D.2.2 – REPORT ON REVISION OF STATE OF THE ART ON ROAD RESTRAINT SYSTEMS

Project Acronym: Smart RRS

Project Full Title: Innovative concepts for smart road restraint systems to provide greater safety for vulnerable road users.

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SUMMARY:
Road restraint systems have characteristics, such as posts and sharp edges, that make them aggressive to Motorcycle riders. To decrease these effects, some products have been developed having two principal solutions: eliminate injurious elements and avoidance of collision with the hazardous obstacles. Two types of system can be found: punctual and continuous. Punctual energy absorption systems are generally located in the guardrail posts, are made out of a polymer based material and are good for speeds up to 60 km/h. They protect the riders against sharp edges, yet allow them to go underneath the beams. Continuous systems that redirect the rider are generally metallic or plastic elements located underneath the guardrail and all along the barrier, serving as a limiting wall for the rider to lose energy and stay on the road. They protect the rider from contacting objects behind the guardrail. Some systems are looking to make a combination of energy absorption and redirection, providing the benefits of both systems. Shown in this paper are a series of examples of systems actually in use or development. A reference on active and tertiary safety systems for the road has also been performed, with useful information on the future of the road safety technologies.
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Report on revision of State of the Art on Road Restraint Systems

1. INTRODUCTION

In recent years, motorcyclist safety in the road has become a more important and relevant issue in many countries throughout the world. Motorcycle usage is quickly expanding, so is the accident rate for their users and this specific safety topic needs to be addressed in an early stage. In Europe, some countries have already started with some practices like substituting I posts for Sigma or C posts, to shield or cover the guardrail posts, and to include additional motorcyclist protection; yet, this is just a beginning and no special protocols have been uniformly considered among the countries.

As stated in earlier projects and chapters of this research, conventional roadside barriers have been designed to provide protection for automobiles or trucks running off the road, without considering their effect on more vulnerable users such as motorcycle and bicycle riders. This lack of consideration is manifested through the inefficiency of actual containment systems to provide adequate protection for motorcyclists, reflected on the alarming statistical data that shows severe injuries produced by these barriers.

In order to offer better protection in case of a motorcycle accident, it is necessary to install special safety systems that absorb or attenuate the rider and motorcycle energy producing the lowest damage possible. To achieve this, the systems must comply with their goal of retaining heavy vehicles (autos, trucks) yet enabling riders who are involved in an accident to avoid any obstacle considered hazardous such as trees, poles or guardrail posts.

Today, we can find a series of systems used throughout different countries to provide motorcyclist protection in case of skidding out of the road or direct collision against a guardrail. These systems have two main classifications: punctual protection systems and continuous protection systems. In this stage of the project, we have given two approaches to analyze the available designs: a type of protection or design approach, including the categorized systems and a materials approach, in order to obtain the best information available.
2. REVIEW ON THE STATE OF THE ART OF MOTORCYCLIST PROTECTION SYSTEMS

2.1 TYPE OF SYSTEMS

In the area of road restraint systems, we can observe that the actual systems in use have the principal function of absorbing energy from the vehicle, redirect it to a safe area within the road and avoid the impact with hazardous obstacles behind the restraint system (trees, poles, cliffs and rocks). The system has, then, to comply with certain standards and conform to official testing, confirming that the performance is safe enough for road users.

Nevertheless, these systems are not tested for two wheel vehicles. As for bigger and heavier vehicles, the systems tend to be sturdy and with high endurance, allowing a car or heavy truck to slow down and stay on the main road. For motorcycles, these systems are too exceeded in performance, since two wheel vehicles are smaller, lighter and respond to different dynamics.

In the light of making these systems friendlier to motorcycle users and keeping the performance levels for cars and heavier vehicles, two major systems are tested and proposed. The main goal of these proposed systems is to avoid the injuries provoked by the posts and sharp edges of the road restraint systems.

The dynamics of a fallen rider show us that the motorcycle, with or without the rider, slide out of a curve and hit the restraint system, where generally, a space beneath the beam is not enough for the rider and/or bike to go through nor is the system able to contain them. This results in severe injuries to the limbs, thorax and head, as the sharp edges and posts inflict localized forces.

Knowing that the injury mechanisms of the road restraint systems as for vulnerable users are the contacts with the posts, sharp edges or the under running of the beam (where a more hazardous object or ravine might be found), some solutions have been proposed. The two major selections are:

- Punctual Energy Absorbers
- Continuous Systems to Redirect the Riders

PUNCTUAL ENERGY ABSORBERS

Nowadays some models of crash barrier impact attenuators exist, they are made of foam or plastic (polystyrene, polyurethane, polyethylene, neoprene or other synthetic materials) and in addition to absorbing rider energy when being compressed they prevent him from impacting the sharp edges of the posts. Some systems (very simple and inefficient) can also consist of a metallic pipe surrounding the post and filled with sand.

This positive effect is however reduced with the speed of the impact since the amount of energy which is absorbed is limited by the size of the device (up to speed about 50
to 60 kph). This makes those systems suitable for urban areas or tight bends. In order to make them more appropriate, an important volume of material (most probably impossible to be mounted on the barriers since the size of the device is restricted by the norm) would be required.

The maximum deceleration experienced by the rider during the crash is halved as well as the maximum forces; the absorbing material allows increasing considerably the impact time.

**CONTINUOUS SYSTEM TO REDIRECT THE RIDERS**

Some solutions have the same shape of the guardrail upper system, the classic two waves beam; some others are made with two tubes filling the gap between the upper beam and the ground; while others are made of a special cloth or mesh. These systems are technically very advanced, as they are projected to adapt the shapes and the materials’ properties to absorb as much energy as possible reducing the severity of impacts for motorcyclists. At the same time, their shape does not interfere with the main function of the safety barrier. These protections can be integrated in steel restraint systems connecting them to the existing structure, without main modifications to the original geometry.

Therefore, research has been leaded on how it was possible to redirect the riders on the road or along the barrier, preventing them from any contact with the aggressive posts or obstacles. The most used solution consists of a lower flat rail which is added to the conventional W beam barrier. Generally made in steel, this device is light and quite flexible and redirects the driver preventing him from getting off the road underneath the barrier posts.

