**D6.1.3 Public Workshop Proceedings**

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<td>M. Sotola</td>
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<td>I. Ducci, M. Pieve</td>
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**Consortium:**

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Abbreviations list

ABD  Active brake-force Distribution
ABS  Antilock Braking System
ACEM  Association des Constructeurs Européens de Motocycles (Association of European Motorcycle Industry)
APROSY S Advanced Protection Systems
ASIC  Application Specific Integrated Circuit
ATP  Automotive Testing Papenburg
BTCS  Brake Traction Control System
CAD  Computer Aided Design
CAN  Controlled Area Network
CFD  Computational Fluid Dynamics
EC  European Commission
DG-TREN  Directorate-General for Energy and Transport
DG-RTD  Directorate-General for Research
ECU  Electronic Control Unit
FE  Finite Elements
FIB  Full Integral Brake
GIDAS  German In-Depth Accident Study
HIC  Head Injury Criteria
HMI  Human Machine Interface
HUD  Head-Up Display
IMB  Information Management for motorBikes
MAIDS  Motorcycle Accidents In-Depth Study
MP3  PIAGGIO Motorbike 3 (in Italian “Moto PIAGGIO 3”)
MOV  Moving
OEM  Original Equipment Manufacturer
PISa  Powered-two wheelers Integrated Safety
PTW  Powered Two-Wheeler
SAFERIDER  Advanced Telematics for enhancing the SAFEty and the comfort for motorcycle RIDERs
SIM  Safety In Motion
SP4  Subproject 4
STA  Stationary
STREP  Specific Targeted REsearch Project
TC/TCS  Traction Control/Traction Control System
TRACE  TRaffic Accident Causation in Europe
TTF  Time To Fire
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Executive summary

Two public workshops took place during the project timeframe, as main milestones for disseminating ongoing activities, partial and final results of Safety In Motion (SIM) project.

The first SIM workshop, organised in collaboration with PISa Project was held on the 29th of May 2008 in Bologna (Italy). Partial results at mid of 2008 of both SIM and PISa projects were presented, together with interventions from ACEM, TRACE and SAFERIDER projects and also from Italian Ministry of Transport and Italian National Council on Road Safety and representative of EC DG-TREN.

The agenda of the 1st Public workshop is reported in the present document.

Presentations in pdf version are available on public website of SIM project or can be directly requested to the SIM project coordinator (marco.pieve@piaggio.com).

The SIM Final Workshop was held in Pontedera (Italy) at the Piaggio Museum on 27th of November 2009. The whole process of SIM project activities was described through oral presentations starting from adopted methodology and analysis, following by the development of the safety Systems and their integration into the final prototype as well as the assessment, test and final results. Additionally a demonstration of the SIM vehicle prototype has been carried out together with the presentation of a Poster Session about SIM Project inside Piaggio Museum.

Within the present document the abstract of the SIM final workshop are reported.

Oral presentations in pdf version as well as poster pictures are available on SIM website or can be requested to the SIM project coordinator.
1. 1st Common Workshop SIM and PISa Projects - Agenda

**AGENDA**

8.45  Welcome and coffee

09.00 Opening

**Outcome of PTW research projects**

09.15 Powered two-wheelers Integrated Safety (PISa):
Project overview and results

10.15 Safety in Motion (SIM):
Project overview and results

11.15 Coffee break

11.45 Industry conspicuity research:
Status and next steps

12.15 The TRACE project: Accident causation and risk factors from the point of view of PTW users

12.45 Light lunch

14.00 The SAFERIDER project: Advanced telematics for enhancing the safety and comfort of motorcycle riders

14.30 **Round Table**

The future of PTW safety

- International harmonization and its effects on road safety
- European policies on PTW safety
- Action plan to improve PTW safety
- Sustainable urban mobility: a proposal

16.30 Closing

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2. SIM Project Final Workshop

2.1 Agenda

Programme

9:00 Registration
9:30 Welcome
9:45 Overview of SIM Project:
  - inputs, methods, main results – M. Fieve (Piaggio & C. S.p.A.)
10:15 Methodology and Analysis
  - Effectiveness evaluation of PTW’s Safety Devices in real accident scenarios – J. Koenig (DEKRA)
  - Motorcycle Dynamic Analysis through Multibody Simulations – M. Guiggiani (UNIPi)
  - PTW crashworthiness studies in Virtual Environment – J. Vazquez de Prada (CIDAUT)
11:15 Coffee break

11:45 Safety Systems Development
  - Enhanced Antilock Brake System – O. Hoffmann G. Roll (CONTI)
  - Electronically Controlled Suspension System – A. Ishii (OHILINS)
  - HMI System and Information Management – E. Bianco (CRF)
  - Airbag development – R. Munoz (DALPHIMETAL)
  - Airbag Control Unit – H. Steurer (CONTI)

13:30 Lunch and Poster session

14:30 Demonstration
15:00 Assessment, Tests and Results
  - Test and Results of Active Safety Systems – O. Di Tanna (Piaggio)
  - Crash Tests Results and Injury Reduction – J. Koenig (DEKRA)
    - J. Vazquez de Prada (CIDAUT)
  - Exploitation of Results – M. Santucci (Piaggio)

16:15 Question and Answers
16:30 End of the workshop
2.2 SIM Consortium

Figure 1 – Representatives of SIM Consortium
2.3 Abstracts of presentations
OVERVIEW OF SIM PROJECT: INPUTS, METHODS, MAIN RESULTS
Marco Pieve (SIM Project Coordinator) – Piaggio & C. SpA

Introduction
A general presentation of the Safety In Motion (SIM) project is provided, describing which are the reasons why SIM started, which approach has been adopted and which are the main results that have been achieved. SIM is a collaborative project (STREP) co-funded by the European Commission DG-RTD under the 6° Framework Programme within the research domain of powered-two-wheelers Safety. The specific request of the call launched in 2005 was to develop integrated safety systems focusing in particular to system implementation. The project lasted 39 months with the involvement of 12 partners among 6 European Regions. According to the Technical Annex, 45 reports have been produced (many of them are public and available on SIM website [www.sim-eu.org] as well as 6 prototypes between vehicles and components. 4 papers have been presented in Scientific Conferences and the partial results have been shown in 5 public events, from Transport Research Arena in (Gothenburg, 2006) to Intelligent Transport Systems (Stockholm, 2009). The project objectives are the identification of a safety strategy and the development of the most relevant technologies in active, passive and preventive safety areas to be implemented in a vehicle prototype. The Consortium is well-balanced in terms of industrial partners (OEM and suppliers), universities and Research Centers with a strong expertise in vehicle safety field.

