Road Safety Data, Collection, Transfer and Analysis

Deliverable 5.5 Drivers needs and validation of technologies

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Project Coordinator:

Professor Pete Thomas, Transport Safety Research Centre,

Loughborough University, Ashby Road, Loughborough, LE11 3TU, UK

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IFSTTAR, France

Report Author(s):

Pierre Van Elslande	IFSTTAR
Thierry Hermitte	GIE RE PR
Magali Jaffard	IFSTTAR
Jean-Yves Fournier	IFSTTAR
Angela Silvestrelli	IFSTTAR
Christophe Perrin	IFSTTAR
Bastien Canu	IFSTTAR
Joël Magnin	IFSTTAR
Céline Paraud	IFSTTAR

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EXECUTIVE SUMMARY

The DaCoTa project Deliverable D5.5 is devoted to the evaluation of the capacity of safety functions to compensate for drivers' needs as they can be diagnosed through in-depth accident analysis.

Two main criteria are used in this purpose: 1) the ability of each function to meet the needs of the drivers (e.g. if the driver shows a need in detection or diagnosis, is the system considered devoted to giving the information or diagnosis needed?); 2) their capacity to cope with the parameters of the situations in which these needs were found (e.g. time/space constraints, trigger threshold of the system, physiological state of the driver, behavioural considerations, etc.).

The study is conducted on a sample of 445 road traffic in-depth accident studies involving passenger cars, two-wheelers and pedestrians. It is applied to the e-safety functions addressed in detail within the technical DaCoTa Deliverable D5.2 ("Catalogue of the current safety systems") plus some e-safety functions dedicated to powered-two wheelers (PTW) and also infrastructure-based functions.

The results present in detail for each accident configuration (car versus car, car versus PTW, car versus pedestrian, single vehicle accidents), and for each phase of the accident (approaching phase, rupture phase, emergency phase), the potential capacity of the safety functions to meet driver's needs. They also give a precise indication on all the parameters that could act as a potential limitation to the effectiveness of the systems.

It is impossible to sum up all these results in a general figure. Everything must at least be analyzed relatively to 1) The accident configuration and 2) The moment of the accident process concerned. On the one hand, the context of the accident production and the failures of the drivers involved are different depending on the whether the accident scenario concerns passenger cars, PTWs, pedestrian or involve single vehicle accidents. Reflecting this difference, the drivers' needs to fulfill by the systems and the situational constraints to cope with are different depending on the configuration considered. On the other hand, depending on that fact that the aid system is able to intervene at the approach / rupture / emergency phase, the required functionalities are necessarily different. That is why it is necessary, not only to evaluate the capacities and weakness of the system as a whole, but as a function of their moment of intervention.

The interest of the detailed results presented in the report are first to allow estimating the more or less appropriateness of the current and on study safety systems, but also their weaknesses when considering real accident situation constraints. They also give some clues on the needs which are still not covered by the present devices. As such, these results can be considered as a contribution to the prospective ergonomics of safety systems, allowing their improvement for a better answer to the needs shown by drivers in accident situations and to the contextual constraints found in these situations.

1. INTRODUCTION

Major technological changes have taken place in the automotive field over the last few decades. Many research and development programs in Europe, USA and Japan have been devoted to the design of new driver support systems (for route planning, obstacle detection, car-following situations, speed control, and so on). The development of these systems raises several theoretical and methodological questions related to the ability of such systems to cope with accident situations in such a way to prevent crashes or mitigate efficiently their impact. From an ergonomics/human factors point of view, the main issues can be stated as follows (Saad and Van Elslande, 2012):

- What type of support could be appropriate for an activity such as driving, considering the complexity of the task, and the fact that it is an activity performed in extremely diverse conditions by a highly heterogeneous population, both in terms of car usage (professional or private use, daily or occasional, etc.) and individual characteristics (age, experience, driving style, etc.)?
- Will the functions ascribed by the designers be compatible with drivers' needs, objectives and priorities when driving?
- How to assess the relevance of the support systems proposed?

The DaCota project (Road safety Data Collection, Transfer and Analysis), co-funded by the European Commission within the Seventh Framework Programme, has an overall objective to contribute to the reduction of fatalities and injuries resulting from human mobility in the road traffic system. More particularly the aim of the project is to develop and implement new approaches to gather, structure and apply policy-related safety data. A wide range of vehicle and road safety policy measures are developed and implemented toward this objective. In the frame of DaCoTa project, a work package is dedicated to e-safety systems, the purpose of it being to evaluate to what extent actual and on project electronic safety functions could be able to contribute to reduction of casualties resulting from traffic crashes by preventing these crashes or mitigating their consequences.

1.1. Aim of the report

The relevance of the choices made to help the drivers largely depend on our knowledge on the difficulties met by the users of the traffic system, and also the factors likely to explain the occurrence of traffic accidents. In depth-accident analysis presents a good potential for understanding these difficulties and factors. It allows us to reconstruct in detail the different steps of each accident process –from the approach phase up to the crash- and to put forward at these different steps the malfunctions that occurred and the patterns of elements acting on them.

The purpose of the report is to present a study based on accident analysis so as to put forward the safety needs met by road users and estimate the capacity of ITS (Intelligent Transport Systems) safety functions to meet drivers' needs and compensate for the constraints found in real accident situations.

The study is addressing 21 electronic Safety functions (e.g. "Blind Spot Detection", "Electronic Stability Control", etc.) which were precisely defined in DaCoTa Deliverable D.5.2.3, plus some infrastructure based safety functions (e.g. "Rumble Strips", "Intersection Alert", etc.). The characteristics of these functions are described in detail in the following chapter.

These functions were evaluated regarding their capacity to cope with accident situations. The approach is based on detailed analyses of a sample of 445 traffic crashes for which were estimated the different **drivers' needs** in assistance and the **situational constraints** that safety functions should address in an appropriate manner in order to be efficient. By comparing the capacity of the safety functions to the needs and constraints coming from accident situations, it was possible not only to see the suitability of the functions but also their lacks and, as a consequence, their capacity of evolvement for better safety effectiveness.

1.2. Analysis of drivers' needs and contextual constraints

Driving activity constitutes a demanding, complex, variable and risky activity for which human capacity is often over-solicited and sometimes overwhelmed, potentially resulting in road crashes. Traffic crashes indirectly reflect that drivers need in certain situations some help in performing certain aspects of their activity under certain circumstances. It can be said that traffic crashes reveal drivers' needs.

One of the main components of driving difficulty consists for the road user in the necessity to permanently share and control his/her limited attention resources at the right places and the right moments. This also involves keeping available a part of these resources in case of unexpected events, and to spare them in order to be able to function efficiently in the long term. In every drive, drivers succeed in adapting to driving difficulties, but it can happen that human functional capacity is exceeded in compensating for driving demands. Thus, every component of information added to the driving task is potentially able to consume attention capacity and maybe to lessen performance by leading to different forms of attention disturbances (Hoel, Jaffard, Boujon and Van Elslande, 2011). For that reason, ITS functions must be restricted to the drivers' needs in order to not overload or disturb their capacity: every technical system aimed at helping an operator has to be thought of in light of the real difficulties encountered by this operator. Whatever the devices, they should be defined so as to be valid and effective for their users.
As far as drivers are not willing to have an accident, every crash goes through a failure in one or another regulating function that would usually enable them to compensate for the difficulties met at the wheel. Consequently, one way to get knowledge on the drivers safety needs is to analyse these human function failures, their factors and the characteristics of the situations in which they occur. In this purpose, in-depth accident studies make it possible to put forward these malfunctions, in relation to both the situational driving context (interaction with the vehicle, the road and with other road users) and the internal driving context (status, intentions, motivations, etc.) (Van Elslande and Nachtergaële, 1993). A previous study conducted in the frame of the European TRACE project has shown how the use of such accident data allows the evaluation of the capacity of safety functions; 1) to fulfil drivers' needs in safety, 2) to compensate for the contextual constraints found in accident situations (Van Elslande, P., Vatonne, V., Vallet, H., Fouquet, K., Canu B., and Fournier, J-Y., 2008). The method used, which is illustrated in Figure 1, has been further developed in the frame of the European DaCoTa project so as to extend the scope of the study and to analyse more safety systems in that way.

1.2.1. From human functional failures to drivers needs

From a systemic conception, a driver's safety need refers to something lacking inside the driving system's functions, in its defences and/or in its protections (Dekker, 2002). Accidents are the symptoms of these lacks, and human functional failures are a more precise sign of what was lacking to the driver in order to compensate for the difficulties he met on the road. Consequently, a driver's need can be considered as the "negative" (the mirror) of a functional failure experienced by a driver when being unable to compensate for a difficulty met at the wheel: the need represents what would have avoided the failure if it had been fulfilled (Malaterre, Fontaine and Van Elslande, 1992).

Once the needs have been established, they can then be confronted with safety functions, in order to estimate the ability of these functions to compensate for these needs.

1.2.2. From accident contexts to situational constraints

But another step of analysis is necessary in order to evaluate the capacity of the functions to compensate for the constraints (temporal, spatial, behavioural, etc.) characterising accident contexts. The purpose of this step of analysis is to show the conditions under which the safety functions studied could compensate more efficiently for the difficulties that drivers found in context. The potential capacity to compensate for these constraints has been analysed, function by function, considering their specifications. The purpose of this step of the analysis is to show the potential drawbacks and weaknesses of each function when confronted with actual accident situations. It allows, in turn, the definition of the parameters that these functions should integrate in order to maximize their safety benefit.

The detail of the method, including the description of the variables used, is presented in the next chapter. Then the results are presented for each phase of the accident process and for each kind of accident configuration.

2. METHOD

The method used in this study is strongly based on a previous research work conducted in the frame of the European TRACE project (Van Elslande et al., 2008) and other previous studies (Van Elslande and Nachtergaële, 1993; Van Elslande, and Contri, 1991; Van Elslande and Fouquet, 2008). It relies upon the in-depth analysis of road accidents with the purpose to put forward the difficulties found by road users and the causal elements which impeded them to adapt to the situations encountered.

The principle is to confront the data coming from accident reconstruction to the data characterizing safety functions so as to evaluate their compatibility. As mentioned above, there are two aspects to consider: drivers' failures and situational constraints.

From the drivers' failures are inferred the drivers' needs which are then compared to the safety functions in order to estimate their capacity to meet the needs (Figure 1).

The situational constraints are inferred from the characteristics of the contextual parameters found in accident data, some of them having the capacity to limit the potential efficiency of the system.

The details of the variables studied are provided in the next sections.

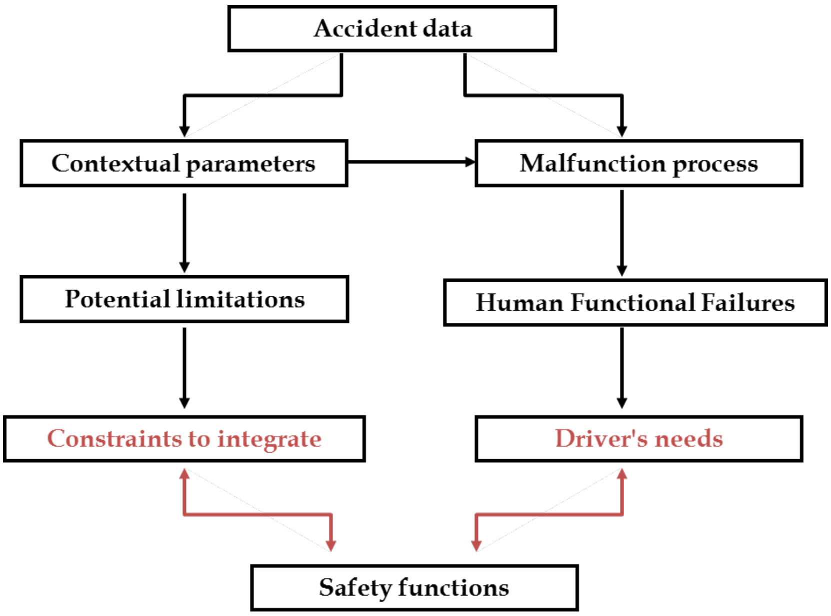

Figure 1: Methodological chart

Another important point to consider is the fact that every crash is the result of not only a complex but also a temporal process (Figure 3). This sequential component of the accident process should be taken into account when searching for the measures to put forward in order to improve traffic safety. If considering only the last step of the process, i.e. the crash situation, there is a strong risk that causes and consequences are mixed resulting in an useless analysis both from a scientific as operational point of view. Of course the resulting crash situation is essential to analyse in a secondary safety purpose, but the earlier steps of the accident generation must also be taken in a primary safety perspective. This has been clearly demonstrated in methodological work completed in OECD report (1988).

So, when thinking about the capacity of electronic functions to act in favour of road safety, the first stage of analysis consists of drawing up the accident scenario in terms of the sequence of events along: the driving phase, the rupture phase, the emergency phase and the collision phase. This involves describing the initial system status, identifying the triggering event and reconstructing the emergency manoeuvre.

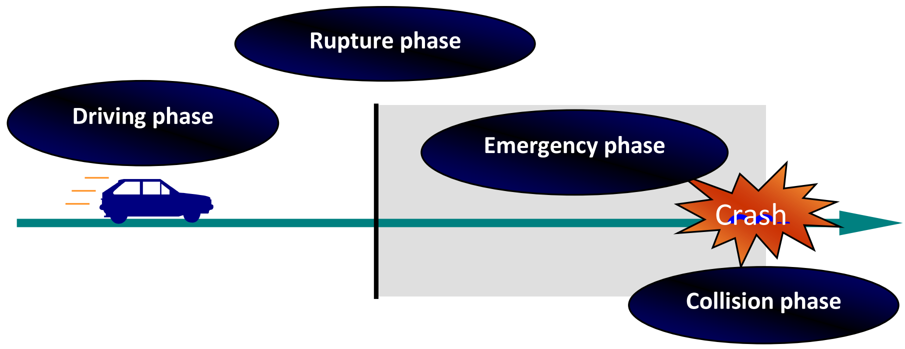

Figure 2: Major phases to consider in a sequential analysis of accidents

The identification of these accident phases (or 'situations') enables the different sequential stages of the accident to be reconstituted in a homogeneous manner, which makes it possible not only to analyse each case from the viewpoint of the process that causes it, but also to set up horizontal studies of several accidents by comparing the successive stages in their development.