Sala and Astori (1998) stated that these devices were shown to reduce both the number and the severity of motorcycle crashes. While the main function is, as mentioned above, to redirect the riders on the road, these systems are designed to absorb energy during the impact by flexion of the steel holding the plates. Nowadays, the studies and researches carried out on this field are working on systems that combine the absorption during the impact and the redirection of the riders on the road.

**COMBINING ENERGY ABSORPTION AND REDIRECTION OF THE RIDERS**

Some companies have started developing systems that provide the best characteristics of both systems into one single product. These systems have been designed in order to absorb the kinetic energy of the rider while redirecting him back to a safe area. To accomplish this, the systems use plastic based products to absorb the energy while having a long profile to redirect. One of the systems uses plastic tubes underneath the guardrail while the other is a punctual beam attached to a post with a special damping system.

**2.2 MATERIALS USED IN THE SYSTEMS**

Actually, there are several known road restraint systems that consider motorcyclist protection:
- **Steel roadside barriers.**
2.3 STEEL ROADSIDE BARRIERS

The development of motorcyclist friendly roadside protection systems is not yet standardized. Solutions that exist today are additional systems installed to regular roadside barriers. Some of them are merely steel plates placed in the lower part of the barrier, closing the gap between the beam and the ground with the objective of protecting the rider from hitting the barrier posts or other hazards such as trees, rocks or poles behind the barrier.

Present solutions have not been designed to soften the shock of the motorcyclist impact. That is one reason why the most important parameter to consider, HIC (Head Injury Criterion), that should define the effects of an impact of the head against another object is still very high (current steel systems vary between 150 and 350 HIC). It is worth noting that there are two HIC index criteria currently in use: HIC 15 and 36. Most of the systems, practically all of them, consider HIC 36 for the evaluation of their systems.

The difference between HIC indexes is the time interval considered to perform the calculations. The original HIC developed by the NHTSA in 1972 is the HIC 36, which is based on the resultant translational acceleration rather than the frontal axis acceleration. This evaluation system arose some questions on whether it was used for head deceleration only or was it considering a glancing blow to the head.

HIC 36 having a 36 millisecond interval is meant to encompass the maximum loading impact for impact waveforms that last longer that 36 ms. Relatively short waveforms are related to direct head contact whereas longer duration HIC intervals are associated with head deceleration without impact. A pre established limit of 1000 HIC is considered as the limit for injury (1972), yet, it was not based on tests where HIC was measured and injuries observed and related.

The new HIC 15 is a revision, made in the year 2000, for the 50th percentile male dummy. This index reduces the maximum time for measurement to 15 milliseconds revising the limits for the different sizes of dummies. This was due to the fact that the head structure used for testing is rigid aluminium shell that does not deform as a human skull, yet, the amount and type of deformation of real human skulls varies greatly with age, especially between older people and very young children. For FMVSS 208 a limit of HIC 700 has been established.
Steel guardrails with steel motorcyclist protections could be a good solution to have safer products, with very low HIC values. This is a viable option because steel protections can be conformed in different shapes, can be shaped with different thicknesses and be combined with spacers; each one of these modifications can help to increase the energy absorption properties of the barrier and reduce the severity indexes.

Most of the present steel systems are based on traditional S235JR grade steel, with hot dip galvanization process. HDG technology gives long term corrosion protection, where based results published by Czech and Slovak Galvanizers Association, zinc coating corrosion is varying between 0.64 – 1.57 μm/year, which gives for 70 μm thick coating lifetime of at least 45 years. Further implementation of new modern steel grades with better properties can be expected.

### 2.3.1 PLASTIC MOTORCYCLIST PROTECTIONS

Plastic motorcyclist protection systems come in two types: punctual energy absorbers and continuous protection systems. Plastic has been selected to produce these protective devices as it has interesting impact absorbing capabilities, ease of shape creation and light weight. On the downside, plastics are more vulnerable to weather degradation and rodent attacks. These systems consist of either a beam or a punctual absorber made out of special polymers that connect to the actual road side barrier, whereas to the posts, the spacers or the beam itself.

### 2.3.2 CONCRETE BARRIERS

Presenting a flat surface with no sharp edges, the concrete walls have the advantage of replacing a punctual impact with a surface impact. Consequently, they appear as safe to a motorcyclist, especially with small impact angles (< 20º), in comparison to traditional steel barrier with unprotected posts.

They also prevent heavy vehicles from crossing into the opposing traffic lane. As a consequence they are often used on central reserves, or where there is no room for a
metal barrier to deform. On the other hand, this type of barrier is totally unable to absorb any kinetic energy from the rider and should therefore be limited to the cases where small impact angle is the typical crash configuration.

2.3.3 WIRE ROPE BARRIERS

Wire rope safety fences are a system composed of posts and horizontal cables. Related to other systems exposed above, WRSF are considered even more dangerous, because posts and cables are working as cutting edges in two different directions at the same time. Moreover, it should be considered that 40% of motorbikes accidents happen with the biker interacting directly with the restraining system.

Recently there have been cases of motorcyclists being killed in crashes involving wire rope barriers but there is no evidence yet available to reveal the potential role of the barrier or its design features in the injury mechanisms. As noted earlier, it is clear that motorcyclist impacts with wire rope barriers have the potential to cause serious injury.

In this case, there is not a continuous large enough surface to protect the body, the cables could be considered as a cutting edge in all the directions, while concrete and steel could be considered relatively safer. Another type of Wire Rope Safety Barrier protection, developed in Sweden, includes an aluminium protection surrounding the wires. This is one of the systems proposed to reduce injuries to riders, additional to the post covers that are being used.

2.3.4 WOODEN PROTECTION

Wood is another material used in the manufacturing of road restraint systems. Wooden guardrails are generally found in natural protected areas and need to comply with the same safety features as regular, steel guardrails. Wood is a hard material and some models include a steel core to provide the tensile resistance to hold a vehicle on the road.

Some models make use of wood to cover the posts and guardrails providing some energy absorption, though not as good as a plastic system. Nevertheless, wood can be treated and have a higher weather hazard resistance. Wood barriers can also be installed in the lower gap to prevent the rider to slide underneath, yet no tests have been carried on HIC indexes for riders. Wood barriers do not expose any sharp edges to the riders.