Inputs
Powered two wheelers vehicles are an effective solution for mobility in urban context (less the travel time and less the consumptions and emissions, compared to a car), since they contribute at solving two out of the three global challenges that every road users have to face daily: traffic jam and emissions. Nevertheless the third challenge, rider safety, is a critical point because motorcycle riders are one of the most vulnerable road users and the numbers are quite worrying. SIM project is aimed at answering to the critical issue of road safety for powered-two-wheelers riders. The background of the project are the findings of MAIDS project, promoted by ACEM (the association of the European PTW manufacturers) and carried out by the Motorcycle Industry with basically two objectives: to identify the main factors that contribute to PTW accidents causation and to propose effective solutions in order to reduce the number of accidents and mitigate the consequences for the rider. On the basis of MAIDS results and the R&D guidelines a matrix approach to PTW safety was adopted according to the Safety Matrix (Figure 2).
SIM project activities covered some items of the matrix, focusing on vehicle aspects in all safety areas and on HMI improvement and on protective devices for the rider.
Methods
Project activities are structured in six workpackages and started with the analysis phase, based on accidentology and effectiveness evaluation, followed by the system development in Active and Passive Safety areas, then the application phase and the testing.

As a first step a Safety Strategy was defined starting from Accident Analysis and on the other hand pre-selecting the technology that was fundamental to get to innovative but very concrete solutions.

A preliminary selection of the most promising technical solutions has been done through literature review and the state-of-the-art, and based on the partners’ expertise. Pre-selection criteria are: technical feasibility, market availability (looking also at the automotive sector), potential transfer in PTW domain.

The effectiveness evaluation identified the potential benefits of the candidate technologies. The outcome is a proposal of safety systems requirements and their technical specifications.

At the end of the analysis phase, the following safety systems requirements were selected to be developed, implemented and tested:

- Active brake system and stability management by traction control and a semi-active suspension system
- Airbag and inflatable wearable device.
- The overall requirements of an HMI management concept for PTW and an enhanced HMI by means of HUD, wireless communication and ergonomic handlebar controls.

Virtual simulation tools for designing and analysing the performances of the safety systems have been widely used and different models were developed for different applications (i.e. the multibody model used for vehicle dynamic analysis and the CFD model for aerodynamic and comfort analysis, as well as the models used for passive safety systems development).

Results
The Safety Strategy has been made concrete in terms of achieved technical results:
Active Safety Systems

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Two active systems (advanced brake system and electronic suspension system) have been developed and integrated in the final prototype.

The two systems are not standalone but they continuously exchange data through a dedicated CAN bus architecture so the suspension system cooperates with the brake system adapting its behaviour according to specific target functions.

**Preventive Safety System**

Within SIM preventive safety was focused on HMI improvement.

An HMI system made of an Information Management concept for motorBike (IMB) that manages the messages and sends them to HMI display and helmet in different modes. Also handlebar controls for enhancing easy-of-use while riding have been implemented.

**Passive Safety Systems**

The improvement of passive safety has been the most challenging objective in SIM project, due to the highly variable rider motion during crash or fall.

At the end a cooperative architecture made of frontal airbag and an inflatable device has been implemented as well as an airbag control unit with a specific algorithm for firing the devices.

The development process followed a new methodological approach that started from crashworthiness studies till to the test of the whole chain in full crashes.

All the safety features have been implemented in the SIM vehicle platform, based on the tilting three wheelers Piaggio MP3 that has been selected because of one of the most promising PTW concepts in terms of safety.

**Conclusions**

Within a comprehensive safety approach to the problem, SIM contributed to some aspects.

A number of advanced safety features has been chosen according to the identified safety strategy and based on their effectiveness evaluation in real accident scenarios, as well as taking into account their technical feasibility.

The final result is a concrete concept design (vehicle+helmet+clothing) that that integrates all the features.
**Effectiveness Evaluation of PTW Safety Devices in Real Accident Scenarios**

**Jens König - DEKRA Automobil GmbH**

**Georg Roll - Continental Automotive**

**Oliver Hoffmann - Continental Automotive**

**Methodology**

In the previous APROSYS project 7 main accident scenarios have been selected for further investigation. These scenarios have been identified and elaborated within the APROSYS SP4 report D4.1.1 [1] where the overall accident occurrence as well as the injury severity distributions has been taken into account, studying the National Statistics from Germany, Italy, Spain and The Netherlands. The following 7 scenarios have been identified as being the most common and severe in terms of accident consequences:

- Mofa/Moped – Car – Urban – Intersection
- Mofa/Moped – Car – Urban – Straight Road
- Motorcycle – Car – Urban – Intersection
- Motorcycle – Car – Urban – Straight Road
- Motorcycle – Car – Rural – Intersection
- Motorcycle – Car – Rural – Straight Road
- Motorcycle – Single vehicle accident – Rural

These main PTW accident scenarios have been the basic input for the accident analyses task in the subsequent SIM project.

Within the EC-funded SIM Project (Safety In Motion), Deliverable D2.1 [2] in-depth accident databases such as MAIDS, GIDAS 2002 and 2003 and the DEKRA PTW database have been explored. The parameter-queries were chosen in close collaboration with the industrial partners in the SIM consortium, so as to ensure the implementation of their special needs.

A detailed listing of all analysed variables is to be found in SIM deliverable D2.1. Here, in a first step the DEKRA database was analysed in order to find suitable cases matching the above mentioned accident scenarios. The actual DEKRA PTW database comprises 350 cases from years 1996 – 2005. The fundamental basis of the DEKRA accident database is the accumulation of written expert opinions containing the accident analyses that are drawn up by skilled forensic experts at the DEKRA branches throughout Germany.

Apart from the database also the raw material (written expert opinions) is available for investigation having the advantage to extract parameters which were originally not directly implied in the database.

A detailed analysis of different accident scenarios with PTWs (Powered Two Wheelers) has been performed, using the DEKRA PTW-database. From this database containing 350 real-world accidents, 51 cases have been selected by imposing a reaction demand and a following braking of the motorcycle rider in order to evaluate the benefit of an advanced braking system.

**Results**

In each accident case, one PTW (Powered Two-Wheeler) is involved.

In almost all cases the reason for the accident seems to be that a car driver couldn’t estimate the speed of the PTW correctly or didn’t recognise the PTW in time.

