CONCEPT STUDY OF ADAPTIVE SEATBELT LOAD LIMITER USING MAGNETORHEOLOGICAL FLUID

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ABSTRACT

Most current seatbelt load limiter technologies could only offer three or fewer predetermined patterns of seatbelt restraint force. However, researches have shown that, to better realize adaptive protection to different occupants under different crash severities, a continuously and real-time adjustable load limiter may be one step further. This concept could be especially favorable to vulnerable occupants such as small stature females and elderly people. Ideas have emerged suggesting possibility of using magnetorheological fluid (MRF) to realize such load limiter (MR-LL). This paper presents a concept study of MR-LL, aiming at evaluating its feasibility and establishing basic guidelines for prototype development. Configuration of an MR damper integrated with seatbelt retractor is selected in the study, in which the seatbelt force can be controlled by varying the strength of magnetic field exerted on the MRF inside the damper. The MR damper is numerically modeled and validated against experimental data found in the literature. Then by merging the MR damper model with a simplified occupant and seatbelt model subjected to sled impact loading, the performance of MR-LL under different parameter settings is studied and optimized. The simulation results demonstrate proof of the concept, indicating that the proposed MR-LL can generate various seatbelt force patterns with a wide adjusting range, thus to meet the requirement of both occupant adaptability and crash severity adaptability. Possible limitations of the proposed MR-LL are also discussed.

INTRODUCTION

Evolution from Load Limiting to Adaptive Restraint Force Control

When first introduced into market, seatbelt load limiter was initially adopted to prevent the seatbelt force from exceeding certain critical level in crash accidents, so as to reduce the risk of severe thorax compression and the corresponding injuries [1]. A typical design of load limiter has a deformable metal part integrated with the seatbelt retractor spool. The part will yield plastically when certain critical load is reached, so as to allow the previously locked seatbelt to be released out at a constant force level. Based on this mechanism, together with a seatbelt pretensioner, a constant force restraint (CFR) can be realized approximately. CFR has been identified to be the optimal pattern of restraint force when the occupant-vehicle system is considered as a simple single-DOF mass-spring-damper model [2]. Further analysis based on more complex models [2, 3] and other considerations (such as cooperating with airbag [4]) has identified other seatbelt force patterns such as CFR following an initial peak or the two-stage pattern to be more favorable than pure CFR(Figure1).

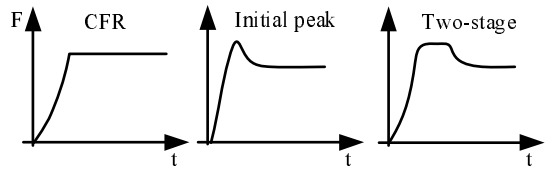

Figure 1. Different patterns of seatbelt force during crash.

Together with the research on restraint force optimization, more and more attention has been drawn to the concern about "adaptive restraint". The main focus is the influence of different occupant physical attributes, crash severity, and other factors on the restraint effectiveness. Researches have shown that if the parameters of the seatbelt force pattern such as load limiting level and the stage shifting time can be tailored according to the specific occupant and crash conditions, the protection result will be enhanced considerably [5, 6]. A widely cited example is the conclusion about the influence of age on the relation between thorax injury and the seatbelt load (Figure 2) [7, 8]. Because most restraint systems are designed based on 50th

percentile male occupant only, the concept of adaptive restraint is especially meaningful to other occupant categories such as small females and elderly people.

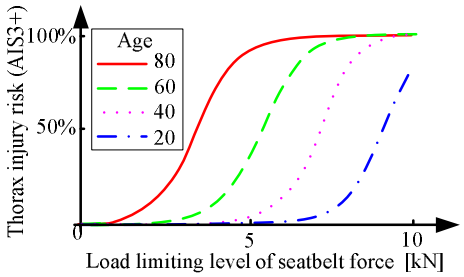

Figure 2. Age influence on thorax injury risk [8].

Beyond the above theories, some researchers have foretold a future form of restraint system, where the restraint force is controlled by a close-loop actuation system. During the crash, with the occupant motion as the feedback signal, the system can tune the seatbelt (and airbags) to compel the occupant tracking an optimal deceleration process, thus to minimize the injury for all kinds of occupants involved in various crash conditions [9] (Figure 3).

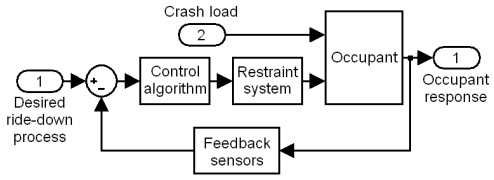

Figure 3. Future restraint system: close-loop control in crash real time.

Current Technology of Adaptive Load Limiter

Along with the evolution of restraint force theories, seatbelt load limiter has been widely used to realize the desired pattern of seatbelt force during crash. Despite the name "limiter", the role of seatbelt load limiter has been more and more considered to be beyond just limiting the maximum seatbelt force. Many designs of adaptive load limiter have been proposed in the literature to meet the desire of adaptive restraint force control proposed in the theories. Most of them provide "multi-level load limiting" with a "multi-deformable-part mechanism" [4, 10-13], which may be viewed as the upgrade of the traditional load limiter. By triggering the two or three deformable parts with different combination, this kind of load limiter could provide two or three predetermined levels of seatbelt force with CFR or multi-stage pattern (Figure 4).

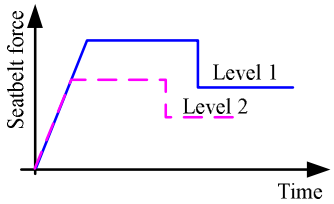

Figure 4. Multi-level load limiting.

This kind of mechanism is probably the only design of adaptive load limiter that has been maturely developed into real products. However, its limitations are also obvious. First, instead of adjusting the load limiting level steplessly, only two or three predetermined levels can be provided. Thus it cannot fully meet the optimal requirement of occupants with various physical attributes involved in various crash conditions. In addition, mechanism with deformable parts is not reusable. Moreover, this kind of load limiter has no potential of realizing continuously real-time control over seatbelt force, which renders it being insufficient for more advanced future restraint system mentioned earlier.

Advanced Adaptive Load Limiter and MR-LL

More advanced designs have been discussed in the literature with the aim of building a continuously and even real-time adjustable seatbelt load limiter. One of the proposals is controlling the seatbelt force during crash with the motorized seatbelt retractor (Figure 5a) [14]. Equipped with an electric motor to actuate the rotation of the retractor spool, the motorized seatbelt retractor has already been successfully used on seatbelt adjusting for wearing comfort and slack removing. However, considering the level of the seatbelt force and the short duration of action during the crash, the power needed for the motor to actuate the retractor spool during crash will be very considerable. This means the motor may have big size and high cost, which are highly undesirable for the retractor design.

Another idea under discussion is equipping the seatbelt retractor with a rotary brake (Figure 5b), which could control the resistant torque of the retractor spool, so as to control the seatbelt paying out and the corresponding restraint force during crash [15-18]. To meet the requirement of quick response and low power consumption, electro-mechanical brake with self-energizing mechanism is favorable. In 2007, Siemens VDO (Continental) announced the development of such a product based on its "Wedge Brake" technology [19]. However, no available product has been demonstrated yet.

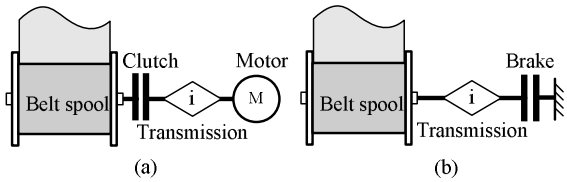

Figure 5. Retractor equipped with motor (a) or brake (b).

Besides the above two proposals, a new idea emerged in the recent years suggests the possibility of building adaptive load limiter with magnetorheological fluid (MRF). As a kind of the so-called "smart fluid", MRF is a suspension of magnetic polarizable micro-particles in a carrier fluid. When subjected to magnetic field, the fluid greatly increases its apparent viscosity, and develops a yield stress which monotonically increases with the strength of the applied magnetic field (Figure 6). The transmission is fully reversible and almost instantaneous. This rheological character is very favorable for developing simple, quiet, rapid-response interfaces between electronic controls and mechanical systems [20].

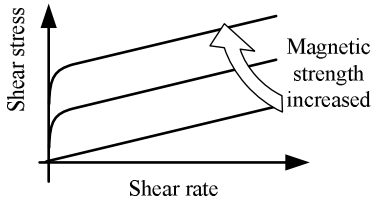

Figure 6. Rheological character of MRF.

Many researches have been carried out to study the application of MRF on various areas such as vibration damping, rotary brake, human prosthetics, and optical polishing. In the recent years, several patents [21-24] have proposed the idea about MR load limiter (MR-LL), which equips the seatbelt retractor spool with a piston damper or a rotary brake built with MRF. These designs could enable the seatbelt force to be controlled by varying the magnetic field applied on the MRF inside the damper or bake. Considering the rheological feature of MRF, this kind of mechanism may have the potential of realizing a continuously and real-time adjustable seatbelt load limiter.

Moreover, unlike load limiter which adopts electro-mechanical mechanism like the motorized retractor or electro-mechanical brake, MR-LL does not need motor and has relatively fewer moving parts, which ensures reduction of the device complexity. In addition, considering the advance of manufacturing technology which has considerably reduced the cost of MRF, MR-LL may have much lower cost compared to other designs.

However, despite its seemingly promising outlook described in the patents, no substantial study has yet been published to discuss the feasibility of MR-LL and the corresponding design principles. In the following sections, this paper presents a concept study of MR-LL, aiming at evaluating its feasibility and establishing basic guidelines for prototype development.

CONFIGURATION OF MR-LL

Comparison between Possible Configurations

Generally, MRF inside MR devices works in one of the three basic operation modes [20]. As illustrated in Figure 7, the three modes are different from each other by the driving force and the moving direction of the boundary. Among the three modes, except the squeeze mode, which is usually used only at controlling millimeter-order movements, the other two modes could both be used to build MR-LL.

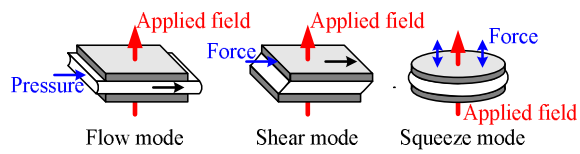

Figure 7. Three basic operation modes of MRF.

Based on the flow mode, a piston damper can be built and linked to the seatbelt retractor spool directly or via mechanical transmission (Figure 8). The resistant force is generated by the damper when the seatbelt is pulled by the occupant during crash.

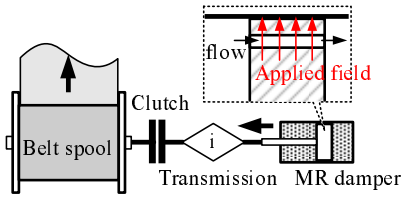

Figure 8. Retractor with MR damper.

Based on the shear mode, an MR rotary disk brake is linked to the retractor spool (Figure 9). When the MRF filled in the gap between the brake disk and the shell becomes more viscous as the result of the applied magnetic field, the brake could generate resistant torque due to the shear force of the MRF caused by the relative motion between the brake disk and the shell.

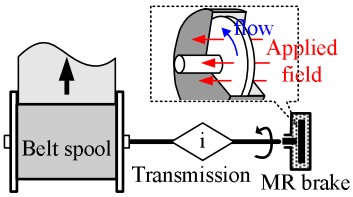

Figure 9. Retractor with MR brake.

By varying the strength of magnetic field spread across the orifice of the MR damper or the cavity of the MR brake, the apparent viscosity of MRF can be controlled, and thus the resistance force of the damper or the torque of the brake can be adjusted.

Although both have been proposed in the patents, a quick comparison shows that MR damper is more suitable for MR-LL configuration. Consider the size of MR device to generate enough seatbelt resistant force during crash: It has been reported that MR piston damper with an outer diameter about 40mm is capable of generating 3~6kN peak resistant force under 3m/s impact loading speed [25, 26], which is close to the energy absorbing intensity of seatbelt load limiter during vehicle crash. Further, if assume the transmission ratio between the piston motion and the belt paying out to be 1, then the stroke of the MR damper piston will be equal to the paying out of the seatbelt from the load limiter during crash, which is approximately at 100mm level. The above estimation indicates that the size of MR damper needed to generate enough seatbelt resistant force during crash could be acceptable for vehicle onboard installation.

On the other hand, there have been reports stating that under the current technique, an MR rotary disk brake with a size up to 100mm in diameter and 40mm in length could only generate resistant torque no more than 4Nm [27, 28]. Thus to meet the approximately 80Nm torque needed for the load limiting operation, a gear set with a transmission ratio up to 20 is needed. Besides the increase of system complexity, size and cost it brings, such a large transmission ratio will also significantly increase the dynamic inertia of the moving parts, and thus add difficulty to device controlling.

MR-LL using MR Damper

Based on the above analysis, it can be seen that MR damper is more suitable than MR brake for MR-LL application. Generally, MR-LL using MR damper involves an MR piston damper linked to the seatbelt retractor spool via certain transmission. Figure 10 demonstrates one of the typical designs where a screw transmission is adopted.

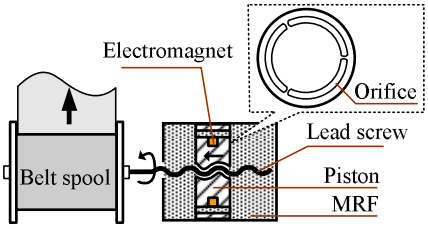

Figure 10. One of the typical designs of MR-LL using MR damper.

When the MRF is forced to flow through the circular orifice on the piston by piston sliding, resistant force will be generated mainly by the pressure difference between two sides of the piston. Magnetic field is generated transversely along the orifice by electromagnet, controlling the apparent viscosity of MRF and the corresponding damping force.

SIMULATION PLATFORM OF MR-LL

In order to identify, optimize and determine appropriate design parameters of the proposed MR-LL, a simulation platform is built. As for the modeling environment, although finite element simulation is very popular for fluid motion modeling, it is not very convenient for simulating continuously real-time controlled rheological behavior, and is also difficult to be linked to control theory analysis software. Because of these considerations, MATLAB/Simulink is widely preferred by various studies, including this one, for the modeling of systems engaging MR devices.

MR-LL Modeling

Under the proposed MR-LL configuration, the loading force and the paying out velocity of the seatbelt will be proportional to those of the MR damper, with the scale equaling to the transmission ratio i between the seatbelt paying out and the damper piston sliding. Thus the modeling of MR-LL is mainly the modeling of MR damper.

Considering the width of the circular orifice on the piston ($2h$), which is much smaller than the length (L) and the central circle radius of the orifice (R_o), the flow field of MRF through the orifice could be simplified as one-dimensional and central symmetrical (Figure 11) [29-31].

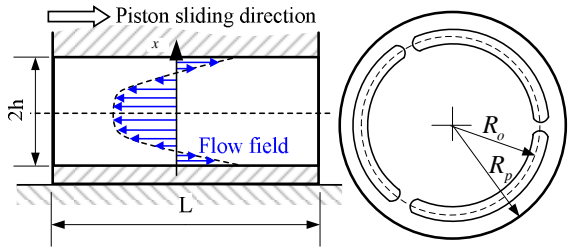

Figure 11. The flow field of MRF through the orifice.

The modified Herschel-Bulkley model [30] is adopted to describe the constitutive property (Figure 12) of the MRF, and the shear stress τ of MRF is given by the following constitutive equation:

$$\tau(x,t) = \left(\frac{\tau_{yd}}{\left|\frac{\partial u(x,t)}{\partial x}\right|^n + \varepsilon} + \eta\right)\cdot\left(\frac{\partial u(x,t)}{\partial x}\right)^n \quad (1).$$

where yield stress τ_{yd} is determined by the average strength of the applied magnetic field H, which is proportional to the current of the electromagnet $H = \alpha I$. Parameter ε is used to describe the pre-yield behavior, and η is the post-yield viscosity. Parameter n is used to describe the shear thinning behavior at high shear rate, which is believed to be necessary when studying damper subjected to impact load [31]. All the parameters and the relation between τ_{yd} and H can be obtained based on the test data provided by the MRF manufacturer.

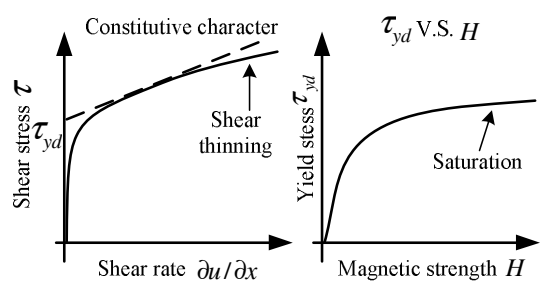

Figure 12. Constitutive property of MRF.

Besides the constitutive equation, other governing equations are listed as follows:

Equation of fluid motion:

$$\rho\frac{\partial u(x,t)}{\partial t} = -\frac{\Delta P(t)}{L} + \frac{\partial \tau(x,t)}{\partial x} \quad (2).$$

where ΔP is the pressure difference between two sides of the piston, and ρ is the fluid density.

Flow boundary condition:

$$u(0,t) = u(2h,t) = v_p(t) \quad (3).$$

where v_p is the moving speed of the piston.

Equation of continuity:

$$v_p(t)\cdot A_p = -\int_0^{2h} u(x,t)\cdot dA_o \quad (4).$$

where A_p is the top (and bottom) area of the piston, and A_o is the cross-sectional area of the orifice.

Equation of piston motion:

$$F_d(t) - F_\tau(t) - F_{press.}(t) = m_p\frac{dv_p(t)}{dt} \quad (5).$$

where F_d is the loading force of the damper. F_τ is the shear force caused by the MRF shear stress distributed across the orifice side surface. $F_{press.} = \Delta P\cdot A_p$ is the force caused by the pressure difference between two sides of the piston.