2.3.5 REVIEW ON MATERIALS

Restraint barriers actually seen in the market are usually rigid steel structures that redirect vehicles as cars or trucks on a safer trajectory, but concerning post protectors and more generally all types of punctual impact attenuators intended to motorcyclists, research is continuously being leaded considering new materials and their potential for energy absorption improvement.

Synthetic materials such as Polyurethane (PU), Polyethylene (PE) or Neoprene present good properties for energy absorption and are usually the materials used for the impact attenuators. On the other hand, work still has to be carried out on their
durability, to ensure that consequences of the rodent attacks and weather do not lead to weakened safety properties. However, following the statements of Sala and Astori (1998), posts protected by polymeric dampers might not be very effective for velocities higher than 50-60km/h, their cost is very high and therefore their installation has to be limited to the more dangerous stretches of road.

More than these punctual barrier protections, the continuous barrier intended to redirect the riders are also subjected to material evolution. The upper parts of the barriers are made of relatively thick steel since they have to withstand the kinetic energy of the cars or even trucks without letting them go through. However in the case of the lower part, intended for motorcyclist protection, a much more flexible structure is required not to hurt the riders. Wooden barriers are also in use, although not much research is being made on this material.

Attending the needs of new materials that are less aggressive to riders, some companies have begun testing systems made out of plastic with special interior designs and manufacturing techniques that reduce the forces on impact and are economically viable. Another type of material being developed is a type of synthetic mesh or cloth that combines three important characteristics: it is elastic to allow for energy absorption, it is strong enough to withstand the crash forces while redirecting the driver and avoiding him to hit the posts and it is resistant to weather conditions and other hazards. It is easy to install and does not modify the barriers’ original performance.

On some newer contexts, there are some efforts in the creation of barriers that make use of recycled products, such as used tyre rubber. This system, actually in development phase, will make use of a regular steel core covered in recycled rubber, avoiding the need to galvanize the steel plate. This brings a double benefit as it reduces pollution from the galvanization process and also reduces the end pollution generated by used tyres, which are difficult to reuse and are not easy to dispose off. Rubber has the quality of absorbing high amounts of energy and has ample tolerance to weather hazards.

2.4 SYSTEMS IN USE

Continuing with the analysis of the motorcyclist friendly protection systems, we hereby present a list with the most common products and some of their technical specifications.

SEC ENVEL

System called “Protection des deux roues” (ECRAN Motard), manufactured by the French SEC ENVEL. The system conforms to exigency tests described by the LIER protocol, providing HIC numbers from 65 to 233 out of a 1000 permitted (HIC 36), depending on which of the two models is selected. The system is manufactured in galvanized steel, with simple mounting systems.

SOLOSAR

Solosar’s Ecran de Protection pour Motards is a motorcycle safety system that complies with European norm EN 1317, and was tested with a dummy impacted at 60 km/h with a 30° angle. It is made out of steel plate with simple mounts.

SODIREL

The French company Sodirel produces the system known as MOTO.TUB®, which is a system destined to protect riders that is installed under regular metallic or wooden guardrails. All the elements are made out of polyethylene that comes from recycling, up to a 75%. After testing, the product scored a HIC of 99 out of 1000 (HIC 36) permissible at 70 km/h.
The French company Sodilor produces this moulded plastic system. The device consists of soft plastic fence covering barrier posts that can be fitted to existing barrier systems. It aims to combine both energy absorption and impact spreading properties.

![Figure 3 Moto.Tub®](image)

**SODILOR**

This German company has designed and installed a series of safety systems called MotoRail Feldberg, MotoRail Euskirchen and SPU Crash Absorber.

MotoRail Feldberg consists of an under run protection device with a box profile, avoiding the impact with the posts.

![Figure 4 Rail-Plast](image)

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4 [http://www.volkmann-rossbach.com/two_wheeler_protection0.html](http://www.volkmann-rossbach.com/two_wheeler_protection0.html)
MotoRail Euskirchen is a deformable under-run protection device, which is installed underneath the normal guard rail beam, has been designed to protect the motorcyclist from crashing into the posts. The under-run protection device is fixed to the beam by suspension lugs.

The joint of the under-run protection element is in the centre of the guard rail beam, preventing from bursting during an impact. Furthermore a distance of only 0.05 m between the under-run protection device and the upper guard rail beam prevents the driver from slipping behind the safety barrier system.

The SPU Crash Absorber is used to cover the guardrail posts. It is made out of Polypropylene, resistant to UV-radiation and salt water, holding under high variations in temperature and humidity. It has a height of 0.49 m and can be mounted without any tools. It does not affect the performance of the barrier and is not reflective.

SAFE GERMAN GUARDRAIL TECHNOLOGY (SGGT)

http://www.sggt.de/index.php?id=bike-guard&L=1
BIKE-GUARD® is the system developed by SGGT; a company part of the Heintzmann Group (includes SOLOSAR). The system is a special steel plate of only 2.5 mm thickness and mounted flexibly underneath the guardrail. It can easily be adapted and be coated to blend into different environments.

![BIKE-GUARD®](image)

Figure 8 BIKE-GUARD®

**ASA PROTECT**

bike-PROTECT is a system made out of a rubber coated steel strip that replaces a rigid metal barrier. This structure is elastic and stable. It can be made in many colours, increasing the concentration of riders and other road users. The system reaches down to the ground and guides away gently and safely in the direction of travel. It comes with a system of height choice. Special rounded dampers are fitted to the ends.

![bike.PROTECT](image)

Figure 9 bike.PROTECT

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6 http://www.asaprotect.at/en/bikeprotect/
HIGHWAY CARE

BikeGuard is a high quality, lower steel beam that can be attached to “W” beam type safety barriers and Open Box Beam systems to improve the safety performance of these barriers when impacted by motorcyclists. It prevents motor cycles and particularly their riders from sliding under the barrier and becoming snagged on the barrier support posts.

BikeGuard is manufactured in galvanised steel, and is fixed to the barrier with specially shaped brackets which attach to the rear of the barrier rail, allowing the BikeGuard to perform independently of the barrier during impact. The BikeGuard system utilises slotted holes and a hanging bracket to enable horizontal and vertical adjustment.

Figure 10  BikeGuard
MOTOPROTEC

It is made up solely of two pieces: a frontal made with a plastic compound of last generation, non-flammable, which settles underneath the W beam and a robust back metallic structure that is fixed to the beam. It is made with a black weather and U.V. rays resistant paint. It is made with recovered material from car bumpers.