In several cases the standard situation can be observed, where a car driver intends to drive a U-turn without taking notice of a PTW approaching from behind. Another class of severe accident situations results from car drivers turning into a road without giving way to PTWs driving on this road with considerable speed. In all these collision cases, the speed of the involved car was rather low, and the severity of the impact just...
depended on the speed of the PTW, which usually crashed into the car. Normally the speed of the PTWs was not above the allowed speed limits, so that the PTW drivers behaved correctly. On the contrary the accidents were in almost all cases caused by the erroneous behaviour of the involved car drivers, who were not able to properly evaluate the traffic situation. In about 43% of the studied cases, the braked PTW gets unstable (due to over braking) and hits the ground before the collision with the car occurs. Even a standard ABS should considerably reduce the effects of PTW accidents, providing braking stability for the PTWs on one hand, so that falls can be avoided and the PTWs remain in a manoeuvrable state, and on the other hand increasing braking deceleration due to adjusting operating points just near the friction optimum. Furthermore, a so-called integral brake can help in case of panic braking. A PTW driver may focus only on one brake lever during an emergency case, because he is shocked by the suddenness of the situation. It may be impossible then to manage two separate brake levers in an adequate manner simultaneously. In those cases the integral brake adjusts balanced pressure amounts to both wheels, even if the driver applies only one brake lever. In addition, a brake-assist function can improve the first pressure build-up time interval just after the first reaction of the PTW driver, which results in applying the brake(s) with a high pressure increase gradient.

The overall result of the analyses performed for 51 DEKRA accident cases is shown in Figure 3 and Figure 4 highlighting how many of the 51 studied accidents could have been avoided or highly mitigated with the help of the respective brake system or braking behaviour of the driver.

![Figure 3 - Accident avoidance](image)

![Figure 4 - Energy and speed reduction](image)

The black frame bar marks the number of the 51 cases. The coloured bars represent the numbers of collisions, which would have been totally avoided due to the higher braking deceleration with the according brake-control system. The hatched bars show the numbers of collisions, for which the collision speeds of the PTWs could have been reduced below 8m/s. In these cases, the energy of the crash would have been rather low and moreover, due to the reduced speed and the gained reaction time before the crossing of the collision courses, it is possible to assume that the rider would have had a considerable chance to avoid the crash by steering.

The most important task of ABS is to exploit the maximum friction amounts between tires and road surface and nevertheless to provide the PTW with sufficient driving stability for the performed manoeuvre. But the even more important effect of antilock brake control for motorcycles should be, that the system gives the driver confidence concerning braking stability even in case of hard brake application. Calculations show us unambiguously the best way of reducing speed in time is to have early and hard brake activation. Saving just 100ms or 200ms of brake-filling time means to reduce the whole stopping distance considerably.
MOTORCYCLE DYNAMIC ANALYSIS THROUGH MULTIBODY SIMULATION
Massimo Guiggiani, Andrea Barbetti, Riccardo Bartolozzi, Francesco Frendo,
Antonio Sponziello - Università degli Studi di Pisa

The task of the University of Pisa within the SIM project was to develop numerical
models of the SIM vehicle, in order to analyze the dynamic behaviour through
simulation and to support the prototype development; two independent models, a multi-body model and a
numerical model, have been developed.
The first one was built in Adams environment, while the second one is an in-house developed mathematical
model, which was implemented in Matlab/Simulink environment.
Compared to the multibody model, the analytical one appears to be more suitable to perform design studies,
since it is easy to change physical and geometrical characteristics of the vehicle and run simulations. The
multibody model has a better graphic interface and may result more useful for very complex models (e.g.
including the flexibility of joints or bodies).
Both models are made up of three basic parts: the motorcycle, the virtual controller, and the tire.
The motorcycle is composed of rigid bodies, whose inertial properties were imported from technical drawings.
Also the driver was considered as a unique rigid body attached to the frame. The stiffness and damping
properties of springs and dampers were obtained on the basis of experimental measurements.
A virtual controller, able to follow the desired path or a desired roll angle, by acting on the steering, was
employed to drive the scooter.
Tire modelling was an important task of the SIM model development. In order to properly characterize the
behaviour of tires, dynamic measurements were carried out on the high speed oval ATP in Papenburg,
Germany where forces and moments were measured under varying vertical loads, camber and slip angles.
Afterwards, the experimental data were used to identify the parameters of the MF-MC tire model developed by
TNO Automotive, which is able to describe the behaviour of the tire under different conditions.
Several simulations (handling and three post rig analyses) were performed to validate the models; the results
show a very good agreement between the multi-body and the analytical model and between models and
experimental data.
Some simulations show that the safety of an ordinary two wheeler is increased by the MP3 front architecture.
For example, it was shown that the driver is able to maintain the control of the motorcycle if one of the front
tires suddenly loses the grip with the ground during a curve. Furthermore, it was shown that the front tires of
MP3 have a lower probability to simultaneously lose the contact with the ground, when it runs on a bumpy
road.
One of the goals of the SIM project was to implement in the SIM vehicle the control strategies developed by
other partners for active safety (ABS/TC and semi-active suspensions) to further increase the safety features
of the SIM vehicle. The logics were implemented in the models in order to use them to find the best setting
able to increase the safety as much as possible and to reduce the number of experimental tests.
Crashworthiness of the vehicle has been developed according with two software tools, MADYMO and LS-DYNA.

The LS-DYNA software is dedicated to non-linear Finite Element (FE) analysis (modelling and calculation). It has been used for Structural crashworthiness in order to find the layout of the crash sensors and ECU and to have an estimation of acceleration. It has been used also for firing strategy definition by performing several tests at different speeds and configurations. Some of them have been tested in real crashes in further steps of the project.

A representative Finite Element (FE) model has been developed with LS-DYNA software. This FE approach has been used to improve crashworthiness, from the vehicle viewpoint. The pre-processed phase included the tasks of cleaning the geometry and transforming it in a finite element discrete mesh, as well as the process of allocation the physical properties of the components and the mutual interaction. The FE model of the vehicle prototype was built starting from the existing CAD model.

The model has been tuned with real tests data acquired in different impact conditions. Obtained data in real crash were compared with simulation and the accuracy of the model is evaluated, in order to validate the virtual model. Next step was to evaluate MP3 behaviour in terms of crashworthiness during the crashes against a real car. Before this crashes against a real car some previous analysis were performed by means of simulation for the four different constellations ISO 13232 413 and 114 in moving-stationary and moving-moving configurations.

These “baseline” simulated models, without considering the rider, were created for the different accident scenarios selected from the ISO 13232 configurations in order to achieve information about the MP3 crashworthiness.