The governing equations are solved with the ODE solver of MATLAB/Simulink. In order to use the ODE solver of Simulink, which is designed to solve time-continuous problems rather than space-continuous problems, a "semi-discrete" method has to be adopted [32]. The method divides the flow field along the x direction into many divisions ($2N$) of equal width, replaces the space distributed variable with discrete vector, and the space differential term with difference quotient:

$$\begin{cases} u(t,x) \to \mathbf{U}(t) = \left[u_1(t), u_2(t), \cdots, u_N(t)\right]^T \\ \tau(t,x) \to \mathbf{T}(t) = \left[\tau_1(t), \tau_2(t), \cdots, \tau_{N+1}(t)\right]^T \\ \frac{\partial u}{\partial x} \to \frac{\partial \mathbf{U}}{\partial x} = \left[\frac{u_i - u_{i-1}}{\Delta x}\right]_{i=1\sim N+1} \begin{pmatrix} u_0 = v_p \\ u_{N+1} = u_N \end{pmatrix} \\ \frac{\partial \tau}{\partial x} \to \frac{\partial \mathbf{T}}{\partial x} = \left[\frac{\tau_i - \tau_{i-1}}{\Delta x}\right]_{i=2\sim N+1} \end{cases} \quad (6).$$

(Spatial symmetry of the flow field is considered. Subscript 1 marks the boundary of the orifice, and N marks the center.)

The difference quotient can be operated in Simulink using the "selector" module illustrated in Figure 13.

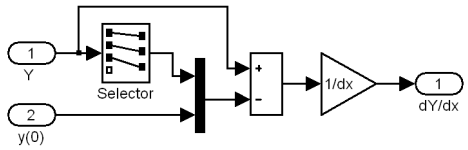

Figure 13. Operation of difference quotient under Simulink [32].

Based on this method, the governing equations can be rewritten as:

$$\mathbf{T} = \left(\frac{\tau_{yd}}{\left|\frac{\partial \mathbf{U}}{\partial x}\right|^n + \varepsilon} + \eta\right) \cdot \left(\frac{\partial \mathbf{U}}{\partial x}\right)^n \quad (7).$$

$$\rho \frac{\partial \mathbf{U}}{\partial t} = -\frac{\Delta P}{L} + \frac{\partial \mathbf{T}}{\partial x} \quad \left(u_1 = v_p \ , \ \tau_{N+1} = 0\right) \quad (8).$$

$$v_p A_p = -2\sum_1^N u_i dA_o \quad (9).$$

$$F_d - F_\tau - \Delta P \cdot A_p = m_p \frac{dv_p}{dt} \quad (10).$$

Before solving the above equations in Simulink, some additional transformations are made in order to prevent the appearance of algebraic loop, which will significantly slow down the solving process:

Eq. (8) $\rightarrow$ $$\rho \sum_1^N \frac{\partial u_i}{\partial t} \Delta x = -\frac{\Delta P}{L} h + \sum_1^N \frac{\partial \tau_i}{\partial x} \Delta x \quad (11).$$

Eq. (9) $\rightarrow$ $$\frac{dv_p}{dt} A_p = -2\sum_1^N \frac{\partial u_i}{\partial t} dA_o \quad (12).$$

Eqs. (11) and (12) $\rightarrow$

$$\frac{dv_p}{dt} \frac{A_p \rho}{4\pi R_o} = \frac{\Delta P}{L} h - \left(\tau_{N+1} - \tau_1\right) \quad (13).$$

Eqs. (10) and (13) $\rightarrow$

$$\frac{A_p \rho}{4\pi R_o m_p} F_d = \Delta P \left(\frac{A_p^2 \rho}{4\pi R_o m_p} + \frac{h}{L}\right) + \tau_1 \left(\frac{A_p \rho L}{m_p} + 1\right) \quad (14).$$

Most modules in Simulink support vector parameters, Eqs. (7) (8) (9) and (14) can be linked in Simulink with the configuration shown in Figure 14.

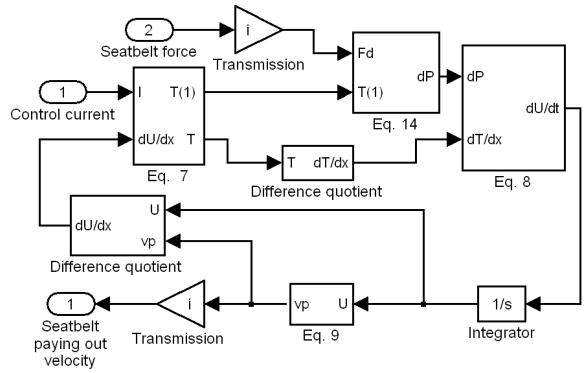

Figure 14. Model configuration of MR-LL.

The seatbelt force and the control current of the electromagnet (proportional to the magnetic field strength) are set as the input variables, and the seatbelt paying out velocity is set as the output variable.

Validation of the MR-LL Model

The model of MR-LL is validated by comparing the dynamic character of its main part, the model of MR damper, against the test data found in literature [20, 26, 33]. Two types of load have been studied: steady load and impact load. Under the steady load, a constant loading force is applied and the piston moves at a constant velocity. Under the impact load, the damper is subjected to a drop tower test. The parameters of the damper structure, the MRF properties and the loading condition are set according to the data in the literature. Figures 15 and 16 show the comparison between the simulation and the actual test results, good correlations can be seen.

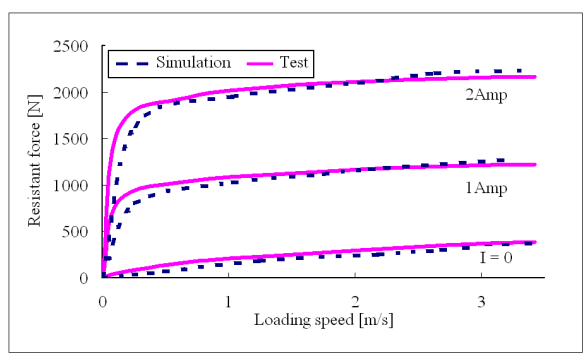

Figure 15. MR-LL model validation - steady load.

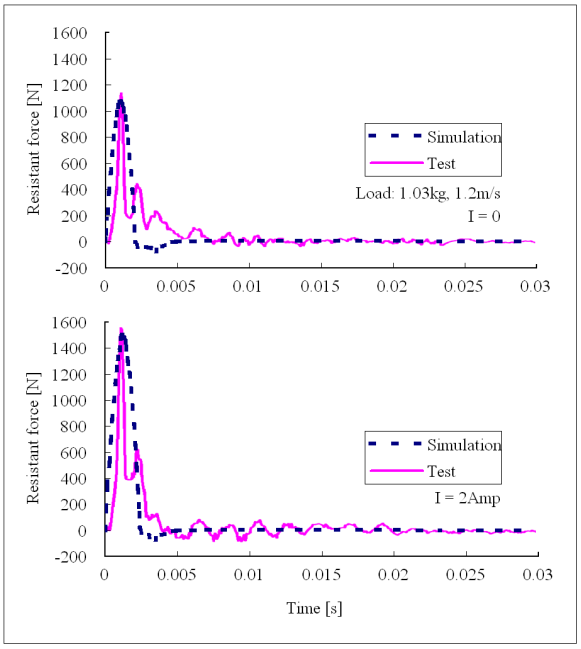

Figure 16. MR-LL model validation - impact load.

Occupant and MR-LL Seatbelt System Modeling

An "occupant and MR-LL seatbelt system" model subjected to sled impact load is further established, in which the MR damper model is part of it. This model will serve as the simulation platform for the parametric study of MR-LL in the next section.

A simplified three-body, two-dimensional dynamic model of occupant is adopted (Figure 17). Although not as sophisticated as more complex occupant models like those available in MADYMO software tool, such a model has been proved to be capable of providing good representation of the actual system response, and has been frequently used to provide better understanding of the dynamics and interaction of the occupant and restraint system [34]. Simulating the model is highly time-efficient, thus it is very suitable for parametric study, in which many iterations are required. Due to this merit, this kind of model has been recommended for concept study of adaptive restraint devices [35], while the more sophisticated MADYMO occupant models will be preferably used in further design and analysis following the concept phase.

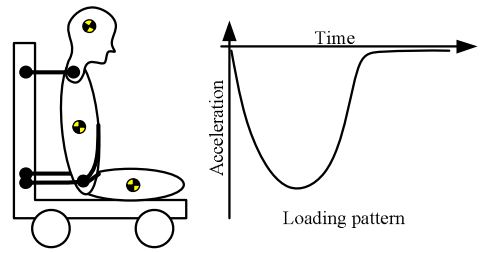

Figure 17. Three-body, two-dimensional occupant model.

The occupant model is built using the Simmechanics package of Simulink. The dimensional and inertial parameters of the occupant body, the viscoelastic property of the seatbelt, and the sled impact loading pattern are set using the data from the studies by Paulitz et al. in 2005 and 2006 [34, 35], in which a three-body, two-dimensional 50th percentile ATD model is used to simulate the actual process of a standard 56 km/h frontal impact test conducted by NHTSA.

The sled model is linked to the MR-LL model in Simulink with the configuration shown in Figure 18. This combined model of "occupant and MR-LL seatbelt system" is used to simulate the performance of MR-LL under given MR-LL control current pattern during crash.

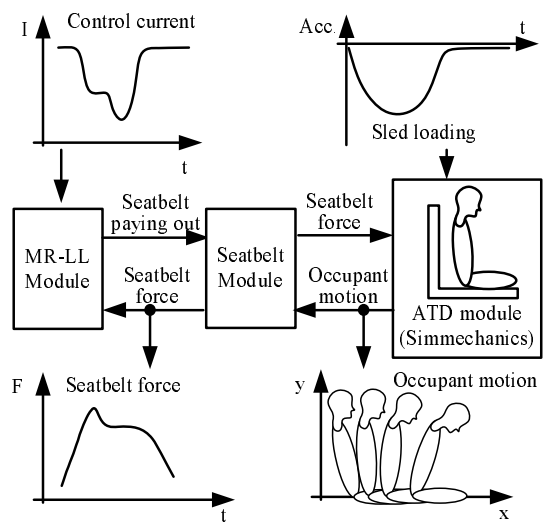

Figure 18. Model configuration of "occupant and MR-LL seatbelt system".

PARAMETRIC STUDY AND OPTIMIZATION OF MR-LL STRUCTURE

The objective of parametric study is to find the influence of each main design parameter on the performance of MR-LL, so as to establish the basic

guidelines for design. In addition, the optimized settings of the parameters and the corresponding MR-LL performance can be used to evaluate the proposed concept.

Evaluation Indices

Adaptive load limiter is supposed to provide restraint force with a suitable and widely adjustable range, so as to be capable of offering tailored protection to occupants from teenager to elderly, from small stature to large stature, and to impact from low speed to high speed. Based on this aim, two indices are defined to evaluate the performance of MR-LL:

$$\begin{cases} \Delta F = F_{p-\max} - F_{p-\min} \\ \overline{F} = \dfrac{F_{p-\max} + F_{p-\min}}{2} \end{cases} \quad (16).$$

where $F_{p-\max}$ is the peak seatbelt force during crash when the magnetic field is always applied with the maximum strength (the saturation limit of the MRF), and $F_{p-\min}$ is the peak seatbelt force during crash when no magnetic field is applied at all (Figure 19).

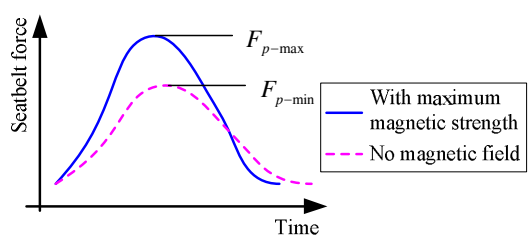

Figure 19. Definition of $F_{p-\max}$ and $F_{p-\min}$.

To a large extent, ΔF and $\overline{F}$ can represent the adjusting range of the seatbelt force controlled by MR-LL, and can be acquired easily from simulation runs. Thus it is reasonable to choose them as the evaluation indices of the parametric study.

Parametric Study and Optimization

The performance of the proposed MR-LL under different settings of parameters is evaluated by the indices ΔF and $\overline{F}$ defined in Eq. (16). The concerned variables and their initial settings are listed as follows (also see Figure 11):

- Type of MRF – "MRF-122" by LORD Corp.
- Radius of the piston $R_p = 20.5$mm
- Mass of the piston $M_p = 200$g
- Central circle radius of the circular orifice $R_o = 15$mm
- Width of the orifice $2h = 1$mm
- Length of the orifice $L = 20$mm
- Transmission ratio between the seatbelt paying out and the piston sliding $i = 1$

Fractional parametric study is conducted, where only one parameter is varied at a time while the others remain at their initial settings. Figure 20 shows the corresponding changes of the MR-LL performance.

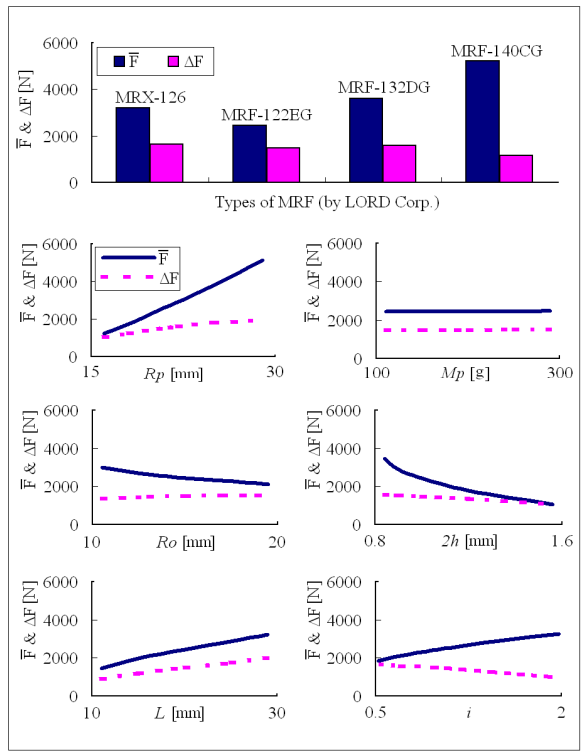

Figure 20. The influence of MR-LL parameters.

Although cannot show the interaction between variables as a full parametric study can do, these fractional studies are efficient at revealing the general influence trend of each parameter on the performance of MR-LL. As shown in Figure 20, different parameters have different features of influence. Some parameters such as R_o and h have significant influence on $\overline{F}$, but do not have much effect on ΔF. While some others such as the type of MRF, R_p, L and i can only change both indices together. In the process of performance optimization, the parameters of the second kind are first tuned within the reasonable range to enlarge ΔF, while the ones of the first kind are tuned next to obtain a suitable $\overline{F}$. Following this routine, a set of optimized parameters is acquired and listed in Table 1, with the final evaluation indices as $\Delta F = 3092N$ and $\overline{F} = 4156N$.

Table 1.
Optimized settings of MR-LL parameters

Design variable	Setting
Type of MRF	MRF-132DG
Radius of the piston [mm]	23
Mass of the piston [g]	200
Central circle radius of the circular orifice [mm]	20
Width of the orifice [mm]	1
Length of the orifice [mm]	30
Transmission ratio between the seatbelt paying out and the piston sliding	2

ADAPTABILITY OF THE PROPOSED MR-LL

Based on the optimized parameters obtained, the crash severity adaptability and occupant adaptability of the proposed MR-LL are examined using the simulation platform. To examine the crash severity adaptability, several different crash speeds are applied. While to examine the occupant adaptability, the physical parameters of the occupant model are varied from the initial 50th percentile male setting to 5th percentile female and 95th percentile male settings. The MR-LL is controlled to provide basic constant force pattern. Different levels of constant force are assumed to serve different crash cases. Figures 21 and 22 show the resulting patterns of the seatbelt force and the corresponding control current of the electromagnet (the ratio between the average magnetic strength and the control current is assumed to be 100 [kAmp/m]/[Amp]).

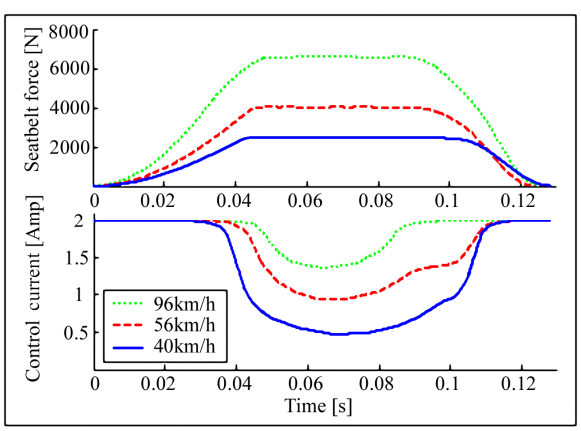

Figure 21. Crash speed adaptability (50th ATD).

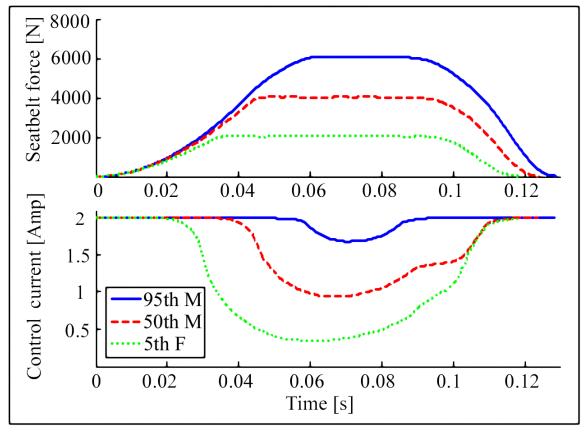

Figure 22. Occupant adaptability (56km/h).

Besides the basic constant force pattern, the simulation result also demonstrates the capability of the proposed MR-LL to generate other possibly desired patterns of seatbelt force as demonstrated in Figure 23.