This system is different to the rest because it is only fixed to the guardrail post, not to the beam. It provides protection and redirection, being smaller than other systems. With this, maintenance and winter snow cleaning becomes easy. It can be installed in curves with minimum radios.

Figure 11 Motoprotec®

PRINS DOKKUM

MOTO-SHIELD® ensures that a fallen motorbike rider is prevented from sliding or getting trapped under the guardrail construction, and simply slides in parallel along its length. It consists of a standard flat board with inverted edges which can be mounted with the aid of brackets under any type of guardrail construction. The boards have a working length of 4 metres and a post distance mounting of 4 metres, centre to centre. On curves or bends the boards should be mounted 1.33 metres apart, centre to centre.

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8 http://www.motoprotec.com/eng/index2.html
9 http://www.verkeersveiligheidssystemen.nl/?pag_id=9355&site_id=96
SafetyBaer is a concrete containment system manufactured in accordance to Euro Standard 1317-2. It fulfils H2 and H4B containment levels. Added to this product, there is Softbaer, an in-situ concrete barrier complying with the H2 norm.

**Figure 13 MOTO-SHIELD® test results**

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<th>Collision test results</th>
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</tbody>
</table>

**Figure 14 TSS Softbaer**

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10 http://www.tss-koeln.de/produkt/produkte.engl.htm
Hiasa is a Spanish company that offers 3 similar products in relation to motorcyclist protection. The products offered are called SPM-ES2, SPM-ES4 and SPM-ES4TUB. They are all similar systems, constituted by a steel plate with a flat-trapezoid design underneath the guardrail, fixed to each of the guardrail posts.

All of these systems have been tested according to Spanish norm UNE 135-900 with a Hybrid III dummy at 60 km/h with a 30º angle, hitting a post and the middle of the beam. HIC criteria range from 93 to 158 (HIC 36).

![Figure 15 UNE 135-900 test](image15)

Figure 15  UNE 135-900 test

![Figure 16 HIASA SPM-ES system](image16)

Figure 16  HIASA SPM-ES system

**AMATEX**

Amatex is a company that produces wooden guardrails for natural and protected areas. The product is called UBM (Una Barrera de Madera) and was designed considering 4 aspects:

- Elevated vehicle containment and redirection.
- Vehicle occupant protection, including motorists.
- Integration to the surroundings.
- Functionality.

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This barrier is constructed by combining wood and steel. The steel frame is the structure that gives containment while the wood provides a softer material to absorb impact energy and eliminates any sharp edges. This barrier has passed EN 1317-2 testing.

Figure 17  UBM (Una Barrera de Madera)

**IDIMA**

IDIMA is the Centre for Environmental Research in Navarra, and is developing a motorcyclist protection system utilizing recycled tyre rubber to cover thin steel plates. This system is still under development and will provide good protection due to the nature of rubber (elasticity, energy absorption) and the resistance of steel. Also, it will provide an environmental benefit by recycling used tyres that could end up in garbage dumps or burnt in concrete factories.

**BASYC Protection System**

The system is composed of a mesh made up of:

- Polyethylene terephthalate (PET) of high tenacity. Non-existent elasticity.
- Polyester of high tenacity. Elasticity 50%
- Polyester of high tenacity. High Elasticity.
- Teflon
- Paraffin

The shoe support, metal part screwed on each post on the level of the ground ensuring the mesh a sufficient tension to prevent any contact of the victim with the post itself.

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The Basyc protection system settles using a machine designed especially for this purpose. Three people are necessary for the installation.

The classical colour of the mesh of Basyc is grey, but can be any colour. The Teflon which covers the mesh prevents the durable deposit of dust, grounds, graffiti, etc.

The tests were made on the protection system BMSNA4/120 according to 321/95 took place following norm 135900-1.2, which is the most common barrier used worldwide. The tests were carried out at 63 km/h and 30° angle.
3. COMMENTS AND DISCUSSION ON STATE OF THE ART OF MOTORCYCLIST PROTECTION SYSTEM

The major brake to a massive installation of safety barriers along the roads remains the same with many systems: the cost effectiveness of the device and its installation on the roads. A study undertaken through the Ministry of Transport in France estimated “the cost of equipping all the crash barrier with Motorcycle Friendly Devices would be 600 million euros. With an average of 60 death motorcyclists due to crash barriers and a pessimistic hypothesis that these devices would halve the number of deaths […] it would take 20 years for a full installation to be cost effective. With the given estimated durability of 4 years for the MFD, this seems economically not sound”.

Although this economic viability contradicts the VicRoads concept of creating a “safe system” (Victorian Motorcycle Road Safety Strategy), it enforces the authorities to define the “black spot zones” regarding motorcyclist crashes into barriers in order to prioritize the installation of safety devices in these areas. However it turns out that while some black spots can be clearly identified, the major part of motorcyclists-barriers impacts are randomly distributed along the roads.

In response to that economical brake, industries should aim at improving the cost efficiency of these products. Different actions could be led along the life cycle of the devices:

Design: the devices should be easily adaptable to existing barriers in order to reduce the installation time and difficulty. The materials that are used also have to be considered for questions of production rate, manufacturing duration, eventual recycling and reusing.

Manufacturing: optimization of the manufacturing process

Life: Research about materials and maintenance of the systems is required to improve the durability of the systems.

Although the lack of scientific knowledge of the motorcyclist-guardrail’s impacts is partly responsible for the difficulties to improve the devices, it has been noted that a lot of studies and research has been focusing on developing MFDs, which lead to good motorcyclist protection. If the systems installed on our roads nowadays are somehow not always adapted, it is maybe due to the way of homologating them more than the way they are designed. This remark pointed our attention on an analysis of the regulations, norms and protocols for homologation of MFDs.

Apart from considering the cost of manufacturing and installation of the systems, an in-depth analysis on the performance and the establishment of a more strict protocol are needed. Nowadays, the performance criteria is established by the HIC 36 and pretty much all the systems mentioned have complied, having amongst them some important variations, even for the same system in two configurations. A further study on the relation of HIC with motorcyclist head injuries would help establish the optimal threshold for the devices to perform. From the obtained data, we can note that punctual
systems have higher HIC than continuous systems, and higher angles induce higher HIC results.