Once an optimal MP3 FEM was obtained in LS-DYNA input deck, the next step was to complete the virtual ISO 413 and 114 configurations against car scenarios crash tests. This task was performed introducing a car FEM and defining contact interfaces between MP3 and car models in order to obtain a first approach of the PTW crashworthiness in a real crash. In these simulations a dummy from LSTC database (Livermore Software Technology Corporation, development source for the LS-DYNA software program) and a car available in the Web of FHWA/NHTSA National Crash Analysis Center (http://www.ncac.gwu.edu/vml/models.html) have been adopted. Next step was to place the vehicle in the different positions of the chosen configurations, and to define the suitable contacts between both vehicles.

The analysis of these different simulations have provided the base for defining and placing the crash sensing system and control unit that activated the different safety functions developed in further stages of the project. The outcomes of these simulations are the final layout of crash sensors and ECU in the final prototype, as a compromise for guaranteeing a suitable quickness of signal and a safe position for the surviving of the equipment to the crash event, or at least to the first stages until the necessaries signals for the activation of the safety devices.

The crashworthiness analysis for each configuration was performed through the analysis of the kinematics of the MP3 during the crash. Also the acceleration data obtained in the same positions where the accelerometers
are placed during the real crash test is achieved. These signals were the starting point for the analysis of the placement of the sensors to be used in the activation of the safety systems mechanism.

![Figure 5 - LS-DYNA simulation of a full scale crash test](image)

To study the rider protection and to make a virtual analysis from safety functions viewpoint it has been used the MADYMO Software. This software is based in models of multibodies and FE and it has been used for analysing the rider protection with a simplified methodology. The simplified model of multibodies of the MP3 is showed with the PTW functions related to crashworthiness implemented, as well as the FE cover through facets surface representative of the motorbike external shape. In a first stage the analysis of the Potential benefits of proposed passive safety devices was performed analysing the biomechanical parameters of the dummy with different safety devices in the selected scenarios. A matrix with the results is showed. From this analysis it is decided to develop a frontal airbag and an inflatable garment. Some simulations videos of this study are shown. Also the development of the frontal Airbag was done with the MADYMO Software. Inside this development it was performed the definition of a sled test of the crash test results by a simulation studio on rigid sled configurations, able to be representative of the crash test results. Through this studio, a one degree of freedom configuration capable of being representative of a six degree of freedom real test was assessed. The sled test configuration selected was built up. A picture with the real and simulated test is shown below.

![Figure 6 - MADYMO simulation vs. real sled test](image)

As a last stage the parameters study via MADYMO simulation of the seating geometry and the different dummy sizes is presented.
Definition of Concept
Technology and Effectiveness evaluation

From the analysis of the DEKRA accident data base it has been pointed out that 27 out of 51 collisions could have been avoided, if the wheels had not locked and the vehicle had been braked with the highest possible deceleration.

Figure 7 shows the number of crashes out of 51 selected cases with the following definition x/y:
x: number of cases where the motorcycle would have stopped before the collision
y: number of cases where the collision speed would have been below 30 km/h

<table>
<thead>
<tr>
<th>Definition</th>
<th>x/y</th>
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<tr>
<td>No electronic brake-control system, orignal accident data</td>
<td>0</td>
</tr>
<tr>
<td>ABS, only front wheel braked</td>
<td>12 / 10</td>
</tr>
<tr>
<td>ABS, front wheel braked, rear wheel braked delayed</td>
<td>17 / 11</td>
</tr>
<tr>
<td>ABS, both wheels braked simultaneously</td>
<td>27 / 2</td>
</tr>
<tr>
<td>ABS, integral brake and brake-assist system</td>
<td>29 / 4</td>
</tr>
<tr>
<td>ABS, integral brake, brake-assist and automatic pre-fill system</td>
<td>39 / 7</td>
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Figure 7 - DEKRA accident data base

Definition of Active Safety Concept for the Brake System

First a number of functions were defined that assist the motorcycle rider in certain driving situations in order to improve safety and comfort. As a result it was decided to use for the investigation a brake system that controls the brake pressure for all three wheels independently. Figure 8 shows the Brake System. The right hand lever activates the front brakes, the left the rear brake. Each hydraulic channel is able to modulate and build up pressure independently. In addition a FIB (Full Integral Brake) function can be realized by measuring the right hand lever pressure and building up brake pressure in the rear by the hydraulic pump (and vice versa).

System Development
ABS (antilock brake system), FIB (full integral brake) and TCS (traction control system) have been developed and adjusted as brake control functions.
The main focus of the ABS development was to study the advantage of two front wheels and to find a strategy for improving the driving stability during full braking. It turned out that a select-low control strategy for the front wheels provides the MP3 with the best braking facilities. Additionally the roll angle can be measured in a simple manner in the MP3 enabling the brake control system to adjust many parameters and even the control strategies dynamically to the degree of cornering. Another important topic was the networking via CAN for information interchange between different controllers. Thus synergy effects can be achieved from external sensors, and systems can react on the control state of other systems.

The FIB functionality enables the driver to perform full braking with all wheels by applying just one brake lever.

For the active brake-force distribution (ABD) from front to rear and vice versa, the characteristic lines have been optimized, and moreover some filters have been implemented and tested which are helpful to avoid driver disturbances.

The TCS function is activated when the driven wheel tends to spinning due to a surplus in driving torque especially on low-friction road surfaces.

It has been very interesting to investigate stability and accelerating facilities of different control strategies based on brake and engine interventions. As a result a combined strategy can be recommended for the MP3, where an appropriate brake pressure is adjusted to the spinning wheel as a kind of basic control part, whereas new spinning tendencies are instantly softened by very short digital engine cut-off interventions.

Moreover, for ABS only devices without active pressure facilities, a special TCS strategy has been created based on the digital engine cut-off mechanism providing analog system behaviour.