We are particularly interested in the analysis that follows in the so-called 'rupture' situation, which is a key stage that pitches the driver from a normal driving situation into an impaired one. This rupture phase forms the pivotal moment of the accident generation and the human functional failure at this moment will be essential to consider in a purpose of primary safety development. Safety functions will be essential to consider in this respect. But it is also essential to consider the whole malfunction process by looking also at the parameters that caused the pivotal malfunction, which are found at the approaching driving phase of the accident spot, and also the parameters which have impeded an emergency manoeuver, insofar as some safety systems can have a role to play at these two other phases of the accident process.

The description of the variables studied given below follows the sequential process of accidents.

2.1. Variables studied

From the detailed information included in each single accident case of the sample, the following variables have been extracted in order to perform the analysis.

2.1.1. Pre-accident situation

The pre-accident situation is defined by the type of driving task being performed, the location of the vehicle and any ‘conflicts’ (opposing manoeuvres from other road users) prior to the rupture phase. It describes what the road user was doing or intended to do when he met a difficulty. The pre-accident situation can also been defined as the "malfunction task", i.e. the task during which the road user will meet a malfunction.

The classification used in the present study took advantage of the work done in TRACE project deliverable 5.2 (Naing et al, 2007), extended with some variables. The main categories of pre-accident situations are the following:

A. Stabilised Situations

The situations defined in this category are those which do not occur at intersections and where no manoeuvres are being undertaken (the road user is going ahead, not on a straight road or a bend).

B. Intersection Situations

These situations can occur at an intersection or on approach to an intersection. An intersection is defined as a connection of two or more public roadways (i.e. a main road and at least one side road). The road user was either on the main road or on the side road, and will either have to 'give way', 'stop' or have right of way for turning or crossing manoeuvers.

C. Manoeuvre Situations

These are situations where the road user was undertaking a specific manoeuvre which does not occur at an intersection (already specified in the previous section): overtaking, changing lane, slowing, starting, turning (away from traffic, out of private driveway or path), reversing, etc.

2.1.2. Factors of failures

A list of factors acting at different levels in the accident process has been established through the repeated analysis of a large amount of accident data, collected and examined in-depth. As for the *pre-accident situations* (classification presented above), the present classification of *factors* takes notable benefit from the TRACE project deliverable 5.2 (Naing et al, 2007) extended with some variables. The list of factors, displayed in the following, will be used at three steps of the analysis:

- First, at the Driving phase of the accident process, so as to put forward the 'initiating factors' contributing to the onset of the accident (at Step 2 of the overall analysis);
- Secondly, at the Rupture phase of the accident process, so as to put forward the 'triggering factors' leading to the human functional failure (at Step 4 of the overall analysis),
- Third, at the Emergency phase of the accident process, so as to put forward the 'impeding factors' hampering the capacity to perform an adequate emergency manoeuvre (at Step 8 of the overall analysis).

With most accidents being multi-causal, several factors (up to 5) can be identified at each of the above mentioned steps of the accident process.

The main categories of factors classically encompass the road user, the environment, and the vehicle. A specific category has been added to integrate the factors linked to meeting a PTW.

Road User (Human) factors

This category of factors is described as any factors related to the individual and personal demographic. This includes any physical and psychological disorders that may be of relevance or any psychosomatic states that the user may have incurred through alcohol or misuse of drugs or emotional/motivational states. The road user is defined as any human in charge of a vehicle within the accident (e.g. driver, motorcyclist, cyclist) or any pedestrian injured in the accident.

From reviewing the literature and current data collection systems, three main subcategories of user factors were decided on, as listed below.

- User State

The ‘state’ of the user includes physical, physiological or psychological conditions, either pre-existing or brought on by substances taken, such as alcohol or drugs.

- Internal Conditioning of Performed Task

These factors are related to the task that the driver is performing, but refers more specifically to the ‘conditioning’ of the driver to the task (i.e. the informal rules the driver follows, either consciously or sub-consciously). They cover parameters such as: confidence in right of way status or in the signals given to others, time constraints, identification of potential risk on another part of the situation, etc.

- Risk Taking

This category of factors refers to general ways of behaving on the road which deviate from the behavioural standards socially shared by most road users. They integrate elements such as illegal or inappropriate speed, overlooking traffic control signs/signals/markings, ‘eccentric’ motives, atypical behaviour, etc.

- Experience

The user’s prior exposure to the task in hand or their surroundings will affect the way they process information. The problems of experience can be dealing with driving in general, or with the specific route, the vehicle or the environment (night time, urban, poor weather, etc.). Note that problems of experience can take two opposite ways: poor experience or over experience.

- Attention

The level of attention of the road user can affect the way they control their vehicle and respond to both their internal and external surroundings. Three categories of attention problems are: inattention, distraction and attention competition problems.

Environment factors

The environment encompasses all aspects related to the users’ surroundings (i.e. external to the vehicle and road user). Six categories of environment-related factors have been defined and are outlined below:

- Road Condition

The condition of the road surface will affect the road user’s ability to be able to control their vehicle on the road. The condition of the road will be affected by the contaminants and defects, plus the road surface type itself.

- Road Geometry

The layout of the road itself will also affect the road user’s ability to control their vehicle, for example the characteristics of bends, road width, speed-inciting layout, monotonous layout, etc.

- Traffic Condition

The flow, speed or density of the traffic on the road will potentially affect the road user’s ability to undertake their task. This can come from variables such as a difficulty to obtain an insertion slot, the surprising behaviour of other road users (ambiguous, atypical, without signalling), etc.

- Visibility Impaired

If the road user's visibility of the road ahead is impaired in some way, this will undoubtedly increase the possibility of a functional failure occurring. The road user's visibility of the road ahead can be affected by: road lighting, vehicle lighting, day/night, roadside objects, terrain profile, etc.

- Traffic Guidance

If there is a weakness in the traffic guidance system (signs, traffic signals and road markings, including reflective studs and painted lines), this will affect the road user's ability to undertake the driving task.

- Other Environmental Factors

Obstacles and other factors which suddenly appear within the road/roadside will affect the road user's ability to undertake their journey, even when an impact does not occur with these obstacles.

Vehicle factors

This category involves the equipment or devices the user is interacting with in the task. The subcategories developed to deal with the vast array of tools were:

- Mechanical: vehicle failures which directly affect vehicle control;
- Maintenance: anticipated vehicle fault, indirectly affects control of vehicle;
- Design: design of vehicle affects safe/efficient operation;
- Load: when a vehicle load affects the ability to control it.

Factors related to meeting a two-wheeler

These factors are related to the physical and behavioral characteristics specific to the two-wheelers (TW) which can be involved in the functional failure genesis of the driver facing this two-wheeler: atypical acceleration, filtering, atypical positions on the road, etc. they were thought useful to identify separately in order to better acknowledge the specificities of the processes at play in the production of accident scenarios involving PTW.

2.1.3. Pivotal Human functional failures

Human Functional Failure (HFF) features the impairment of one (at least) of the cognitive, sensory-motor or psycho-physiological functions that usually allow the road user to adapt to the difficulties he meets when fulfilling his task. This notion accounts for three different categories of human failure: error, violation, ineptitude/unfitness.

'Error' is by definition not deliberated. This question of intentionality led Reason (1990) to distinguish what concerns 'error' and what corresponds to deliberate unsafe acts. There would be an error only when the subject does not reach the purpose aimed during the execution of a strategic sequence of mental or physical activities, and when these failures cannot be attributed to the intervention of fate only. The notion of error does not thus cover all the forms of contribution of the human beings to the accidents. Unsafe acts, which are deliberately operated, are identified by this author as 'violations'.

'Violation' is defined as the deliberate infringement (but not necessarily hostile, nor inevitably reprehensible from a legal point of view) of a behaviour code well established or socially admitted to ensure the safe functioning of a potentially dangerous system (Parker and al., 1995). In this explanatory system, it is also a question for extreme -even if they are rarer-deliberately criminal behaviours and those which have the will to damage: they are qualified as 'sabotages' by these authors. They match on the road those acts named delinquent, and which are different from the more 'classic' road insecurity: Car chases, search for revenge, etc., which characterize certain atypical accidents.

The notion of human functional failure also allows us to integrate more diffuse problems which are connected to the more or less durable ineptitude of the individual to realize his task and which can be a determinant link in the accident process: falling asleep, an illness, an impairment or an exceeding of the sensory-motor and cognitive capabilities.

Delineation of Human Functional Failures

To make things easier, failures found in accident cases are delineated below in a 'Classification model for human functional failures in road accidents' following a sequential information processing chain of human functions involved in information gathering, processing, decision and action (Figure 3). It doesn't imply at all that drivers effectively function in a linear way (i.e. beginning with perception, going then to diagnosis, then to prediction, and so on). In the common functioning of the individual, there are numerous feedbacks between the various modules, and the data processing is strongly looped (for example an action undertaken will determine a certain form of information gathering). But, when dealing with accidents, the classification grid proposed interrupts this functional loop at the moments when the drivers are confronted with specific difficulties in their functioning, i.e. at certain points of the functional chain which usually allows him to adapt and to control the situations and events encountered in the progress of their journey. It is thus a grid of analysis of the dysfunctions to which drivers can be subjects and not a model of driver's functioning.

At a general stage, the classification model allows distinguishing 6 categories of functional failures: Failures at the information detection stage, Failures at the diagnostic stage, Failures at the prognostic stage, Failures at the decision stage on the execution of a specific manoeuvre, Failures at the psychomotor stage of taking action, and Overall failures dealing with the psycho-physiological capacities of the driver. At a more detailed level (Figure 4), it shows the specificities of the types of failures found in in-depth accident data. 20 precise HFF are so defined which gives an innovative view on the difficulties met by drivers on the road, notably in that it opens toward the definition of divers needs in aid, where classical work on 'human errors' tends to finally conclude in the destiny of accidents simply due to 'human nature'.

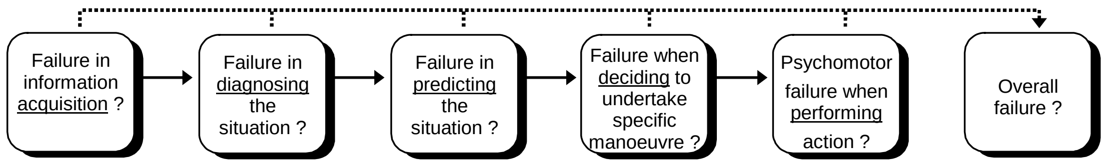

Figure 3: General stages of human malfunction chain potentially involved in accidents

By examining in detail the in-depth data collected on accident scenes, the following types of functional failures can be defined within each of these categories. These failures are described, stage by stage, in the following pages. A methodological point to mention is the fact that making the typical HHF scenarios list (step 7) sometimes helps to clarify the corresponding failure in cases of hesitation.

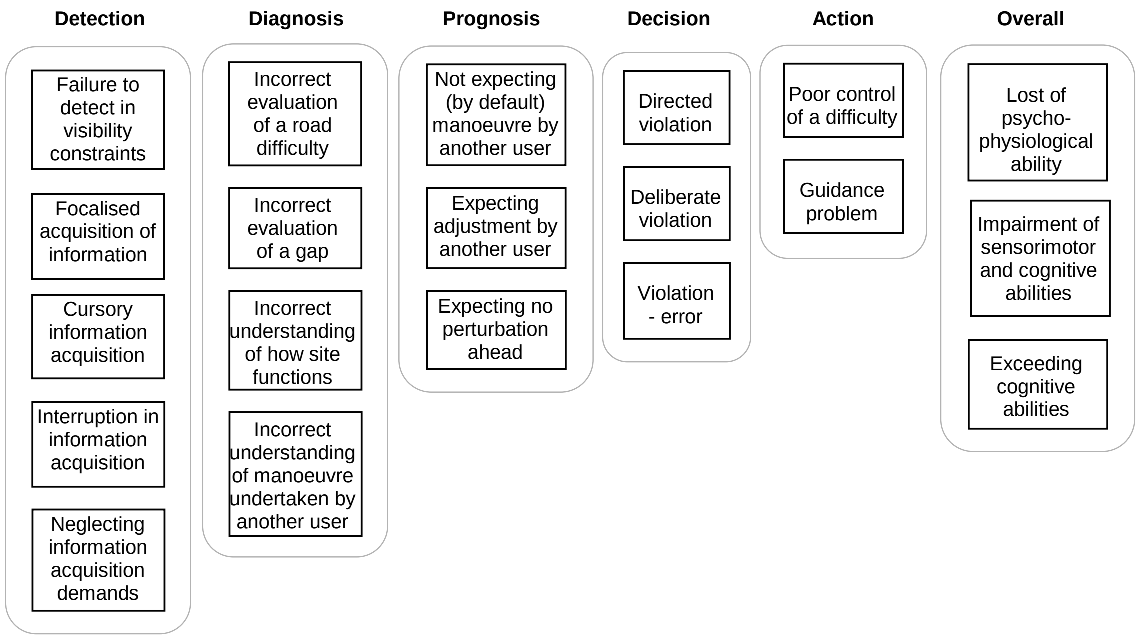

Figure 4: Delineation of functional failures found from In-depth accident analysis

Such a classification, based upon in-depth analysis of the real difficulties encountered by drivers in accident histories, allows being well operational when trying to diagnose malfunctions in the purpose of promoting a safe driving system.

To conclude with this analysis of HFF, it has to be well kept in mind that the clear finding of the human failures involves of course relying upon quality data collected by specialists in accident analysis, and notably involving verbal data collected by psychologists (or specifically trained people) following a predefined protocol. This point seems problematic when conducting extensive in-depth data collection, sometimes more oriented toward statistical purpose than really intensive research of the mechanisms (notably psychological) involved.

2.1.4. Emergency failures

The analysis of the emergency situation has the purpose to report on the road users' attempts of recovering the driving situation broken at the rupture stage. The specificity of emergency situations, easily explainable by the time and space constraints, reduces the span of potential failures to which drivers can be subject. That is why a specific grid has been established to code the difficulties met by road users at this accident phase.

The emergency situation is the phase where attempted avoidance manoeuvres are engaged and very severe dynamic requests are expressed. When these manoeuvers succeed, the accident sequence is interrupted and there is no crash situation. This scenario is obviously infrequent in accident cases as far as most generally if the emergency situation is recovered from there is not an accident. However it happens that an accident occurs nevertheless, implying another vehicle to come into collision, annihilating the efficiency of the performed emergency manoeuver of the driver considered.