A comparison of the performance provided by each system could be a helpful tool to find the strengths and weaknesses of the different proposals, aiding in the cataloguing and establishment of a unified criteria to assess the motorcyclist friendly systems. This comparison will then become a reference for the interested parties in selecting the most adequate system according to the specific needs of the road (closed or ample curves, black spots)
4. STATE OF THE ART OF THE PRIMARY AND TERTIARY SAFETY SYSTEMS FOR THE SMART RRS PROJECT

This part of the document examines the technological state of the art as it relates to Smart RRS’s primary and tertiary safety systems (the terms “primary” and “tertiary” are covered in requirements 1 and 2 below). It summarizes the top-level requirements or goals for these systems then provides an overview of the state of the art in the light of these goals. It considers what sensing systems are already in existence in the roadside infrastructure (Section 0) as well as those currently available on vehicles (Section 1). The final section deals with the state of the art relating to communications technologies that might be relevant to the project.

4.1 REQUIREMENTS

At this stage in the project, formal requirements have not yet been written down for the primary and tertiary sensing systems. However, there are a number of goals for the project which will help us review the state-of-the-art in this area. These are derived from the original project proposal and are listed below.

1. Smart RRS will contribute to providing timely and useful information to road users that will assist in preventing road incidents. This is the aim of the Primary Sensing System.
2. Smart RRS will contribute to providing timely and useful information to emergency services, road authorities and other road users in the event of a road incident. This is the aim of the Tertiary Sensing System.
3. The primary and tertiary systems will be integrated with the road restraint system. There are many infrastructure based sensing systems already in existence. One of the unique features of this project will be that the sensing systems are built into the road restraint system.
4. The primary and tertiary sensing systems will be cost effective – in terms of materials costs, installation costs and running costs.
5. The primary and tertiary sensing systems will minimize additional demands on the infrastructure such as power and communications buses. This goal leads us down the route of using energy scavenging systems and wireless communication. This in turn puts severe constraints on power requirements for sensing and communications nodes.
6. The primary and tertiary sensing systems will not provide additional risks to those colliding with the road restraint systems – particularly vulnerable road users such as motorcyclists.
7. The primary and tertiary sensing systems will be robust against the environment.
8. The primary and tertiary sensing systems will be robust against system degradation (e.g. the loss of a sensing node will still allow the system as a whole to function – or at the very least, be able to detect when a node is not functioning correctly).
9. The primary and tertiary sensing systems will be robust against false triggering (so that, for example, emergency services are not called unnecessarily).

10. The primary and tertiary sensing system will ensure that each sensing node should know its location. This can be set at time of installation or provided for automatically through the use of GPS receivers embedded in sensing nodes.

11. The primary and tertiary sensing system should be modular – additional functionality to be easily integrated depending on the location.

12. The primary and tertiary sensing system shall be capable of being integrated with other roadside infrastructure and traffic management systems.

The particular parameters to be sensed will be determined partly by the feasibility of the sensing technologies available and how these fit with the goals listed above. However, of still more importance will be the relative likelihood of the various risks that might be sensed in the road environment. This risk analysis has not yet been completed but the list below identifies at a top level a number of candidate parameters might be sensed.

Primary Sensed Parameters

- Traffic related parameters – including volume estimates, vehicle speed and acceleration/deceleration estimates, vehicle separation and position or proximity to crash barrier. Heavy braking might also act as an indicator of potential risk for upstream traffic.
- Road conditions – perhaps of greatest concern under this category would be issues of road surface state and visibility.
- Obstacle related parameters – static obstacles in the carriageway (or indeed hard-shoulder) perhaps representing the most difficult parameters to sense.

Tertiary Sensed Parameters

- Essentially this will be to identify, locate and begin to classify barrier crash events. The sensing suite may be able to identify other features of the crash event such as fire or fuel vapour spillage.

4.2 INFRASTRUCTURE BASED SENSING SYSTEMS

Inductive Loops

Inductive loops are perhaps the most ubiquitous and oldest of all infrastructure based sensing systems. They rely on measuring the change in inductance of a large wire loop structure as a ferrous object such as a car travels over them. The wire loops are embedded in the road typically by cutting a trench in the tarmac and filling in with a polymer. These can be used for estimating traffic flow, vehicle speeds and some element of vehicle identification.
Note that the UK Company, Golden River, produces a wireless magnetometer\(^\text{15}\) which is also embedded in the carriageway, but only at a single point and does not require a wired connection to a roadside infrastructure. While it would not be suitable for the Smart RRS application, it does demonstrate some of the features needed in a Smart RRS system – namely low power and wireless operation.

**Issues**

While inductive sensors are relatively low cost, extremely familiar to installers of road sensing infrastructure and resistant to vandalism, a number of issues make them less suitable for the Smart RRS application. These include:

- Difficulty of embedding inductive systems into a ferrous crash barrier.
- Cost of installation work and lane closure logistics.
- Physical connection required to the roadside infrastructure.
- Power consumption (although the newer solutions referred to above overcomes this issue).
- Limited range (the sensitivity of standard inductive loops falls off in proportion to distance cubed).

**Infrastructure-based imaging systems**

Cameras have developed in recent years from being simple monitoring devices – feeding images back to control centres for inspection by human operators (for which application they are still used) – to employing advanced image processing techniques to undertake vehicle counting, lane occupancy measurement, vehicle presence detection, queue detection, queue length measurement, speed estimation, vehicle classification and incident occurrence.

Existing camera systems tend to be mounted high above carriageways (the UK Highways Agency traffic monitoring cameras are mounted on 12 m high masts) and are often capable of moving and zooming to examine incidents in more detail\(^\text{16}\). The height provides for a good vantage point, allows the cameras to be above the worst excesses of traffic-generated dirt and also provides a measure of protection against vandalism.

Although Automatic Number Plate Recognition\(^\text{17}\) (ANPR) was first developed in the late 1970s, in recent years applications for the technology have mushroomed. It is now possible not only to detect and classify a vehicle but to identify it uniquely. The technology has numerous applications in law enforcement (detecting tax evasion for example) and enabling the measurement of a specific vehicle’s average speed between two points.


\(^{16}\) See for example, the HANET system from SciSys: [http://www.scisys.co.uk/casestudies/Transport/cs_sword_hanet.asp](http://www.scisys.co.uk/casestudies/Transport/cs_sword_hanet.asp) .