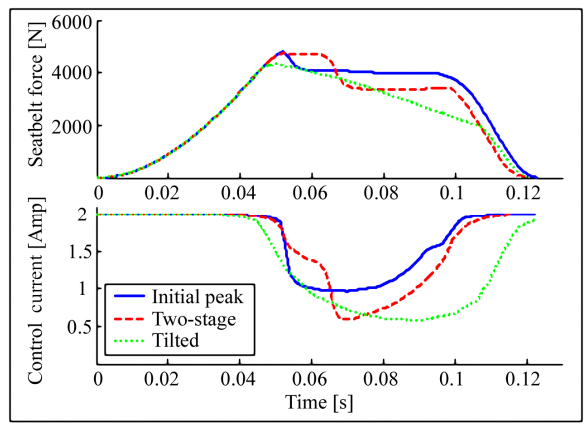

Figure 23. Generating different patterns of seatbelt force.

As demonstrated above, the simulation result indicates that the proposed MR-LL has strong potential to provide continuously and real-time adjustable control over the seatbelt force, thus possess good adaptability to different occupants under different crash severities.

CONCLUSIONS

Magnetorheological fluid has been suggested to have the potential of being used to build adaptive seatbelt load limiter, which could provide continuously and real-time adjustable control to seatbelt force during vehicle crash. This kind of function has been identified to be quite necessary to the protection of occupants with various physical attributes involved in different crash severities. In order to study the feasibility of the proposal, a concept study has been

carried out and documented in this paper. First, the structure that has an MR damper integrated with seatbelt retractor is identified as the most promising configuration for MR-LL. Then, based on a simulation platform, parametric study and performance optimization have been conducted. The simulation result using the optimized parameters indicates good adaptability of the proposed MR-LL. Depending on the need of protection to occupant with different statures involved in different crash speeds, the optimized MR-LL can generate various patterns of seatbelt force with a wide adjusting range.

On the other hand, despite the proved concept, there are still some possible limitations of the proposed MR-LL. One concern is the device size. Although the size-related parameters are constrained within reasonable range in the performance optimization, the resulting size of MR-LL is bigger than traditional load limiters. If a 200mm maximum paying out of seatbelt is assumed, the size of MR-LL can be approximately estimated to be 50mm of diameter and 150mm of length. This might pose a problem for vehicle onboard installation. Other concerns include the sealing of MR damper and the depositing of MRF. Although mature solutions have been claimed by MRF manufacturers, the impact of these factors on the device durability of MR-LL is still uncertain.

To examine the above considerations, a physical prototype is desired. The work documented in this paper is the first phase of MR-LL development. Under the guidelines obtained in this concept study, the next steps include further analysis of the system, detailed components design, magnetic circuit analysis, and the electric power source development. Moreover, the simulation platform presented in this paper could also benefit the study of the close-loop control algorithms for the future adaptive restraint systems.

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COMPARISON BETWEEN NEW DATA ON CHILDREN ANTHROPOMETRY AND CRS DIMENSIONS

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ABSTRACT

The objective of this paper is to compare the morphology of children aged from 3 to 15 years old with actual Child Restraint System dimensions.
First, an anthropometry study has been performed on about 2000 French children aged from 3 to 15 years old. For each subject, 15 external measurements have been acquired in particular in sitting position. They include classical dimensions like weight and heights (head-seat, shoulder-seat, etc) but also new data concerning for example the sternum length, the xyphoid angle or the thorax and abdominal widths.
In a second step, 13 dimensions have been measured on about 30 actual CRS. These CRS concern only forward facing system such as booster seat and they represent the different standard groups: 0+,1, 2, 3. To complete the geometry acquisition, 6 dimensions concerning the back seat of 6 different vehicles have been measured. Dimensions have been focused in particular on the belt position in the car or in the CRS. For each child anthropometric dimension, the 5th, 25th, 50th, 75th and 95th percentiles curves are given and discussed. Then, these dimensions are compared with the measurements performed on the CRS and on the vehicles. In particular, data concerning the belt position regarding the children morphology along ages are detailed. The location of the belt on the shoulder is more specifically evaluated.
Results highlight that some of the CRS appear as unsuitable regarding the children anthropometry. This article shows for example a gap between the CRS classification based on children weight.

INTRODUCTION

Road transport safety, particularly for children, has become a priority for all government. Indeed, statistical analysis in the field of accidentology and epidemiology show that the proportion of killed children on the road needs to encourage researches on this field (OECD, 2004). For example, in France, the ratio of children killed in road accidents is about 4% and even if this percentage is not excessive, it can not be acceptable (ONISR, 2006). Children are mainly involved in pedestrians and bicyclist accidents but the mostly killed children have been observed as car passengers (OECD, 2004, ONISR, 2006; CHILD, 2006).
In order to reduce this fatality, the most important measure to protect child occupants of vehicles is the provision and use of efficiency child safety restraint system (CRS).
Concerning this last point, a lot of researches has been performed these last years in order to evaluate performance of the CRS (NCAPS, 2006; EEVC, 2003). Nevertheless it appears important gaps in this field. The first major problem concerns in particular the large range of child sizes and the child anatomical structure. The second is the incorrect use of restraints, either because the restraint is inappropriate for the age of the child, is badly fitted, or incorrectly used.
Systems such as ISOFIX or Latch have improved the efficiency of CRS by integrating seating systems to the vehicle (OECD, 2004). But some problems still stayed on the adaptability of these systems to the children morphology.
In parallel restraint standards have been defined in order to propose categories of CRS (ISO/TR13214; Bell, 1997). But this classification is mainly based on the child's weight and it appears incoherence between the regulation which imposes to have a CRS for every child with a height lower than 150cm while the selection of the CRS is based on the weight or the age. Previous studies have shown that this classification is not well appropriate to child

anthropometry (Griffith King, 1969; Durbin, 2003; Huang, 2006; Anderson, 2007). However, these studies are based on old anthropometric databases such as (Snyder, 1977), incomplete one or are focused on only few geometrical parameters such as only the weight or the seat cushion length regarding the buttock-knee length.
The objective of this paper is to evaluate the adaptability of CRS by having a general approach which includes all anthropometric characteristics of the children in sitting posture. It consists on acquiring new data on the morphology of children aged from 3 to 15 years old in sitting position and to compare them with several actual Child Restraint System dimensions.

ANTHROPOMETRICAL DATA

Material and method

French healthy children aged from 3 to 15 years old have been measured in order to acquire new anthropometrical information. Subjects come mainly from the south of France (suburb of Marseille). Measurements have been performed in paediatric services of Marseille hospitals and in different schools. Children have been measured with the agreement of their parents, themselves and a paediatric doctor or school headmaster. Data anonymity has been respected.
The sample is made up of about 2000 children. This sample is decomposed in range groups of one year. Each group includes minimum 60 children with a sex ratio at least 30 boys and 30 girls.
Because it was important to have geometrical information in seating posture, some measurements have been performed in this position. The subject sat erect on a flat horizontal surface with the head held in order to have the Franckfurt plane horizontal.

The acquisition protocol was based on the same one classically used for adults in the field of biometry. Only the somatology has been considered and 15 dimensions have been acquired (see figure 1):

1. weight
2. stature (in standing position)
3. sitting height
4. acromion-seat height
5. knee-ground height
6. buttock-sole length (leg shoot out)
7. thigh length
8. abdominal depth
9. thorax depth
10. abdominal width
11. thorax width
12. bi-trochanter width
13. bi-acromial width
14. sternum length
15. xyphoid angle

Classical anthropological instruments have been used: anthropometer, sliding caliper, spreading caliper with rounded ends, tape measure (accuracy 1mm), goniometer and scales (accuracy 100gr).

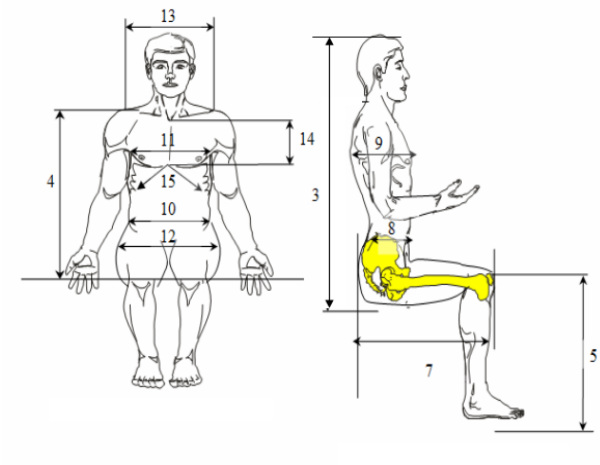


Figure 1. Anthropometric measurements

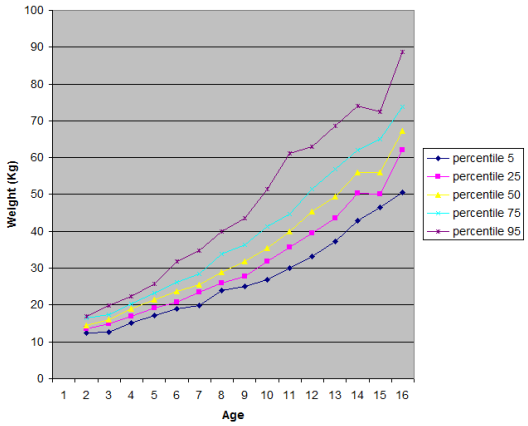
Finally, the acquisition date and the date of birth of the child are noted in order to calculate exactly his age when the measurements were taken

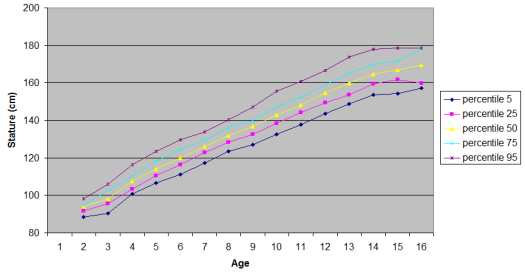
It is important to highlight the fact that in particular the sternum length or the xyphoïd angle were acquired in order to provide new information which can not be found in literature (Biard, 1997). These measurements have been taken in order to compare them with the belt position.

Results

For each dimension and each age, a classical statistical analysis was performed. It concerns the computation of the 5th, 25th, 50th, 75th and 95th percentile values using the Microsoft Excel software.

The following figure 2 gives the corresponding curves for the respective measured dimensions in function of age (in year). All dimensions are given in cm except the xyphoid angle which is given in degrees and the weight in Kg.


Weight (Kg)
Age
percentile 5
percentile 25
percentile 50
percentile 75
percentile 95


Stature (cm)
Age
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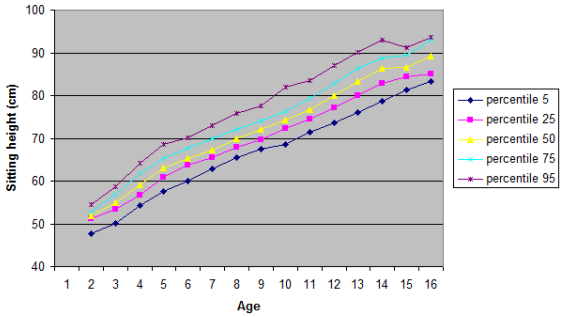
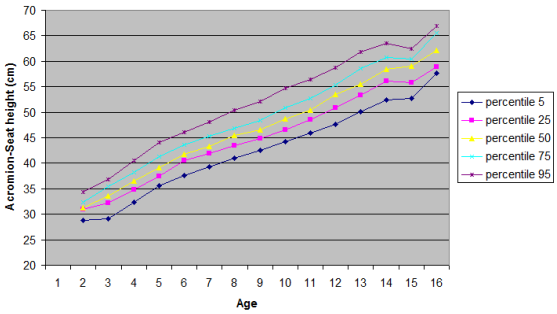
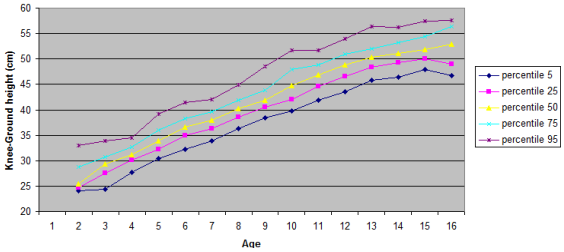
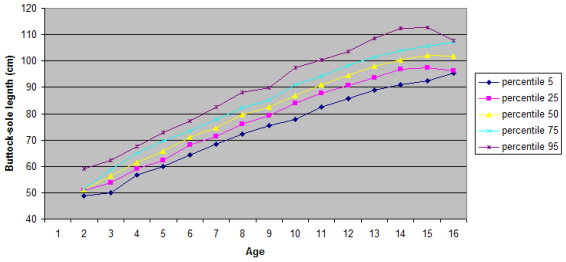
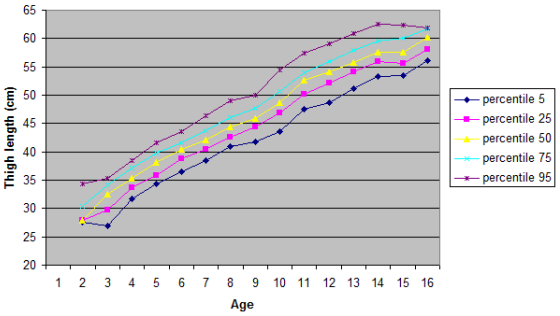
percentile 25
percentile 50
percentile 75
percentile 95

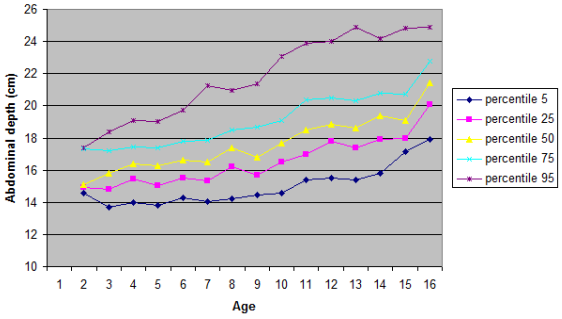

Sitting height (cm)
Age
percentile 5
percentile 25
percentile 50
percentile 75
percentile 95

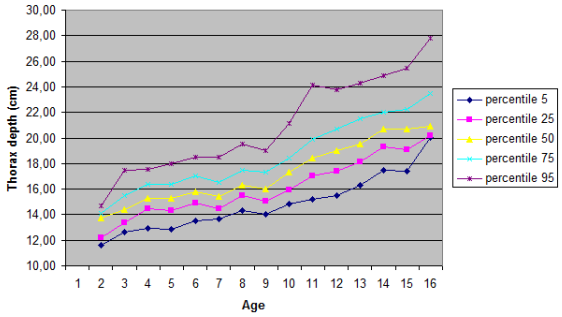

Acromion-Seat height (cm)
Age
percentile 5
percentile 25
percentile 50
percentile 75
percentile 95

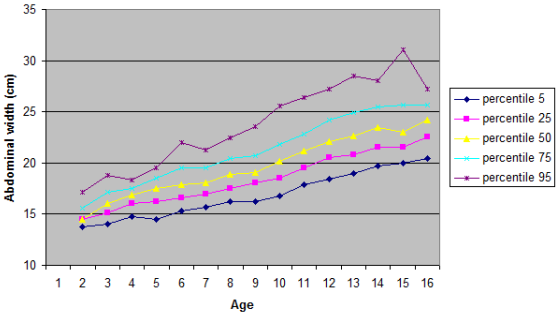

Knee-Ground height (cm)
Age
percentile 5
percentile 25
percentile 50
percentile 75
percentile 95


Butock-sole legnth (cm)
Age
percentile 5
percentile 25
percentile 50
percentile 75
percentile 95


Thigh length (cm)
Age
percentile 5
percentile 25
percentile 50
percentile 75
percentile 95


Abdominal depth (cm)
Age
percentile 5
percentile 25
percentile 50
percentile 75
percentile 95


Thorax depth (cm)
Age
percentile 5
percentile 25
percentile 50
percentile 75
percentile 95


Abdominal width (cm)
Age
percentile 5
percentile 25
percentile 50
percentile 75
percentile 95

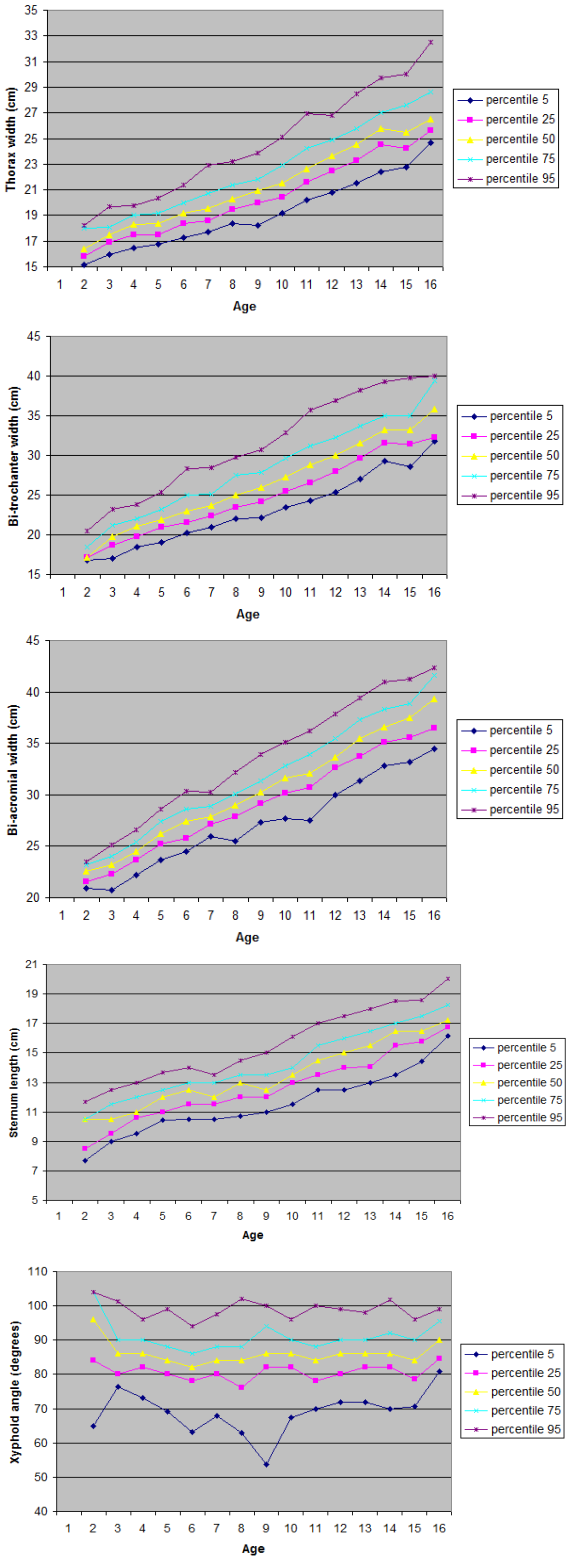


Figure 2: Curves of the 5th, 25th, 50th, 75th and 95th percentile values for each dimension and each age

Discussion

From a global point of view, curves show a constant growth of all parameters except few ones. In particular, the weight corridor increases in function of the age. This particularity can be attributed and tend to show obesity signs for the children population. Abdominal dimensions such as the width or the depth follow the same tendency and can be linked also to the obesity.
Concerning specifically the xyphoid angle, no specific increasing can be observed. This means that this parameter stays constant during the child growth.