If there is collision, it may be due to different problems, such as an absence of detection of the danger (therefore no emergency manoeuver attempt), to a wrong decision on what emergency manoeuver to perform (brake, avoid on the left or on the right, combine, etc.), to a poor control of the action engaged in the avoidance phase. It can also be the case that any attempt of recovery is in vain, considering the characteristics of the accident situation; indeed let us remind ourselves that an emergency manoeuver is subject to very strong time, dynamic and material constraints

The 4 modalities for coding the emergency failure are the following:

- ND: Road users who did neither detect the accident situation nor the emergency situation.
- D: The choice of the manoeuver that the road user decided to put forward is not suitable.
- E: The intention of the manoeuver is appropriate (adapted option) but performance is not successful because of poor execution control issues.
- Unavoidable: Distance / time / space conditions are too short or too restricted to achieve a successful avoidance.

2.1.5. Drivers needs

It has been stressed above that an accident is a process which can be decomposed into sequences. This '*sequentiality'* complicates the analysis of the problem behind accident generation and can lead to mistakes in the definition of solutions if the moment when the problem appears is not taken into account cautiously. Thus, we need to know which problem we are addressing and at which step of the accident process (during the approach phase, the rupture phase or the emergency phase) we must put the counter action. As a matter of fact, the operative human functions can fail to adapt at these different phases of the accident, showing successive needs in help. It can also be the case that a driver is confronted with several sequential failures along the accident process.

The sequential analysis of the accident process allows defining which problems refer to the driving approach of the accident site, at the rupture moment between a still controlled situation toward an uncontrolled one, or to the phase when the driver attempts an emergency manoeuver. The failure found at the rupture stage of the accident process is qualified as the 'pivotal failure', meaning it is critical to the accident production: it is the "pivot" between a controlled situation and an impaired situation. The failure found at the emergency stage of the accident process is qualified as the 'emergency failure',

For each driver showing at least one failure, we can define at least one corresponding need. When this need refers to a pivotal failure, it will be considered as the 'pivotal need'. Of course, this doesn't apply for drivers who are completely 'passive' in the accident production (for example being hurt when stopped). Having no failure, these drivers don't manifest any safety need for themselves, but only needs for others to not hit them[1]. But it can also be the case that several driver needs can be defined. In such a case, these failures and corresponding needs are dispatched along the accident process (Figure 6).

To go further in the analysis following this accident process, the drivers needs have been diagnosed in the frame of the present study at 3 moments:

- At the *driving (or approach) stage*: the needs are diagnosed when elements in the driving context (including human and external factors) met before the rupture event have put the system in weakened conditions, more or less directly favouring the malfunction to be encountered at the rupture phase or impeding its prevention. Needs at this stage will be qualified as 'Upstream Needs', meaning that they correspond to the situation preceding the meeting of the rupture event. The upstream needs are coded as a response to the "initiating factors" characterizing the pre-accident situation.
- At the *rupture stage*: the needs found correspond to the failure of the function which did not allow the driver to compensate for the difficulty encountered. They consist in the

[1] For more precision, cf. TRACE deliverables D5.1 (Van Elslande and Fouquet, 2007) & D5.2. (Naing et al, 2007).

'Pivotal Needs'; and they can be defined as the mirror of the pivotal failure described above.

- At the *emergency stage*: The needs are diagnosed when a function failure has hindered the driver from taking over the situation met at the rupture phase of the accident process. Considering the dynamic and temporal constraints, these 'Emergency Needs' only refer to the decision or execution processes. As for 'emergency failures' a specific grid has been established for these emergency needs.

2.1.5.1. Drivers needs at the driving and rupture phase

22 needs have been established from the difficulties expressed by drivers' functional failures. These needs are dispatched along 6 categories: Needs in internal diagnosis, Needs in detection, Needs in external diagnosis, Needs in prevision, Needs in control and Needs in communication.

Needs in internal diagnosis

Needs in internal diagnosis refer to the driver’s capacity to evaluate and understand information relative to its own state and the state of his vehicle. These needs relate to the global question of the capacity of the driver and the vehicle to carry out a task.

- N01 Diagnosing driver condition

The problem of 'driver condition' applies when driver performance is diminished by fatigue, alcohol, drugs, etc., or when a low level of attention is playing a role in the accident process. The relevant need consists in being aware of one's own level of alertness and attention. It is coded each time a driver shows a strong decrement in these functions. This general need in driver internal diagnosis is subdivided into 3 more particular needs, dealing with: N01.1 Level of vigilance, N01.2 Level of attention and N01.3 Level of alcohol.

- N02 Diagnosing vehicle condition

The problem of 'vehicle condition' applies when a mechanical defect contributes to the accident production or to the ineffectiveness of the emergency manoeuver (tyre pressure, condition of tyres, shock absorbers, braking system, etc.). The relevant need is an early diagnostic of the vehicle defect. There is 'no need' when the driver is aware of the defect in question but neglect the necessity to do something to fix it. This general need in vehicle diagnosis is subdivided into 5 more particular needs, dealing with: N02.1 Tyre state, N02.2 Brakes state, N02.3 Mechanic state (Steering, engine, etc.), N02.4 Acoustic disturbances in the vehicle (radio, passengers, etc.), N02.5 Visual disturbances in the vehicle (dust, etc.).

Needs in detection

These needs relate to the perception of a difficulty or an obstacle to the progression.

- N03 Detecting an unexpected road difficulty

This need applies for different difficulties linked with the road.

- o Dangerous bend, particularly if it forms a discontinuity in the route.
- o Intersection with no indication about right of way.
- o Ice, fog patches, slippery road, roadwork, etc.

For this need to be coded, the driver must have encountered an unexpected difficulty. So it can also the case of roadside visibility problems (e.g. fog), and not only for "intrinsic" road problems.

- N04 Detecting a fixed obstacle on the road

This need applies to any fixed obstacle that the driver has not seen, or has seen too late to avoid the accident. It must not to be confused with the question of understanding the manoeuver of another road user, or anticipating his intentions. For this need to be coded, the obstacle (pedestrian, object, animal or vehicle) must be fixed in position on the road sufficiently in advance for drivers to be able to detect it, and so take this information into account.

- N05 Detecting a slowly moving obstacle on the road

Next to the previous one, this need corresponds to the slowing down of vehicles ahead. For this need to be coded, the obstacle (pedestrian, object, animal or vehicle) must be in slow movement, in a position on the road sufficiently in advance for drivers to be able to detect it and so take this information into account.

- N06 Detecting an oncoming user in one's lane (moving)

This applies to rear end collisions, frontal collisions, and to certain overtaking maneuvers (excluding those due to poor evaluation of the time required to overtake). It may apply for vehicles obscured by a bend, a hump, another vehicle or poor visibility (fog, rain, ill-lit obstacle, sun glare, etc.). It can also correspond to drivers not paying enough attention to the driving scene.

- N07 Detecting a user on an intersecting course

This need is coded only if sure that the other user (pedestrian, animal or vehicle) has been seen too late to avoid the accident (in cases of obscured visibility, particularly in built-up areas). This also applies to pedestrians who cross the road without seeing the approaching vehicle (need for pedestrian to detect vehicles).

- N08 Detecting a user outside the forward field of vision (behind, on the side or in blind spots)

This need emerges essentially when another vehicle behind or on the side is overtaking, changing lane, etc., which impedes the manoeuver in progress by the driver (changing direction, overtaking). This need typically follows an attention problem.

- N09 Detecting a user in the forward field of vision (masked by an object)

This need corresponds essentially to vehicles masked; by vegetation, a traffic panel, or by another vehicle (car, truck) which is overtaking, changing lane, etc., and which impede the manoeuver in progress (change of direction, overtaking). This need directly comes from an external element which represents an obstacle to visibility.

- N10 Detecting deviation from the path

This need applies when drivers do not detect their own vehicle course deviation (on the other way or the pavement), because of an attention problem or drowsiness.

Needs in external diagnosis

Needs in external diagnosis refer to the driver's capacity to evaluate and understand information relating to the environment. These needs relate to the capacity of the driver to develop a behaviour adapted both to the road and to the other road-users.

- N11 Adapting speed to the road - 1: road geometry

This need applies when speed is excessive in relation to the road layout or skid resistance: in case of losing control in bends or in straight sections (except when due to falling asleep). This need does not apply when speed is excessive only in relation with moving obstacles which cannot be avoided.

- N12 Adapting speed to road network - 2: legislation

This need applies when speed is not in agreement with the traffic flows circulating, according to the type of road network (city, countryside, highway). It makes reference to violations of the traffic rules.

- N13 Evaluating catching up on a slower road user

This need applies when the driver underestimates the speed of a vehicle ahead travelling slower than his/her own vehicle. This need applies in two cases:

- o When, on a fast lane, the driver is suddenly faced with a vehicle travelling at a slower speed or who is just stopping, due in particular to traffic congestion.
- o When, while moving in a traffic queue, a road user is surprised by the sudden braking of a vehicle ahead.

- N14 Estimating a collision course with another user

This need applies at an intersection, when a user badly assesses the relative movements between him and another user who is coming transversally to him. This does not apply when the other user is seen too late (otherwise it is a detection need).

- N15 Assessing gap when overtaking or changing lane

This need only applies if the other users have been seen. It corresponds to cases where the relative movements or time required for the manoeuver engaged have been badly assessed.

- N16 Assessing gaps when merging into or cutting across traffic

This generally applies to users who do not have right of way and who must cut across or join a denser or faster-moving traffic flow. This often corresponds to moving off from a stop sign, or re-accelerating after changing direction at low speed.

Needs in prevision

Needs in prevision refer to the driver's capacity to predict:

- The behaviour adapted to layout functioning
- The other road users' behaviour.

- N17 Predicting that another user will pull out or fail to stop

This applies mainly at intersections where a driver who has right of way, thinks right up until the last moment that the other vehicle will let him through. This need is related to predicting the intentions of others.

- N18 Predicting that another user will slow down, stop or fail to disengage

This applies mainly in linear sections where a driver on his way is surprised at the last moment when the other vehicle ahead of him suddenly brakes. This need is also related to predicting the intentions of others.

- N19 Predicting the manoeuvre of another user or pedestrian

This need is similar to the previous case but is not related to right of way. It applies in cases where intentions of others are wrongly interpreted (a vehicle which overtakes, changes direction, a pedestrian who suddenly cross the road).

- N20 Predicting the appropriate manoeuvre for the functioning of the site

This is a need in anticipation of the adequacy between an action and the infrastructure. The driver did detect the traffic signals, but interpreted them poorly. Or the driver did detect the presence of an intersection (often complex), but did not understand how to behave in it (problem of insufficient, erroneous or even suppressed road signals and markings).

Needs in control

The need in control refers to the driver's capacity of actions on his vehicle as regard to the traffic, the layout, or the dynamic solicitations of the vehicle.

- N21 Controlling one's vehicle

There may be several causes at the origin of lack or loss of control of the car, in particular the non-perception of a difficulty. In the present frame, the need relates to the correct assessment of vehicle capabilities and the achievement of the appropriate skills, particularly concerning steering wheel movements.

Needs in communication

- N22 Needs to show own presence / intentions

These need refers to the feeling expressed by some drivers that if they could have better signalled to the other road users where they were and what they wanted to do in a non ambiguous way, the accident would probably not have happened.

2.1.5.2 Drivers needs at the emergency phase

The emergency situation faces the drivers with a very temporally and physically constrained task, only offering him a restricted span of actions. At the same time it leads to only few ways to fail in attempting those actions. Corresponding to these emergency failures, five Emergency Needs are distinguished:

- Need in assistance trajectory control (NE1)
- Need in brake assistance / brake control (NE2)
- Need for infrastructure development (NE3)
- Need for decision support / decision making (NE4)
- Need in emergency diagnosis (NE5)

2.1.6. eSafety functions studied

The purpose of the study consists in an evaluation of safety functions, based on a comparison between their technical capacity and the data coming from accident studies. The protocol consists of estimating the potential efficiency of these safety functions under the hypothesis they were equipped to the vehicles and/or the infrastructure. The interest of such a protocol is first to help highlight the most promising aspects of the functions. Secondly it is aimed at diagnosing eventual drawbacks and lacks in the functions with regard to drivers needs and accident material facts. Indeed, such weaknesses of the functions, once clearly identified, could be counteracted in the future by a new implementation of the systems. In brief, this evaluation work includes a prospective component for a better matching of road users' needs found in accident situations.

Dealing with new and often future systems, the analysis has been based on the information available about their functioning. This information was essentially got from DaCoTa Deliverable D.5.2.3, which compiles all the information gathered on most of the safety functions studied, to which was added some information on other functions, notably dealing with the infrastructure.

Three categories of safety functions and measures can be distinguished:

- Safety functions addressed to car drivers;
- Safety functions addressed to Powered Two Wheelers (PTW) riders. Even if some redundancies exist with those addressing car drivers, it was thought interesting to

distinguish them in a separate list corresponding to the potential benefit for the specific components of PTW safety;

- Safety measures applying to the road infrastructure. These infrastructure measures concern both car drivers and PTW riders.

When putting forward this analysis, in order to homogenize things, we started from the postulate that all the vehicles in the traffic flow (even the vehicles surrounding) were equipped with the safety systems studied. Accordingly, the results will have to be taken 'à la baisse' if a period of transition is to be expected in the progressive introduction of the functions in the traffic.

A/ eSafety functions addressed to car drivers

The following systems have been detailed in DaCoTa Deliverable D.5.2.3. Their main functions are only briefly described below:

- **AAFLS**: Advanced Adaptive Front Light System

Improved vision in darkness and poor visibility (weather conditions) when manoeuvring through bends.

- **BS**: Blind Spot Detection

Detection of a road user outside the frontal field of vision.

- **NV**: Night Vision

Visual identification of animals, pedestrians or cyclists earlier than possible with conventional headlights.

- **AL**: Automated lights

Headlights and rear lights (driving lights) are activated if the driver forgets to activate them in darkness (night, tunnels etc.).

- **ACC**: Adaptive Cruise Control

Keeps a set time (distance relatively to speed) to the vehicle in front.

- **BA**: Brake Assist

Automatically gives full braking when it senses that is the intention of the driver.

- **CA / CW**: Collision Avoidance / Collision Warning

Estimating a collision course with another user.

