2

Belt retractor model

In order to mimic real life situations as closely as possibly, the belt retractor model, including a detailed locking mechanism was used in the simulations. Similar to a real-world example, a small ball triggers the locking mechanism after it has travelled 2 mm of distance against a sloped surface. The angle of this surface represents the acceleration level at which the locking device should trigger. The mechanism is designed to trigger only when subjected to accelerations of more than 0.30 g, see Figure 5 for an illustration.
In order to prevent seat belts from slipping down on the occupant during the pre-braking phase, a continuous retraction force of 5N is applied to the retractor belt output, until the locking mechanism is triggered.

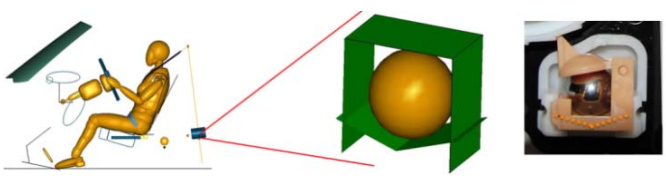

Figure 5. Simulation model of the belt locking mechanism

Using these models, a series of simulations were run to assess injuries and injury mechanisms of occupants by intentionally introducing the braking effect before the crash. In this study, the simulation was done as follows:

1. The pre-defined vehicle acceleration illustrated in Figure 3 was applied to the MADYMO model with occupants to predict the position of the occupants;
2. Subsequently, the occupant was subjected to the crash pulse belonging to the specific load case being analysed, see Figure 4;
3. Injury numbers from MADYMO models were obtained and normalized to the injury targets specified in Table 1. The new injury numbers were compared to the baseline injury numbers from models without braking effect.

RESULTS

The objective of this study is to identify any changes affecting the occupant safety level from the activation of AEB, for example changes in injury mechanisms. In order to compare all simulation results, a selection of injuries is made based on what is common for US and EU regulations such that the four main areas (Head, Neck, Chest and Femurs) of an occupant are covered in the comparison. For each of the areas a target performance was selected based on maximum values allowed in various protocols. These target performances, see Table 1, are only used to calculate the relative improvement or degradation of a "crash situation with AEB" compared to the standard crash situation without AEB, i.e. the calculated percentage is a percentage of the Target Performance. For the Active Human Model the injury target values for the Hybrid-III 50%ile dummy are used.

Table 1.
Summary of the target injury performances

Type	Region	Injury	Unit	Target	Ref.
Hybrid-III 5%ile	Head	HIC15	-	700	3
		a 3ms	g	80	1
	Neck	Nij	-	1	3
	Chest	Chest deflection	mm	52	3
		a 3ms	g	60	3
	Femur	Load LHS/RHS	kN	6.805	3
Hybrid-III 50%ile	Head	HIC36	-	1000	1
		a 3ms	g	80	1
	Neck	Nij	-	1	2
	Chest	Chest deflection	mm	50	1
		a 3ms	g	60	2
	Femur	Load LHS/RHS	kN	9.070	1
Active Human Model 50%ile	Head	HIC36	-	1000	1
		a 3ms	g	80	1
	Neck	Nij	-	1	2
	Chest	Rib deflections	mm	50	1
		Rib 3ms	g	60	2
		a 3ms	g	60	2
	Femur	Load LHS/RHS	kN	9.070	1

*1 ECE R95 - injury limit values for a Hybrid-III 50%ile
*2 FMVSS 208 - injury limit values for a Hybrid-III 50%ile
*3 FMVSS 208 - injury limit values for a Hybrid-III 5%ile

The comparison between the injuries calculated from the 48 standard and 48 AEB load cases shows that the majority of the injuries *improves* due to pre-crash braking even though the impact velocities for standard and AEB load cases are the same, see Figure 6. The comparison also shows that injury mechanisms may change due to the pre-crash braking which results in an increase of some injuries. In the next section we will investigate the mechanisms responsible for these changes in more detail, using two cases for which an injury becomes worse by more than 20% and for which the injury value is close to the target value.

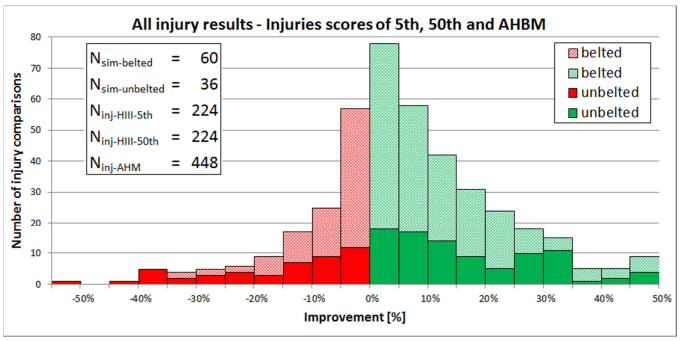

Figure 5. Distribution of injury scores comparisons between the collisions with and without AEB activation

Changed belt loading

Generally, it was observed that the pre-crash braking pulse causes the Hybrid-III 5%ile, 50%ile and Active Human to slide forward on the seat due to the pre-crash braking decelleration. For the Hybrid-III 5%ile this results in a change in injury mechanism observed in vehicle 1.