Concerning the same database identified in bibliography, if a lot of them exist on the stature and the weight of children, few indicate dimensions by body segment. Moreover, main databases describing precisely and completely the children anthropometry are based on US population (Weber, 1985; Dreyfuss, 2002, Pheasant, 2001) and are sometimes dated (Snyder, 1977). Others concern European population but none describe the anthropometry of French children. For example, a UK survey was conducted by Smith and Norris in 2001 (Smith, 2001). Two identical American studies have also been performed. The first one is totally available on internet and was conducted by Snyder in the 1970's on more than 4000 infants and children (Snyder, 1977). The second one referred to (Dreyfuss, 2002). A comparison between our results with these European or American databases has been performed in a previous work (Serre, 2006). From a global point of view, values provided by these authors are 12% lower than ours.
This previous study was also focused on the 3 and 6 years old children data in order to compare these data with the corresponding dummies (HybridIII-3 HybridIII-6, P3 and P6). Comparisons with child dummies show that the difference is negligible because it is close to 3% (Serre, 2006).

CRS AND VEHICLE MEASUREMENTS

Child Restraint System data

In order to compare the children morphology with actual restraint system, measurements have been performed on several commercialised child seat and booster. These CRS concern only forward facing system such as booster seat and they represent the different standard groups: 0+, 1, 2, 3. Thirteen dimensions have been measured on 28 actual CRS.
The corresponding recorded data are the following ones (see figure 3):

1. the standard group of the system regarding the ECE R44 classification
2. the total seat cushion depth
3. the seat cushion depth from the anchorage point
4. the seat cushion width
5. the seat cushion height
6. the seat height
7. the maximal height of the belt position
8. the minimal height of the belt position
9. the headrest height
10. the backrest depth
11. the abdominal belt height (at the anchorage point)
12. the maximal lateral distance for the thigh
13. the maximal height for the thigh

Figure 3: CRS dimensions

Table 1 summarises all the measured dimensions. All the values are given in centimetres and a "0" value signifies that this parameter is not applicable for the system.

Table 1.
CRS measurements

Restraint system	Standard Group (regarding ECE R44)	Seat cushion depth	Seat cushion depth from the anchorage point	seat cushion width	seat cushion height	Seat height	Maximal height of the belt guide	Minimal height of the belt guide	Headrest height	Backrest depth	Abdominal belt height	Maximal lateral distance for the thigh	Maximal height for thigh
1	1	32	17	27	22	55	0	0	37	10	0	16	10
2	1	32	15	26	22	36	0	0	37	10	0	17	13
3	1	28	14	26	30	54	0	0	27	10	0	13	10
4	1	28	13	30	23	55	0	0	0	23	0	13	11
5	1	32	17	27	22	57	0	0	40	10	0	14	10
6	2-3	35	0	26	10	0	0	0	0	0	10	0	0
7	3	33	0	25	11	62	45		42	8	11	0	0
8	2-3	37	17	27	12	65	23	0	0	5	12	14	14
9	2-3	37	17	26	12	64	24	0	0	6	12	14	15
10	1-2-3	37	22	26	12	72	18	0	49	5	12	14	
11	0+	34	16	27	20	53	0	0	0	8	0	17	15
12	0+	33	11	27	21	53	0	0	36	10	0	14	14
13	2-3	36	19	25	11	65	26	0	42	8	11	15	14
14	0+	38	19	29	24	45	0	0	0	4	0	14	12
15	2-3	34	0	27	10	62	38	0	0	7	13	0	0
16	3	27	0	26	12	59	36	0	36	4	11	0	0
17	2-3	31	0	27	13	59	35	0	38	3	11	0	0
18	2-3	39	0	33	17	59	50	37	72	5	10	0	0
19	2-3	34	0	28	11	74	49	31	52	8	11	0	0
20	2-3	34	0	26	14	78	55	36	55	7	12	0	0
21	1-2-3	33	15	28	15	61	41	32	41	5	14	21	13
22	2-3	33	0	25	15	76	57	40	57	12	12	0	0
23	1-2-3	33	11	21	14	66	55	0	36	5	16	12	14
24	1-2-3	30	10	30	22	64	50	0	40	5	0	9	13
25	2-3	35	0	25	12	70	46	38	46	8	12	0	0
26	1	29	15	29	18	56	0	0	0	10	0	14	11
27	2-3	27	0	31	23	58	35	0	34	12	23	0	0
28	1	28	17	30	19	35	0	0	0	10	0	15	13

Vehicle measurements

In order to complete the geometrical characterization of the sitting position of the children, some measurements have been taken on family cars. Dimensions concern only the rear seat of the vehicle and the corresponding belt position. These measurements allow to evaluate the adequacy of the booster+vehicle's belt coupling and the transition when the child will not use any more CRS. Six dimensions have been performed on six different vehicles. Three lengths concern the rear seat while the six others concern the seatbelt position.

The performed measurements on the vehicle are listed below (see figure 4):

1. the seat height (backrest)
2. the seat width
3. the bench seat depth (which corresponds to the seat cushion length as defined by (Huang, 2006)
4. the maximal height of the seatbelt anchorage point which correspond to the shoulder belt
5. the minimal height of the seatbelt anchorage point (when an adjustment is available on the vehicle)
6. the lateral distance between the two anchorage points of the abdominal seatbelt (from the buckle to the lateral edge of the bench seat).

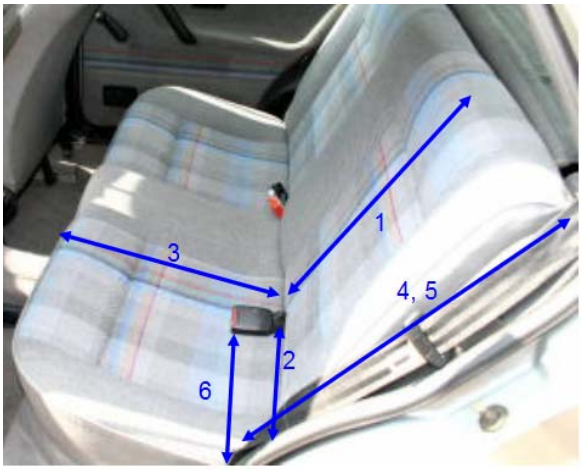


Figure 4: Vehicle dimensions

Table 2 gives all the measured dimensions. Values are given in centimetres and a "0" value signifies that this parameter is not applicable for the vehicle (only concern the availability of a seatbelt height adjustment).

Table 2.
Vehicle measurements

Vehicle ID	Seat height	Seat width	Seat depth	maximal heigth of the seatbelt	minimal heigth of the seat belt	lateral distance between anchorage points
1	59	49	46	70	0	41
2	57	59	44	72	61	41
3	60	59	44	58	0	49
4	61	44	48	69	0	42
5	67	65	44	70	0	48
6	58	50	47	59	0	29

COMPARISON OF THE DATA

Evaluation of the seatbelt position

Previously to compare the amount of anthropometric data with CRS's dimensions, it appears necessary to estimate the seatbelt position regarding child's trunk. So, the objective of this first work is to evaluate in particular the position of the webbing against the clavicle or the sternum. Indeed, it is accepted that the good position of the seatbelt is on the middle of the clavicle and on the sternum (Chabert, 1996).
To do this work, considering the following scheme which represents the child trunk and the seatbelt position (see figure 5).

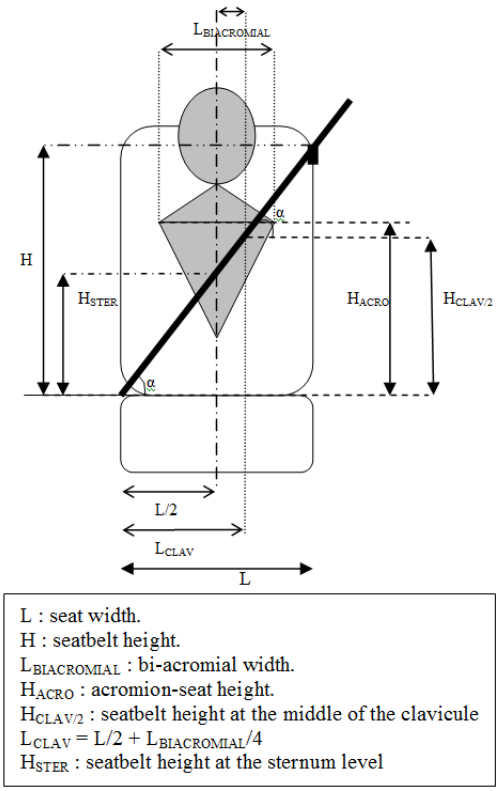


Figure 5: Computation of the seatbelt position regarding child's trunk

The middle of the clavicle is so estimated at the quarter of the bi-acromial distance from the sagittal plane. With this assumption, the height of the vehicle seatbelt at the level of the middle of the clavicle can be calculated by:

$$H_{CLAV/2}=H/L*L_{CLAV} \qquad (1)$$

Concerning the sternum, the height of the seatbelt at the level of the sternum can be calculated by:

$$H_{STER}=H/L*L/2 \qquad (2)$$

Of course, these equations are mainly valid when only the seatbelt of the vehicle is used i.e. when no CRS is present or when a booster is installed. In this last case, the booster cushion height has to be added to the acromion height. Finally, if a child seat is considered, these calculations have to be adapted to the configuration.

Comparison of the seatbelt position

Regarding the amount of recorded data, a lot of comparisons can be done. So, we have decided to focus the exploitation on few characteristics.

Clavicle height versus vehicle seatbelt without CRS – This comparison concern the real clavicle height of the children in sitting position (considered as the acromion height) and the seatbelt height of the vehicle at the clavicle level (such as calculated using equation 1) without CRS. Figure 6 superimposed the 5th, 25th, 50th, 75th and 95th percentile values of the acromion height for all children (curves in black) and the corresponding seatbelt height for each vehicle (other coloured curves).

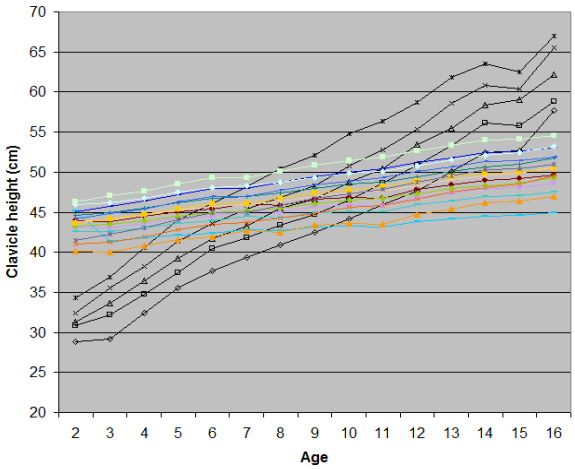


Figure 6: Comparison of the real clavicle height of the children in sitting position (black curves) with the seatbelt height of all vehicles at the clavicle level (coloured curves).

These curves shows that until age of 7, children can not used only the vehicle seatbelt. From 7 years old, 50% children can avoid the CRS to consider only the seatbelt of the vehicle. In fact, this limit corresponds to the minimal clavicle height (i.e. acromion height) needed to reach the minimal height of the seatbelt vehicle at the clavicle level. After this limit the real clavicle height of the children is higher than the seatbelt vehicle height at the clavicle level and this last one fitted and followed the shoulder height growth.

Clavicle height versus vehicle seatbelt with CRS – This comparison is the same as above but it is considered that the children are sited in a CRS. The height of the CRS cushion is so added to the acromion height of the children. In this case, all the black curves of the figure 6 go up from 10 cm (CRS n° 6) to 30 cm (CRS n°33). So it is easy to notice that all children older then 3 are correctly protected by the coupling CRS+seatbelt vehicle.

Comparison of the CRS's cushion width with the bi-trochanter dimension.

The objective of this comparison is to evaluate if the dimension of the CRS's cushion is adequate with the children morphology at the pelvis level. Figure 7 compares, for all ages, the bi-trochanter distance measured on the children sample with the seat cushion width measured on all CRS.

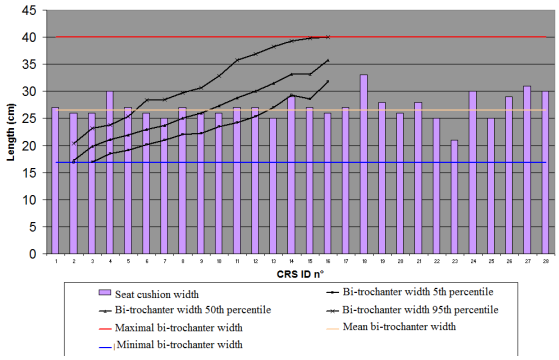


Figure 7: Comparison of the bi-trochanter width (curves) with the seat cushion width measured on all CRS (bar chart).

This comparison shows that all CRS (except n°23) are enough large to be used until 9 years old. Regarding the morphology of the children pelvis, this parameter does not appear as a limit for the use of the CRS.

Comparison of the children weight and the standard classification.

The objective of this comparison is to evaluate the adequacy of the standard classification of the CRS based on the children weight. The standard classes have been defined by the ECE R44 (Bell, 1997) as follow:

- group 1: from 9 to 18kg, age lower than 3,5 y.o.
- group 2: from 15 to 25 kg, age from 3 top 7 y.o.
- group 3: from 22 to 36 kg, age from 6 to 12 y.o.

These data have been reported on the following figure 8 and superimposed with the weight growth of the sample.

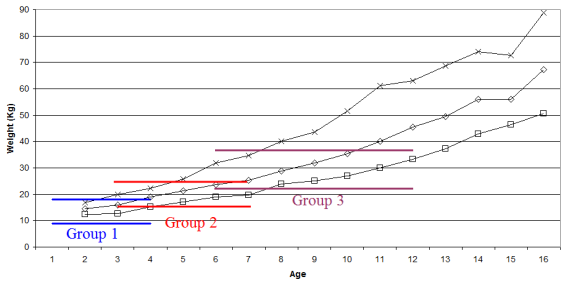


Figure 8: Comparison of the children weight (black curves of the 5th, 50th and 95th percentiles) with the standard classification

Due to obesity signs previously discussed and observed, this figure highlights that for children aged between 5 and 6, the standard classification is inadequate. Indeed, for children aged around 6, about 50% of them have a restraint unsuited to their weight. This incoherence of the classification confirms the results obtained by Anderson in 2006 and tends to show that the standard classification has to be improved.

CONCLUSION

This research allows to acquire new anthropometric data on the children morphology aged from 3 to 16 years old. Acquisition of complementary data on CRS geometry and cars allows also to have a first evaluation of the adequacy of CRS regarding the children anthropometry. Results highlight some discrepancies in particular concerning the standard classification of the CRS.

Nevertheless, these results have to be considered as a preliminary study. Indeed, a small part of the geometrical database has been exploited to compare children anthropometry with CRS dimensions. More work could be performed like verifying the seatbelt position on the children thorax (sternum length or xyphoid angle). In the same way, geometrical data on lower limb have not been analysed too. It could be useful to investigate the distance between the rear seat and the front one.

Finally, it could be valuable to work on a revision of the standard classification in order to base it on other parameter than the weight.

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CHARACTERISTICS OF POWERED TWO WHEELERS ACCIDENTS SUSCEPTIBLE TO BE AVOIDED AND MINIMIZED THROUGH ADAS AND IVIS IMPLEMENTATIONS

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ABSTRACT

Powered Two Wheelers (PTWs) accidents constitute one of the road safety problems in Europe. PTWs fatalities represent 22% at EU level in 2006 [1], having increased during last years, representing an opposite trend compared to other road users' figures.

In order to reduce these figures it is necessary to investigate the accident causation mechanisms from different points of view (e.g.: human factor, vehicle characteristics, influence of the environment, type of accident). SAFERIDER project [2] ('Advanced telematics for enhancing the SAFEty and comfort of motorcycle RIDERs', under the European Commission '7th Framework Program') has investigated PTW accident mechanisms through literature review and statistical analyses of National and In-depth accident databases; detecting and describing all the possible PTW´s accident configurations where the implementation of ADAS (Advanced Driver Assistance Systems) and IVIS (In-Vehicle Information Systems) could contribute to avoid an accident or mitigate its severity.