- **ISA**: Intelligent Speed Adaptation

Adapting speed to road conditions.

- **LKA**: Lane Keeping Assistant

Detecting a course deviation.

- **PBA**: Predictive Braking Assist

Lowers threshold limit for brake assist system.

- **VRU**: Vulnerable Road Users Protection

Detection of pedestrians, cyclists and animals - potential collision.

- **ABS**: Antilock Braking System

System that avoids locking the wheels when braking

- **LDW**: Lane Departure Warning

Helps support the driver in keeping the vehicle in its lane of travel.

- **RollD**: Rollover Detection

Rollover detection and protection (extra function of the ESC system).

- **ESC**: Electronic Stability Control

ESC helps the driver stabilise the vehicle (within the limits of the physical laws governing the dynamic behaviour of the vehicle).

- **LCA**: Lane Changing Assistant

Assessing gaps when joining or cutting across a traffic flow after changing direction at low speed.

- **TPMS**: Tyre Pressure Monitoring and Warning

Diagnosing tyre state (mechanical)

- **AK**: Alcolock Keys

Diagnosing driver condition in terms of breath alcohol level.

- **DDS**: **D**rowsy Driver Detection System

Diagnosing driver condition (fatigue).

- **YK**: Youth Key

Programmable key that can limit a vehicle's top speed, limit radio volume and encourage safety-belt usage by muting the radio until front occupants buckle up.

- **IC**: Intersection Control

Assessing gaps when joining or cutting across a traffic flow after changing direction at low speed.

- **TSR**: Traffic Sign Recognition

Informs the driver of all the respectively applicable road signs along the road.

- **LoFrctD:** Low friction detection

Alert to the driver of a road surface condition ahead that will lead to low friction (grip).

- **RS**: Rear parking proximity sensor

Alert the driver to unseen obstacles (pedestrians…) during parking manoeuvres.

B/ Safety functions addressed to PTW riders

Some of the systems mentioned in this section are a replicate of a safety function for cars, others are specifically dedicated to PTWs, but of course all these systems are addressing PTWs.

- **PTW AS-1**: Forward and intersection collision avoidance
- An automatic or semi-automatic system which detects a position of collision with another vehicle or environment. This system operates by warning the driver / rider or exerting pressure on the brake system.**PTW AS-2**: Adaptive Cruise Control

A vehicle-vehicle communication (by radar, laser, or other technical means) which maintains a safe distance to the vehicle by automatically slowing down, but no emergency braking. To keep a constant distance, the system may also be allowed to accelerate.

- **PTW AS-3**: Intelligent Speed Adaptation

The system controls or informs the driver about speed limits.

- **PTW AS-4**: Lane Departure Warning/ Lane Keeping Support

The system warns the driver when unintentionally crossing a line. The driver may receive a visual warning or a vibration in the steering.

- **PTW AS-5**: Blind Spot Monitoring

The system allows the detection of vehicles in the driver's blind spots. This system involves implanting small cameras behind the helmet and broadcast video in the visor. There also appears a system that allows you to place the projector so that the video stream is visible on the inside of the windshield bubble of the vehicle.

- **PTW AS-6**: Black Spot Warning

The system informs the driver about dangerous sections of road.

- **PTW AS-7**: Incident Warning

The system informs in real time about incidents on the path of the driver.

- **PTW AS-8**: Vehicle-to-vehicle communication

The system informs in real time the driver on traffic conditions, incidents, accidents and weather conditions.

- **PTW AS-9**: Vehicle-to-infrastructure communication

The system provides information on weather conditions.

- **PTW AS-10**: Tyre Pressure Monitoring and Warning

Tyre pressure sensor, this system seems to be very similar to the cars'.

- **PTW AS-11**: Motorcycle Electronic Stability Control

MSC helps stabilize the PTW and prevent loss of control in all driving phases involving heavy braking by distributing braking forces and limiting the tendency of the vehicle to get in a vertical position when braking in curves.

- **PTW AS-12**: Anti-Lock Brake Systems

As for cars, ABS prevents the wheels from locking the bike when braking.

PTW AS-13: Combined Brake Systems

CBS distributes braking when it is triggered only one brake. For example, during heavy braking of the front brake only, the system transmits a part of the energy into the rear brake to balance the braking.

- **PTW AS-14**: Traction control System

Traction Control system, or Automatic Stability Control, this system helps avoid skidding during acceleration phases by maintaining traction, regardless of the type of surface on which stands the bike.

- **PTW AS-15**: Telelever or Duolever

The system allows a distribution of the pressure exerted on the front fork in case of a powerful braking. Therefore, the system reduces the phenomenon of 'diving forward', which has the effect of providing better stability and better handling of the motorcycle during braking and emergency phase.

- **PTW AS-16**: Paralever

This is a system which allows a better grip of the rear wheel during heavy acceleration or braking.

- **PTW AS-17**: Daytime running lights

The front DRL with typical shape and color for motorcycles in order to obtain optimum visibility.

- **PTW AS-18**: Adaptative Front lighting / Active Headlight

The system allows the front light to be oriented according to the line of the road, specifically in bends.

- **PTW AS-19**: Vision enhancement

Based on the detection by infrared, radar or laser, coupled to a display, the system provides a better visual detection of the driving environment, traffic and incidents.

- **PTW AS-20**: Reevu rearview helmet

Helmet that allows by a set of mirrors placed in the cap of the helmet to see behind without turning his head or using the mirrors

C/ Safety measures applying to the road infrastructure

- **INFRA AS-1**: Rumble Strips

Equipping systematically all roads (not only highway) of Rumble Strips, i.e. asperities causing vibrations and a driving sound when the tyre passes over it. This system alerts the driver that he is crossing the line.

- **INFRA AS-2**: On practicable width

Equipping all roads with a supplementary practicable width of 1m clear of obstacles (trees, panel, post, etc.) allowing leeway for the vehicle in case of lane departure.

- **INFRA AS-3**: Bend Alert

Beacons posted at bends, sending a warning message to vehicles in the vicinity. The beacon knows the geometrical characteristics of the curve and produces an estimate of the surface adhesion. It suggests a speed "limit" for a safe passage. The signal is sent to all vehicles but only those whose running speed is greater than the speed "limit" are alerted.

- **INFRA AS4**: Intersection Alert

Tags on the intersection providing information: i) in the case of a non-priority axis, a speed warning as a function of the distance between the vehicle and the stop line, and indication of a detected approaching vehicle; ii) in the case of right of way, an over speed alert and indication of approaching vehicles on non-priority axis.

This system allows in particular overcoming the problems of visibility masks of speed and feeling of "priority".

2.1.7. Contextual Limitations (constraints to integrate)

In the previous steps of analysis the safety needs of the drivers have been delineated, as they are expressed by the human failures found in accidents, and the potential ability of the safety functions to meet these needs (i.e. their capacity to address the difficulties encountered by drivers).

Once a need is diagnosed, and once a function is evaluated as being able to fulfil this need, we still have to consider the contextual elements that could impede the potential effectiveness of the aid. These potential impeding elements define the contextual constraints that safety functions have to integrate in order to really constitute "safety devices" able at counteracting the traffic system malfunction. A wide variety of such parameters are to be studied, a lot of them being already identified in the literature, referring both to ergonomics and psychological and social acceptance. The present analysis only covers one aspect of all these potential limitations, i.e. the parameters that can be identified from accident data.

As a matter of fact, in order to get a precise knowledge of the difficulties possibly met in an operating context, it is necessary to consider all the parameters found in real accident situations which could prevent the driver from taking advantage of information added to his task, or which could materially weaken the efficiency of an assistance function. The present Step of analysis constitutes contribution to this purpose, dealing with the constraints to integrate in order to make a safety function efficient in the context of its real accident contexts. As a matter of fact, even if well addressing a need, if a system doesn't comply with the situations in which this need is met, it wouldn't get its full efficiency.

Considering all the parameters stressed above, the added value of the present study is to search for the limitations which could come from real accident contexts. For each case studied, we searched for the parameters characterizing the conditions in which the accident occurred, that could have a lessening effect in the capacity of an added function to help the driver. These contextual limitations must be taken into account by the safety functions as constraints to cope with for being more effective in the context of accidents.

Thus, the question examined in the present work is not to imagine what could be the action of the driver if he had at his disposal such or such system. It is to define in the effective accident context which elements could lessen the efficiency of a safety system. In brief: this study doesn't try to guess the potential impact of systems at more or less long term, but to define under which conditions these systems could be more efficient because more adapted to the real context of accident production.

Each given safety function may meet several limitations corresponding to several accident context parameters which could lessen its effectiveness. These potential limitations of a safety functions effectiveness were searched for, case by case, in the accident context each time a safety function was addressing a driver's need. During the in-depth analysis, we took into account when necessary the useful parameters from kinematics reconstruction (speed, adherence, stopping distance, etc.). This accident reconstruction put forward in EDA IFSTTAR methodology consists of a scenario reproducing the pre-collision, the collision and the post-collision phases. The impact and initial velocities are calculated for each case, giving a simulation of the real crash with respect to energy, vehicle trajectory, road marks and vehicle deformations. In order to analyse the safety functions effectiveness, we made use of these cinematic reconstitutions to evaluate parameters such as the braking effectiveness. And more globally, every information referring to the context of the accident occurring was considered, and ergonomic criteria were taken into account insofar as they dealt with the parameters found in accident.

The overall approach is based on the following reasoning: accident-producing mechanisms often reveal one or several functional user failures (perceptive, interpretative, etc.). Prior to this malfunction, a certain number of precursory factors which help to produce the malfunction can be identified. The detection or processing of information and action by the driver in the effective situation was, in fact, influenced by these accident-initiating factors. It could therefore be assumed that they would intervene in the same way with regard to information provided by a driving aid if it is not designed to take into account the actual way in which human operators function and their limits. By identifying accident initiating factors which are likely to limit drivers' assimilation of added information, it is thought to define constraints that safety functions have to integrate. Thus, the principle of the method is to find out one or several initiating factors in the accident production which could impede optimal use of an information aid, and by so, constitute a potential limitation to the integration of this aid in the driving task as far as they could lessen the expected effectiveness of the safety function.

The accident context parameters taken into account for this study gather the whole characteristics of both the drivers (internal context) and environment (external context):

- The internal (endogenous) elements refer to the driver's psycho-physiological state, attention, motivations, risk taking, self-confidence, and so on that contributed to the accident process. These elements can -in the same way as they did in the accident- lead to a weak integration of information provided by a safety function, whether because of an involuntary negligence or to a more or less voluntary refusal of an advice given.
- The external (exogenous) elements refer to everything which does not depend on the driver. It can be linked to the dynamic properties of the vehicle, to the road state, or to the characteristics of the traffic in interaction: every physical parameter found in the context of accident cases which could also limit the effective safety benefit of these functions.

2.1.7.1. Internal limitations linked to drivers

Variables potentially limiting the influence of a safety function referring to the driver himself (so-called "endogenous" or "internal") can be dispatched in two categories according to their effect, whether they could lead to an unintentional disregard or an intentional reject of the aid by the driver.

Contextual variables which could lead to intentionally reject the aid

- AL1: Motivation for the journey. Applies when the driver feels a strong necessity to join his destination.
- AL2: Desire for speed. Applies when the driver feels a strong urge to join his destination, or simply wants to go fast.
- AL3: Fatigue assumed. In the case that the drivers already detected that they are tired but refused to stop.
- AL4: Signs of faintness detected. In the case that the drivers already detected that they feel wrong but refused to stop.
- AL5: Chronic alcoholism. This element accounts for the eventuality that a driver would find a way for not obeying an advice or try to get round a safety disposal
- AL6: Feeling of right of way. The right of way status tends to give the driver the impression that he is protected, whatever the event surrounding him.
- AL7: Well-known itinerary. When the driver feels they know perfectly well a situation, they are able to not trust any information contradictory to what they feel.
- AL8: Deliberate traffic violation
- AL9: Opposite action of the driver. For example, the safety function could decelerate whereas the driver could insist on accelerating (if he has the capacity).

- AL10: Other causes of rejection (e.g. when confronted with atypical situations, the drivers can be sure that the other driver who should react instead of him).

Contextual variables which could lead to an unintentional disregard of the aid

An impaired psycho-physiological status or an attention-related problem can prevent the drivers from detecting and integrating part of the information required to correctly manage the situation they were faced with. The factors corresponding to these malfunctions could hinder the assimilation of additional information in the same way, without this being intentional on the part of the driver. This is at least what we attempt to substantiate in the following paragraphs.

- **Driver state**

The deterioration of the psycho-physiological state of the driver can be found at the level of reduced alertness and impaired driving ability. Diminished alertness is associated with fatigue, state of health and age, factors that are sometimes associated with a slight alcohol intake. This condition results in a minimal operating level, which may occasionally result in falling asleep. Impaired driving ability is associated with a substantial intake of psychotropic products (alcohol, medicaments, and illegal drugs) that put a disturbance in driving capacities. However it shall be noted that these two types of effects can combine. That is why these unintentional endogenous potential limitations are put together below:

Hypo-vigilance at his different states is a variable able at more or less to drastically prevent the driver from detecting and appropriately processing information provided:

- AL11: Tiredness
- AL12: Drowsiness
- AL13: Falling asleep
- AL14: Faintness. Even if not frequent faintness –as found at the origin of accidents– is a parameter radically limiting the potential of a safety function.
- AL15: Influence of drugs
- AL16: Influence of alcohol
- AL17: Chronic alcoholism

- **Attention-related problems**

The concept of attention, defined as an instance of control and orientation of mental activity (Hoël et al, 2011), refers in this context to the psychological resources the individual allocates to the task to be performed (Naing et al, 2008). A malfunction in the allocation of attention resources can have an influence on processing added information. Different types of malfunctions can affect the attention processes, some acting more as a deficit of resources, some as a deviation of these resources toward something else than driving, others as a too narrow focusing to a specific part of the road scene. The level of attention can also be degraded when being stressed or upset. All these elements have shown the decrement in information processing during the accident. So there are able to play the same role as regard as driving aids.

- AL18: Inattention. Inattention refers to a global weak allocation of attention resources to the driving task, notably in monotonous situations, leading the driver to be distracted by his thoughts and concerns.
- AL19: Passive distraction. Distraction refers to a transfer of the attention required for the driving activity to a source of attraction outside this activity (discussion, supplementary task, etc.). "Passive" distraction relates to a deviation of attention during monotonous itinerary (e.g. reporting attention on the landscape).

