# Road Safety: trends and strategy of the research

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## SYNOPSIS

One of the most recent and interesting trend in the field of the passive road safety, concerns the containment level of the road restraint systems linked together with the reduction of the injuries caused to the crash victims.
Among the research projects approved by the European Commission and carried out with positive results, the most significant are those concerning the concept of safety understood in its widest and global meaning, which is the synthesis of the highest containment levels and the drastic reduction of the injuries caused to the crash victims.
The functionality of the passive road restraint systems allows a range of performances which includes – in the same structure – the characteristic related to the maximum energy absorption linked to the structural liability, necessary where there is a high presence of light traffic, up to how to deal with the crash of the motorcyclists sliding on the roadway.
The method adopted by the recent research – and even more so the guidelines for the next future – foresees the synergy between the technical-scientific-engineering specialisation and the medical-traumatology specialisation, while the evaluation methods are carried out by the computational mechanics, with particular attention to the biomechanics aspects and the testing validation.
The illustration both of the obtained results and of the programs for the next future underlines the necessity to have a wide accidents databases, organized through the standardization of the collection methods, and requires the cooperation – at a project and normative level – both of the manufacturers of the passive road restraint systems and the motor vehicle industry in general and the automobile sector in particular.

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## INTRODUCTION

The SAFEWAY project – Safety Improvement of Vehicle Passengers through Innovative On-road "Biomechanics" Safety Features (February 2001- January 2004) is a research and technological development project, created by an industrial-based consortium led by Metalmeccanica Fracasso SpA, funded by the European Union under its GROWTH Programme.
SAFEWAY's aim is to develop a prototype barrier that not only conform to standard manufacturing requirements, but is also based on the knowledge of the traumatological impact that a collision with road safety barriers can have.
Specifically, SAFEWAY main objectives are:

- design a Very High Containment Barrier leading to a safety device that redirects vehicles to the carriageway, preventing them from passing to oncoming traffic carriageway, or hazardous roadside areas, especially for the case of Heavy Goods Vehicles.
- 20% reduction on the barrier severity performance according to ASI (Acceleration Severity Index) leading to a safer barrier to the vehicle occupants including the driver and passengers, especially for the case of passenger cars.
- 20% reduction on the material consumption, leading to a more environmentally friendly device.

In addition to the prototype barrier, the project has resulted in a series of recommendations or guidelines for road barrier design integrating medical as well as engineering aspects into road safety barrier design, as SAFEWAY innovation steams from the synergy between engineering and medical expertise.

## SAFEWAY CONTRIBUTION TO ROAD SAFETY

In the European Union, there are more than 210 million vehicles (out of which 26 million are lorries and buses) circulating on the 4 million kilometres of roads (out of which 50,000 Kilometres are motorways). Each year about 1.3 million accident take place, with 42,000 deaths, 1.6 million injuries and 170,000 permanent invalids, and with an economical and societal damage of more than 160 billion Euro, corresponding to 2% of EU's total GNP.

Injuries due to road accidents are a problem that can be controlled considerably if adequate attention is given to accident injury prevention strategies.

In this context, SAFEWAY Project has studied, designed, and validated an "on-road" safety barrier concept using an innovative approach. The innovative Very High Containment (VHC) steel barrier, besides respecting the EN1317 Standard Requirements, takes into consideration starting from the real traumatological effects observed on the passengers (vehicle occupants or passengers, including drivers) after on-road accidents.

Accordingly, the innovative VHC steel barrier is "more forgiving" than the present ones and guarantees higher passenger safety levels. Hence, SAFEWAY allows fewer deaths, less human injury and less social and economical costs for the Community.

## SAFEWAY CONTRIBUTION TO ROAD INFRASTRUCTURES'S ECONOMIC EFFICIENCY

Already in its former 1997-2001 Programme "Promoting Road Safety in the EU" the European Commission established the "One-million Euro" rule, stipulating that each death causes social costs of one million Euro.

According to this rule, and taking into account that 3% of all road casualties are caused by collisions with road barriers, a social cost of approximately 1,200 million Euro is generated per year by insufficient road barriers.
The technological developments in safety barriers suggested by SAFEWAY Project are expected to cut casualties by 35-50%. Hence a widespread installation of improved safety barriers is estimated to save between 420 and 600 million Euro each year.
Moreover in the context of an enlarged Europe (as of 1st May 2004), the amount of Euro saved could reach a range between 530 and 760 million Euro each per year.