DIANA, the Spanish in-depth database developed by CIDAUT, has been analyzed for that purpose. DIANA comprises of accident investigation teams, in close cooperation with police forces, medical services, forensic surgeons, garages and scrap yards. An important innovation is the fact that before injured people arrive to hospitals, photographs and explanations about the possible accident injury mechanisms are sent to the respective hospitals (via 3G GPRS technology). By this, additional information to medical staff can be provided in order to predict in advance possible internal injuries and select the best medical treatment. This methodology is presented in this paper.

On the other hand, the main results (corresponding to road, rider and PTW characteristics; pre and post-accident manoeuvres; road layout; rider behaviour; impact points; accident causations;…) from the analyses of the PTW accidents used for SAFERIDER are shown. Only accident types relevant to ADAS and IVIS devices have been considered

INTRODUCTION

European statistics show that the number of Powered-Two-Wheelers (PTW) road accidents is high. Motorcycle and moped fatalities account for 22% of the total number of road accident fatalities in 2006, in EU-14 member countries. It is therefore evident that the reduction of PTW accidents is of major concern for the European community. The adaptation and implementation of appropriate Advanced Driver Assistance Systems (ADAS) and In-Vehicle Information Systems (IVIS) technologies in PTWs might contribute to the significant enhancement of riders' safety.

SAFERIDER project

During the last decade, ADAS and IVIS development has been one of the main research areas of the automotive industry, in order to increase safety and comfort of passenger cars. These new technologies have been already introduced in the automotive market and their evolution is definitely fast and efficient. However, such technologies in motorcycles and even clean motorbikes (electric), in order to increase the safety and comfort of riders, an extremely susceptible road user group, is currently lacking behind and should be undoubtedly studied further. Thereby it needs to be stressed that such technologies should be designed and developed in a way that will not interfere with driving and/or annoy the rider.

SAFERIDER project ('Advanced telematics for enhancing the SAFEty and comfort of motorcycle RIDERs', under the European Commission '7th Framework Program') has started in January 2008 with the aim of enhancing PTW riders' safety by applying ADAS/IVIS on PTWs of all types for the most crucial functionalities and develop efficient and rider-friendly interfaces and interaction elements for riders' comfort and safety.

Characterization of PTW accident scenarios - One of the first steps carried out in the SAFERIDER project has been the characterization of the PTW accident scenarios susceptible to be avoided or minimized through ADAS and IVIS implementations. For obtaining this purpose, the following tasks have been done:

- ✓ 1. Review of existing European motorcyclists' accident reports [3].
- ✓ 2. Analysis of national accident statistics:
  -*Spain*: DGT (Spanish national database).
  -*Germany*: Official German Road Accident Database.
  -*Italy*: SISS (Italian national database).
  -*France*: Assurance Mutuelle des Motards (French insurance company database).
- ✓ 3. Analysis of in-depth accident databases:
  -*Spain*: DIANA (Spanish in-depth accident database).
  -*Germany*: GIDAS (Germany in-depth accident database).
  -*Europe*: MAIDS (under permission by ACEM), which is an ad-hoc motorcyclists' accidents database developed, with more than 900 motorcyclists' accidents analysed in detail.

This paper will firstly present a description of DIANA database (one of the in-depth accident databases used in the characterization of the PTW accidents scenarios). In the second part, the most relevant accident scenarios concerning to PTWs are described together with the parameters that should be considered in the next SAFERIDER steps (ADAS and IVIS implementations). This identification has resulted in 17 pre-crash scenarios, so called SAFERIDER 'Use cases'.

DIANA: THE SPANISH IN-DEPTH ACCIDENT DATABASE

DIANA is the Spanish in-depth accident database developed by CIDAUT. It has been one of the three in-depth databases used during the analyses of SAFERIDER to obtain the main characteristics of PTW accidents where ADAS and IVIS could avoid them or mitigate the consequences.

CIDAUT counts with accident investigation teams (composed of engineers and psychologists) that travel immediately ('prospective investigations') to the accident scene to perform an 'in-depth investigation', in close cooperation with police forces, medical services, forensic surgeons, garages and scrap yards. When it is not possible to travel immediately to the accident spot, a 'retrospective investigation' is made if sufficient information can be gathered. A complete scene and vehicle analysis equipment and reconstruction software are used. All information gathered is stored in an own database for further exploitation jointly with access to other accident databases, as for example the national one coming from the DGT (Dirección General de Tráfico) which provides information on every injury accident.

Figure 1. DIANA 'Spanish in-depth database'

Sampling plan

The sampling area is located within the Valladolid province (8,202 km^2), covering both urban and non-urban roads. Nevertheless this sampling area can be wider depending of the type of accidents to be researched.

Figure 2. Sampling area (in red)

Accident selection is based on random notification from police control rooms, as the responsibility for accidents within urban areas rely on Urban Police (Policía Municipal del Ayuntamiento de Valladolid) and accidents occurred within non-urban areas rely on other kind of police (Guardia Civil de Tráfico).

Figure 3. Prospective in-depth investigation of a PTW accident

Data coding and quality control

After data collection, an accident reconstruction is carried out with the aim of finding out what happened and assessing the causes that led to the accident. Accident reconstruction allows to discover the collision severity and to obtain a detailed simulation of the accident dynamics. It is carried out based on vehicle deformations, vehicle marks and remains, etc. The reconstruction is performed using PC Crash obtaining the estimation of delta-V and EES. In some cases, analytical calculations are also performed (conservation of linear/angular momentum and conservation of energy).

Furthermore, interviews to the people involved in the accident and witnesses (if any) are performed in order to collate both sources also together with police information. When it is not possible to interview these people, different sources are asked for, such as police forces or medical services.

Figure 4. Interview by hospital staff

Police reports are always obtained by accident investigation teams, and later are contrasted with the in-depth information gathered on the spot by themselves.

Finally, information about injuries is collected by the medical staff belonging to the DIANA consortium (‘Río Hortega’ hospital in the cases of injured people or ‘Legal Anatomic Institute of Valladolid’ in the cases of fatalities) in order to obtain both the injured people statements and the injury report with the AIS codifications.

Information gathered

More than one thousand of different variables are defined in DIANA database (this figure increases when there is more than one vehicle, occupant or pedestrian involved). These variables are classified into three modules: ‘Accident’, ‘Vehicle’ and ‘Occupant/Pedestrian’.

In the case of the accidents used for SAFERIDER project, specific information about PTW´s was gathered:

- Motorcyclist dynamic: It was collected specially in cases in which motorcyclist impacted against a safety barrier, even when a motorcyclist protective device is present.
- Motorcyclist clothing: Type and thickness.
- Helmet: Use, type, screen existence, subjection, ejection, damage localization and cause of this damage.

On-line photosafety

In the cases of 'prospective investigations', the technical members of CIDAUT, just after arriving to the scene, send photographs of the accident to the respective hospitals where the injured people are going to or are being taken. This process is called 'On-line photosafety'.

The objective of this process is that medical staff receives these photographs (via 3G GPRS technology) before the injured people arrive and they can diagnose/predict possible internal injuries. Obviously, it is necessary that CIDAUT´s team arrives to the scene before the EMS (Emergency Medical Service) takes the injured people to the hospital. The information sent to the hospital concerns photographs and explanations (also by mobile phone) about the possible accident injury mechanisms.

Figure 5. Member of CIDAUT taking photographs at the accident scene

Figure 6. Member of CIDAUT sending the photographs before injured people arrive at respective hospitals

Figure 7. Hospital members analysing the photographs before injured people arrive

PTWS ACCIDENTS SUSCEPTIBLE TO BE AVOIDED OR MINIMIZED THROUGH ADAS AND IVIS

Once SAFERIDER carried out the first steps of the project (literature review about PTW accidents, analyses over National PTW accident databases and analyses over in-depth PTW accident databases), it has been possible to characterize the PTW accident scenarios susceptible to be avoided and minimized through ADAS and IVIS implementations.

It should be underscored the importance of matching the information derived from National and In-depth databases. While the general figures from National databases have allowed obtaining the scope of each problem over the whole PTW accidents, the in-depth databases have given very detailed and deep information.

Following, the description of the seventeen accident scenarios selected is given. For each one of these scenarios, the structure of the information is:

-Characterization: Variables and respective values describing each scenario, for instance, 'Accident causes', 'Accident characteristics', 'Type of vehicles involved', 'Relative trajectories', 'Vehicle speed'. 'Road conditions', 'Rider type', 'Rider experience'…and any possible variables needed for reproducing (via tests or via simulations) the same conditions in which the accident happened. Furthermore, specific variables have been chosen as 'Priority variables' with the aim of having a general use case description.

- List of possible ADAS/IVIS: A list of the 'Main variables to be studied in this accident' as well as

‘Possible ADAS/IVIS detected which can be avoid or minimize this accident scenario’. The reason of listing these ADAS/IVIS is because, at the end, the result of this study is to detail (‘Characterization’) the main scenarios where the accidents happen as well as the possible ADAS/IVIS that could avoid these accident.

- Example of ADAS/IVIS working: Finally, an example of a possible ADAS/IVIS working in that scenario is given.

Urban Single Motorcycle Accident On Straight Road.

Characterization:

CASE NAME	Urban single motorcycle accident on straight road
GOAL	27% of all crashes (literature), 4.5 % (national), 7.5% (in-depth)
TYPE OF EGO-VEHICLE (MOPED, MOTORCYCLE)	Motorcycle (L3), 32.9% (scooter style), 30% (sport style)
TYPE OF OTHER INVOLVED VEHICLE	None
ACCIDENT CAUSES	Loss of control (70%) **Priority High** Travelling too fast [10.2% (national) - 55% (in-depth)] **Priority High** Lack of attention (28%) Distraction (26%) Road environment (23.8%) Driver behaviour or experience (90%) **Priority High**
ACCIDENT CHARACTERISTICS	Running off the roadway (23% of all single vehicle accidents) **Priority High** Breaking side-outs (15%) Motorcycle capsize (10%)
EGO NO OF OCCUPANTS	-
TYPE OF ROAD	Urban, Flat road (79%) **Priority High**
RELATIVE TRAJECTORIES	Straight road: 67% of relevant accidents **Priority High**
EGO-VEHICLE SPEED	<40 km/h (10%) 40-59 km/h (51.4%) **Priority High** 60-99 km/h (14.3%)
OTHER VEHICLE SPEED	N/A
TIME TO COLLISION	-
TIME OF THE DAY/ WEATHER	Day/ Clear: 16.9% (in-depth) - 51.4% (national) **Priority High** Day/ Slight Rain: 15.5% Dawn Clear: 13.4% Night/ Clear: 22.6% **Priority High**
ROAD CONDITIONS	Dry: 64%-96% **Priority High** Wet: 4%-19% Bad weather [10% (GIDAS) - 70% (MAIDS)]
VISIBILITY	Visibility problems on 40% of relevant accidents
RIDER TYPE	18-25 years (13-14.7%) 26-35 years (27-34.4%) **Priority High** 36-45 years (26.9-29%) **Priority High** 46-55 years (11-12.7%)
RIDER EXPERIENCE	1-4 years (23-30%) **Priority High** 5-10 years (17%) >10 years (31-36%) **Priority High**

List of possible ADAS/IVIS:

Variables to be studied in each type of accident	Possible ADAS/IVIS related with the factor detected (which can help to minimize or avoid the accident)
Impaired visibility	ADAS - Intersection support ADAS - Visibility improvement system (infrared)
Driver physical status	ADAS - Hypovigilance system
Age of driver	ADAS - Hypovigilance system
Driver experience	ADAS - Hypovigilance system
Driver inattention	ADAS - Frontal collision warning (Obstacle detection)
Inappropriate speed	ADAS - Speed alert functionality ADAS - Adaptative cruise control
Loss of control to the left or to the right	ADAS - Warning of a dangerous curve ADAS - Speed alert functionality
Bend negotiation	ADAS - Warning of a dangerous curve
Environmental factors: weather	ADAS - Warning of low temperature (frost)
Vehicle status	ADAS - Warning of mechanical failure, low tyre pressure

Example of ADAS/IVIS working: If the support system is on: A motorcycle is driving straight on an urban road in its own lane. The speed is too high for the circumstances. The "Speed Alert" system effectively warns the rider to reduce speed. There is a sudden event (i.e. pedestrian suddenly crossing, car leaving parking place), which might cause an accident, if the rider does not decrease speed.

Urban single motorcycle accident on bends.

Characterization:

CASE NAME	Urban single motorcycle accident on bends
GOAL	15% of all crashes (literature), 1.9 % (national), 3.7% (in-depth)
TYPE OF EGO-VEHICLE (MOPED, MOTORCYCLE)	Motorcycle L3, 18.8% (scooter style), 20.8% (sport style), 18.8% (conventional street style)
TYPE OF OTHER INVOLVED VEHICLE	None
ACCIDENT CAUSES	Loss of control (95%) **Priority High** Travelling too fast [20.4% (national) - 70-100% (in-depth)] Lack of attention (28%) Distraction (25.4%) Road environment (25.6%) Driver behaviour or experience (70%) **Priority High**
ACCIDENT CHARACTERISTICS	Running off the roadway (23% of all single vehicle accidents) **Priority High** Breaking side-outs (15%) Motorcycle capsize (10%)
EGO NO OF OCCUPANTS	-
TYPE OF ROAD	Urban Safety Barrier (6%) Lane width 6-7m (19%) Flat road (68.8%) **Priority High** Uphill (16.7%) Downhill (12.5%)
RELATIVE TRAJECTORIES	Left Curve: Curve radius <90m (15.8%) Curve radius 90, 450 (20.6%) **Priority High** Right Curve Curve radius <90m (10.8%) Curve radius 90, 450 (21.6%) **Priority High**
EGO-VEHICLE SPEED	<40 km/h (16.7%) 40-59 km/h (29.2%) 60-99 km/h (43.8%) **Priority High**
OTHER VEHICLE SPEED	N/A
TIME TO COLLISION	-
TIME OF THE DAY/ WEATHER	Day/ Clear: 24.1% (in-depth) - 50.3% (national) **Priority High** Dawn Clear: 5.6-13.1% Night/ Clear: 25.7% **Priority High**
ROAD CONDITIONS	Dry: 71.8%-96% **Priority High** Wet: 4%-13%
VISIBILITY	Visibility problems on 40% of relevant accidents
RIDER TYPE	>18 years (5.9-12.5%) 18-25 years (16.4-18.8%) 26-35 years (29.2-35.7%) **Priority High** 36-45 years (12.5-24.3%) 46-55 years old (11.5%)
RIDER EXPERIENCE	1-4 years (22.9-31.1%) **Priority High** 5-10 years (17.2-27.1%) >10 years (12.5-28.6%)

List of possible ADAS/IVIS:

Variables to be studied in each type of accident	Possible ADAS/IVIS related with the factor detected (which can help to minimize or avoid the accident)
Impaired visibility	ADAS - Intersection support ADAS - Visibility improvement system (infrared)
Driver physical status	ADAS - Hypovigilance system
Age of driver	ADAS - Hypovigilance system
Driver experience	ADAS - Hypovigilance system
Driver inattention	ADAS - Frontal collision warning (Obstacle detection)
Inappropriate speed	ADAS - Speed alert functionality ADAS - Adaptative cruise control
Loss of control to the left or to the right	ADAS - Warning of a dangerous curve ADAS - Speed alert functionality
Bend negotiation	ADAS - Warning of a dangerous curve
Environmental factors: weather	ADAS - Warning of low temperature (frost)
Vehicle status	ADAS - Warning of mechanical failure, low tyre pressure

Example of ADAS/IVIS working:

If the support system is on: A motorcycle is approaching a bend on an urban road. The riding conditions are not appropriate for the bend. The "Curve Warning" system effectively warns the rider about the appropriateness of the current riding conditions in order to ride safely through the curve. If the rider reduces speed, it is likely that he/she keeps the motorcycle under control and no accident occurs.

Rural single motorcycle accident on straight road (motorways and two carriageways roads excluded).

Characterization:

CASE NAME	Rural single motorcycle accident on straight road (motorways and two carriage roads excluded)
GOAL	2.7 - 2.8% of all crashes
TYPE OF EGO-VEHICLE (MOPED, MOTORCYCLE)	12.1% (scooter style) 30.3% (sport style) 18.8% (enduro motorcycle style)
TYPE OF OTHER INVOLVED VEHICLE	None
ACCIDENT CAUSES	Loss of control (30%) Travelling too fast [21.5% (national) - 45-100% (in-depth)] **Priority High** Distraction (30%) Animal or object on carriageway (25%) Driver behavior or experience [13%(national)-45%(in-depth)]
ACCIDENT CHARACTERISTICS	-
EGO NO OF OCCUPANTS	-
TYPE OF ROAD	Rural Safety Barrier (6%) Lane width 6-7m (15%) Lanes separation and verges (27%) Flat road (67%) **Priority High**
RELATIVE TRAJECTORIES	-
EGO-VEHICLE SPEED	> 100 km/h 21% (literature) 40-59 km/h (21.2%) 60-99 km/h (54.5%) **Priority High**
OTHER VEHICLE SPEED	N/A
TIME TO COLLISION	-
TIME OF THE DAY/ WEATHER	Day/ Other: 38.9% (in-depth) - 59% (national) **Priority High** Day/ Clear: 13.9% Dawn Clear: 10.6% Night with artificial luminosity/Other: 13.9% Night/ Clear: 19%
ROAD CONDITIONS	Dry: 83-96% **Priority High** Wet: 3.5-11%
VISIBILITY	Visibility problems on 40% of relevant accidents
RIDER TYPE	<18 years (12.5%) 18-25 years (14.4-18.2%) 26-35 years [9.1% (national) & 35.1% (in-depth)] 36-45 years (24.5-27.3%) **Priority High** 46-55 years (12-13.5%)
RIDER EXPERIENCE	<1 year (15-24.9%) 1-4 years (16-18%) 5-10 years (12-28%) >10 years (36%) **Priority High**

List of possible ADAS/IVIS:

Variables to be studied in each type of accident	Possible ADAS/IVIS related with the factor detected (which can help to minimize or avoid the accident)
Impaired visibility	ADAS - Intersection support
	ADAS - Visibility improvement system (Infrared)
Driver physical status	ADAS - Hypovigilance system
Age of driver	ADAS - Hypovigilance system
Driver experience	ADAS - Hypovigilance system
Driver infraction	ADAS - Frontal collision warning (Obstacle detection)
Inappropriate speed	ADAS - Speed alert functionality
	ADAS - Adaptative cruise control
Loss of control to the left or to the right	ADAS - Warning of a dangerous curve
	ADAS - Speed alert functionality
Bend negotiation	ADAS - Warning of a dangerous curve
Environmental factors: weather	ADAS - Warning of low temperature (frost)
Vehicle status	ADAS - Warning of mechanical failure, low tyre pressure

Example of ADAS/IVIS working:

If the support system is on: A motorcycle is driving straight on a rural road (which is not a motorway or a two carriageway road) in its own lane. The speed is too high for the circumstances. The "Speed Alert" system effectively warns the rider to reduce speed. There is a sudden event (i.e. animal suddenly crossing, car crossing road), which might cause an accident, if the rider does not decrease speed.