\(^{17}\) There are many suppliers in this field – see for example: [http://www.pipstechnology.co.uk/products.php?section_id=1&article_id=3](http://www.pipstechnology.co.uk/products.php?section_id=1&article_id=3) or [http://www.citysync.co.uk/go.php/en/home.html](http://www.citysync.co.uk/go.php/en/home.html) .
Imaging systems cover a wide variety of camera based technology allowing for great flexibility in choice of range, field of view, image resolution, optical spectrum used, monochrome or colour, dynamic range and 3D capability (for example through the use of stereo cameras).

**Issues**

Imaging systems are clearly extremely versatile however a number of points must be considered if they are to be included in a Smart RRS system.

- **Cost.** Current cameras have complex mounting arrangements (on masts or gantries) and some systems will have image processing capability adding to camera complexity and cost. Nonetheless, the embedding of camera technology with advanced functionality (e.g. face recognition software) into low-cost consumer products points the way to the possibility of integrating low cost systems into the infrastructure.

- **Power budget.** Particularly as frame rates and complex real-time image processing algorithms are added to imaging systems, it will become more difficult to manage the power budget.

- **Connection to the infrastructure.** Cameras used for traffic monitoring will require high bandwidth connections to the infrastructure, typically using optical fibres. The use of cameras in systems that aim to minimize the need for a wired communications infrastructure will require careful examination of what data is to be transmitted road infrastructure control centres and what processing takes place locally at the camera.

- **Robustness against dirt.** Image quality and therefore useful functionality will deteriorate over time as dirt builds up on a camera’s lens. The high mounting position of many traffic cameras gives them immunity to the very worst of traffic-generated contamination. If imaging systems are to be used within the Smart RRS system, serious consideration will have to be given to this in the design stage.

**Infrastructure-based radar**

Radar is also a commonplace technology in the modern road environment\(^\text{18}\). It can achieve many of the same functions as camera based imaging systems but has the great advantage of being able to function in most weather and illumination conditions. Traffic based radar tend to be of the Doppler kind, measuring the frequency shift of radar returns to provide a signal proportional to the speed of the target. Thus roadside radar sensors are often optimized for moving targets rather than stationary.

Radar for traffic applications in Europe commonly operate in the 10.5 (X-band), 24 (K-band) and 77 GHz (W-band) regions of the electromagnetic spectrum. Radar is often used in conjunction with imaging systems: for example in speed cameras, they tend to

\(^{18}\) Likewise, there are many suppliers in this field – see for example: http://www.agd-systems.com/en/index.asp or http://www.radarlux.com/site/index.php.
be used as the triggering device while the imaging system provides the vehicle identification and in some cases the speed measurement.

**Issues**

- **Power budget.** The concern about any technology continuously radiating energy (albeit in some cases only a few mW) is the drain on available power.
- **Cost.** While the simplest continuous wave Doppler radar used for motion sensing are in widespread use (e.g. at pedestrian road crossings), it is likely that some cost optimization would be needed for a Smart RRS application.

**Other infrastructure-based sensing systems**

A wide range of other technologies have been developed and deployed in the road traffic infrastructure. A representative sample of these is listed below:

- **Energy Absorption Systems Inc. Impact Monitoring System**\(^\text{19}\). This is the only example of a tertiary sensing system tied to a roadside safety structure that has been identified to date. The sensor appears to be designed particularly for roadside energy absorbers (as opposed to a crash barrier). The sensing mechanism appears to be a number of normally open “vibration switches” wired in parallel. Closing of a switch causes a message to be sent wirelessly to a transmitter station which alerts a control centre using SMS.

- **Road ice detection systems**
  A number of methods have been developed for road ice detection\(^\text{20}\). These rely on remote optical (infrared) sensing\(^\text{21}\), embedded in-road temperature sensors or inference from atmospheric measurements\(^\text{22}\).

- **Weather systems**
  A number of manufacturers have developed (and sometimes operate on behalf of road authorities) systems of roadside weather systems\(^\text{23}\). Typically these might measure wind speed and direction, pressure, temperature, relative humidity and precipitation. They might be combined with more specific road sensors (such as ice detection) in a roadside application.

- **Acoustic sensing systems**

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\(^\text{21}\) See for example the Swedish company Sensice [http://www.sensice.com/](http://www.sensice.com/).

\(^\text{22}\) The Gent-headquartered ICST has proposed the use of a wireless sensor network of simple atmospheric measurements to infer and map road-ice risks across a region [http://www.icst.org/portals/content/an-innovative-system-to-monitoring-ice-road-conditions-based-on-wireless-sensor-networks](http://www.icst.org/portals/content/an-innovative-system-to-monitoring-ice-road-conditions-based-on-wireless-sensor-networks).

There has been considerable patent activity in this area – passive acoustic systems representing a relatively low cost, low power method for roadside sensing. However the number of products on the market appears to be few\textsuperscript{24}.

- **Laser Scanners**
  Laser scanners (sometimes called Lidars) have been used to perform a number of traffic monitoring related tasks\textsuperscript{25}. Because of the need for mechanical scanners to scan the optical beam across the scene being examined, these are relatively expensive instruments. Lower cost systems aimed at the automotive market have been developed\textsuperscript{26}.

- **Air quality monitoring systems**\textsuperscript{27}
  As governments and local authorities seek to understand the impact of road traffic on air quality, monitoring systems are increasingly being installed – particularly in urban areas. These typically monitor NO\textsubscript{x}, SO\textsubscript{x}, CO, O\textsubscript{3} and airborne particulate matter – particularly the smaller particles such as PM\textsubscript{10}. A number of companies and project consortia have sought to develop low cost, low power systems suitable for ubiquitous wireless sensor nodes\textsuperscript{28}.

### 4.3 VEHICLE BASED SENSING SYSTEMS

The modern motor vehicle has many sensing systems some of which overlap in function with some of the infrastructural sensing systems being considered within this project. In fact automotive systems are potentially a good source of sensing technology because of their low cost and high level of robustness.