Improved safety barriers reduce accident casualties and injuries for vehicle passenger without causing major expenditure.

## SAFEWAY KEY FACTS

Since its conception, the project has been structured in a series of individual Work Packages (WPs), by which each activity outcome feeds into the following activity according to the three year project time table, and in some cases triggers a feedback process to previously undertaken ones.
Within WP1 a recognition of existing data banks at European level has been made, correlating the accident types, safety barriers behaviour and traumatological effects on vehicle passengers; frequent injuries have been identified and classified. Within WP2 an innovative computational mechanics tool has been developed, able to foresee the influence of the impact on whole barrier/vehicle/passenger system. Within WP3 a parametric investigation in terms of simulation and tests at laboratory scale has been carried out to identify the most important parameters to be considered in the prototype barrier; design guidelines have also been prepared. The goal of WP4 is to study, design and manufacture the innovative VHC barrier at prototype level, with an iterative process.
Through this iterative process, the results of the computational mechanics in WP3, could enable a modification of the software specifications previously elaborated within WP2.
These 3 years of thorough research efforts combined data collection and analysis activities on performance of road barriers (containment and safety properties), computational mechanics (study on the most appropriate type of components and their assembling), tests under lab conditions, and real field trial in a motorway. This study has permitted the conceptual design of a steel barrier which has taken in fully account the results from these simulation/real-life tests on its design and materials composition.
The picture below illustrates the projects Work Packages and their interaction:

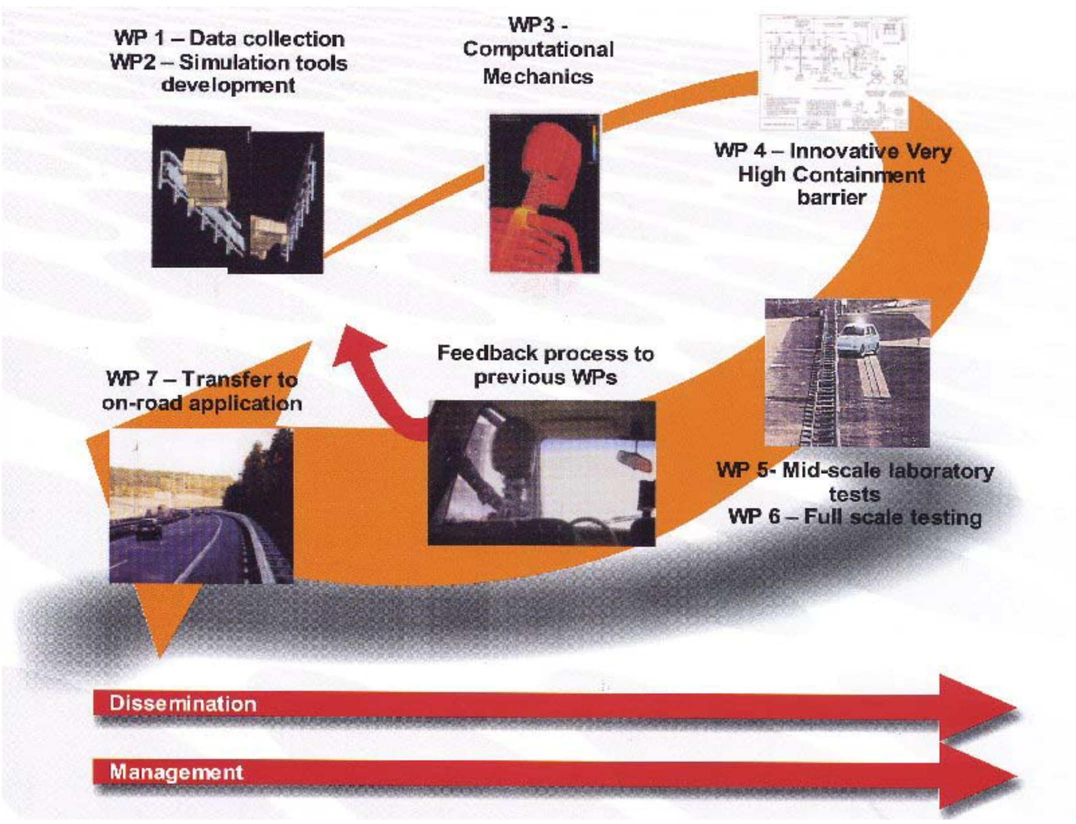


**Figure 1 SAFEWAY key facts**

## GENERAL CONSIDERATIONS

From a mechanical point of view, and making reference to the barrier characteristics, the three barrier types structural behaviour may be considered:

1. 2N steel barrier type: very deformable,
2. 3N steel barrier type: deformable,
3. NJ concrete barrier type: very rigid.