Rural single motorcycle accident on straight road (only motorways and two carriageways roads).

Characterization:

CASE NAME	Rural single motorcycle accident on straight road (only motorways and two carriage roads)
GOAL	0.3 - 2.7% of all crashes
TYPE OF EGO-VEHICLE (MOPED, MOTORCYCLE)	44.4% (Cruiser motorcycle style) **Priority High** 22.2% (sport style) 11.1% (Sport touring motorcycle style)
TYPE OF OTHER INVOLVED VEHICLE	None
ACCIDENT CAUSES	Loss of control (80%) **Priority High** Travelling too fast [13.9% (national) - 70-100% (in-depth)] Distraction (38%) Disobeyed traffic rules (18.1%) Changing lane (40%)
ACCIDENT CHARACTERISTICS	-
EGO NO OF OCCUPANTS	-
TYPE OF ROAD	Motorways or two carriageways roads Safety Barrier (67%) Lane width 6-7m (33%) Lanes separation and verges (67%) Flat road (78%) **Priority High**
RELATIVE TRAJECTORIES	-
EGO-VEHICLE SPEED	> 100 km/h 21% 40-59 km/h (11.1%) 60-99 km/h (55.6%) **Priority High** 120-150 km/h (22.2%) >150 km/h (11.1%) (in -depth)
OTHER VEHICLE SPEED	N/A
TIME TO COLLISION	-
TIME OF THE DAY/ WEATHER	Day/ Clear: 55.2% **Priority High** Day/ Other 37.5% **Priority High** Day/ Slight rain: 37.5% **Priority High** Dusk/ Dawn Clear: 11.4% Dusk/ Dawn Other: 12.5% Night without artificial luminosity/ fog: 12.5% Night/ Clear: 19.7%
ROAD CONDITIONS	Dry: 67-84% **Priority High** Wet: 12-33% Bad weather (60%)
VISIBILITY	Visibility problems on 40% of relevant accidents
RIDER TYPE	18-25 years (13%) 26-35 years (33 - 37.3%) **Priority High** 36-45 years (28.8-56%) 46-55 years (13.5%)
RIDER EXPERIENCE	1-4 years (28.9%) 5-10 years (18.6-22%) >10 years [32.9% (national) 67% (in-depth)] **Priority High**

List of possible ADAS/IVIS:

Variables to be studied in each type of accident	Possible ADAS/IVIS related with the factor detected (which can help to minimize or avoid the accident)
Impaired visibility	ADAS - Intersection support
	ADAS - Visibility improvement system (Infrared)
Driver physical status	ADAS - Hypovigilance system
Age of driver	ADAS - Hypovigilance system
Driver experience	ADAS - Hypovigilance system
Driver infraction	ADAS - Frontal collision warning (Obstacle detection)
Inappropriate speed	ADAS - Speed alert functionality
	ADAS - Adaptative cruise control
Loss of control to the left or to the right	ADAS - Warning of a dangerous curve
	ADAS - Speed alert functionality
Bend negotiation	ADAS - Warning of a dangerous curve
Environmental factors: weather	ADAS - Warning of low temperature (frost)
Vehicle status	ADAS - Warning of mechanical failure, low tyre pressure

Example of ADAS/IVIS working:

If the support system is on: A motorcycle is driving straight on a rural road (motorway or two carriage road) in its own lane. The speed is high for the circumstances. The "Speed Alert" system effectively warns the rider to reduce speed. An animal (for example) suddenly crosses the road. The accident may be averted if the rider reduces speed and thus has more time to react. The "Frontal Collision" system may also warn the rider to brake, thus avoiding the accident.

Rural single motorcycle accident on bends (motorways and two carriageways roads excluded).

Characterization:

Case Name	Rural single motorcycle accident on bends (motorways and two carriage roads excluded)
Goal	5.7% (national) and 35.9% (in-depth) of all crashes
Type of ego-vehicle (moped, motorcycle)	49.1% (sport style) **Priority High** 11.8% (Conventional Street Style)
Type of other involved vehicle	None
Accident causes	Loss of control (100%) **Priority High** Travelling too fast for the conditions [65.4% (national) - 100% (in-depth)] **Priority High** Distraction (24.3%) Disobeyed traffic rules (8.9%) Driver behaviour or experience (7.1%)
Accident characteristics	-
Ego no of occupants	-
Type of road	Rural Safety Barrier (35%) Lane width 6-7m (35%) Lane separation and verges (56%) Edge marks (55%) Flat road (44%) **Priority High** Uphill (15%) Downhill (20%)
Relative trajectories	Left Curve: Curve radius <90m (40.3%) **Priority High** Curve radius 90, 450 (17.9%) Right Curve: Curve radius <90m (18.2%) **Priority High** Curve radius 90, 450 (9.1%),
Ego-vehicle speed	40-59 km/h (14.5%) 60-99 km/h (40%) **Priority High** 100-119 km/h (19.1%)
Other vehicle speed	N/A
Time to collision	-
Time of the day/ Weather	Day/ Other: 38% Day/ Clear: 68.6%(National), 33.1%(In-depth) **Priority High** Night/ Clear: 12.7% **Priority High**
Road conditions	Dry: 87-88%
Visibility	Visibility problems on 40% of relevant accidents
Rider type	18-25 years (14.8 - 16 %) 26-35 years [44.6 %(national), 23 %(in-depth)] **Priority High** 36-45 years (23- 23.2%) 46-55 years (10.5%)
Rider Experience	<1 year (13%) 1-4 years (20-28.1%) 5-10 years (19.9%) >10 years (27-32.2%) **Priority High**

List of possible ADAS/IVIS:

Variables to be studied in each type of accident	Possible ADAS/IVIS related with the factor detected (which can help to minimize or avoid the accident)
Impaired visibility	ADAS - Intersection support ADAS - Visibility improvement system (Infrared)
Driver physical status	ADAS - Hypovigilance system
Age of driver	ADAS - Hypovigilance system
Driver experience	ADAS - Hypovigilance system
Driver interaction	ADAS - Frontal collision warning (Obstacle detection)
Inappropriate speed	ADAS - Speed alert functionality ADAS - Adaptative cruise control
Loss of control to the left or to the right	ADAS - Warning of a dangerous curve ADAS - Speed alert functionality
Bend negotiation	ADAS - Warning of a dangerous curve
Environmental factors: weather	ADAS - Warning of low temperature (Frost)
Vehicle status	ADAS - Warning of mechanical failure, low tyre pressure

Example of ADAS/IVIS working:

If the support system is on: A motorcycle is approaching a bend on a rural road (not motorway or two carriageways road). The riding conditions are not appropriate for the bend. The "Curve Warning" system effectively warns the rider about the appropriateness of the current riding conditions in order to ride safely through the curve. If the rider reacts according to the system warning, it is likely that the rider does not lose control and no accident occurs.

Rural single motorcycle accident on bends (only motorways and two carriageways roads).

Characterization:

Case Name	Rural single motorcycle accident on bends (only motorways and two carriage roads)
Goal	0.5-3.1% of all crashes
Type of ego-vehicle (moped, motorcycle)	71.4% (sport style) **Priority High** 28.6% (Conventional Street Style)
Type of other involved vehicle	None
Accident causes	Loss of control (100%) **Priority High** Travelling too fast for the conditions [58.3% (national) - 100% (in-depth)] **Priority High** Distraction (22.9%) Driver behaviour or experience (75%)
Accident characteristics	-
Ego no of occupants	-
Type of road	Rural Safety Barrier (43%) Lane width >7m (57%) Lanes separation and verges (71%) Edge marks (29%) Flat road (57%) **Priority High** Uphill (14%) Downhill (14%)
Relative trajectories	Left Curve: Curve radius <90m (33.7) **Priority High**
Ego-vehicle speed	60-99km/h (42.9%) **Priority High** 100-119km/h (28.6%) 120-150 km/h (14.3%)
Other vehicle speed	N/A
Time to collision	-
Time of the day/ Weather	Day/ Other :22.2% **Priority High** Day/ Clear: 60.1%(national), 33.3% (in-depth) **Priority High** Day/ Heavy rain: 22% **Priority High** Day /Slight and heavy wind: 22.2% Night/ Clear: 17.5% **Priority High**
Road conditions	Dry: 71-83% **Priority High** Wet: 14-29% **Priority High**
Visibility	Visibility problems on 40% of relevant accidents
Rider type	18-25 years (15.5-29 %) 26-35 years [42.5 %(national), 14 %(in-depth)] **Priority High** 36-45 years (26.5%) 46-55 years (10.5-14%)
Rider Experience	1-4 years (29-30.9%) **Priority High** 5-10 years (19.6%) >10 years (14-33.8%)

List of possible ADAS/IVIS:

Variables to be studied in each type of accident	Possible ADAS/IVIS related with the factor detected (which can help to minimize or avoid the accident)
Impaired visibility	ADAS - Intersection support ADAS - Visibility improvement system (Infrared)
Driver physical status	ADAS - Hypovigilance system
Age of driver	ADAS - Hypovigilance system
Driver experience	ADAS - Hypovigilance system
Driver interaction	ADAS - Frontal collision warning (Obstacle detection)
Inappropriate speed	ADAS - Speed alert functionality ADAS - Adaptative cruise control
Loss of control to the left or to the right	ADAS - Warning of a dangerous curve ADAS - Speed alert functionality
Bend negotiation	ADAS - Warning of a dangerous curve
Environmental factors: weather	ADAS - Warning of low temperature (Frost)
Vehicle status	ADAS - Warning of mechanical failure, low tyre pressure

Example of ADAS/IVIS working:

If the support system is on: A motorcycle is approaching a bend on a rural road (motorway or two carriageways road). The riding conditions are not appropriate for the bend. The "Curve Warning" system effectively warns the rider about the appropriateness of the current riding conditions in order to ride safely through the curve. If the rider reacts according to the system warning, it is likely that the rider keeps the motorcycle under control and no accident occurs.

For the night lighting condition, a motorcycle is approaching a bend on a rural road (motorway or two carriageways road). The lighting conditions are not appropriate. The radius of the curve is smaller than expected. The speed is high for the bend. The "Adaptive Light" system effectively informs the rider about the real radius of the bend. If the rider reduces speed to the one appropriate for the bend, it is possible that the rider does not lose control and no accident occurs.

Front-side urban junction accident with car.

Characterization:

CASE NAME	Front-side urban junction accident with car.
GOAL	22% (literature), 11.4% (national), 1.6% (in-depth) of all accidents
TYPE OF EGO-VEHICLE (MOPED, MOTORCYCLE)	Motorcycle L3 27.9% (sport style) 15.3% (Conventional Street Style) 17.1 (Scooter Motorcycle Type) 7.2 (Cruiser Motorcycle Type)
TYPE OF OTHER INVOLVED VEHICLE	Passenger car (in the majority)
ACCIDENT CAUSES	Perception failure OV (56%) Decision failure OV (26.6%) MC traffic scan error (25.3%) OV traffic scan error (50%) MC loss of control (25.3%) OV disobeyed give-way or stop-sign or markings (37.1%) **Priority High** MC disobeyed traffic rules (62.5%) **Priority High** Poor turn or maneuver (40%) **Priority High** MC mistakes during overtaking (20%) MC distraction (23.9%)
ACCIDENT CHARACTERISTICS	*First PTW contact point with the passenger car:* Centre front: 25.2% Right front (9.9%) Right centre (9%) Left centre (9%)
EGO NO OF OCCUPANTS	-
TYPE OF ROAD	T or Y-junction [4.3 %(national), 26.8% (in-depth)] X or +junction [9.4 %(national), 33.3 %(in-depth)] **Priority High** Traffic Light (18%) Flat road (84.5%) **Priority High** Downhill (10%)
RELATIVE TRAJECTORIES	Perpendicular, *Motorcycle:* Moving in a straight line with constant speed (60%) **Priority High** Moving in a straight line accelerating (13.3%) Moving in a straight line- throttle off (8%) *Passenger car:* Stopped in traffic with zero speed (26.7%) **Priority High** Moving in a straight line with constant speed (25.3%) **Priority High** Moving in a straight line braking (10.7%) Moving in a straight line accelerating (9.3%) *Angles of trajectories:* 76º-90º (19.8%) **Priority High** 91º-105º (9%) 121º-135º (9%) 226º-240º (9%) 256º-270º (11.7%)
EGO-VEHICLE SPEED	<40km/h (22.5%) 40-59 km/h (48.9%) **Priority High** 60-99 km/h (25.2%)
OTHER VEHICLE SPEED	Up to 50 km/h (literature)
TIME TO COLLISION	-
TIME OF THE DAY/ WEATHER	Day/clear (57.5-80.7%) **Priority High** Day/fog (15.8%) Day/slight rain (15.8%) Day/slight wind (29.8%) Dusk-Dawn/clear (14.6%) Night with artificial luminosity/Clear (10.5%) Night/clear (18.7%)
ROAD CONDITIONS	Dry: 83-93% **Priority High** Wet: 7-14%
VISIBILITY	28% visibility obstruction
RIDER TYPE	18-25 years (17.4-21 %) 26-35 years (22-34.3%) **Priority High** 36-45 years (21-24.2%) 46-55 years (11-11.4%)
RIDER EXPERIENCE	1-4 years (32%-39%) **Priority High** 5-10 years (16.8-22%) >10 years (29.8-32%)

Example of ADAS/IVIS working:

Variables to be studied in each type of accident	Possible ADAS/IVIS related with the factor detected (which can help to minimize or avoid the accident)
Light conditions (night/day/light)	ADAS - Night vision ADAS - Adaptative light control
Rider manoeuvre	ADAS - Blind Spot detection
Inappropriate speed	ADAS - Speed alert functionality ADAS - Adaptative cruise control
Type of intersection (crossroad, T or Y junction)	ADAS - Intersection support IVIS - Navigational and route guidance IVIS - Weather, traffic and black spot warning
Intersection regulated by	ADAS - Intersection support IVIS - Navigational and route guidance
Right of way violation	ADAS - Intersection support IVIS - Navigational and route guidance
Visibility impaired	ADAS - Intersection support
Poor or incorrect evidence collision strategy/action	ADAS - Frontal collision warning (Obstacle detection)

Example of ADAS/IVIS working:

If the support system is on: A motorcycle is approaching an urban '+' junction type. The motorcycle is on a priority road. A passenger car is approaching the same junction at 90º relevant to the motorcycle. The passenger car does not obey the give priority sign and does not brake. The "Intersection Support" system warns the rider to pay attention to the next intersection. The possible accident may be averted, if the rider does reduce speed in the proper time.

Front-side rural junction accident with car (motorways and two carriageways roads excluded).