**Vehicle-based imaging systems**

In vehicle camera systems have been developed over the past five or ten years as a component to driver assistance systems. Functions enabled by imaging systems include: lane departure warning (LDW) and lane guidance (or lane keeping support). They have also been used to help rear view visibility (by providing rear view images on a display at the front of the car). Still more advanced feature recognition systems have recently come onto the market – an example being road sign recognition.

\begin{itemize}
  \item SmarTek’s SAS-1 device is an example of a product on the market – see http://www.trafficsensor.com/ .
  \item OSI Laserscan is an example of a company working in this area – see http://www.osi-ls.com/index.html .
  \item Ibeo Automobile Sensor GmbH has developed a lower cost system. http://www.ibeo-as.com/english/products_ibeolux.asp .
  \item Enviro Technology Services plc sell commercial systems – see http://www.et.co.uk/cgi-bin/products.cgi?product=1029&section=1002&productcategory=1000&application=1001&function=moreinfo.
  \item Pirelli Labs describe a system on their website: http://www.et.co.uk/cgi-bin/products.cgi?product=1029&section=1002&productcategory=1000&application=1001&function=moreinfo and the UK funded MESSAGE project has developed a wireless “mote” currently installed in a number of English cities – see http://bioinf.ncl.ac.uk/message/ .
\end{itemize}
Many of the major tier 1 automotive suppliers have camera-based safety systems on the market (e.g. Bosch, Continental). TRW are in production with an LDW camera which takes data from a low cost CMOS camera and identifies feature such as the lane markings. The camera calculates parameters relating to the lane ahead of the vehicle and passes these to the LDW system over the vehicle’s CAN bus\textsuperscript{29}.

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{TRW_LDW_Camera.png}
\caption{TRW's LDW Camera}
\end{figure}

**Issues**

These are largely the same as for the infrastructure based systems. The cost issue has been partially addressed in that the camera is typically a high volume product. However:

- these sensors in their current form are not optimized for the low power requirements of this application;
- these devices are usually designed for integration into a vehicle’s electronic architecture by means of a CAN bus – again not the optimum configuration for a Smart RRS subsystem;
- and most cameras are designed for in-cab mounting – so issues of sealing would need to be addressed.

**Vehicle-based radar**

Automotive radar operates mainly in two frequency bands, 77 GHz and 24 GHz. The former have tended to be used for longer range (up to 200 m) narrow beam applications such as autonomous cruise control (ACC), whereas the latter have been used for shorter range (up to 100 m) wider beam applications such as blind spot monitoring and detecting vehicles in adjacent lanes as they cut into the path of the host vehicle. These tend to be more sophisticated than radar used in the infrastructure in that they not only measure velocities of vehicles but also detect range and have the capability to track multiple targets over time.

\textsuperscript{29} More details of TRW’s camera product can be found at http://www.trwauto.com/sub_system/camera_technology .
Automotive radar sensors are mounted externally to the vehicle cab and so are already extremely robust to the road environment. TRW offer both 24 GHz (short and medium range) and 77 GHz (long range) radar systems\(^\text{30}\).

![TRW's 24 GHz Radar](image)

**Figure 21 TRW's 24 GHz Radar**

**Issues**

Again these are largely the same as for the infrastructure based systems. The cost issue has been partially addressed in that the radar is relatively a high volume product. However:

- automotive radar in their current form are not optimized for the low power requirements of this application;
- and these devices are usually designed for integration into a vehicle's electronic architecture by means of a CAN bus – again not the optimum configuration for a Smart RRS subsystem.

**Cabin air quality and other vehicle comfort sensing systems**

A wide variety of sensors have been designed into vehicle comfort systems. All of these will have been designed for low cost, robustness (meeting in-cab requirements rather than external) and lifetime (at least 10 years without calibration or maintenance). Some of these which might have relevance to a crash barrier based sensing system include:

- Temperature sensors these are typically thermistors and platinum resistance sensors and are commodity items.
- Infra-red sensors are used in cab to sense the skin temperature of driver and passengers for air conditioning systems. Similar technology (based on micro machined silicon thermopiles) may be applicable to sensing tasks within the Smart RRS project.
- Air quality sensors detecting cabin CO/HC levels and others detecting NOx are fitted to a number of higher specification vehicles and are used to control the

\(^{30}\) More detail on TRW’s radar products can be found at [http://www.trwauto.com/sub_system/radar](http://www.trwauto.com/sub_system/radar).
cabin air vents. These particular gases would not be priorities for a Smart RRS module but similar technology would be applicable to VOC measurement. One concern regarding these metal oxide semiconductor devices is their need to operate at high temperature – which potentially makes a significant demand on a limited power budget.

- **Humidity.** A number of manufacturers produce stable relative humidity sensing products which have also been used in the control of cabin air quality.

- **Rain sensors.** A number of automotive tier one suppliers offer rain sensors – although these are designed very specifically for the task of automatically operating windscreen wipers based on the detection of rain on the windscreen. They are not optimized for a more general precipitation sensing task such as might be used within Smart RRS\(^{31}\).

- **Solar / twilight sensors.** Some up-market vehicle cabins are equipped with sensors to detect solar radiation coming into the vehicle cabin and the onset of night – the former used to control the cabin cooling system, the latter to provide an input to automatic headlamp control. Again, the basic technology may have applications within Smart RRS\(^ {32}\).

**Vehicle crash sensors**

Vehicle airbag systems are triggered by combinations of safing switches, accelerometers and pressure sensors. Still more complex systems take data from gyros (in the case of rollover situations) and even from other vehicle systems (such as ACC). Of these, accelerometers are the most relevant form of sensing to Smart RRS. The basic sensor technology is produced at extremely low cost but is robustly packaged and interfaced to the airbag system by means of proprietary high integrity buses\(^ {33}\).

**Tyre pressure monitoring systems**

Tyre pressure monitoring systems are not directly applicable to the crash barrier sensing scenario. However, the in-tyre components do represent an interesting analogue for a potential Smart RRS sensing module. These devices contain sensing, control circuitry, power management that ekes out the life of a lithium coin-style battery over 10 years and a wireless transmission system. They are also extremely robust – living as they do within one of the harshest environments on a vehicle\(^ {34}\).

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\(^ {31}\) TRW produce a combined rain and light sensor details of which are at [http://www.trw.com/sites/default/files/BdyCntrl_RainSensr_eng.pdf](http://www.trw.com/sites/default/files/BdyCntrl_RainSensr_eng.pdf).

\(^ {32}\) ibid.