Compared to the standard case, the occupant loads the restraint system differently in the AEB case which causes the lap belt to slip off the illiac wings of the Hybrid-III 5%ile and submarining occurs. This results in an increased risk of abdominal injuries. The submarining additionally results in a further increased forward motion of the pelvis, i.e. the lapbelt is less effective in restraining the pelvis. Subsequently this results in a heavier impact of the femurs on the IP and consequently higher femur forces (see Figure 7).

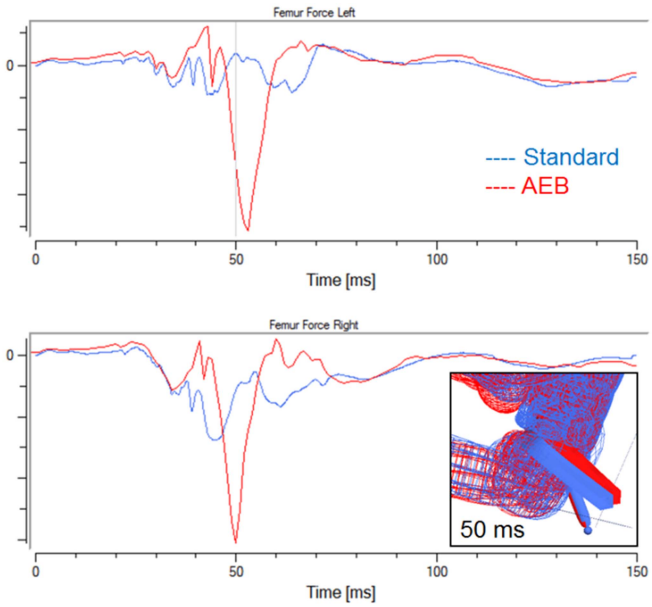

Figure 6. Illustration of the different belt loading causing higher femur forces and possible abdominal injuries.

Out-of-position effect

Another general observation is that due to the pre-crash braking the occupants bend forward. Although this was observed for the Hybrid-III's as well as the Active Human, the Hybrid-III dummy does not represent the human behaviour accurately enough under low acceleration loading conditions [6,8].
In all belted cases the Active Human Model shows a more forward motion for both driver and passenger than the standard Hybrid-III dummy, see Figure 8. The increased forward motion is mainly present in the neck and head region due to the higher flexibility of the human compared to the Hybrid-III dummy. The unbelted load cases show that the occupants bend forward significantly and that, whereas the Hybrid-III dummy falls forward onto the IP, the Active Human model is able to withstand the out-of-position effect due to the braking decelleration by active muscle tensioning and predicts a more realistic (initial) position prior to the crash, see Figure 9.
The change in injury mechanisms for all these cases result either in different neck or different head injury values and in all cases this is related to the airbag hitting the occupant (bag slap).

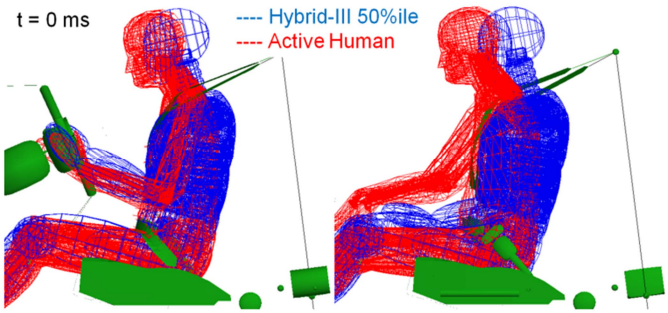

Figure 7 Forward motion of the Hybrid-III 50%ile compared to the Active Human driver (left) and passenger (right) for vehicle 05