The barrier behaviour under the truck impact may be used only to classify the barrier with respect to its resistance. Moreover the safety characteristics of the barriers have to be evaluated on board of the cars (sedan and small car) analysing the impact effects on the passengers.
It is also assumed that the stiffness of the external car structures is the same in all the cases as well as the cockpit deformability, even if the safety performances on board are different.

The injuries have been classified - in the accident database - with respect to the type, assuming that the injury level depends only on the localisation of the injury itself in the organism district. Further in-deep analysis confirmed that the same injury - located in the same district of the human organism - may have different levels, depending on the acting force.

So the relationship between the impact condition and the occurred injury links the ***injury level*** (when the injury type is the same) to the kinetic energy relevant to the velocity component orthogonal to the longitudinal axis of the barrier.

**Table 1 Injury type and injury level**

| INJURY TYPE DESCRIPTION | LEVEL |
|---|---|
| Head & Thoracic trauma<br>Head & Spinal trauma<br>Head & Abdominal trauma<br>Head & Torso trauma | 6 |
| Thoracic & Spinal trauma<br>Torso trauma & Pelvic and Lower Extremity injuries<br>Torso trauma | 5 |
| Abdominal & Spinal trauma<br>Abdominal & and Pelvic and Lower Extremity injuries | 4 |
| Thoracic trauma<br>Spinal trauma<br>Abdominal trauma | 3 |
| Upper limbs and Lower Extremity injuries | 2 |

In addition to that the injury level seems to be deeply related to the acceleration component of the vehicle transversal to the passenger inside the car.

The ***injury localisation*** appears dependant on the zone of maximum stiffness of the barrier as well: poor height of the barrier seems to localise the injury in the lower limbs and in the abdominal zone as well as thoracic and head traumas may to be related with the height of the stiff zone of the barrier and with high speed impacts.

The most significant factor seems to be the barrier stiffness. In fact the sedan car type, more powerful and with safer cockpit if compared to the small cars, generates 23 level 3 injuries on 3N steel barriers (deformable type) and 67 level 3 injuries on NJ concrete barriers (rigid type) and the small car generates roughly the same number of level 3 injuries on 3N and NJ barriers. The number of level 2 injuries seems to be less significant considering that a low injury always occurred to passengers in the vehicle-barrier impacts.

## Computational biomechanics considerations

The accident database analysis seems to indicate - from the structural and engineering point of view - that high rigidity of the road containment barrier produces high level injuries, whose localisation depends on the stiff zone of the barrier structure.

On the contrary the low level injuries appear to be prerogative of deformable road containment structures and the localisation of the injury itself depends - also in this case - on the stiff zone of the barrier structure and on its geometry.

Taking into account all the previous considerations the design criteria of the new barrier prototype may be so summarised:

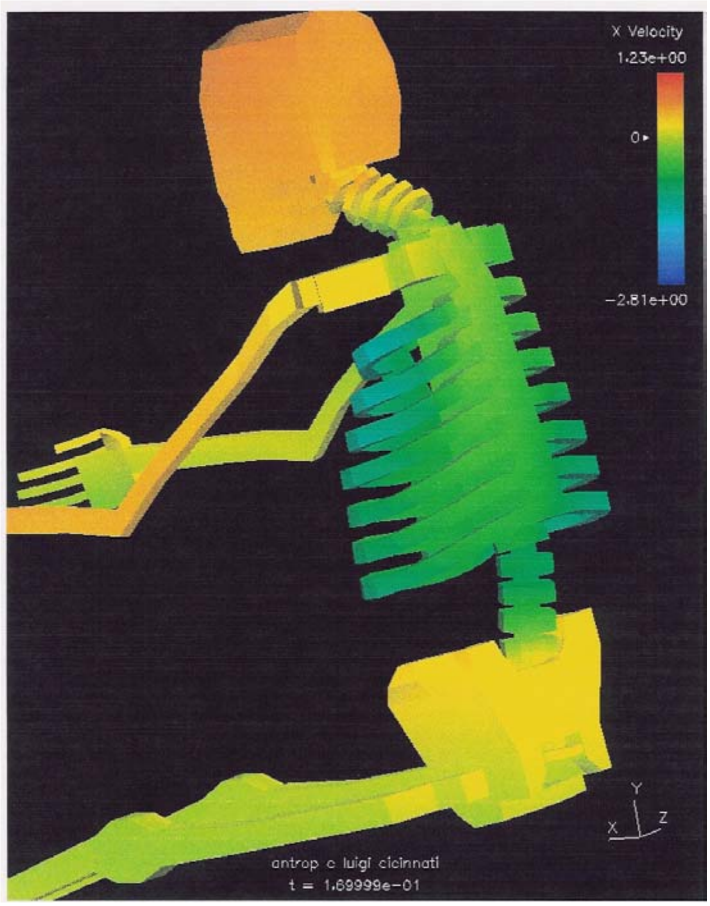


**Figure 2 Stress and strain level and localisation**

- with respect to the resistance, the steel barrier structure has to be designed in accordance to the European Norm EN 1317 and complying to the Safeway project objectives, with the base requirements of the Very High Containment class. It means that the structure has to support the impact of a rigid 4 axles lorry whose mass is 30.000 kg, hitting the barrier at the velocity of 65 km/h an with an angle of 20 degree, or - as an equivalent alternative - the structure has to support the impact of an articulated lorry whose mass is 38.000 kg, hitting the barrier in the same condition of velocity and angle;

- with respect to the stability, the hitting vehicles have to remain upright during and after the impact;

- with respect to the trajectory, the hitting vehicles have to exit from the impact zone within a corridor similar to a standard road lane;

- with respect to the deformability, the maximum dynamic deflection of the structure - under the impact of the lorry - has to be compatible with the road median reserve width or with the hard shoulder dimension. Under the impact of a small car of 900 kg, hitting the barrier at the velocity of

100 km/h and with an angle of 20 degree - the structure has to determine on the equipped dummy (Hybrid III, for example) on board, an average deceleration of about $60 \div 80$ m/s $^{2}$ ;

- with respect to the vehicle-barrier system, the maximum stiffness zone has to be located at the height of the lower extremity of the dummy or at the height of the abdominal zone.

The computational biomechanics considerations, coming out from the carried out analysis, in the full respect of the Safeway objectives and complying with the European Norm and with the traumatological prevention criteria, seems to indicate that the best result - in the passenger-vehicle-barrier interaction - may be obtained using a deformable but resistant row material with an elastic-plastic behaviour.

In the mean time the structure of the barrier seems to need the minimum stiffness zone located in correspondence of the critical - or not well protected by the car structure - human body districts.

The upper edge of the main containment element of the barrier may be about 0.90 meter high above the ground, provided that the geometry of the structure gives enough stability to the whole range of vehicles to be contained.

Also the mathematical model of the equipped dummy should be preferably suitable to well evaluate especially the lateral actions without unrealistic failures: the dummy should be also suitable to detect the zones where the rising of injuries is possible (injury localisation) - giving evidence of the stress and of the strain in its parts - to completely understand the nature and the intensity of the action.