Summary and Results
The analysis of the accident cases selected from Dekra database showed that roughly 50% of the fatal accidents, with brake actuation, could be have been avoided with ABS only. Several Functionalities (ABS, FIB, ABD, TCS, BTCS) were implemented and tested on the Piaggio MP3 400. Based on the testing a select low strategy for the front wheels is sufficient, resulting in an affordable ABS concept for the Piaggio MP3 400.
This project has been co-funded by the European Commission DG RTD in the 6th Framework Programme. The content of this publication is the sole responsibility of the project partners listed herein and does not necessarily represent the view of the European Commission or its services.
Summary
The suspension of a motorcycle is a very important element to provide a good handling to a motorcycle. Since the digital revolution started in the eighties, mechanical products have one by one been transformed into a mechatronic product.
Within the purposes of the project the conventional mechanical suspension of the Piaggio MP3 motorcycle has been replaced with an application specific electronically controlled suspension system. The aim with the mechatronic suspension system is to optimize the vehicle handling in terms of safety, performance and comfort.
The activities for the realization of suspension system consisted of four major steps:
- development of suspension hardware
- development of the electronic control unit
- development of control algorithm
- laboratory and on track vehicle tests.
The effort in this project resulted in a Piaggio MP3 motorcycle equipped with a state of the art electronically controlled suspension system and with improved motorcycle handling.

Suspension hardware
The suspension hardware developed for the SIM project is based on the Öhlins CES valve (Continuously controlled Electronic Suspension). This hydraulic pressure controller integrates the latest technology in hydraulics and electronics into a highly advanced suspension. Use of the CES valve in a shock absorber removes most of the compromise between ride and handling found in conventional shocks. It enables the suspension to provide sporty characteristics in cornering, lane changes and panic situation while giving the ride of a limousine during cruising.
The CES valve was integrated in smart damper design with no risk for cavitation regardless of damping levels, the cavitation free system layout was an important objective to enable algorithm development work with maximum freedom and minimal constrains. In order to maximize the suspension performance, computer-based simulations of the damper structure have been carefully carried out to ensure that the final product has the optimal functionality.

Suspension Management system
In order to realise the advanced control strategies of the suspension system, a totally new suspension control unit was developed for this project. The ECU was designed with the mind to have superior performance in a minimal form factor. This work resulted in a 32 bit 150Mhz μC/DSP powered compact sized rugged ECU able to fit inside a motorcycle where the available space is very limited.

Development of control algorithms and evaluation
The control algorithms developed for this project was first simulated in a virtual environment to understand its overall behaviour. Once the satisfying simulation results was found the control strategies was implemented in the target system and evaluated in a laboratory environment. The lab test was followed by track test with experienced test riders with track record from World Championship motorcycle competition. The riders could
instantly feel the performance improvement by using a mechatronics suspension system without relaying any negative points.

The algorithm work resulted in 3 different suspension modes in order to maximize the benefit of a mechatronics suspension system:

- **Comfort mode**: aimed at maximizing the road noise insulation for rider and passenger.
- **Dynamic mode**: maximize the vehicle handling.
- **Automatic mode**: the suspension system automatically adapts the setting to always provide a comfortable vehicle with optimal handling.

**Conclusion**

The state of the art Mechatronics suspension system has proven that the performance – comfort – safety objective of the MP3 vehicle was improved significantly. Standard MP3 is a class leader in terms of safety level nevertheless by using Mechatronics suspension on the SIM-MP3 vehicle, the performance was improved even further compared to the standard. During this project the potential and effectiveness of an advanced electronically controlled suspension system has been assessed.

![Figure 13 - Hardware components of electronically suspension system](image-url)
Most of the road accidents involving powered two-wheelers are influenced by human behaviour. Based on this statement, in SIM project an important effort has been carried out with the challenge to decrease the number of powered two-wheelers accidents and related consequences for riders (injuries and deaths).

While riding, the rider could be distracted for example by the use of a mobile phone or a navigation system and could mislead some dangerous situations, losing the motorcycle control and causing or being involved in road crashes.

For this reason a good management of the flow of information provided to the rider as well as the use of devices that increase the motorcycle stability while manoeuvring has been studied in SIM project.

In this vision, the selected active and preventive safety devices implemented in the SIM prototype are the following:

- semi-active electronic suspension system
- traction control system
- enhanced anti-lock braking system
- information management concept (IMB) for motorbikes
- enhanced HMI (additional display and handlebar controls, head up display placed in the helmet).

Therefore, at the same time, the rider can be supported by the enhanced brake and suspension devices, and by the IMB and HMI system helping him/her to be more concentrated on the riding task.

However, not all the information provided to the rider has to be considered only as a source of distraction. In fact for example thanks to new technologies, the rider can be alerted on time about vehicle status and potentially critical conditions or can be informed by advanced navigation systems about the best route to follow by means of visual and acoustic reminders.

The fruition of all this information needs therefore to be designed taking into account the need to reach rider’s attention avoiding distraction and creating the proper balance of information distribution among the different elements constituting the innovative motorbike Human Machine Interface.

Inside the SIM project, the IMB collects information from:

- rider’s input (by voice or by handlebar controls)
- vehicle functions (i.e., specific ECU malfunction, ECU settings and vehicle alerts)
- mobile phone device including Bluetooth hands-free phone and SMS reader
- navigation system
- media player

All this information generally displayed only in the central dashboard is redistributed through an enhanced HMI set-up by:

- an additional IMB display
- dedicated HMI handlebar controls
- an head-up display (HUD) mounted in the helmet
- a microphone and headsets mounted in the helmet

In this way, the rider is focused on his/her primary task without moving the eyes from the road or the hands from the handlebar.
The information redistribution, managed by the Information Management Board, is studied based on the following safety logic: critical information needs to be notified and highlighted to the rider overcoming non-critical information.

Therefore some vehicle alerts have a higher priority in terms of safety criticality with respect to navigation information and mobile phone functions, thus for example when a malfunction of the ABS system should occur, a navigation message would be postponed and displayed to the rider only after the failure notification.

Inside the project, a hierarchic strategy is also thought in order to manage possible conflicts among messages classified as non-critical information.

Unlike critical information, that are presented to the rider one after the other, the non-critical ones will follow the next rules:

- navigation information overcomes media player sound,
- incoming phone call or SMS overcomes navigation information and media player sound.

Moreover, taking into consideration this subdivision, a different HMI logic is also implemented.

Non-critical information is displayed on the HMI display and repeated into the helmet speakers via audio Bluetooth, while critical messages are sent to the rider in a redundant way.

For instance, a warning related to ECU malfunctioning or speed limit overcoming is displayed on the HMI display and replicated either in audio mode and in visual mode through led bars switching on in the head-up display integrated in the helmet.

More in details, the HMI input and output devices involved in the SIM project are:

- voice input (voice recognition system)
- tactile input (IMB display buttons and IMB handlebar controls)
- visual output (instrument cluster display, IMB display and head-up display)
- audio output (earcons in the helmet)

The SIM MP3 prototype HW architecture has been modified in order to realize an open, flexible and faster connection among the on-board electronic control units (ECUs).