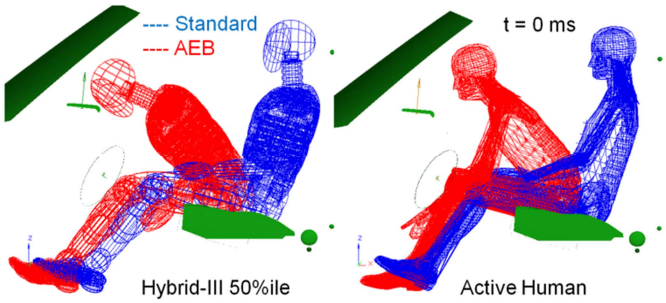

Figure 8 Illustration of the FMVSS 208 unbelted load case for the Hybrid-III 50%ile and Active Human passenger for vehicle 05

Ride-down effect

The analysis also revealed an improvement of the occupant injuries when AEB was activated. To understand the mechanism that gives this positive effect the ride down velocities of the occupant's head, thorax and pelvis were calculated and compared for all simulations. The comparison shows that activation of AEB results in an earlier and softer "Ride Down" compared to the standard crash case. This effect is visible for most of the simulated cases and is expected to have a positive effect on the occupant injuries.

To illustrate the ride-down effect, Figure 10 shows the ride-down velocities and the femur forces for the Hybrid-III 5%ile dummy in the FMVSS208 unbelted loadcase for both the standard crash condition as well as the case where AEB was activated. In the standard case the knees have an initial distance to the kneebolster which results in an almost constant forward velocity of the occupant's pelvis until the knees impact the knee bolster. From that moment (around 70ms) the pelvis velocity drops and the "ride down" of the pelvis is much steeper compared to the vehicle deceleration. In the situation where AEB is activated the occupant slides forward during the pre-crash braking phase which causes the knees to touch the kneebolster prior to impact. As a result the ride-down of the occupant's pelvis follows the ride-down of the vehicle much more closely which in turn results in lower femur forces.

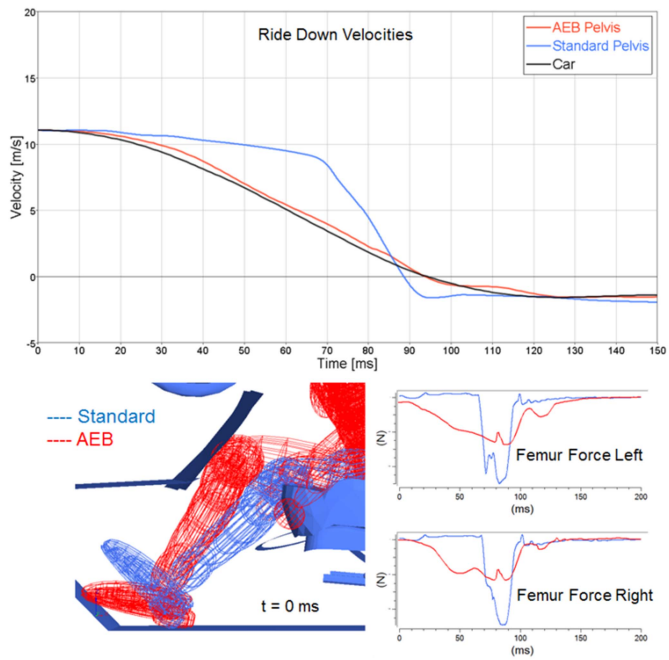

Figure 9. Ride down example femur forces and pelvis ride down velocities of the Hybrid-III 5%ile in vehicle 04 for FMVSS208 unbelted

Figure 11 shows an example of a (belted) USNCAP case with a Hybrid-III 50%ile passenger dummy. It is observed that in the AEB case there is an earlier and softer ride down for the head, thorax and pelvis, which improves the head acceleration and chest deflection. Additionally a slight improvement of the femur loads is observed.

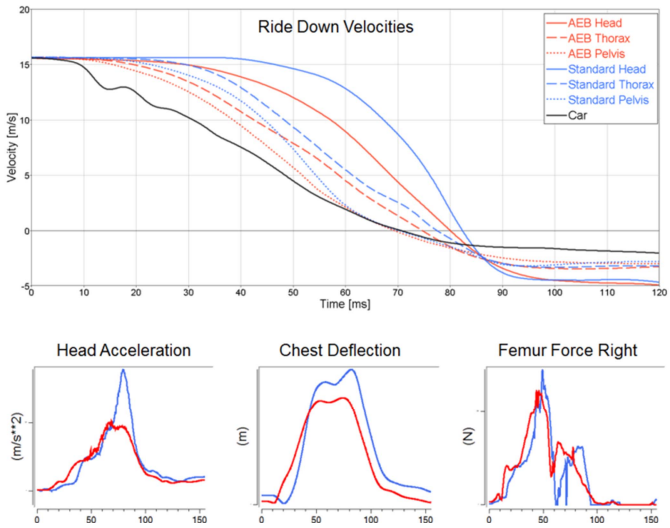

Figure 10. Comparison of the "ride down" effect during the in-crash phases with and without AEB activation in 35 MPH US NCAP crash simulation for vehicle 05 Hybrid-III 50%ile passenger