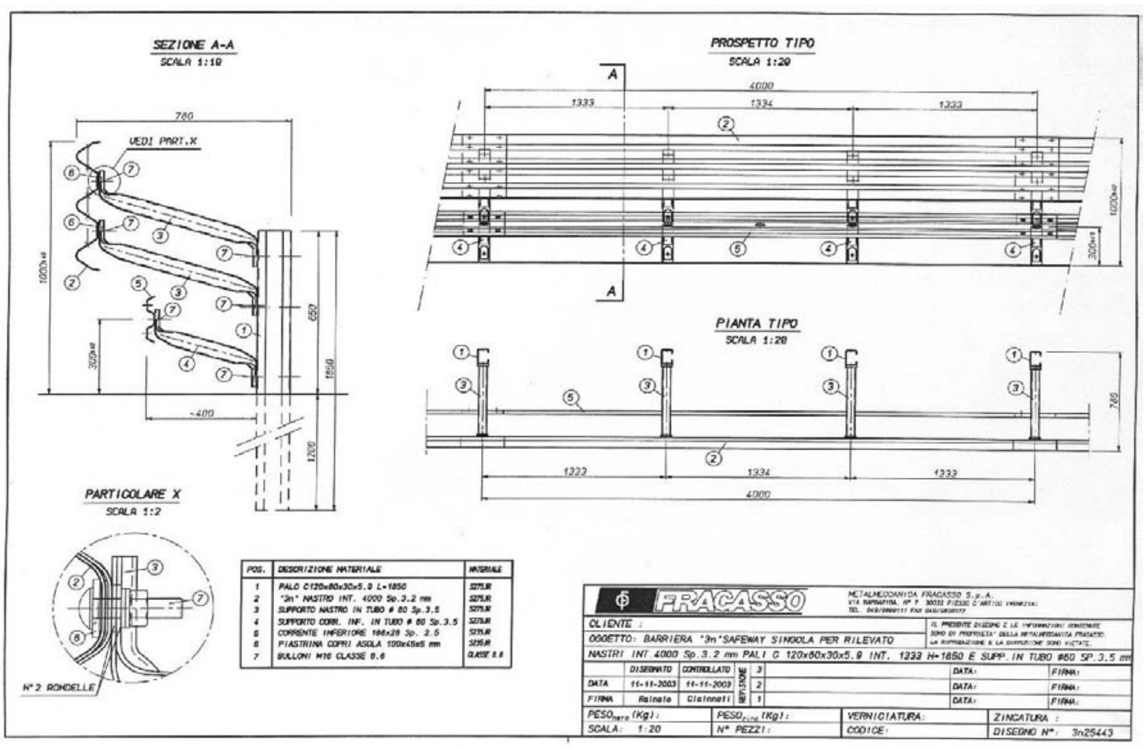


**Figure 3 SAFEWAY barrier**

## Injury index

Since 1960, the American Medical Association, the Association for the Advancement of Automotive Medicine (previously American Association of Automotive Medicine) and the Society of Automotive Engineers carried out a study of the entity of the localised injuries in the whole human body and furthermore issued the first version of the **A**bbreviated **I**njury **S**cale, **AIS**, in 1971.

The AIS, very simple in its structure, became the standard tool for the accident studies and in the automotive industries in the United States, in Europe and in Australia.

The AIS was originally developed to be used by crash investigation to standardise data on the frequency and severity to motor vehicle related injuries. Its use has been extended to epidemiological research, trauma centre studies to predict survival probability, patient outcome evaluation and health care systems research. It also features in studies to assess societal costs of injuries.

In AIS 90 edition - update 98 - each injury description is assigned a unique 6-digit numerical code – to assist in computerisation of data - in addition to the AIS severity score. As summarised in the diagram below, the first digit identifies the body region; the second digit identifies the type of anatomic structure; the third and fourth digits identify the specific anatomic structure or, in the case of injuries to the external region, the specific nature of the injury; the fifth and sixth digits identify the level of injury within a specific body region and anatomic structure.

The digit to the right of the decimal point is the AIS score:

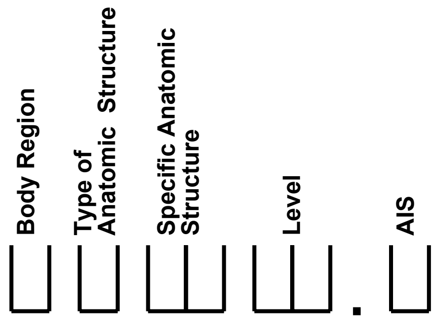


**Figure 4 AIS score**

The AIS has been universally accepted. Accurate and consistent application of the AIS, therefore, is fundamental to sound injury collection globally.