\(^ {33}\) TRW offer both accelerometer and pressure sensor modules for crash bag applications - [http://www.trwauto.com/sub_system/crash_sensors](http://www.trwauto.com/sub_system/crash_sensors).

\(^ {34}\) Details of TRW’s TPMS offering can be found at [http://www.trwauto.com/sub_system/tpms](http://www.trwauto.com/sub_system/tpms).
4.4 COMMUNICATION SYSTEMS

This is a brief review of some of the communications options for Smart RRS. A more detailed examination of different protocols as greater definition of the communications requirements emerge.

**Wireless Personal Area Networks**
A number of protocols and standards have been defined by the IEEE 802.15 working group. Personal area networks may be appropriate for low power communications between Smart RRS modules. Some of the options include:

- **Bluetooth.** The various Bluetooth specifications have been widely used for communication between items of consumer electronics, most notably mobile phones and computer peripherals. Variants include different classes for different transmission ranges and Bluetooth low energy.
- **ZigBee.** ZigBee is based on the IEEE 802.15.4 standard for Low Rate Wireless Personal Area Networks and is one of the most widely used low power wireless network protocol. There are others, however – such as WirelessHART (mainly for industrial control networks) and MiWi (from Microchip).
- **6LoWPAN.** This standard has been developed to allow Internet Protocol (v6) to be used over low powered 802.15 – based networks.
- **Non-802.15 protocols.** A number of protocols exist that do not make use of the 802.15 family of standards but have been developed either as proprietary standards for specific manufacturers or by other consortia. These include:
  - CyFi (proprietary to Cypress)
  - Z-wave (mainly used for low power switching, remote controls and home appliances).
  - ONE-NET is an open source wireless specification designed for low-power applications.

**Wireless LAN**
The IEEE 802.11 family of standards are the basis of for Wireless LAN. These are not optimized for the low power levels that are likely to be required by this project. However IEEE 802.11p is a draft amendment to the 802.11 standards which allows Wireless Access in Vehicular Environments (WAVE). This may be of relevance to Smart RRS related systems in the longer term.

**Mobile telephone networks**
It is likely that mobile telephony will provide the platform for communication from any remote roadside infrastructure to a control centre. The particular standard (GPRS or 3G networks) to be used will depend on the required data rates and also network coverage.
**Infrastructure to Vehicle (I2V) Communications Standards**

Longer term, it seems likely that Smart RRS-type systems will need to communicate directly with vehicles. A framework for doing this is still under development by the ISO TC204 Working Group 16 under the name CALM (Communications, Air-interface, Long and Medium range) and through EU projects such as CVIS. These make use of a variety of communication standards such as WAVE (mentioned above) and Dedicated Short Range Communications (DSRC). The latter is a form of RFID and in Europe is mainly used for electronic toll collection.

**Connection to existing ITS infrastructure**

Existing ITS infrastructure (such as camera, radar and variable messaging system gantries) makes use of Ethernet both wired and for higher bandwidth applications fibre optics. The exact standards used for connecting to the infrastructure are thought to vary widely across the EU.
5. CONCLUSION

The review on the state of the art of motorcyclist protection systems shows some clear evidence that the governments and private companies are starting to look for a solution to the serious injury problem. Some of the actions taken are governmental initiatives that impulse the development of new technologies within the entrepreneurial sector, which is the sector with the capability to develop such products.

One of the important issues regarding the safety systems is their application. As we know, governments are responsible for providing road infrastructure and maintenance, while citizens have the obligation to make good use of such elements. The conflict relies on the selection and adaptation of motorcycle friendly security systems, which are not harmonized on a European level and are manufactured by indistinct companies with different performances.

Some countries have already established their own regulations for testing motorcyclist protection systems (France, Spain, Portugal) while others are relying on these criteria to adopt the system. Nevertheless, the systems still have very different designs and effectiveness, and the development path needs to be increased.

As of now, we can clearly select two basic protection systems that need to be improved and designed according to unified regulations. These types of systems are the punctual and the continuous protection devices. These systems are manufactured in a selection of different materials and combinations and offer diverse protection levels.

As for punctual systems, the norms establish a maximum allowed volume and geometry, limiting their effectiveness to a lower range of speeds (max. 60 km/h) which in turn converts into very select installation points. An added problem is that the black spots for motorcycle accidents are unclear, as they are wide spread through the road network. Anyhow, punctual energy absorbing systems provide interesting characteristics such as kinetic energy absorption, deformation, ease of installation and manufacturing that should be considered relevant for their development.

In the case of continuous protection systems, their main focus relies on avoiding the rider to go underneath the guardrail and impact the posts or other hazardous obstacles that produce severe injuries. These systems can also include some energy absorbing characteristics, yet, the materials are different. Also, the mechanics of the protection device are different, as in a punctual system the impact tends to be more direct (higher angle) while the continuous system mitigates shallower impact angles.

The trend to follow is to design a polyvalent system that can provide protection in all senses to the rider, by attenuating the impact energy and redirecting him to a safe area. Some products have already started considering these aspects. It is important to recall that the most severe injuries come from the contact with obstacles or by harsh falls, when a rider impacts in an upright position. These injury mechanisms need to be taken in count when designing a motorcycle friendly device.
When considering the new systems to be adapted for primary and tertiary systems, we can easily notice that there is a wide variety of choices and studies to be performed. If the principal aim of the system proposed will be to avoid or prevent the riders of road hazards and, if required, inform of an incident that has occurred, a careful selection and protocol preparation will be required based on the most appropriate systems for the functions to be made.

Many of the actual technologies are applicable to the road restraint systems, but some issues need to be solved. The inclusion or preparation of in-vehicle systems are an option, yet the power requirements and weather resistant features need to be addressed. Actual road analysis systems can be an ideal pre set platform if used correctly and the benefits are exploited correctly. In fact, the use of pre existing road systems could save in installation and operating costs, whilst providing new safety conditions for general road users.

Having the ability to inform the drivers of all kind of vehicles about hazards on the road, accidents that have occurred, weather changes, traffic conditions and new proposed routes are the tasks for the primary safety roadside systems. Informing emergency services, incoming traffic, and providing valuable information on where the accident happened, what kind of accident, number of vehicles involved, etc... will be the task for the tertiary safety systems. Embedding both systems into one is the challenge, and the actual technology provides the elements necessary to develop such system.