In particular, two CAN bus networks have been developed:

- an high speed CAN bus connected to the active safety ECU, named SIM CAN bus
- a low speed CAN bus connected to the preventive ECU, named IMB CAN bus

The IMB constituted a bridge between the two CAN lines: it collects the safety and infotainment information and redistributes it through the different output channels.
AIRBAG DEVELOPMENT
Ruth Muñoz, Sergio Choya - Dalphimetal

The main objective of an Inflatable Restraint System is to absorb the kinetic energy of the rider during the accident. It should avoid the injuries produced by the impact between the motorbike and the obstacle (the car, in this case).

The development of this device has been carried out in two steps:
- **1st phase**: Design and test the components of the module
- **2nd phase**: Adapt this device to the environment.

The components of the module have been designed according to the technical available volume in the Piaggio Mp3.

The objective of this first phase was to design and check the performance and integrity of the module itself. Prototypes have been mocked up and activated in static tests without environment.

In the second phase, the module has been tested in its environment. Deployment stability and positioning of the bag have been evaluated. Linear Impactor Tests (LIT) have been carried out in order to determine the appropriate absorption of energy by the airbag.

After these LIT, dynamic tests (crash) have been done in order to determine biomechanical requirements in 4 different crash configurations:

This research shows the significant reduction of rider injuries during an accident if the restraint system device is on the motorbike. There is an improvement on the safety of the rider due to the airbag.
Airbag Control Unit

The airbag control system used in the SIM project is based on an airbag control system developed for a car. This system is in series production since the fourth quarter of 2008. The main parts of the airbag control unit are two microcontrollers, central and satellite acceleration sensors, firing ASICs, energy reserve, connector and stable housing.

For the purpose to use it in the SIM project the car airbag control unit is downsized to a system with one central unit and three acceleration sensing satellites. The number of served firing loops is four. The ignition of the firing loops is connected to the airbag stage 1 and stage 2 for driver and passenger. The threshold used in the algorithm is the belted airbag stage 1 threshold. If this threshold is exceeded by the trigger integral the decision for firing all of the four firing loops is done. That means the decision for firing all four stages is done at the same time point. At exact this time point the ignition of the first stage of the airbag and the first stage of the airjacket is realized whereas at this time point the delay counters for the second stages are started. The ignition of the second stage for the airbag and the second stage for the airjacket is activated after the according delay counter has reached the preset value. Thus means the resulting firing current can be delayed individually for the second stages. The delays can individually be set in the parameter setting and are calibration values.

Algorithm

The basic calculation in the algorithm is an integral of the measured acceleration. All integrals are the sum of the acceleration values within a chosen time window. The sum is built by adding the current acceleration value and subtracting the value that has to leave the integration window. For each new value coming in the window, the oldest value has to leave the window, FIFO (first in, first out) principle. We talk of the loss of velocity within a defined time span. Pure integration is used to make sure that the algorithm is always based on fundamental physics. But to be able to fulfill also more complicated requirements, it is necessary to do more than just integrate. For this reason, the Continental algorithm uses a special integral to make its trigger decisions. This integral is called the 'Trigger-Integral'. In addition to the measured accelerations, the algorithm adds a modification value to influence the original integral.

Safety Strategy

The general idea of the safety strategy is that one error is not able to cause an inadvertent trigger. Therefore in the first term each firing decision is based on two independent sensor signals, which in this implementation is realized in the way that one of the upfront satellites signal AND one of the central unit signal shall have exceeded an according threshold with their integrals.

The second term of the safety concept is that the firing decision is calculated on two micro controllers. This is implemented in one detailed calculation in the master controller and one rough calculation in the slave controller. Both decisions are AND connected via an according control of micro controller dedicated electronic switches. This so called "safing" function can also be realized in a different way. An alternative could be that one rough calculation is done in an ASIC implementation whereas the detailed valuation is calculated in a micro controller. Both results are again AND connected via serial switches.

Time to Fire (TTF) Requirements and Sensor Architecture

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The initial sensor architecture for the airbag control unit of the SIM project was based on an ECU with two internal sensors and two satellite sensors. The ECU was planned to be mounted below the foot rest of the scooter in order to have a very safe position for the main unit of the airbag control system. The upfront sensors were planned to be mounted on each front wheel trust to deliver an early crash signal in all thinkable field crash configurations. The logic behind the detection system was to get a severity impression via the upfront signals and a plausibility signal via the central unit accelerations. With this configuration TTFs of about 15 to 20 ms could be realized in a stable and robust way.

After the first crash tests with such a fire time presetting one found out that this is not fast enough to realize a robust complete inflation of the airbag before the first contact of biker and inflated airbag happens. Therefore the demand appears to have the trigger times at least before the 12th millisecond after t0, the first contact of the bullet to the target. The idea came up to mount one upfront satellite to the most forward part of the scooter to get an very early crash signal which shows the severity of the accident within several few milliseconds. Because of the mounted radiator the most frontal part of the scooter had a solid metal structure and was therefore ideal for a satellite position.

With this new position the required firing times could be realized. In all five crash tests with the new sensor architecture the suitability could be directly demonstrated. In the final sensor architecture one will have three satellites to reach the best performance in the various types of crashes which may appear in the field. One satellite will be mounted in the most forward part of the scooter next to the radiator. The remaining two satellites will be mounted to the compression struts near the driving collar.

Conclusion
The new sensor architecture has proven that it can fulfill the requirements in crash lab tests. It has a great potential to fulfill all crash scenarios in the field. The strategy is simple and the detection levels high which leads to a robust behaviour. Nevertheless a lot of static and dynamic misuse tests have to be executed to show the expected robustness. Also a defined no fire crash test has to be established. For example a 15 or 20 km/h impact according ISO 413 definition is an absolute no fire situation. With this additional amount of tests a final release for the field can be done.

The advantages of the airbag and airjacket in a motorcycle implementation are obvious. In all crash test films it can be seen that the biker dummy looses most of his kinetic energy in the airbag contact and a slam of the head against the edge of a cars roof can be avoided. The final fall to the ground is at least damped through the airjacket and the helmet. Knowing that most fatal injuries of a biker in an accident are from the impact to an obstacle or in the second impact to the ground this passive system prevents with high probability from losing live or getting heavily injured.
In the final phase of the project full crashes have been performed in order to assess the effectiveness of the developed passive safety devices as working in a combined way and to verify they are not harmful in the worst selected crash configurations (i.e. ISO 13232 114 configuration).