To apply this criterion the AIS Dictionary has been organised. In the dictionary each type of injury may be codified according to specified rules.
An Anatomic index, which follows the dictionary, lists all the dictionary descriptions in AIS 90 in alphabetic order, the body region in which the injury is located and the page on which it can be found.
Each injury description has been assigned a unique 7-digits numerical injury identifier. The single digit to the right of the decimal point is the AIS number according to the following severity code:

| AIS Code | Description |
|---|---|
| 1 | Minor |
| 2 | Moderate |
| 3 | Serious |
| 4 | Severe |
| 5 | Critical |
| 6 | Unsurvivable |

**Figure 4 AIS code**

Furthermore Baker's **I**njury **S**everity **S**core, **ISS** gives a much better fit between overall severity and probability of survival.
The AIS is fundamental for the Injury Severity Score, and will likely remain the basic system for future methods to assess overall injury severity.
The ISS is the sum of the squares of the highest AIS score in each of the three most severely injured body regions.

## Theoretical Injury Level, Th.I.L.

If the AIS and the ISS indexes are now universally used to evaluate - in a standardised and unified way - the effective injuries due to a real accident, in the computational biomechanics analysis field a standardised and unified injury index is also needed.

In particular, it is necessary to use a criterion that can become, soon and easily, common. To reach these proposes the criterion has to be based on commonly known theories and concepts and on standardised and unified indexes - in full analogy with existing procedures used in the real accident situations as - for example - the AIS and the ISS indexes.

So the conventional ***Theoretical Injury Level***, ***Th.I.L.*** is defined, as the ISS, calculated on the base of the AIS, evaluated on the mathematical model of a dummy, by means of computational biomechanics.

These base requirements - necessary to develop the computational biomechanics of this project - are also useful in all computational biomechanics process to evaluate the impact effects on the dummy - and could guarantee the lowest level of the injury and its localisation in the lowest risk zone.

# THE INTELLIGENT BARRIER

Indeed, the steel road barrier designed and constructed within the SAFEWAY project sees the light at a most convenient time for both Europe's road transport safety policy and for the establishment of a single European market of safety performance based products currently under discussion at European Standardization Bodies (CEN Technical Committee on Road Equipment – TC 226).

## The final model

This 3-year research project has resulted in a new design with the following abilities:

- Very High Containment following results of the last real life tests at TÜV Laboratory (November 2003).
- Unforgiving Quality showing an Acceleration Severity Index (ASI) = 0.95 25% reduction from current state-of-the-art on Very High Containment barriers.
- Environmentally Friendly with reduction of material consumption by more than 20%.

Under a safety perspective, following the results achieved from the analysis of the data collected, and the results of the traumatological tests the main concern for the proper elaboration of the final model is:

- toward the vehicle occupants: avoid driver's head collision with the barrier.
- Towards the other road users: Very High Containment Level for all types of vehicles (with a high point of gravity in order to ensure the redirection of vehicles, especially those heavy goods).

In order to effectively address these two main requirements the only possible model design is a low height barrier, which 1) does not contact the driver's head on the occurence of a small vehicle colliding to it, and that 2) raises its position when receiving a much stronger impact from a heavy goods vehicle.

## SAFEWAY methodology

The data collection effort undertaken by SAFEWAY project shows a clear need for the improvement and harmonization of accident data collection at European level. To this extent, tremendous differences between different Member States and research centres/institutes have been observed, not only on the fields covered by the different databases, but also on the terms commonly used on each field. (e.g. "injured", "slightly injured", and "seriously injured" refer to different national definitions).

A survey on the state of the art in modelling systems for the development of road-safety related numerical simulations was carried out. This survey shows the lack of models regarding the design of a barrier taking into account the barrier/vehicle/passenger interactions. This model has been developed within the project.

The chosen methodology has proven the efficiency of the use of computational mechanics for the simulation of accidents. Nevertheless, it should not be understood that computational mechanics by itself could reflect real life situations. Its usage is limited to its validation and completion through real life tests.

The parametric investigation leading to the materials characterization has proven the critical need of defining the materials composition aiming to avoid scenarios such as:

- "car sliding" below upper barrier with disastrous consequences,
- "pocket effect", barrier pockets around the vehicle during the impact,
- "direct impact" between most rigid part of the barrier and softest part of the vehicle.

This will result on the minimization of the traumatological consequences to the vehicle occupants (be it car passengers, heavy vehicles occupants, or motorcyclists).

This investigation has been successfully carried out through the comparison of the results obtained from experimental and numerical evaluations.