- AL20: Active distraction. This variable stresses a higher level of attention deviation toward an external task (e.g. phone, chasing a wasp, etc.).
- AL21:Attention focusing on right of way roads. Focusing refers to the specific allocation of attention on a partial aspect of the driving task which the driver considers to be of prime importance. This hinders the assimilation of other parameters found in the situation where a hazard is coming from. It is specifically the case for roads with right of way.
- AL22: Attention focusing on another potential hazard. This element comes when driver's attention is already mobilized by an identified source of danger.
- AL23: Exceeding the cognitive capacities – novices drivers. Drivers with low practice of driving activity are able to be overwhelmed when confronted with a too complex situation. This is a constraint that has to be taken into account for safety functions.
- AL24: AL23: Exceeding the cognitive capacities – episodic drivers (e.g. elderly people)
- AL25: Upset – Stressed. When stressed or upset, the drivers proved to have their capacity of integrating information impaired. This impairment could affect in the same way the processing of additional information given by an ITS function.

o **Expectation-related problems**

The concept of expectation refers to the fact that the driver, during his task, waits for some elements or some events to come, or on the contrary expect them not to come. These expectations are made from the experience and could lead to an unintentional disregard of the aid as far as people tend to believe more in what they think than in information given by a device (De Keyser, 1990). The following elements have been identified in the context of accident production, and could have a lessening effect in the driver taking into account a safety system.

- AL26: Expecting absence of interference: deceleration of the vehicle in front.
- AL27: Expecting absence of interference: other.
- AL28: "Dragging" effect. It is often the case that the drivers delegate the decision and control to another driver, notably when inserted into a flow of vehicles. And relying on the other drivers' behaviour, he does not see the necessity to take other information on the situation.

Some road users (pedestrian, PTW, bicycle, etc.) are infrequent to encounter in certain places. In the accident process these road users have been proved to not be taken into account, even visible, as far the drivers were not expecting them on the place. This expectation can minimize the integration of information.

- AL29: Unexpected road use: pedestrian
- AL30: Unexpected road use: PTW
- AL31: Unexpected road use: bicycle
- AL32: Danger careless

Certain drivers have manifested in their behaviour and declaration a very poor consciousness of any danger connected to driving, they could consequently tend to neglect recommendations connected to safety.

- AL33: Poor interpretation of a signal

This potential limitation comes from the fact that drivers on well-known roads or situations tend to function at a low level, in an automatic way that did not allow them to be receptive to information from the road scene. So could it be for information from a safety function.

- **Action-related problems**

  - AL34: Constrained manoeuver (e.g. layout constraint)
  - AL35: Spontaneous speeding. This element refers to a tendency shown to accelerate or reaccelerate, even in spite of disposal inciting them to slow down.
  - AL36: Slow reaction. Some drivers manifest a strong tendency (because of age or lack of experience) to react very lately. Such an effect could have repercussions on the capacity to integrate the safety benefit of a function.
  - AL37: Uncontrolled reaction due to surprise. The surprise when detecting unexpected events can lead to react excessively.
  - AL38: Freezing up reaction. The surprise can lead for some drivers to the incapacity to react.

2.1.7.2. External limitations linked to accident context

The parameters characterizing the context in which accidents occur can have an important incidence on the potential efficiency of safety functions, due to material, temporal and dynamic constraints that are at play. Identifying these constraints is an important step in order to better target the system functionalities to develop.

- **Situational constraints**

  - AL39: Reduced adherence: gravels
  - AL40: Reduced adherence: wet road
  - AL41: Reduced adherence: oil
  - AL42: Reduced adherence: ice
  - AL43:Strong dynamic constraints: loss of control)
  - AL44:Strong dynamic constraints: load
  - AL45:Strong dynamic constraints: speed
  - AL46: Insufficient width of the radar (in intersection)
  - AL47: Insufficient width of the radar (multi-way road)
  - AL48: Insufficient width of the radar (opposite side of the road)
  - AL49: Insufficient length of the radar

- **Visibility**

  - AL50: Visibility limited (pedestrian in black)
  - AL51: Visibility limited by a vehicle
  - AL52: Visibility limited by infrastructure: roundabout
  - AL53: Visibility limited by infrastructure: vegetation
  - AL54: Visibility limited by infrastructure: curve
  - AL55: Visibility is limited by infrastructure: buildings
  - AL56: Lightening conditions (at night)

- AL57: Lightening conditions (diminished)
- AL58: Lightening conditions (dazzle)
- AL59: Defect of lighting of the zone

o **Layout and weather conditions**

- AL60: Defect of road design: impracticable or missing verge
- AL61: Defect of road design: signals
- AL62: Defect of road design: atypical intersection
- AL63: Defect of road design: other
- AL64: Meteorological conditions: rain
- AL65: Meteorological conditions: snow
- AL66: Meteorological conditions: fog
- AL67: Meteorological conditions: wind
- AL68: Type of intersection: roundabout
- AL69: Type of intersection: private way
- AL70: Type of intersection: car park
- AL71: Type of intersection: with central storage
- AL72: Inappropriate regulation: speed in bend
- AL73: Inappropriate regulation (speed in an intersection in city
- AL74: Inappropriate regulation (speed in an intersection out-city
- AL75: Obstacle on the roadway (e.g. piece of wood)
- AL76: Obstacle: toll booth
- AL77: Obstacle: non visible vehicle

o **Other**

- AL78: Reduced conditions of time and space
- AL79: No detectable conditions of poor adherence by the aid (e.g. oil)
- AL80: Insufficient intensity of the alarm
- AL81: Inappropriate perceptive channel
- AL82: Poor localization of the source of information
- AL83: Traffic on the wrong sense
- AL84: Problem of tyre (under inflated)
- AL85: Pedestrian out of protected passage
- AL86: Threshold of the system: too low speed
- AL87: Threshold of the system: legal blood alcohol level
- AL88: Threshold of the system: late braking by the driver

- AL89: Dense traffic (in city)
- AL90: Trigger threshold of the system: distraction duration

2.1.8. Response efficiency of the safety-functions to contextual limitations

This section deals with the consequences of the above mentioned potential limitations on the function ability to tackle the problems in hand. As a matter of fact, two aspects are to be considered in the assessment of safety function effectiveness. As described in the methodological chart presented in Figure 1, it has first been studied the fact that safety functions are more or less addressing such or such needs of the drivers; this aspect has been referred as the adaptation of the safety function to drivers' needs. But each time a safety function has the potential to meet a need, this function can be more or less able to compensate for it, considering both its functionalities and the potential limitations linked to accident context parameters, as they have been described above.

This second aspect of the assessment will be referred as to the response efficiency of the safety functions to contextual limitations. It is the focus of the present section which aims the analysis of the influence of accident contextual parameters as regard to their potentiality to lessen the effective capacity of the safety-function to compensate for drivers' needs.

As already mentioned, the Safety systems studied have been described in detail, notably in the frame of Dacota deliverable D5.2.3, to determine their precise roles and purposes. This definition allowed to determine for each system the kind of accident situations and also the accident phases in which they are likely to play a role, so as to meet the different needs which was the first part of evaluation. But for each system was also precisely described their operational specifications (detection range in length and width, capacity to detect through material obstacles, trigger threshold, etc.). This description make it possible necessary to assess their potential effectiveness in the context of accident occurring. Precisely, when a need was identified in the accident cases, we first looked among the safety functions for which ones were able to meet this need. Then, for each safety function that was adapted to the need, we defined a level of efficiency, taking into account the impact of the potential limitations according to the technical specifications of the function (this was coded only when system specifications suggest that it is able to meet the needs)

By taking into account all these limiting factors, it was possible to evaluate the potential capacity of the systems to overcome the potential limitations described above, considering their specifications. Three levels of potential efficiency were established to this respect:

- Level 1: It is assumed that the system in question would have been effective because of the absence of identifiable limitations affecting it;
- Level 2: It is assumed that the system in question would have a moderate efficiency when limiting factors are identified but their impact is assumed minor on the effectiveness of aid.
- Level 3: It is assumed that the system in question would have been ineffective when the system limiting factors found in the context of the accident probably would have impaired the aid to fulfill this need.

This analysis took advantage of the cinematic reconstruction of the accident cases, together with the specifications of the safety functions.

It is important to notice that the safety-functions were evaluated independently from one another. So, for one given need, two safety functions could be adapted; and if the first safety function had a response efficiency cue of level 1, the other one could also get a response efficiency cue of level 1.

2.2. Coding process

A coding process has been established and formalised a coding manual to the intention of the analysts, with the purpose to define a systematic guide for every participant to the research work. The coding process involved several steps supported by corresponding coding sheets in the manual.

The 18 steps of analysis are the following:

Driving phase

- Step 1: Define the Pre-accident Driving Situations
- Step 2: Define the Initiating factors
- Step 3: Define Upstream Needs
- Step 4: Define the safety functions able to meet the Upstream needs
- Step 5: Define the potential limitations to safety functions meeting the upstream needs
- Step 6: Define response efficiency of safety functions in Pre-accident Driving Situations

Rupture phase

- Step 7: Define the pivotal Human functional failure
- Step 8: Define the Triggering factors
- Step 9: Define Pivotal Needs
- Step 10: Define the safety functions able to meet the pivotal needs
- Step 11: Define the potential limitations to safety functions meeting the pivotal needs
- Step 12: Define response efficiency of safety functions at the rupture phase

Emergency phase

- Step 13: Define the Emergency failures
- Step 14: Define the Emergency impeding factors
- Step 15: Define Emergency Needs
- Step 16: Define safety functions able to meet the emergency needs
- Step 17: Define the potential limitations to safety functions meeting the emergency needs
- Step 18: Define response efficiency of safety functions to emergency situations

This process is followed step by step in the next sections, for the successive phases of the accident process and the different kinds of road accidents involved car drivers, powered two wheelers (PTW) and pedestrians, in order to successively present the variables useful to evaluate the relevance of e-safety systems to road users' needs and also their capacity to face the constraints found in accident-production contexts.

2.3. Sample studied

The overall sample consists of 445 road traffic in-depth accident studies coming from two different sources (IFSTTAR-MA and GIE RE PR). This sample will be analyzed according to four types of accidents:

- Car vs. car accidents: 105 cases involving 210 car drivers (105 versus 105)
- Cars vs. PTW accidents: 123 cases involving 246 drivers (123 car drivers versus 123 PTW riders).
- Car vs. pedestrian accidents: 109 cases involving 109 car drivers versus 109 pedestrians
- Single vehicle accidents (cars and PTW): 108 cases involving 87 car drivers plus 21 PTW riders

Each case will be studied at the 3 phases of the accident process preceding the crash: the driving situation, the rupture situation, the emergency situation. The objective is to determine the different needs of the drivers at each phase and thus put forward which safety systems could be an effective way to prevent the situation from ending in an accident.

3. DRIVING PHASE

The driving phase materially constitutes the approach phase of the accident point. It can be functionally described as the situation the road user is in before a problem arises. It is the 'still normal' situation, which is characterized for the driver by the performance of a specific task in a given context, with certain objectives, certain expectations, and so on. It is 'normal' because no unexpected demands are made upon him. The driver can adapt effectively, the events unfold in line with his predictions, expectations and anticipations. He is not overloaded with information. He controls his speed and course; he is 'master of his vehicle'. In more general terms, this means that there is a balance between the demands and ability of the system components to respond one to another: alignment, skid-resistance, sight distance, tyre wear and pressure, condition of shock absorbers, speed, degree of driver awareness, etc. It should be noted that 'normality' in this case refers to effectiveness, but not necessarily to compliance with traffic regulations.

The driving phase is initiated by the driving context which characterizes the conditions under which the journey has been undertaken: the motivation for it, considering the physical and emotional state of the driver, the mechanical state of the vehicle, the choice for it, the reason why this route have been chosen, etc. All these elements are not part of the accident process but can explain some of their roots.

The advantage of studying this situation is to reveal what the driver considers to be both desirable and feasible in a particular place, and in a particular context.

At this stage the driving phase will be defined for each driver involved: the Pre-accident situation (step 1) the Initiating factors (step 2) that will weaken the driver's capacity to adapt to the difficulty about to come, the Needs in corresponding to these weakening factors (step 3), the Safety systems adapted to these needs (step 4) and the capacity of these safety systems to compensate for the constraints found in accident contexts (step 5).

3.1. Car versus car accident

The sample studied consists of 105 accidents involving 210 car drivers (105 versus 105).

3.1.1. Pre-accident situations

In almost one third of cases, when approaching the scene of the accident (i.e. before meeting the rupture event), car drivers involved in an accident with another car were in a stabilized driving situation, (i.e. without undertaking a manoeuvre, nor at an intersection) on a straight or curved road. Then come the driving situations where the drivers were approaching an intersection while having the right of way. These drivers are confronted by cars in the opposite situation: approaching or manoeuvring at an intersection without right of way (table 1). In these accidents between cars, there are very few situations involving a manoeuver out of intersections.

Table 1: Distribution of pre-accident situations in Car vs. Car accidents

Stabilised Situation	Going ahead	31.9%
Intersection	On approach with right of way	23.3%
	On approach without right of way	16.7%
	Stopped/Starting	6.2%
	Turning across/away from traffic	11.0%
Manoeuvre	Overtaking	3.3%
	Changing lane	0.5%
	Slowing	0.5%
	Starting	1.4%
	Turning (not a junction)	1.0%
	U-turn	1.9%
	In wrong direction	1.0%
Other	Stopped in traffic queue	1.0%
	Pedestrian crossing	0.5%
Total		210

3.1.2. Initiating factors

At this first stage of the accident process, the factors initiating the failure to come are mostly linked to the general state of the driver, including physiological condition (fatigue, alcohol, etc.), motivational state (risk taking), problems linked with experience, attention disturbances, and the feeling of right of way. Dealing with infrastructure, initiating factors concern essentially visibility impairment and road geometry and condition.