Characterization:

CASE NAME	Front-side rural junction accident with passenger car (motorways and two carriage roads excluded).
GOAL	22% (literature), 0.9-4.7% of all accidents
TYPE OF EGO-VEHICLE (MOPED, MOTORCYCLE)	10.3% (sport style) 15.3% (Conventional Street Style) 17.3% (Cruiser Motorcycle Type) 17.2% (Sport touring motorcycle type)
TYPE OF OTHER INVOLVED VEHICLE	Passenger car
ACCIDENT CAUSES	Perception failure OV (90%) OV traffic scan error (90%) Loss of control (15%) OV disobeyed give-way or stop-sign or markings (33-50%) MC disobeyed traffic rules (86.8%) **Priority High** Poor turn or maneuver (50%) MC risk action/behaviour (100%) **Priority High** MC distraction (20.4%) Motorcycle is travelling too fast for the conditions (20%)
ACCIDENT CHARACTERISTICS	*First PTW contact point with the passenger car:* Centre front (51.7%) Right centre (6.9%) Left centre (13.8%)
EGO NO OF OCCUPANTS	-
TYPE OF ROAD	Rural junctions T or Y-junction [61.4 %(national), 27.6% (in-depth)] **Priority High** X or +junction [24.2 %(national), 48.3 %(in-depth)] Roundabout (8.8%) Traffic Light (13.8%) Yield sign (3.4-8.2%) Stop sign (44.6%) **Priority High** Flat road (75.9%) **Priority High** Downhill (10.3%)
RELATIVE TRAJECTORIES	*Motorcycle:* Moving in a straight line with constant speed (80%) **Priority High** Moving in a straight line accelerating (5%) Moving in a straight line-braking (5%) Passing maneuver-passing on right (5%) Negotiation a bend-constant speed (5%) *Passenger car:* Stopped in traffic with zero speed (35%) Moving in a straight line with constant speed (10%) Moving in a straight line-throttle off (10%) Moving in a straight line-accelerating (10%) Turning left-accelerating *Angles of trajectories:* 60º-75º (10.3%) 91º-105º (20.7%) 106º-120º (24.1%) 121º-135º (13.8%) 226º-240º (10.3%)
EGO-VEHICLE SPEED	40-59 km/h (17.2%) 60-99 km/h (65.5%) **Priority High**
OTHER VEHICLE SPEED	-
TIME TO COLLISION	-
TIME OF THE DAY/ WEATHER	Day/clear (58.8-58.9%) **Priority High** Day/other (14.7%) Day/fog (15.8%) Day/slight wind (11.8%) Dusk-Dawn/clear (15.9%) Night/clear (15.1%)
ROAD CONDITIONS	Dry: 90-95% **Priority High** Wet: 4-10%
VISIBILITY	
RIDER TYPE	<18 (9%) 18-25 years (14.8-32 %) 26-35 years (18-38.9%) **Priority High** 36-45 years (23.9-27%) 46-55 years (12.2-14%)
RIDER EXPERIENCE	<4 years (18%) 1-4 years (30.9-32%) 5-10 years (9-17.9%) >10 years (32-32.4%) **Priority High**

List of possible ADAS/IVIS:

Variables to be studied in each type of accident	Possible ADAS/IVIS related with the factor detected (which can help to minimize or avoid the accident)
Light conditions (night/day/light)	ADAS - Night vision ADAS - Adaptative light control
Rider manoeuvre	ADAS - Blind Spot detection
Inappropriate speed	ADAS - Speed alert functionality ADAS - Adaptative cruise control
Type of intersection (crossroad, T or Y junction)	ADAS - Intersection support IVIS - Navigational and route guidance IVIS - Weather, traffic and black spot warning
Intersection regulated by	ADAS - Intersection support IVIS - Navigational and route guidance
Right of way violation	ADAS - Intersection support IVIS - Navigational and route guidance
Visibility impaired	ADAS - Intersection support
Poor or incorrect evidence collision strategy/action	ADAS - Frontal collision warning (Obstacle detection)

Example of ADAS/IVIS working:

If the support system is on: A motorcycle is approaching a rural T-junction. The motorcycle is on a give way road. A passenger car is approaching the same junction at 90º relatively to the motorcycle. The rider does not obey the give priority sign and does not brake. The "Intersection Support" system warns the rider. The possible accident may be averted, if the rider does reduce

speed and obeys the priority rules, as a result of the warning.

Rear-end accidents in urban non-junctions with cars.

Characterization:

CASE NAME	Rear-end accidents in urban non-junctions with cars
GOAL	10% (along with 4b) (literature) 2-2.6% of all motorcycle accidents
TYPE OF EGO-VEHICLE (MOPED, MOTORCYCLE)	9.7% (sport style) 41.9% (Scooter/Motorcycle Type) **Priority High** 6.5% (Touring Motorcycle Type)
TYPE OF OTHER INVOLVED VEHICLE	Passenger car
ACCIDENT CAUSES	Illegal overtaking of the rider (8%) Too-short distance from vehicle ahead (17%) MC driving too close (50%) **Priority High** MC perception failure (50%) **Priority High** MC traffic scan error (60%) **Priority High** MC unsafe act (70%) **Priority High** OV perception failure (40%) Poor turn or maneuver (30%) MC distraction (45%) MC disobeyed traffic rules (35.6%)
ACCIDENT CHARACTERISTICS	-
EGO NO OF OCCUPANTS	-
TYPE OF ROAD	Urban non junction Flat road (84%) **Priority High** Downhill (9.7%) Uphill (6.5%)
RELATIVE TRAJECTORIES	*Motorcycle:* Moving in a straight line (29%) *Passenger car:* Moving in a straight line (16.1%)
EGO-VEHICLE SPEED	<40 km/h (25.8%) 40-59 km/h (29%) **Priority High** 60-99 km/h (25.8%)
OTHER VEHICLE SPEED	-
TIME TO COLLISION	-
TIME OF THE DAY/ WEATHER	Day/clear [62%(national), 25% (in-depth)] **Priority High** Day/other (36.1%) Dusk-Dawn/clear (13%) Dusk-Dawn/other (5.6%) Night/clear (16%)
ROAD CONDITIONS	Wet:10-16% Dry: 84-89% **Priority High**
VISIBILITY	Restricted visibility in 5% of the cases.
RIDER TYPE	<18 years (19.4%) 18-25 years (17-19.4%) 26-35 years (19.4-34%) 36-45 years (24%) **Priority High** 46-55 years (11%) 56-65 years (12.9%)
RIDER EXPERIENCE	<1year (12.9%) 1-4 years (29-29.2%) **Priority High** 5-10 years (17.2-22.6%) >10 years (12.9-29%)

List of possible ADAS/IVIS:

Variables to be studied in each type of accident	Possible ADAS/IVIS related with the factor detected (which can help to minimize or avoid the accident)
Visibility impaired (melee)	ADAS - Visibility improvement system (Infrared)
	IVIS - Weather, traffic and black spot warning
Distraction	ADAS - Frontal collision warning (Obstacle detection)
	ADAS - Adaptative cruise control
Inappropriate speed	ADAS - Speed alert functionality
	ADAS - Adaptative cruise control
Surface condition	IVIS - Weather, traffic and black spot warning
	IVIS - Navigational and route guidance
	ADAS - Warning of low temperature (frost)
Poor or incorrect avoidance collision strategy/action	ADAS - Frontal collision warning (Obstacle detection)

Example of ADAS/IVIS working:

If the support system is on: A motorcycle is driving straight on an urban road (non junction). There is a passenger car moving in front of the motorcycle. The motorcycle drives very close to the passenger car. The "Frontal Collision" system warns the rider about the dangerously low distance from the passenger car. The passenger car suddenly breaks abruptly. The possible accident may be averted, if the rider obeys the warning of the system.

Rear-end accidents in rural non-junctions with cars (motorways and two carriageways roads excluded).

Characterization:

CASE NAME	Rear-end accidents in rural non-junctions with cars (motorways and two carriage roads excluded)
GOAL	10% (along with 4a) (literature), 0.8-1.6% of all motorcycle accidents
TYPE OF EGO-VEHICLE (MOPED, MOTORCYCLE)	Motorcycle (L3) 57.1% (sport style) **Priority High** 14.3% (Enduro Motorcycle Type)
TYPE OF OTHER INVOLVED VEHICLE	Passenger car
ACCIDENT CAUSES	Illegal overtaking of the rider (8%) Too-short distance from vehicle ahead (17%)
ACCIDENT CHARACTERISTICS	MC driving too close (66%) **Priority High** MC error during overtaking maneuver (50%) Motorcycle is travelling too fast for the conditions [10.2% (national), 50% (in-depth)] Slippery road surface (50%) MC distraction (46.1%) MC disobeyed traffic rules (46.7%)
EGO NO OF OCCUPANTS	-
TYPE OF ROAD	Rural non junction (motorways and two carriageways roads excluded) Flat road (43%) **Priority High** Downhill (28.6%) Uphill (14.3%)
RELATIVE TRAJECTORIES	*Motorcycle:* Moving in a straight line (14.3%)
EGO-VEHICLE SPEED	40-59 km/h (14.3%) 60-99 km/h (28.6%) **Priority High** 100-119 km/h (14.3%) 120-150 km/h (14.3%)
OTHER VEHICLE SPEED	-
TIME TO COLLISION	-
TIME OF THE DAY/ WEATHER	Day/clear [57-64%] **Priority High** Day/other (14%) Day/fog (14%) Dusk-Dawn/clear (14%) Dusk-Dawn/other (14%) Night/clear (15%)
ROAD CONDITIONS	Dry: 86-93% **Priority High** Wet: 6-14%
VISIBILITY	Restricted visibility in 5% (literature) and 50% of the cases
RIDER TYPE	18-25 years (14.1-29%) 26-35 years (29-36.5%) **Priority High** 36-45 years (23.1-29%) 46-55 years (13.2%)
RIDER EXPERIENCE	1-4 years (14.3-25.9%) 5-10 years (14.3-19.4%) >10 years (28.5-30.9%) **Priority High**

List of possible ADAS/IVIS:

Variables to be studied in each type of accident	Possible ADAS/IVIS related with the factor detected (which can help to minimize or avoid the accident)
Visibility impaired (melee)	ADAS - Visibility improvement system (Infrared)
	IVIS - Weather, traffic and black spot warning
Distraction	ADAS - Frontal collision warning (Obstacle detection)
	ADAS - Adaptative cruise control
Inappropriate speed	ADAS - Speed alert functionality
	ADAS - Adaptative cruise control
Surface condition	IVIS - Weather, traffic and black spot warning
	IVIS - Navigational and route guidance
	ADAS - Warning of low temperature (frost)
Poor or incorrect avoidance collision strategy/action	ADAS - Frontal collision warning (Obstacle detection)

Example of ADAS/IVIS working:

If the support system is on: A motorcycle is driving straight on a rural road (not motorway and two carriage way road). There is a passenger car moving in front of the motorcycle. The motorcycle drives very close to the passenger car. The "Frontal Collision" system warns the rider about the dangerously low distance from the passenger car. The passenger car suddenly breaks abruptly. The possible accident may be averted, if the rider obeys the warning of the system.

Rear-end accidents in rural non-junctions with cars (only motorways and two carriageways roads).

Characterization:

CASE NAME	Rear-end accidents in rural non-junctions with cars (only motorways and two carriage roads)
GOAL	10%, 0.2-04% of all motorcycle accidents (along with 4a)
TYPE OF EGO-VEHICLE (MOPED, MOTORCYCLE)	33.3% (Sport style) 33.3% (Scooter/Motorcycle Type)
TYPE OF OTHER INVOLVED VEHICLE	Passenger car
ACCIDENT CAUSES	Illegal overtaking of the rider (8%) Too-short distance from vehicle ahead (17%) OV traffic scan error (33%) MC error during overtaking maneuver (33%) OV error during overtaking maneuver (33%) Motorcycle is travelling too fast for the conditions [8%(national), 66% (in-depth)] **Priority High** MC distraction (45%) MC disobeyed traffic rules (47.8%)
ACCIDENT CHARACTERISTICS	-
EGO NO OF OCCUPANTS	-
TYPE OF ROAD	Motorways or two carriageways roads, Flat [100%]
RELATIVE TRAJECTORIES	-
EGO-VEHICLE SPEED	40-59 km/h (33.3%) 60-99 km/h (33.3%) 120-150 km/h (33.3%)
OTHER VEHICLE SPEED	-
TIME TO COLLISION	-
TIME OF THE DAY/ WEATHER	Day/clear (33.3-59.1%) **Priority High** Dusk-Dawn/clear (14.3%) Night/clear (17.2%)
ROAD CONDITIONS	Dry:67-94% **Priority High** Submerge-flooded: 33%
VISIBILITY	Restricted visibility in 5% of the cases.
RIDER TYPE	<18 years (33.3%) 18-25 years (13.1%) 26-35 years (39%) **Priority High** 36-45 years (30.1-33.3%) 46-55 years (12.2-33.3%)
RIDER EXPERIENCE	<1 year (33.3%) 1-4 years (32.2-33.3%) **Priority High** 5-10 years (16.9%) >10 years (33.3-33.7%) **Priority High**

List of possible ADAS/IVIS:

Variables to be studied in each type of accident	Possible ADAS/IVIS related with the factor detected (which can help to minimize or avoid the accident)
Visibility impaired (motor)	ADAS - Visibility improvement system (Infrared)
	IVIS - Weather, traffic and black spot warning
Distraction	ADAS - Frontal collision warning (Obstacle detection)
Inappropriate speed	ADAS - Adaptative cruise control
	ADAS - Speed alert functionality
Surface condition	ADAS - Adaptative cruise control
	IVIS - Weather, traffic and black spot warning
	IVIS - Navigational and route guidance
	ADAS - Warning of low temperature (frost)
Poor or incorrect avoidance collision strategy/action	ADAS - Frontal collision warning (Obstacle detection)

Example of ADAS/IVIS working:

If the support system is on: A motorcycle is driving straight on a rural road (motorway or two carriageway road). There is a passenger car moving in front of the motorcycle. The motorcycle drives very close to the passenger car. The “Frontal Collision” system warns the rider about the dangerously low distance from the passenger car. The passenger car suddenly breaks abruptly. The possible accident may be averted, if the rider obeys the warning of the system.

Mopeds single urban accident.

Characterization:

CASE NAME	Mopeds single urban accident (including run-offs, rollover on the carriageway and collisions with road restraint systems).
GOAL	4.1-6.5% of all accidents
TYPE OF EGO-VEHICLE (MOPED, MOTORCYCLE)	Moped (L1) 55.4% (Scooter style) **Priority High** 7.1% (Step-through style moped)
TYPE OF OTHER INVOLVED VEHICLE	-
ACCIDENT CAUSES	Inadequate speed in 80% as a contributing factor **Priority High** Rider behaviour or experience (45%) Rider's lack of attention (35%) MC travelling too fast for the conditions (38%) MC loss of control (65%) **Priority High** MC distraction (32%) Road environment (18.7%) Vehicle defect (1.7%) MC disobeyed traffic rules (8.2%)
ACCIDENT CHARACTERISTICS	-
EGO NO OF OCCUPANTS	-
TYPE OF ROAD	Urban Flat (62.5%) **Priority High** Uphill (17.9%) Downhill (14.3%)
RELATIVE TRAJECTORIES	-
EGO-VEHICLE SPEED	<40 km/h (28.6%) 40-59 km/h (67.9%) **Priority High**
OTHER VEHICLE SPEED	-
TIME TO COLLISION	-
TIME OF THE DAY/ WEATHER	Day/clear [46.5 %(national), 20% (in-depth)] **Priority High** Day/other (32.3%) Day/slight wind (4.6%) Dusk-Dawn/clear (10.5%) Night/clear (16%) Night without artificial luminosity/Other (10.8%) Night/Clear (28.7%)
ROAD CONDITIONS	Dry:73-76.8% **Priority High** Wet: 8.9-17%
VISIBILITY	Visibility was a problem in 20% of relevant accidents, most related to terrain profile (15%).
RIDER TYPE	<18 years (14.3-25%) 18-25 years (25-27%) **Priority High** 26-35 years (8.9-23%) 36-45 years (12-12.5%) 46-55 years (5.4-6%)
RIDER EXPERIENCE	<1 year (14.3-25%) 1-4 years (24-32.1%) **Priority High** 5-10 years (5.4-8%) >10 years (8-17.9%)

List of possible ADAS/IVIS:

Variables to be studied in each type of accident	Possible ADAS/IVIS related with the factor detected (which can help to minimize or avoid the accident)
Visibility impaired (terrain profile)	ADAS - Warning of a dangerous curve
	IVIS - Weather, traffic and black spot warning
Driver inexperience	ADAS - Road departure warning system
Inappropriate speed	ADAS - Speed alert functionality
	ADAS - Adaptative cruise control

Example of ADAS/IVIS working:

If the support system is on: A moped is driving straight on an urban road in its own lane. The speed is too high for the circumstances. The "Speed Alert" system effectively warns the rider to reduce speed. There is a sudden event (i.e. pedestrian suddenly crossing, car leaving parking place), which might cause an accident, if the rider does not decrease speed.

Mopeds single rural accident (motorways and two carriageways roads excluded).

Characterization:

CASE NAME	Mopeds single rural accident (including run-offs, rollover on the carriageway and collisions with road restraint systems) (motorways and two carriage roads excluded).
GOAL	3.7-3.1% of all crashes
TYPE OF EGO-VEHICLE (MOPED, MOTORCYCLE)	Moped (L1) 46.2 % (Scooter motorcycle style moped) **Priority High** 30.8% (Step-through style moped)
TYPE OF OTHER INVOLVED VEHICLE	-
ACCIDENT CAUSES	Problem related to bad road condition (50-67%) **Priority High** Travelling too fast for the conditions (19.8-50%) **Priority High** MC distraction (57.3%) Road environment (6.3%) MC disobeyed traffic rules (7.7%)
ACCIDENT CHARACTERISTICS	-
EGO NO OF OCCUPANTS	-
TYPE OF ROAD	Rural Flat (38.5%) **Priority High** Uphill (23.1%) Downhill (23.1%)
RELATIVE TRAJECTORIES	-
EGO-VEHICLE SPEED	<40km/h (38.5%) 40-59 km/h (46.2%) **Priority High**
OTHER VEHICLE SPEED	-
TIME TO COLLISION	-
TIME OF THE DAY/ WEATHER	Day/clear (47%) **Priority High** Day/other (13.3%) Dusk-Dawn/clear (7.6%) Dusk-Dawn/other (13.3%) Night/clear (33.2%) Night without artificial luminosity/Clear (13.3%) Night without artificial luminosity/Other (20%) Night/Clear (28.7%)
ROAD CONDITIONS	Dry: 76.9-81% **Priority High** Wet: 12% Ice:7.7% Mud: 7.7% Oil:7.7%
VISIBILITY	Restricted visibility in 20% of the cases.
RIDER TYPE	<18 years (25%) **Priority High** 18-25 years (23.1%) **Priority High** 26-35 years (17.4-23.1%) 36-45 years (7.7-13.9%) 46-55 years (7.9-15.4%)
RIDER EXPERIENCE	1-4 years (23.1-24.7%) **Priority High** 5-10 years (7.7-9.6%) >10 years (17.8-23.1%)

List of possible ADAS/IVIS:

Variables to be studied in each type of accident	Possible ADAS/IVIS related with the factor detected (which can help to minimize or avoid the accident)
Visibility impaired (bend in profile)	ADAS - Warning of a dangerous curve IVIS - Weather, traffic and black spot warning
Driver inexperience	ADAS - Road departure warning system
Inappropriate speed	ADAS - Speed alert functionality ADAS - Adaptative cruise control

Example of ADAS/IVIS working:

If the support system is on: A moped is driving on a rural road (which is not a motorway or two carriageway roads) in its own lane. The speed is too high for the circumstances. The "Speed Alert" system effectively warns the rider to reduce speed. There is a sudden event (i.e. animal suddenly crossing, car crossing road), which might cause an accident, if the rider does not decrease speed.