Documentation from full-scale crashes consists of:
- Pictures in the pre-crash phase (setup of the car and PTW as well as the dummy)
- Setup data (main technical characteristics of the vehicles involved like model, engine displacement, weight, tyre pressure…)
- High speed video from different perspectives
- Real time video
- Pictures from post-crash (visual damages, rest position of the dummy….)
- Report on measured acceleration values and comparison with the injury criteria

The protection provided to the PTW rider can be assessed by:
- The measurements of Acceleration, Forces and Momentum obtained from the dummy Hybrid III different parts: Head, Neck, Thorax and femurs
- The comparison of these results of the 8 crash tests performed inside SIM project, equipped with different safety devices, with the results from 3 APROSYS tests or Baseline tests, without any safety systems and with the Limits of regulation 94 for frontal impact driver protection in cars.

First the results of the different ISO 13232 413 MOVING-STATIONARY configuration crashes are compared, here the PTW impacts with a speed at 48km/h in the centre of the side frame of a stationary car.

From the different biomechanical values measured in the Hybrid III, it was observed that in the Baseline test (from APROSYS Project) the rider is suffering serious injuries in the Neck, because of very high tension force and neck tension moment and in the femurs, while values below the limits in all the biomechanical values of the dummy in the parts of the dummy protected by the safety devices are recorded in SIM crash test. The femurs do not receive any protection as expected.

The ratio of the values measured related to the limits of the biomechanical values and the relative improvement of these values versus the Baseline crash test results from APROSYS shows real good protection index and a great improvement on the protection when using any of the safety systems.

The second configuration analysed is the ISO 13232 413 MOVING-MOVING.

In this configuration the PTW impacts with a speed at 48km/h at the centre of the side frame of a car moving with 24 km/h.

The different biomechanical values measured in the Hybrid III during the crashes in this configuration indicate that a great impact of all the parts of the dummy against the side of the moving car occurs in the Baseline test, and so, nearly all the criteria are not fulfilled. Therefore the PTW rider will suffer serious wounds in the Head because very high HIC (Head Injury Criteria) and acceleration values are obtained in the neck (because of the shear force over 1900 Newton and a neck moment in flexion over the limit, 190Nm) and in the femur. The ratio
of the values measured related to the limits of the biomechanical values, and the percent improvement in this values related to Baseline crash from APROSYS shows great improvement in the Head protection for all the configurations with HIC values lower than a 8% of the limit and improvement of over 90% in all the cases with respect to the APROSYS case. The values for the femurs are over the limit; however it has be taken into account that SIM activities in passive safety area were mainly focused on protection improvement of the upper part of the rider's body.

The third and fourth configuration analysed are the ISO 13232 114 MOVING-STATIONARY and MOVING-MOVING. In such configurations the PTW impacts with a speed of 48km/h at the centre of the frontal car stationary or moving with 24 km/h. Data from a crash in APROSYS without any safety systems in the MV-ST configuration are available and one test for each configuration, (MOV-STA and MOV-MOV) with Frontal airbag + airjacket, have been performed within SIM project.

The injury results analysis has been done considering two different stages.

In a first stage the analysis of the biomechanical data in the first milliseconds has been performed, when the rider interacts with the car and his own PTW. These biomechanical values are really low in the first milliseconds of the test for all parameters except for the femurs since there is a contact between the dummy knees and the PTW.

The secondary impact occurs when the rider strikes the ground. In this impact analysis as the rider is ejected from the saddle, the wounds he will suffer depends on the way he lands on the floor. Such an event is random and not repeatable so the related results are not meaningful.

Therefore depending the way the dummy touches down the floor there is a clean landing without high level injuries in the 114 MOV-MOV configuration, and a landing with the head that will have high biomechanical values in the neck in both moving stationary configurations.

As a summary of all the different configurations the different degree of protection in the head chest and neck is represented below with colours. In green the values below the limit and in red over the limit obtaining for all configurations, when we use passive systems on them, green colours in all the three parts we are protecting during primary and secondary impact values, while damage exists in the neck for the 114 moving stationary with the safety systems.

As a conclusion the main outcomes are:

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- All the criteria widely fulfilled in primary impact with all the combination of inflatable devices, except for the femurs.
- Safety systems have proven significant great reduction of injuries in head and neck during crash tests compared with the APROSYS crash tests, with values below the limits and very big safety margins.
- In all the configurations, head injuries were highly reduced. Improvement of protection above 90% in some configurations.
- Great margin of neck tension force and very far to the limit with both inflatable devices separately / integrated.
- Big margin of neck shear force respect to the limit.
- Also the thorax protection is improved.
- Since the focus of SIM’s activities in passive safety area regarded the protection of the upper part of the rider’s body, injuries of the femur had no improvements. Further analysis will be conducted in a future study.
- Although good results have been obtained for 114 MOV-MOV configuration, the protection of the neck resulted not sufficient and will have to be improved in a future study.
TEST AND RESULTS OF ACTIVE SAFETY SYSTEMS
Onorino Di Tanna – Piaggio & C. Spa

SIM project activities have been performed from the beginning toward the ambitious goal of integrating different safety subsystems in order to enhance the capability of accident avoidance and consequences mitigation.

For what concerns the active safety concept the involved subsystems are an active brake plant and an electronic semi-active suspension, linked one to each other in a cooperative way so to perform better than the sum of the parts.

It is worth to mention that the riding behaviour of the Piaggio MP3 is very similar to a motorcycle one since the four bar linkage allows for a totally free roll motion but with significant advantages in terms of adherence that becomes huge on rough surfaces.

Piaggio MP3 results almost unaffected by any road change as indicated by the insensitiveness of braking performances. It stops almost in the same distance on a flat track and on uneven road, on the contrary of conventional PTW.

<table>
<thead>
<tr>
<th>Stopping distance with front brakes (m)</th>
<th>MP3</th>
<th>PTW</th>
<th>Delta %</th>
</tr>
</thead>
<tbody>
<tr>
<td>From 40 km/h on flat track</td>
<td>9.0</td>
<td>10.3</td>
<td>-12%</td>
</tr>
<tr>
<td>From 40 km/h on severe uneven road</td>
<td>9.9</td>
<td>12.5</td>
<td>-20.8%</td>
</tr>
<tr>
<td>Variation percent for single vehicle</td>
<td>+9.5%</td>
<td>+21.6%</td>
<td>-55%</td>
</tr>
</tbody>
</table>

Table 1 - MP3 and PTW active safety systems comparison

For its intrinsic active safety characteristics the MP3 becomes the ideal platform for advanced systems implementation leading to further improvement.