Although we expect that the earlier ride down generally has a positive contribution to the improvement of injuries, this is not confirmed in all simulations with actually improved injuries. In Figure 12 this is illustrated with the results for the Hybrid-III-50%ile driver of vehicle 01 in which differences for the chest deflection are observed. In this situation the chest deflection is increased for the AEB case. The reason for this increased chest deflection is mainly attributed to a changed belt routing caused by the AEB activation. Referring back to the feedback loop in Figure 1, the occupant restraint system may be adapted to prevent this change in belt routing in the pre-crash phase.

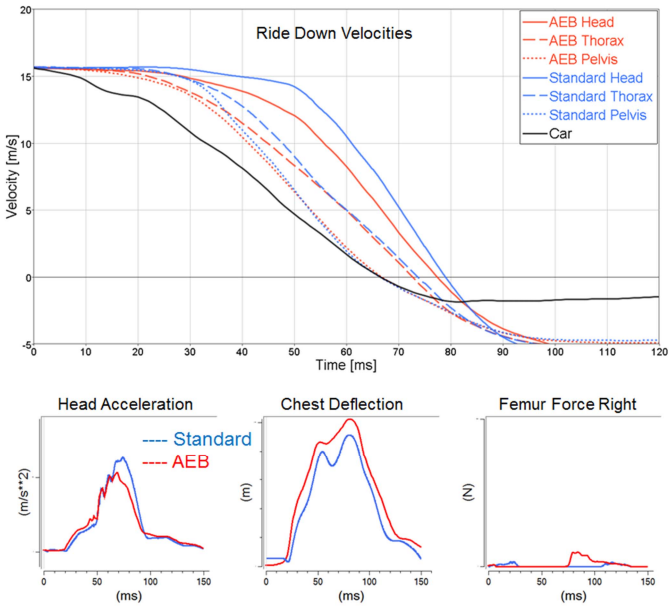

Figure 11. Comparison of the "ride down" effect during the in-crash phases with and without AEB activation in 35 MPH USNCAP crash simulation for vehicle 01 Hybrid-III 50%ile driver

However from our studies we noted that developing a restraint system for only the standard crash conditions can result in a sub optimal solution. An additional verification of the restraint system in cases where AEB is activated is recommended.

CONCLUSIONS

This paper presents a methodology and tool chain that allows to design Integrated Safety systems, i.e. safety systems in which the active safety systems and passive safety systems are designed as one system aiming to protect the occupant. The tool chain's effectiveness is illustrated by analysing the changes in injuries and injury mechanisms for a traditional passive safety system which is supplemented with active pre-crash braking.
The study shows the effect of altered pre-collision conditions on the injuries as a result of activation of AEB. In most cases the pre-tensioning of the safety belts due to the occupant's pre-crash ride-down results in a reduced injury risk in the subsequent crash. In some cases, the earlier and softer ride-down is compromised by, for example, a changed belt routing or an out of position situation prior to the crash. The more accurate representation of human motion with the Active Human Model helps to predict the initial occupant position before the crash and therefore helps to identify countermeasures for these situations.

Figure 13. Current situation where Active and Passive safety systems work independently

At present passive safety systems and active safety systems are often designed independently from each other and countermeasures may often be identified "off-line", i.e. without a further integration of the passive and active systems. We advocate that the Integrated Safety System is a total vehicle safety system in which active safety systems and passive safety systems communicate and collaborate with each other all the time and exchange information such as occupant status, vehicle speed, braking status, etc. in order to provide the maximum protection to the occupants. The methodology described here allows to analyse potential benefits as well as address potential risks of unexpected increased occupant injuries from the (un-)coordinated activation of active and passive safety systems.

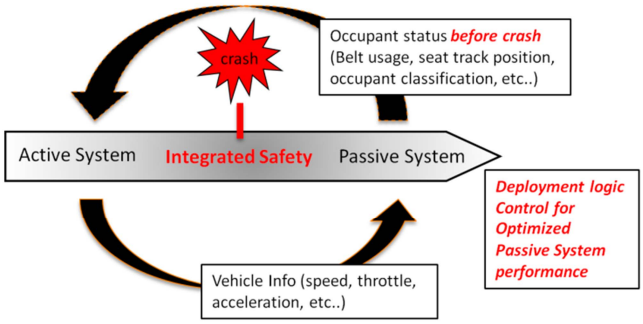

Figure 14. Integrated Safety System Development concept of TASS International.

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