Table 2: Distribution of initiating factors in Car vs. Car accidents

Physical/ Physiological	1.2%
Psycho-physiological condition	23.8%
Road user status	36.6%
Risk taking	20.7%
Little/None Experience	24.4%
Over-experienced	28.0%
Attention disturbances	28.0%
Road Condition	11.0%
Road Geometry	10.4%
Traffic Condition	4.9%
Visibility Impaired	31.7%
Traffic Guidance	3.7%
Other Environmental Factors	3.0%
Electro-mechanical	0.0%
Maintenance	3.7%
Design	0.0%
Load	0.0%
Specific factors linked to meeting a PTW	0.0%

3.1.3. Upstream drivers needs

The driving phase led to the diagnosis of needs in aid for 120 drivers of the sample, showing that, even before meeting the rupture event, drivers could be helped in a way to approach the accident scene in better conditions to master the difficulty they will meet just later on. On the other hand, 90 drivers on the sample show no need in this driving situation. This means that at this stage of the process, there was for them no malfunction in their way of proceeding: they were behaving in a proper way up to there and no accident-initiating factor was involved in their activity. For them the needs will come after, when approaching the rupture stage

Table 3: Distribution of car drivers needs at the driving phase

Needs in internal diagnosis (for drivers)	N01.1	2.5%
	N01.2	9.2%
	N01.3	2.5%
Needs in internal diagnosis (for vehicle)	N02.1	1.7%
	N02.3	0.8%
	N02.5	0.8%
Needs in detection	N03	11.7%
	N05	3.3%
	N06	7.5%
	N07	15.0%
	N08	4.2%
	N10	1.7%
Needs in external diagnosis	N11	2.5%
	N12	12.5%
	N13	1.7%
	N14	0.8%
	N15	1.7%
Needs in prognosis	N17	10.0%
	N18	0.8%
	N19	4.2%
	N20	2.5%
Needs in communication	N22	2.5%
Total		120

Car drivers involved in an accident with another car first show a need to detect a user on a transversal way in 15% of cases. 12.5 % of drivers need to assess the adaptation of their own speed to the legislation. For 11.7% of drivers, the need deals with the detection of an unexpected difficulty related to the road, especially when drivers did not perceive the intersection. Finally, in 10% of cases, drivers (often with right of way) need to anticipate / predict that another user (often without right of way) will not stop where he should or will not restart after stopping.

3.1.4. Safety functions adapted to drivers needs at the driving phase

The most widely useful aid to meet the needs of drivers at this early phase of the accident process are:

- IC (Intersection Control) (30.6% of drivers' needs): this system is specifically dedicated to intersection situations and is primarily useful to enable drivers to detect another car coming in a transversal way (12.7% of drivers' needs). Moreover, according to the description, this aid can "predict the path of any object using the intersection", which explains that it responds in 6.7% of cases to the need in prediction of another user non-stopping;
- ISA (Intelligent Speed Adaptation) (14.2% of drivers' needs): this aid addresses especially the need to adapt speed to the road network and to the legislation (10.4%);
- TSR (Traffic Sign Recognition) (14.2% of drivers' needs): 2 needs are addressed by the system, one dealing with adjusting speed (9%) the other dealing with the early detection of unforeseen difficulties related to the layout, in particular to detect signals (5.2%);
- CA / CW (Collision Avoidance / Collision Warning) (10.4% of drivers' needs): this aid potentially addresses seven types of needs, including the need for detecting another user moving on the same lane in the opposite direction (3%) and detecting another user on a transversal path (2.2%);
- INFRA AS-4 (Intersection Alert) (9% of drivers' needs): this aid is mainly useful in cases when car drivers need to detect a user on a transversal path (6%). Sometimes it is useful to diagnose an over-speed situation (B11 and B12).

Table 4: Distribution of safety functions according to drivers needs

	ACC	AK	BS	CA/CW	DDS	DrvMon	IC	INFRA AS-4	ISA	LCA	LDW	LoFrctD	TSR	VRU	YK
N01.1					1.5%										
N01.2															0.7%
N01.3		2.2%													
N02.1						0.7%									
N03	0.7%						1.5%		1.5%			1.5%	5.2%		
N05				0.7%			1.5%	0.7%						0.7%	
N06			1.5%	3.0%			3.0%			0.7%					
N07				2.2%			12.7%	6.0%							
N08			3.7%							1.5%					
N10											1.5%				
N11							0.7%	0.7%	2.2%						
N12	1.5%						0.7%	0.7%	10.4%			0.7%	9.0%		
N13	0.7%			1.5%											
N14				0.7%			0.7%								
N15										0.7%					
N17				1.5%			6.7%								
N18							0.7%								
N19			0.7%	0.7%			1.5%								
N20							0.7%	0.7%							
Total	**3.0%**	**2.2%**	**6.0%**	**10.4%**	**1.5%**	**0.7%**	**30.6%**	**9.0%**	**14.2%**	**3.0%**	**1.5%**	**2.2%**	**14.2%**	**0.7%**	**0.7%**

3.1.5. Limitations of the most potential useful systems

- **Intersection Control (IC)**

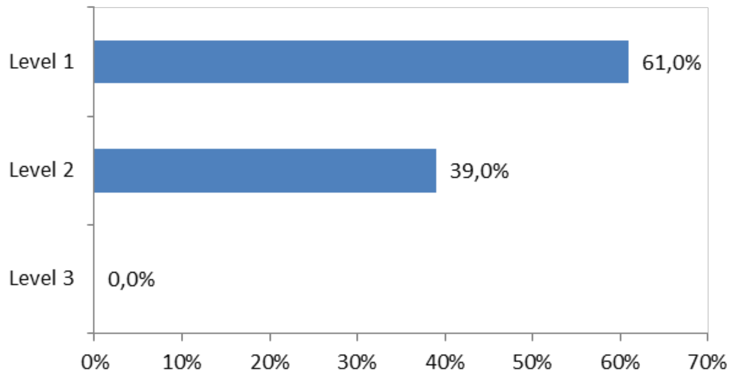

Figure 5: Level of efficiency for IC (n=41)

Intersection Control assistance is particularly effective to meet the needs of drivers in the driving phase before arriving at the rupture: 61% of cases where it can be used, it would have prevented the accident. However, it is sensitive to contextual factors that may modulate its effectiveness in 39% of cases.

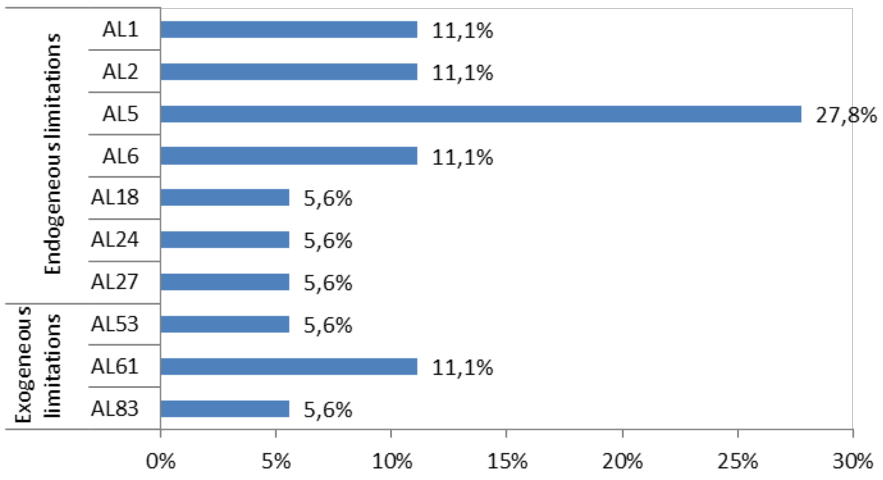

Figure 6: Limiting factors for IC (n=18)

The main factor limiting the effectiveness of the system is the risk that it is not taken into account by the driver given his expectancy that the others will control the situation. Other factors based on the motivations of the driver for the journey (AL1 : 11.1%) for speed (AL2: 11.1%) or a strong feeling of right of way (11.1%) may limit the effectiveness of the aid. Finally, a lack in the layout and especially dealing with the pre-signalling (11.1%) can also affect the effectiveness of the system.

- Intelligent Speed Adaptation (ISA)

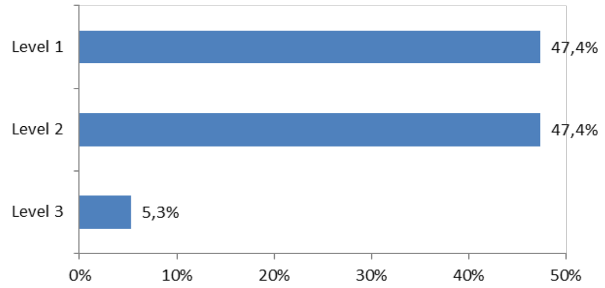

Figure 7: Level of efficiency for ISA (n=19)

In 47.4% of cases where it is useful in car vs. car accidents, the aid is entirely effective. In 47.4% of cases, this efficacy is modulated by contextual elements.

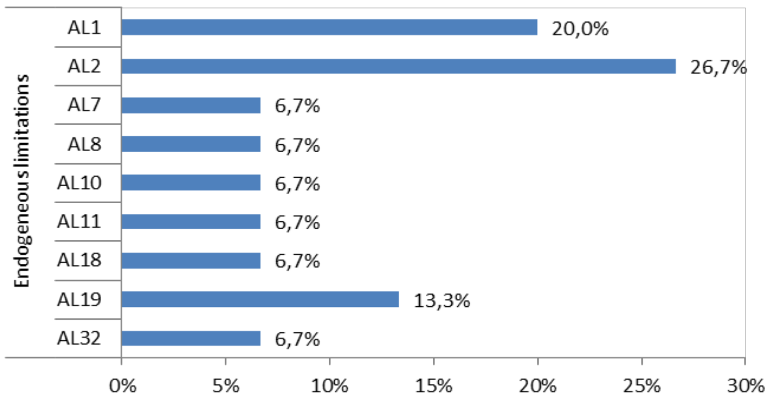

Figure 8: Limiting factors for ISA (n=15)

The elements limiting ISA efficiency are only linked to parameters relating to the drivers (endogenous factors). Among them is the risk that the drivers neglect the information given due to their opposite motivation to speed (26.7%) and the type of travel undertaken (for fun, etc., 20%). There are also attention problems (20%) such as passive distraction (13.3%) and inattention (6.7%).

- Traffic Sign Recognition (TSR)

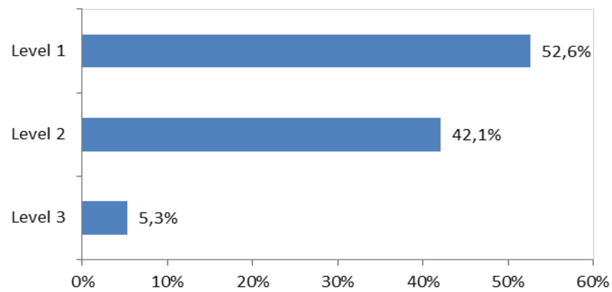

Figure 9: Level of efficiency for TSR (n=19)

In 52.6% of cases using TSR is useful to meet the needs of drivers, it plays a very effective role and helps avoid accidents. In 42.1% of cases, the contextual elements of the accident may limit the effectiveness of aid. Finally, we note that in some cases (5.3%) the aid is totally ineffective.

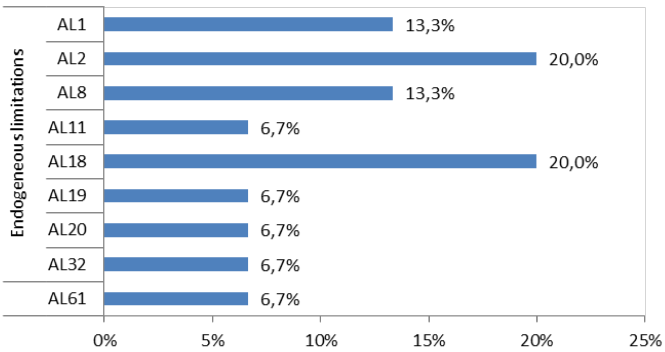

Figure 10: Limiting factors for TSR (n=15)

The limiting factors are mainly endogenous. More specifically, attention problems like inattention (20%), passive distraction (6.7%) and active distraction (6.7%) may limit the effectiveness of the safety system. On the other hand, the wilful rejection due to drivers motivation: type of trip (13.3%) and speed (20%) or deliberate violation (13.3%) can obviously reduce the effectiveness of the help given by the system.

- **Collision Avoidance / Collision Warning (CA/CW)**

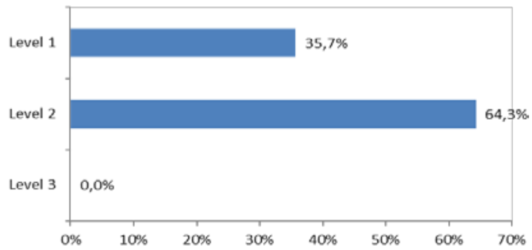

Figure 11: Level of efficiency for CA/CW (n=14)

CA / CW would be effective in 35.7% of cases. This aid, suitable for obstacle detection, seems quite constrained by contextual elements as in 64.3% of cases its effectiveness is limited.

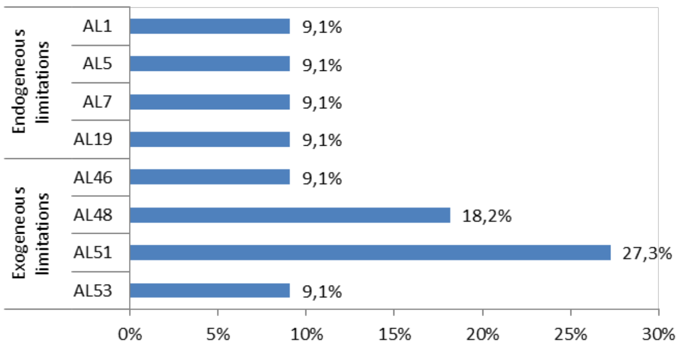

Figure 12: Limiting factors for CA/CW (n=11)

The main factors limiting the effectiveness of using CA / CW are a visibility mask due to another vehicle (27.3%) and a width of radar insufficient to reach the opposite edge of the road (18.2%).