In the graph of Figure 15 the evolution of perceived comfort and road holding capabilities are reported as function of damping values from a very soft setup for comfort optimization to a ‘race’ one that improves the handling on flat road by reducing body movements during direction changes.

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In order to avoid the compromise related to passive suspensions, in SIM application a “Groundhook” algorithm has been optimized through virtual simulation in order to find the best parameters for wheel load optimization on rough roads by reaching a significant improvement respect to a “comfort equivalent” passive suspension. The simulations performed on a lane change situation (common case of obstacle avoidance) confirmed the common knowledge that a strongly damped suspension is able on flat road to reduce vehicle body movements and therefore to minimize the variation of vertical. The GroundHook algorithm (“Dynamic mode” of the suspension setup) is effective for handling purposes due to its capabilities of matching the sport setting performances without the related well known drawbacks on rough roads. Such an algorithm is able to use high damping values only when required by the vehicle behaviour as confirmed by both simulated and experimental results (see Figure 17).

In Table 2 the gains registered from experimental tests (road forces are reconstructed from inverse vehicle dynamic based on wheel and body accelerations) are reported. Within these conditions there is still a compromise between Dynamic mode and soft suspension in terms of comfort. Nevertheless on SIM prototype it is possible to implement a solution that takes the best aspects of the two worlds. From the exact knowledge of the vehicle behaviour obtained by information flowing on specifically designed CAN bus the comfort mode can be used as baseline setup for low acceleration manoeuvres with immediate switch to Ground hook in case of sportier riding or emergency actions (i.e. panic stop or obstacle avoidance). Such a modality keeps the best aspects of each setup with improvement up to 14% in terms of handling (less road forces fluctuation) and up to 9% for comfort respect to conventional MP3.
Table 2 - Road forces fluctuation and discomfort index for various suspension settings

The ABS effectiveness is strictly related to the parameters used for its setup. Such parameters are fixed in conventional applications resulting in a conservative but suboptimal ABS system or to a very aggressive one that does not prevent wheel lock in curve (and leading therefore the unavoidable fall of the vehicle).
On SIM application from the sensors used and shared by the subsystems it is possible to adapt brake plant thresholds to every situation by raising them in case of rough roads (recognised through the communication between suspension and brake ECUs), or implementing a smoother braking when negotiating a bend.

As indicated in Figure 18 the cooperative system implemented on SIM prototype allows for a very effective braking manoeuvre with the possibility of full pressure request through the front lever only, while the vehicle is still at full roll angle. The pressure management and build up on the rear plant are autonomously managed by the system achieving a mean deceleration of 0.85g that represents a limit value in such a complex situation with maximum ease of use for the rider.

![Figure 18 - Lane change braking data](image)

(speed - dark blue; front pressure - light blue; front pressure – red; roll - green)

In conclusion, the integrated system implemented on SIM prototype strongly enhances the active safety levels by means of:

- Increase of vehicle manoeuvrability without drawbacks on rough surfaces with automatic damping adjustment.
- Reduction of stopping distances up to 10% by recognizing ‘bad road’ conditions.
- Wheel spin avoidance while accelerating or braking in curve thanks to the dynamic adaptation of ABS and TCS systems.
- Low sensitivity of performances respect to rider experience (automatic brake distribution with ABS control).
- Comfort improvement up to 9%.
EXPLOITATION OF RESULTS
Mario D. Santucci – Piaggio & C. SpA

As an important PTW manufacturer, Piaggio of course does really believe in PTW role and its future. In scooter field the aim of Piaggio Group is to strongly contribute at solving the urban mobility issues. At SIM’s roots there are mainly three problems for urban mobility. PTW is still one of the most popular solutions to traffic problems, in terms of individual mobility, but there are two important aspects to be considered. Concerning the respect of the environment, PTW are a good way to reduce traffic emissions because of their limited fuel consumption and because of their capability in reducing the travelling time, being quite insensitive to traffic jams. However PTW world is continuously travelling towards new regulations, new engines and alternative energies, spending a lot of effort in improving technology. The third problem is obviously the rider safety. In 2006 Piaggio has come up with a revolutionary and safer vehicle, the Piaggio MP3, a totally innovative three-wheeler with two front wheels which provides safety, road grip and stability levels that no other two-wheeler can match. It’s a fact that Powered Two Wheelers won’t become all Powered Three Wheelers neither the MP3 itself can achieve the high level of safety of the automotive field. Such a level is quite far away and very ambitious to reach for several reasons: technical, structural, dynamical, practical, cultural, economical… For this reason the target drawn for SIM project has been an integrated concept design for active passive and preventive safety based on the revolutionary MP3 to reach new levels of PTW safety.

The Consortium stated then the following fields to research for this Concept Design:
- Integrated Passive Safety Devices
- Enhanced Anti-Lock Brake System
- Electronically Controlled Suspensions
- Electronic Vehicle Management
- Enhanced Human Machine Interface
- Info Exchange Devices
Some of the best partners in order to reach the goal were chosen consisting of a well-balanced consortium, including representatives of all relevant actors involved in the development and integration of systems for road safety as well as representatives of the scientific and academic world. It resulted in a unique blend of expertise and knowledge guaranteed consistency in the implementation of the project, robust results and concrete exploitation of the findings.

Within the actual framework it is quite difficult to predict the future in terms of introduction of technology into the real market as well as to correctly understand the customer’s expectations and their willingness to have safety devices. Undoubtedly the request for safety on PTWs will rapidly increase and the know-how acquired in SIM will be precious in a short time.

Market demand for safety is still weak; it will of course increase and will be sustained by regulations and manufacturers inputs.

It is worth to be mentioned that Piaggio has been the first manufacturer to introduce the ABS on a scooter (same month of Suzuki) on September 2003 (Piaggio X9 500) but the future will be different.

Lot of the knowledge will be soon available for the market, beginning from the active safety devices. In a few years passive safety devices will be spread on production models too, whilst preventive is every day more effective.

Piaggio and the SIM Consortium are confident that SIM has been not only a successful project from a technical and managerial point of view, but also a step in the right direction for future PTW Safety, to be continued in the near future.
2.4 **SIM Prototype Demonstration**

Final prototype of SIM Project, equipped with active, preventive and passive safety devices was shown during the Workshop.

![Figure 19 – SIM prototype in a slalom manoeuvre](image)

![Figure 20- SIM Final Prototype in action](image)
Figure 21 - SIM Final Prototype in action

Figure 22 - Explanation of the main features of the SIM Final prototype
References