Urban front-side accidents in junctions of mopes with cars.

Characterization:

CASE NAME	Urban front-side accidents of mopeds with cars.
GOAL	12.7-13.2% of all accidents
TYPE OF EGO-VEHICLE (MOPED, MOTORCYCLE)	Moped (L1) 67.6 % (Scooter motorcycle style moped) **Priority High** 19.4% (Step-through style moped)
TYPE OF OTHER INVOLVED VEHICLE	Passenger car
ACCIDENT CAUSES	MC traffic scan error (28.6%) OV traffic scan error (33.3-66%) **Priority High** MC view obstruction (27.8%) OV view obstruction (36%) MC careless, reckless or in a hurry (45.9%) OV careless, reckless or in a hurry (40.1%) MC disobeyed traffic rules (65.6%) OV disobeyed give-way or stop-sign or markings (33.3-62.5%) **Priority High** Poor turn or maneuver (18.7%) MC distraction (21.4%) Motorcycle is travelling too fast for the conditions [3.8(national),16.3%(in-depth)]
ACCIDENT CHARACTERISTICS	Priority violation of traffic lights (28%) **Priority High** Violation of stop sign (24%) **Priority High** Violation of yield sign (19%) no sign (22%). *First PTW contact point with the passenger car:* Centre front: 30.2% Right front 10.1% Right centre 9.4% Top centre 14.4% Undercarriage front 19.4%
EGO NO OF OCCUPANTS	-
TYPE OF ROAD	T or Y-junction [8.4 %(national), 25.9% (in-depth)] X or +junction [17.3 %(national), 46.8 %(in-depth) **Priority High** Traffic Light [6.1%(national), 29.5% (in0depth) Yield sign (6.3%) Stop sign (4.2%) Warning junction sign (47.5%) **Priority High** None (application of general priority norm) (34.5%) Flat road (84.2%)
RELATIVE TRAJECTORIES	Perpendicular or converging. *Motorcycle:* Normal driving (on a straight section or on a curve section) (80.6%) **Priority High** *Passenger Car:* Normal driving (on a straight section or on a curve section) (49.6%) **Priority High** Turning left at an intersection (25.9%) Turning right at an intersection (7.9%) *Angles of trajectories:* 60º-75º (25.9%) **Priority High** 75º-90º (7.2%) 91º-105º (11.5%) 106º-120º (5.8%) 226º-240º (5.8%) 256º-250º (12.9%) 271º-285º (10.8%)
EGO-VEHICLE SPEED	<40km/h (56.8%) **Priority High** 40-59km/h (40.3%)
OTHER VEHICLE SPEED	-
TIME TO COLLISION	-
TIME OF THE DAY/ WEATHER	Day/clear (26.7-51.4%) **Priority High** Day/other (23.1%) Day/Slight wind (11.3%) Day/Heavy wind (13.3%) Dusk-Dawn/Clear (13.4%) Night/clear (23.1%)
ROAD CONDITIONS	Dry: 89-90% **Priority High** Wet: 5-95
VISIBILITY	
RIDER TYPE	<18 years [9.4% (national), 35.5% (in-depth)] 18-25 years (18-27%) **Priority High** 26-35 years (5-18%) 36-45 years (5-8%)
RIDER EXPERIENCE	<1year (7.2%) 1-4 years (20.1-27.9%) **Priority High** 5-10 years (6.7%) >10 years (6-6.5%)

List of possible ADAS/IVIS:

Variables to be studied in each type of accident	Possible ADAS/IVIS related with the factor detected (which can help to minimize or avoid the accident)
Light condition	ADAS - Adaptative light control
Visibility impaired	ADAS - Intersection support
Type of intersection	ADAS - Intersection support IVIS - Navigational and route guidance
Priority regulated by	ADAS - Intersection support IVIS - Navigational and route guidance
Right of way violation	ADAS - Intersection support
Driver infraction	ADAS - Frontal collision warning (Obstacle detection)
Poor or incorrect avoidance collision strategy action	ADAS - Frontal collision warning (Obstacle detection)

Example of ADAS/IVIS working:

If the support system is on: A moped is approaching an urban 'X' or '+' junction type. The moped is moving on an inferior road. A passenger car is approaching the same junction at 90º relatively to the moped. The moped does not obey the give priority sign and does not brake. The "Intersection Support" system warns the rider to reduce speed. The possible accident may be averted, if the rider does reduce speed and obeys the priority rules.

Rural front-side accidents in junctions of mopes with cars (motorways and two carriageways roads excluded).

Characterization:

CASE NAME	Rural front-side accidents of mopeds with cars (motorways and two carriage roads excluded).
GOAL	1.7-4.7% of all crashes
TYPE OF EGO-VEHICLE (MOPED, MOTORCYCLE)	Moped (L1) 50 % (Scooter motorcycle style moped) **Priority High** 35.7% (Step-through style moped)
TYPE OF OTHER INVOLVED VEHICLE	Passenger car
ACCIDENT CAUSES	OV traffic scan error (54.5%) MC view obstruction(27.2-33.3%) OV view obstruction (36.6%) MC careless, reckless or in a hurry (36.3%) OV careless, reckless or in a hurry (45.5%) MC disobeyed traffic rules [83.9% (national), 33.3% (in-depth)] **Priority High** OV disobeyed give-way or stop-sign or markings (33.3%) MC lack of attention (6%) MC distraction (20%)
ACCIDENT CHARACTERISTICS	Not obeying traffic signs indications (8%) Absent-minded driving (6%) Overtaking illegally (5%) *First PTW contact point with the passenger car:* Centre front: 35.7% Right front 14.3% Left centre 14.3% Top centre 14.3%
EGO NO OF OCCUPANTS	-
TYPE OF ROAD	T or Y-junction [25.7 %(national), 50% (in-depth)] **Priority High** X or +junction (12.9-28.6%) Roundabout (5.8-7.1%) Traffic Light [28%(national) 7.1% (in-depth) Yield sign (5.8%) Stop sign (19.9-28.6%) None (application of general priority norm) [14.9 %(national), 57.1% (in-depth)] Warning junction signs (42.9%) Flat road (71.4%) Uphill (7.1%)
RELATIVE TRAJECTORIES	Perpendicular or converging. *Motorcycle:* Normal driving (on a straight section or on a curve section) (71.4%) **Priority High** Crossing the intersection straight ahead (14.3%) *Passenger Car:* Normal driving (on a straight section or on a curve section) (71.4%) **Priority High** Turning left at an intersection (28.6%) Turning right at an intersection (14.3%) *Angles of trajectories:* 45º-60º (7.1%) 60º-75º (7.1%) 75º-90º (14.3%) 91º-105º (14.3%) 106º-120º (7.1%) 226º-240º (7.1%) 241-255º (7.1%) 256º-250º (21.4%) 286º-300º (7.1%)
EGO-VEHICLE SPEED	<40km/h (42.9%) 40-59km/h (57.1%) **Priority High**
OTHER VEHICLE SPEED	-
TIME TO COLLISION	-
TIME OF THE DAY/ WEATHER	Day/clear [53.7% (national), 18.8% (in-depth)] **Priority High** Day/other (25%) Dusk-Dawn/Clear (11.9%) Dawn/Other (12.5%) Night/clear (21.2%) Night with artificial luminosity/Clear (12.5%) Night without artificial luminosity/Clear (12.5%)
ROAD CONDITIONS	Dry: 90-92% **Priority High** Wet: 9% Mud: 7.1%
VISIBILITY	
RIDER TYPE	<18 years [14.3% (national), 31.7% (in-depth)] 18-25 years [22.3% (national), 7.1% (in-depth)] **Priority High** 26-35 years (15.4%), 36-45 years (9.9%) 46-55 years (5.6%) >65 years (9.4%)
RIDER EXPERIENCE	1-4 years (21.4-27.3%) **Priority High** >10 years (7.1-13.2%)

List of possible ADAS/IVIS:

Variables to be studied in each type of accident	Possible ADAS/IVIS related with the factor detected (which can help to minimize or avoid the accident)
Light condition	ADAS - Adaptative light control
Visibility impaired	ADAS - Intersection support
Type of intersection	ADAS - Intersection support IVIS - Navigational and route guidance
Priority regulated by	ADAS - Intersection support IVIS - Navigational and route guidance
Right of way violation	ADAS - Intersection support
Driver infraction	ADAS - Frontal collision warning (Obstacle detection)
Poor or incorrect evoidance collision strategy/action	ADAS - Frontal collision warning (Obstacle detection)

Example of ADAS/IVIS working:

If the support system is on: A moped is approaching a rural T-junction. The moped is moving on a give way road. A passenger car is approaching the same junction at 90º relatively to the moped. The rider does not obey the give priority sign and does not brake. The "Intersection Support" system warns the rider to reduce speed. The likely accident can be averted, if the rider does reduce speed, as a result of the warning of the system.

Head-on accidents in urban areas, between mopeds and cars.

Characterization:

CASE NAME	Head-on accidents in urban areas, between mopeds and passenger cars.
GOAL	21% of the moped accidents (along with 7b). 2.3-2.5% of all accidents
TYPE OF EGO-VEHICLE (MOPED, MOTORCYCLE)	45.5 % (Scooter motorcycle style moped) **Priority High** 33.3% (Step-through style moped)
TYPE OF OTHER INVOLVED VEHICLE	Passenger car
ACCIDENT CAUSES	OV traffic scan error (15-38%) MC view obstruction (69%) MC careless, reckless or in a hurry (76%) **Priority High** MC disobeyed give-way or stop-sign or markings (15%) MC disobeyed traffic rules (54.1%) OV poor turn or maneuver (30%) MC wrong choice of lane (61%) OV wrong choice of lane (61%) MC distraction (23.7%) Motorcycle is travelling too fast for the conditions (10.7%)
ACCIDENT CHARACTERISTICS	Rider entering the opposite lane (18%) **Priority High** Absent-minded driving (9%) Driving in a forbidden direction (6%) Overtaking illegally (4%)
EGO NO OF OCCUPANTS	-
TYPE OF ROAD	No junction (21.2-47.9%) **Priority High** T or Y-junction (9.1%) X or +junction (6%) Traffic Light (3-9.8%) Yield sign (7.4%) Stop sign (8.1%) None (application of general priority norm) (12.1-21.2%) Flat road (60.6%) **Priority High** Uphill (12.1%) Downhill (27.3%)
RELATIVE TRAJECTORIES	*Motorcycle:* Normal driving (on a straight section or on a curve section) (21.2%) *Passenger Car:* Normal driving (on a straight section or on a curve section) (21.2%)
EGO-VEHICLE SPEED	<40km/h (57.6%) **Priority High** 40-59km/h (33.3%)
OTHER VEHICLE SPEED	-
TIME TO COLLISION	-
TIME OF THE DAY/ WEATHER	Day/clear [47.7% (national), 14% (in-depth)] **Priority High** Day/other (35%) **Priority High** Day/Slight rain (11%) Dusk-Dawn/Clear (14.8%) Night/clear (22.9%) Night with artificial luminosity (15%)
ROAD CONDITIONS	Dry:78.8-86% **Priority High** Wet: 9.1-13% Submerged-flooded: 12.1%
VISIBILITY	Visibility problems in 40%.
RIDER TYPE	<18 years (32-41%) **Priority High** 18-25 years (24-32%) **Priority High** 26-35 years (8-16%) 36-45 years (8-12%)
RIDER EXPERIENCE	<1year (20%) 1-4 years (27-36%) **Priority High** 5-10 years (5-12%) >10 years (5-20%)

List of possible ADAS/IVIS:

Variables to be studied in each type of accident	Possible ADAS/IVIS related with the factor detected (which can help to minimize or avoid the accident)
Type of intersection	ADAS - Intersection support IVIS - Navigational and route guidance
Bend negotiation	ADAS - Warning of a dangerous curve IVIS - Navigational and route guidance
Inappropriate speed	ADAS - Speed alert functionality
Light condition	ADAS - Adaptative light control
Visibility impaired	ADAS - Intersection support
Driver infraction	ADAS - Frontal collision warning (Obstacle detection) ADAS - Lane departure warning system
Poor or incorrect evoidance collision strategy/action	ADAS - Frontal collision warning (Obstacle detection)
Driver's age	ADAS - Speed alert functionality IVIS - Weather, traffic and black spot warning

Example of ADAS/IVIS working:

If the support system is on: A moped is driving straight on an urban road. There is a slow passenger car moving in front of the moped. The moped wants to overtake and enters in the opposite lane. There is an oncoming car. The "Frontal Collision" system warns the rider that the distance to the oncoming car is reducing. The possible accident can be averted, if the rider obeys the warning of the system.

Head-on accidents in rural areas, between mopeds and cars (motorways and two carriageways roads excluded).

Characterization:

CASE NAME	Head-on accidents in rural areas, between mopeds and passenger cars (motorways and two carriage roads excluded).
GOAL	21% (literature), 0.4-0.7% of the moped accidents (along with 7a).
TYPE OF EGO-VEHICLE (MOPED, MOTORCYCLE)	40 % (Scooter motorcycle style moped) **Priority High** 20% (Step-through style moped)
TYPE OF OTHER INVOLVED VEHICLE	Passenger car
ACCIDENT CAUSES	OV perception failure (100%) MC view obstruction (50%) OV view obstruction (50%) OV not driving on the right side of the road (100%) OV disobeyed give-away or stop-sign or marks (50%) MC disobeyed traffic rules (66.2%) **Priority High** MC distraction (23%) Motorcycle is travelling too fast for the conditions (10.7%)
ACCIDENT CHARACTERISTICS	Rider entering the opposite lane (18%) **Priority High** Absent-minded driving (9%) Driving in a forbidden direction (6%) Overtaking illegally (4%)
EGO NO OF OCCUPANTS	-
TYPE OF ROAD	No junction [70.9% (national), 40% (in-depth)] **Priority High** Yield sign (2%) Stop sign (10.9%) None (application of general priority norm) (11.4%) Flat road (50%) Downhill (25%)
RELATIVE TRAJECTORIES	*Motorcycle:* Normal driving (on a straight section or on a curve section) (20%), Overtaking on the left prior to the intersection (20%) *Passenger Car:* Normal driving (on a straight section or on a curve section) (40%)
EGO-VEHICLE SPEED	<40 km/h (40%) 40-59 km/h (40%) **Priority High** 60-99 km/h (20%)
OTHER VEHICLE SPEED	-
TIME TO COLLISION	-
TIME OF THE DAY/ WEATHER	Day/Clear [49.3% (national), 16.7% (in-depth)] Dusk, Dawn/Clear (9.7%) Night (without artificial luminosity)/Heavy wind (16.7%) Night (without artificial luminosity)/Clear (16.7%) Night (without artificial luminosity)/Other (50%) **Priority High** Night/Clear (27.2%)
ROAD CONDITIONS	Dry:80-86% **Priority High** Wet: 11-20%
VISIBILITY	Visibility problems in 40%.
RIDER TYPE	<18 years (25-41.5%) 26-35 years (23.3-25%) **Priority High** 36-45 years (12.5-25%) 46-55 years (7.7-25%)
RIDER EXPERIENCE	1-4 years (32.1-50%) **Priority High** >10 years (8.9-25%)

List of possible ADAS/IVIS:

Variables to be studied in each type of accident	Possible ADAS/IVIS related with the factor detected (which can help to minimize or avoid the accident)
Type of intersection	ADAS - Intersection support
	IVIS - Navigational and route guidance
Road negotiation	ADAS - Warning of a dangerous curve
	IVIS - Navigational and route guidance
Inappropriate speed	ADAS - Speed alert functionality
Light condition	ADAS - Adaptative light control
Visibility impaired	ADAS - Intersection support
Driver infraction	ADAS - Frontal collision warning (Obstacle detection)
	ADAS - Lane departure warning system
Poor or incorrect avoidance collision strategy/action	ADAS - Frontal collision warning (Obstacle detection)
Driver's age	ADAS - Speed alert functionality
	IVIS - Weather, traffic and black spot warning

Example of ADAS/IVIS working:

If the support system is on: A moped is driving straight on a rural road (no motorway or two carriageway road). There is a slow passenger car moving in front of the moped. The moped wants to overtake and enters in the opposite lane. There is an oncoming car. The "Frontal Collision" system warns the rider that the distance to the oncoming car gets too close. The possible accident may be averted, if the rider obeys the warning of the system.

CONCLUSIONS

The main characteristics of PTW accidents susceptible to be avoided or minimized through ADAS and IVIS implementations have been obtained through 'Literature review' and analyses over 'National' and 'In-depth' PTW accident databases, which have been carried out in the first steps of SAFERIDER project (FP7 European funded project).

One of the in-depth accident databases available to SAFERIDER project has been DIANA. During this paper, a brief explanation has been given about how an important and innovative working methodology developed in DIANA is helping to hospital members to diagnostic possible injuries before people involved in accidents arrive to hospitals.

The use of DIANA accident database, as well as other in-depth and National databases has allowed to obtain the characterization (e.g.: road, rider and PTW characteristics; pre- and post-accident manoeuvres; road layout; rider behaviour; impact points, accident situations) of 17 PTWs accident scenarios 'susceptible' to be avoided or minimized its effect through the implementation of ADAS-IVIS on the PTWs.

The next step of SAFERIDER project will be the use of this information, as well as the information from 'User forums' carried out and 'User needs' analysed, with the only objective of selecting the four ADAS and the four IVIS most important with respect to safety and therefore with highest priority. Then, the systems will be implemented to PTWs and tests either through simulation scenarios on a driving simulator or real test will be developed. Finally, cost-benefit analyses will be performed to identify the social impact of the implementation of the selected ADAS-IVIS systems.

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