## RECOMMENDATIONS FOR THE ROAD USER

In the framework of SAFEWAY research activities, it has become especially clear that even if the absorption level of the barrier is very high, several factors are of critical relevance from the driver's perspective.
In order to ensure a minimum traumatological effect to the car passengers due to a crash the following is required:

- the driver must be well positioned (at least 30 cm from the steer wheel).
- Seat belt of all passengers should be properly adjusted, avoiding blocking the neck and abdomen (with the extremely serious consequences that the results on the test dummy have shown).

## CONCLUSIONS

The project results corresponded fully to the aims of the research.
The preliminary design has been performed by means of computational mechanics in order to identify the behaviour of the most important components of the barrier and of the whole structure. The prototype has been manufactured and tested.
The overall data were carefully analysed bearing in mind that SAFEWAY aimed not only at developing a more "forgiving" barrier but also at identifying a more environmental-friendly road furniture. The material that should be used in order to develop a safer barrier respecting the environment was analysed. The analysis concluded that a barrier made of deformable material such as steel, with either its main rail or its lowest rail close to the ground would yield the best results.
The concept design activity has been varied out in order to find out the optimum in barrier material, dimension, geometry and especially height, capable to contain the 38 tons lorry (rise up of the spacer during the impact phase). The barrier concept design is also intended to avoid the contact of the dummy head against the barrier beam – in case of failure of the window glass with fragile behaviour in the 900 kg old car models.
In particular the steel barrier demonstrated in the tests to be able to contain Heavy Goods Vehicles of 38 ton, it means to be a Very High Containment Barrier.
In addition to that the test recorded a 20% reduction on the impact severity performance according to ASI (Acceleration Severity Index) level A, leading to a safer barrier to the vehicle occupants including the driver and passengers cars.
Finally the reduction on the material consumption was more than 20%, leading to a more environmentally friendly device.

Furthermore the research has identified the need of updating EN1317 in order to take all this research developments into account. More specifically, we may highlight a series of them:

- road barrier height tolerances should be more specified (as the project has demonstrated the need to prevent from a direct impact between driver's head and the barrier itself).
- Traumatological consequences to the vehicle passengers should be incorporated into the standard. (e.g. incorporating additional traumatological indicators such as the ones used at the automotive: neck, chest, femur, and knees, upper and lower tibia...).
- The need for an experimental anthropometric dummy with standard specifications like the ones used for the automotive tests to be included in all tests should be addressed. Without the standardised dummy it will be extremely difficult to accurately evaluate the traumatological effect to the passenger.

In order to more accurately study the traumatological consequences to the vehicle passenger from an impact to the barrier, the project consortium has incorporated the indicators commonly used in the automotive industry (neck, chest, femur, knees, upper and lower tibia...).
This need has proven the insufficiency of existing indicators within EN1317 for the study of the traumatological consequences for the vehicle-passengers in the event of an accident.
The SAFEWAY barrier has been designed with a low height. Nevertheless, if for any reason, the passenger car height is above the average, or the system fails to remain on its height when a small vehicle crashes into it, it is of extreme importance that the vehicle deformation does not break the window permitting a contact between the head and the barrier.

In order to avoid this scenario, "stratified glass" installation in all vehicles has proven not only a very efficient measure (it absorbs the energy of the impact and does not break), but does not imply major investments by the automotive sector.
From existing databases, as well as the data collection effort performed within the SAFEWAY project, it is concluded that at least 30% of all crashes are "oblique". It is believed that the automotive sector can complement infrastructure research developments by further improving its research efforts on this type of crashes.
Conversely, crash tests undertaken by the road barrier manufacturers themselves are often carried out with old generation passenger cars. It is recommended using new generation vehicles in the course of future research efforts conducted by the infrastructure sector.
A technological gap clearly exists between the instruments supporting research within the automotive and infrastructure sectors. Better dialogue – achieved through permanent research platforms open to all stakeholders – will help bridge this gap.
The innovations already introduced in recent years with the 3n guardrail and those that are currently being introduced – thanks also to a specifically targeted research program approved and supported by the European Commission – have strongly contributed and will contribute even further in the future to minimising the injuries resulting from crashes into road barriers.
For engineers, existing standards are still the main source of the guidelines to be followed. However, if there is to be progress in this sector, they cannot remain the sole reference.
Poorly performing barriers should be discarded and new concepts should be continuously introduced through research programs conducted with scientific rigour; the new barriers should go well beyond the standard requirements demonstrating real, significant advantages from a safety standpoint. This is the method for achieving real progress.

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