- **Intersection Alert (INFRA AS-4)**

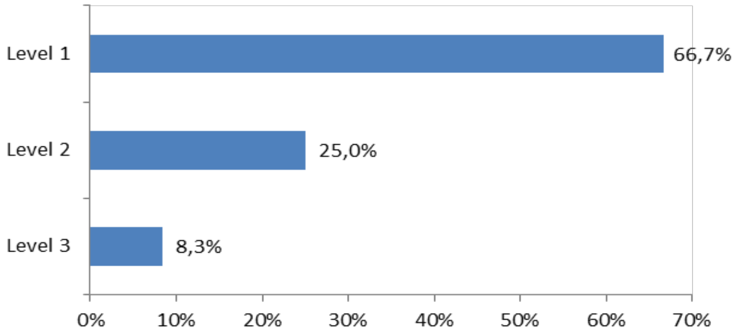

Figure 13: Level of efficiency for INFRA AS-4 (n=12)

In 66.7% of cases where aid is useful to meet drivers' needs, it is very efficient and has a decisive role in the non-occurrence of the accident. However, for 1 in 4, its effectiveness will be limited by several factors, and in 8.3% of cases, it will even be a zero level of efficiency.

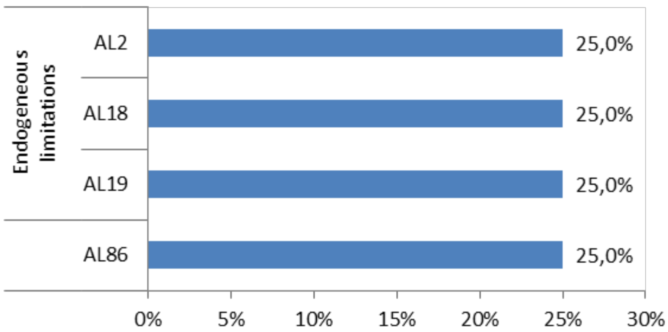

Figure 14: Limiting factors for INFRA AS-4 (n=4)

The effectiveness of INFRA AS-4 is influenced by four factors in a similar way. They refer to the intentional reject of the aid due to motivation for speed, inattention, distraction passive and too low a speed of one of the protagonists for the tag to detect it.

3.2. Car vs. PTW accidents

The sample consists of 123 accident cases involving 246 drivers (123 car drivers versus 123 PTW riders).

3.2.1. Pre-accident situations

PTW riders were more in a stabilized situation (going ahead on the road) or approaching an intersection while keeping the right of way than the car drivers with who they had an accident. They are also overtaking more often. Car drivers are more on a turning manoeuvre, either at intersection points or out of junction.

Table 5: Distribution of pre-accident situations in Car vs. PTW accidents

		Car drivers	PTW riders
Stabilised Situation	Going ahead	17.1%	25.2%
Intersection	On approach with right of way	16.3%	26.8%
	On approach without right of way	6.5%	11.4%
	Stopped/Starting	13.8%	5.7%
	Turning across/away from traffic	20.3%	2.4%
Manoeuvre	Overtaking	1.6%	21.1%
	Changing lane	4.1%	2.4%
	Starting	2.4%	0.8%
	Turning (not a junction)	10.6%	0.0%
	Reversing	0.8%	0.0%
	U-turn	3.3%	0.0%
	in wrong direction	0.8%	3.3%
Other	Parked	1.6%	0.0%
	pedestrian crossing	0.8%	0.8%

3.2.2. Initiating factors

Visibility impairment is a factor strongly affecting the interaction between a car and a PTW both for the car drivers (36.6% of accident cases) and the PTW rider (26.8% of accident cases) in the sense that during the approach to the accident site they are not able to anticipate their oncoming meeting. An important element featuring PTW riders at the initial phase of an accident with a car is a certain form of risk taking in their overall behaviour (such as speeding, atypical acceleration or manoeuvre). They are also often animated with a strong feeling of right of way which doesn't incite them to pay attention or to regulate a potential conflict. From the side of car drivers, an important element characterizing their driving condition is poor attention given to the driving task (34.4%); this is only the case for 15.2% of PTW riders.

Table 6: Distribution of initiating factors in Car vs. PTW accidents

	Car drivers	PTW riders
Physical/Physiological	0.0%	1.8%
Psycho-physiological condition	14.0%	8.0%
Road user status	20.4%	30.4%
Risk taking	12.9%	41.1%
Little/None Experience	19.4%	21.4%
Over-experienced	23.7%	23.2%
Attention disturbances	34.4%	15.2%
Road Condition	5.4%	6.3%
Road Geometry	4.3%	6.3%
Traffic Condition	8.6%	10.7%
Visibility Impaired	36.6%	26.8%
Traffic Guidance	4.3%	1.8%
Other Environmental Factors	1.1%	0.9%
Electro-mechanical	0.0%	0.0%
Maintenance	0.0%	0.0%

Design	1.1%	0.0%
Load	2.2%	0.0%
Specific factors linked to meeting a PTW	2.2%	-

3.2.3. Drivers needs at the driving phase

Corresponding to the above mentioned initiating factors, certain forms of needs characterize more typically car drivers and PTW riders in their conflict. Needs in detection are, generally speaking, very strongly representing the difficulties met by car drivers vis-à-vis PTW. They first refer to the detection of a user on an intersecting course (N07, 31.7%) which is also a need met by PTW riders (16.7%), showing the reciprocity of such a need. Then car drivers show a need in detecting the oncoming PTW while it is theoretically visible (N06, 26.3%) and at last their detection needs also refer to a PTW outside the frontal field of vision (behind, on the sides, or in blind spot: N08, 10.5% of the cases). Riders are more concerned by needs in diagnosis, internal in the sense of the better evaluation of the level of attention required by the situation (N012, 11.7%) but mainly external for a better assessment of their speed with regard to the road legislation (N12, 26.7%).

Table 7: Distribution of car drivers and PTW riders needs at the driving phase

		Car drivers	PTW riders
Needs in internal diagnosis (human)	N01.1	0.0%	1.7%
	N01.2	3.5%	11.7%
Needs in internal diagnosis (vehicle)	N02.2	0.0%	1.7%
	N02.3	0.0%	1.7%
Needs in detection	N03	3.5%	1.7%
	N06	26.3%	3.3%
	N07	31.6%	16.7%
	N08	10.5%	1.7%
	N09	5.3%	0.0%
	N10	1.8%	0.0%
Needs in external diagnosis	N11	1.8%	16.7%
	N12	8.8%	26.7%
	N13	0.0%	1.7%
Needs in prognosis	N17	0.0%	1.7%
	N18	0.0%	1.7%
	N19	0.0%	3.3%
	N20	1.8%	3.3%
Needs in communication	N22	5.3%	5.0%

3.2.4. Safety functions adapted to drivers and riders needs at the driving phase

Table 8: Distribution of safety functions according to car drivers needs

	BS	CA/CW	IC	INFRA AS-2	INFRA AS-3	INFRA AS-4	ISA	LKA
N01.2				2.0%				
N03					2.0%			
N06		7.8%	19.6%					
N07			33.3%			2.0%		
N08	9.8%		2.0%					
N09			2.0%					
N10								2.0%
N11						2.0%		
N12							9.8%	
N20			2.0%					
	9.8%	**7.8%**	**58.8%**	**2.0%**	**2.0%**	**3.9%**	**9.8%**	**2.0%**

The most widely useful systems to meet the needs of car drivers facing PTWs are:

- IC (Intersection Control) (58.8%): this aid particularly meets the need to detect a PTW on a transversal path (intersection, 33.3%) and the need to detect a PTW oncoming on the opposite way and encroaching on its path (path deviation or overtaking; 19.6%);
- ISA (Intelligent Speed Adaptation) (9.8%): this aid specifically addresses the need to estimate the speed for the road network and the legislation;
- BS (Blind Spot Detection) (9.8%): this aid specifically addresses the need to identify a road user out of the frontal visual field that is to say: behind, on the side or in blind spots (overtaking or filtering);
- CA / CW (Collision Avoidance / Collision Warning) (7.8%): again, this aid specifically addresses the need to identify a user oncoming on the opposite way and encroaching on its path (path deviation or overtaking).

Table 9: Distribution of safety functions according to PTW drivers needs

	INFRA AS-2	INFRA AS-3	INFRA AS-4	PTW AS-1	PTW AS-10	PTW AS-17	PTW AS-2	PTW AS-3	PTW AS-4	PTW AS-5	PTW AS-6	SPDCAM
N01.2	1.5%		1.5%				1.5%		1.5%			
N02.3					1.5%							
N06				1.5%								
N07	1.5%		8.8%	8.8%								
N08										1.5%		
N11			4.4%				1.5%	14.7%				1.5%
N12			8.8%					23.5%				
N13				1.5%			1.5%					
N17			1.5%									
N18				1.5%								
N19				2.9%								
N20		1.5%						1.5%			1.5%	
N22						2.9%						
Total	**2.9%**	**1.5%**	**25.0%**	**16.2%**	**1.5%**	**2.9%**	**4.4%**	**39.7%**	**1.5%**	**1.5%**	**1.5%**	**1.5%**

The systems most useful to meet the needs of PTW riders when confronted to cars are:

- PTW AS-3 (Intelligent Speed Adaptation, 39.7%): this aid allowing to estimate a level of speed meets the needs of PTW riders to adjust speed according to the legislation (23.5%) and depending on the characteristics of the road (14.7%);
- INFRA AS-4 (Lane Departure Warning/ Lane Keeping Support, 25%): this aid meets several needs; it is primarily useful to allow PTW riders to estimate their speed relative to the law (8.8%) or the characteristics of the road (4.4%), but also to enable them to detect a car in a transversal trajectory (intersection, 8.8%);
- PTW AS-1 (Forward and intersection collision avoidance, 16.2%): this aid is more adapted to meet the need in detection of another user (car) on a transversal path (8.8%).

3.2.5. Limitations of the most potential useful systems

3.2.5.1. Car drivers

- **Intersection Control (IC)**

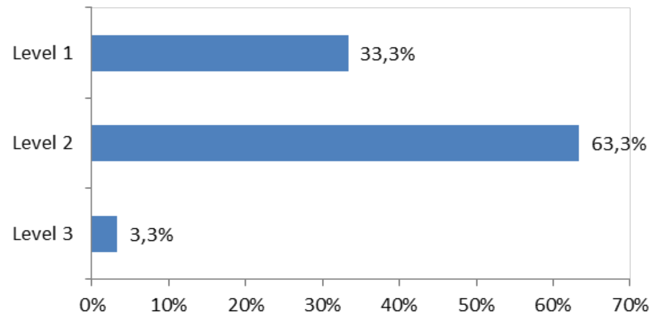

Figure 15: Level of efficiency for IC (n=30)

The effectiveness of IC seems largely limited by contextual factors (63.3%). In a few cases, these factors make it totally ineffective (3.3%). We note however that in 1 out of 3 cases, the aid would be fully effective and would prevent the occurrence of the accident.

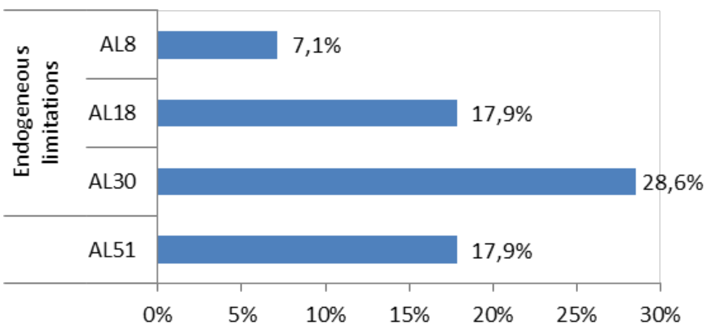

Figure 16: Limiting factors for IC (n=28)

Non-perception of the motorcyclist is the main limitation of the aid effectiveness IC (28.6%). Followed by factors such as inattention (17.9%) and mask to visibility generated by a vehicle (17.9%).

- Blind Spot Detection (BS)

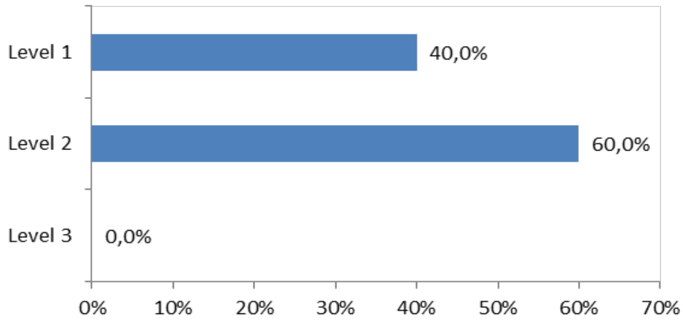

Figure 17: Level of efficiency for BS (n=5)

In 60% of cases, aid effectiveness is modulated by contextual factors. However, in the other cases, it is fully effective.

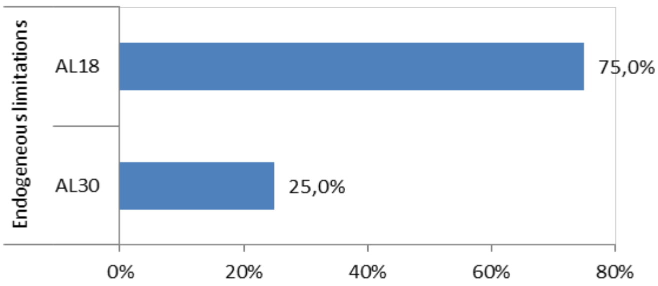

Figure 18: Limiting factors for BS (n=4)

The main limitation to the effectiveness of BS aid is inattention (75%). We also note that the non-perception of the motorcyclist may also limit the effectiveness (25%).

- Intelligent Speed Adaptation (ISA)

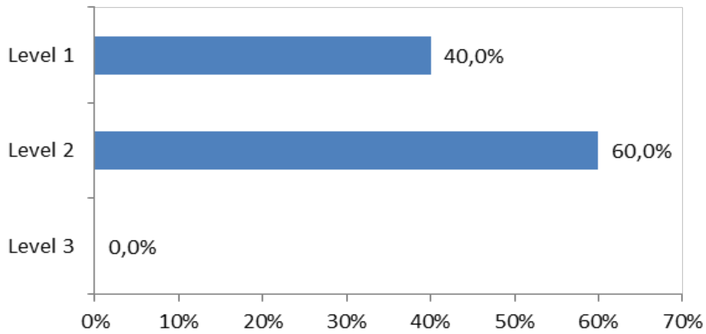

Figure 19: Level of efficiency for ISA (n=5)

In 60% of cases, aid effectiveness is modulated by contextual factors. However, in other cases, it is fully effective.

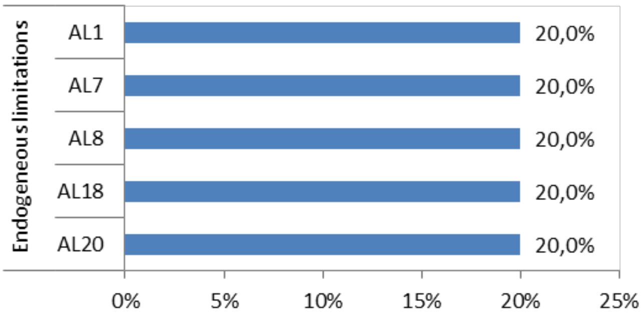

Figure 20: Limiting factors for ISA (n=5)

Factors limiting the effectiveness of ISA are exclusively endogenous. It may be attention problems: inattention (20%) and active distraction (20%), or a wilful rejection according to the type of journey (20%), over experience (20 %) and deliberate violation (20%).

- **Collision Avoidance / Collision Warning (CA/CW)**

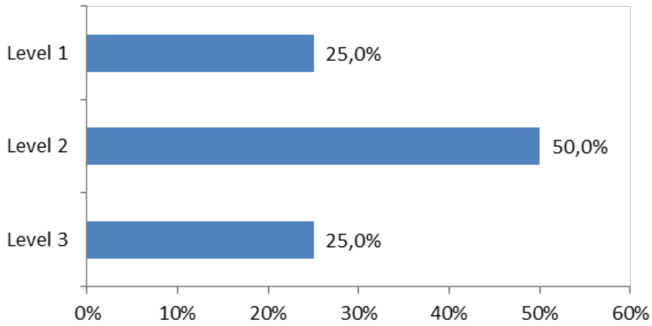

Figure 21: Level of efficiency for CA/CW (n=4)

In 50% of cases with CA / CW it is useful to meet the needs of car drivers when faced to PTWs but its efficacy is modulated by contextual constraints. These contextual constraints can sometimes make it totally ineffective (25%). In other cases, it is fully effective (25%).

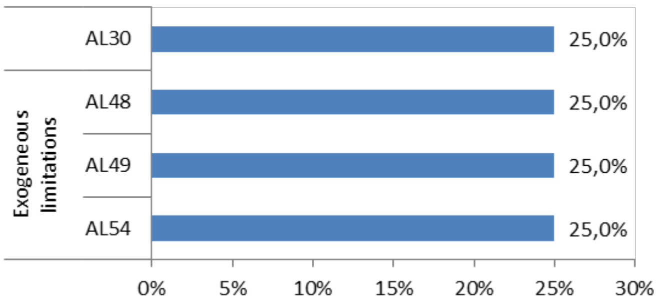

Figure 22: Limiting factors for CA/CW (n=4)

The main factors limiting the effectiveness of the aid are exogenous and come from the width of the radar too small to reach the opposite edge of the road (25%), the insufficient length of the radar (25%) and mask to visibility generated by a bend (25%). We also note the intervention of a factor related to non-anticipation of a motorcycle on the road (25%).

3.2.5.2. PTW riders faced to cars

- **Intersection Alert (INFRA AS-4)**

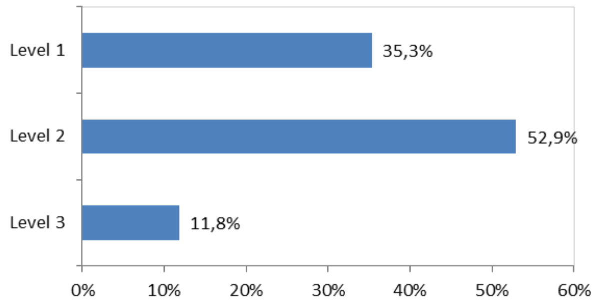

Figure 23: Level of efficiency for INFRA AS-4 (n=17)

This aid seems very constrained by contextual elements, being moderately effective in 52.9% of cases, completely ineffective in 11.8% of cases. In only 35.3% of cases, is it fully effective.

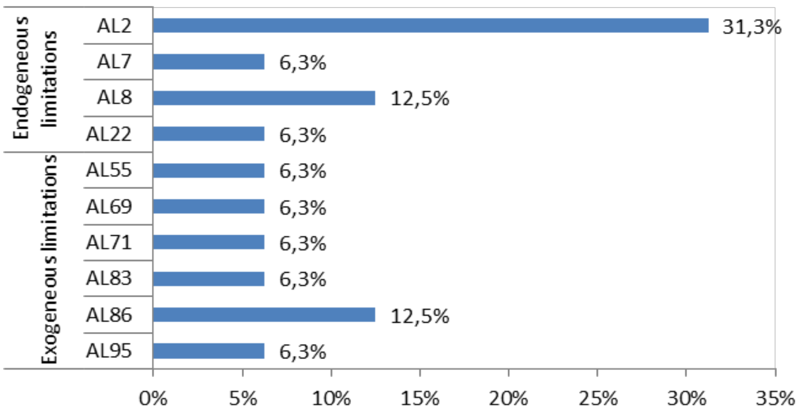

Figure 24: Répartition des limitations sur l'aide INFRA AS-4 (n=16)

The main limiting factors for this assistance are the voluntary dismissal: motivation for speed (31.3%), deliberate violation (12.5%) and over-experience (6.3%). There is also a very low speed of one of the protagonists that may cause the non-detection by the system (12.5%).

- **Forward and intersection collision avoidance (PTW AS-1)**

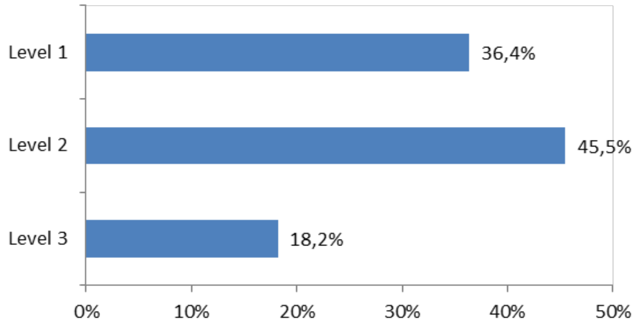

Figure 25: Level of efficiency for PTW AS-1 (n=11)

In 45.5% of cases, the contextual elements influence the effectiveness of aid, sometimes to the point of making it completely ineffective (18.2%). However, we note that in 36.4% of cases it would have a major role in the non-occurrence of the accident.

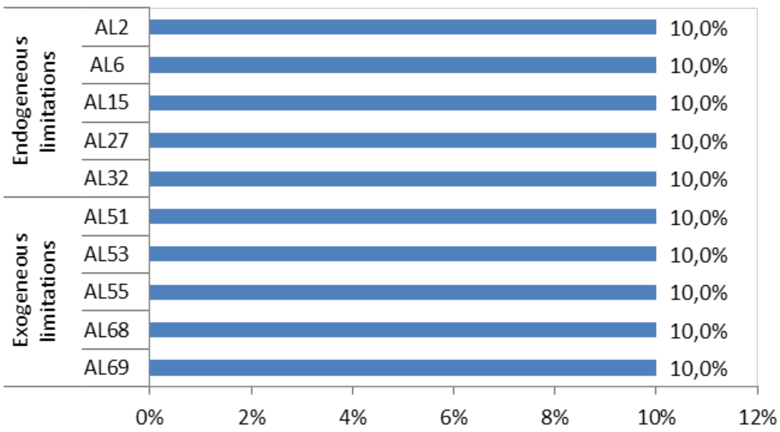

Figure 26: Limiting factors for PTW AS-1 (n=10)

Factors limiting the effectiveness of the aid are both endogenous and exogenous. It can be not taken into account because of motivation for speed (10%) or strong feeling of right of way (10%), the influence of drugs (10%), the expectation of no interference (10%), unawareness of danger (10%), masks the visibility generated by a vehicle (10%), or vegetation (10%) and type of intersection: roundabout (10%) or private road (10%).

- **Intelligent Speed Adaptation (PTW AS-3)**

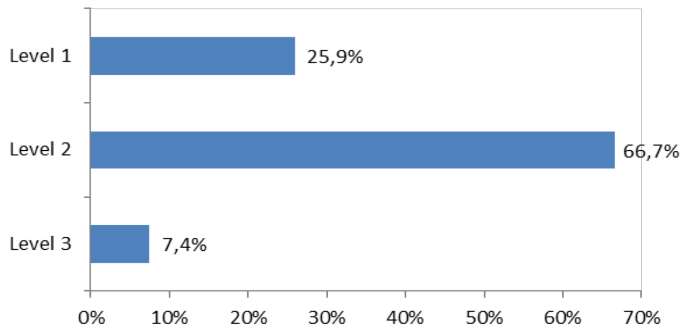

Figure 27: Level of efficiency for PTW AS-3 (n=27)

PTW AS-3 is effective in 25.9% of cases. In other cases, its effectiveness is limited by contextual factors (66.7%), sometimes up to zero (7.4%).

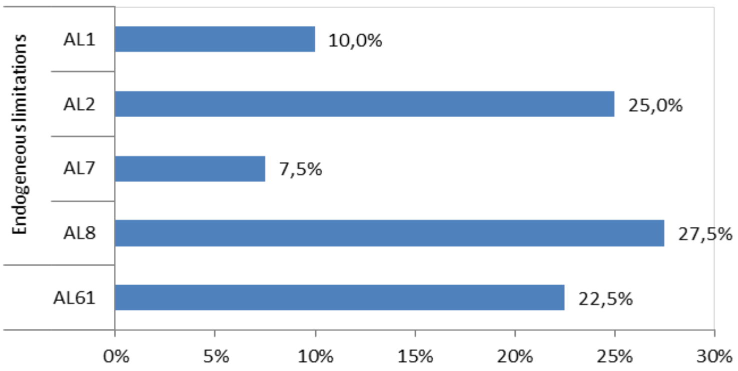

Figure 28: Limiting factors for PTW AS-3 (n=40)

The main factors limiting the effectiveness of the system involve voluntary dismissal. It can be driver motivation dealing with the type of journey (10%) speed (25%) but also over-experience (7.5%) and especially the wilful violation (27.5%). The influence of one single exogenous factor is noted: the absence of pre-signalling (22.5%).

3.3. Car versus pedestrian accidents

The sample consists of 109 accident cases involving 109 car drivers versus 109 pedestrians

This analysis being orientated toward drivers of vehicles, pedestrians are only considered in this report as the victims of the accident. That is why the parameters described in the following sessions only refer to car drivers hitting them.

3.3.1. Pre-accident situations

At this approaching phase of the accident site, 45.9% of car drivers involved in an accident with a pedestrian were driving in a stabilized situation, usually on a straight road. 16.5% were about to turn.

Table 10: Distribution of pre-accident situations

Stabilised Situation	Going ahead	45.9%
Intersection	On approach with right of way	8.3%
	On approach without right of way	2.8%
	Stopped/Starting	9.2%
	Turning across/away from traffic	16.5%
Manoeuvre	Overtaking	5.5%
	Starting	0.9%
	Reversing	3.7%
Other	Parked	0.9%
	Pedestrian crossing	5.5%
	Railway crossing	0.9%

3.3.2. Initiating factors

During the initial phase of the accident process, the accident generating factors mainly consist of Visibility Impairment 33.3% which impede the early perception of the pedestrians, Attention limitations (15.2%) notably associated with Over-experience (10.5%) and poor Psycho-physiological condition 8.6%. In a smaller proportion, problems linked with infrastructure maintenance and design are noticeable.

Table 11: Distribution of initiating factors in Car vs. PTW accidents

Physical/ Physiological	1.9%
Psycho-physiological condition	8.6%
Road user status	14.3%
Risk taking	11.4%
Little/None Experience	6.7%
Over-experienced	10.5%
Attention disturbances	15.2%
Road Condition	1.9%
Road Geometry	1.0%
Traffic Condition	1.0%
Visibility Impaired	33.3%
Traffic Guidance	0.0%
Other Environmental Factors	0.0%
Electro-mechanical	1.0%
Maintenance	5.7%
Design	1.9%
Load	0.0%
Specific factors linked to meeting a PTW	0.0%

3.3.3. Drivers needs at the approach driving phase

36 car drivers out 109 involved in an accident with a pedestrian have no identified need during this initial stage of the accident process. For most of them showing a need, this need consists of detecting the pedestrian on a transversal path, crossing or about to cross (N07, 45.2%). For 15.1% of car drivers, the need deals with the detection of the pedestrian present in the frontal visual field but hidden by an object (N09).

Table 12: Distribution of drivers needs in the driving phase

Needs in internal diagnosis (for driver)	N01.3	2.7%
Needs in internal diagnosis (for vehicle)	N02.1	1.4%
	N02.2	1.4%
	N02.5	2.7%
Needs in detection	N04	2.7%
	N05	1.4%
	N06	8.2%
	N07	45.2%
	N08	6.8%
	N09	15.1%
Needs in external diagnosis	N11	5.5%
	N12	5.5%
Needs in prognosis	N19	1.4%

3.3.4. Safety functions adapted to drivers needs at the driving phase

Most useful aids to meet the needs of drivers are:

- Vulnerable Road User Protection (VRU, 59.1%) this system is specifically devoted to detection of low movement obstacles (pedestrian or bicyclist) and meets several needs. More specifically, and in line with the main needs set out above, it is useful when drivers need to detect a pedestrian on a transversal path (crossing or about to cross, 36.4%) or to detect a pedestrian masked by something (10.2%);
- ISA (Intelligent Speed Adaptation) (10.3%): this aid is specific to estimating the speed. Thus, it is useful when drivers need to adjust their speed to legislation (4.5%) or the characteristics of the road (4.5%).

Table 13: Distribution of safety functions according to drivers needs

	ACC	AK	BS	CA/CW	IC	ISA	NV	RS	TPMS	TSR	VRU
N01.3		2.3%				1.1%					
N02.1									1.1%		
N02.2											1.1%
N04				1.1%			1.1%				1.1%
N05							1.1%				1.1%
N06				2.3%	1.1%						4.5%
N07				2.3%			3.4%				36.4%
N08			4.5%					3.4%			
N09				1.1%							10.2%
N11						4.5%					2.3%
N12	1.1%					4.5%	1.1%			2.3%	2.3%
	1.1%	**2.3%**	**4.5%**	**6.8%**	**1.1%**	**10.3%**	**6.8%**	**3.4%**	**1.1%**	**2.3%**	**59.1%**

3.3.5. Limitations of the most potential useful systems

- **Vulnerable Road User Protection (VRU)**

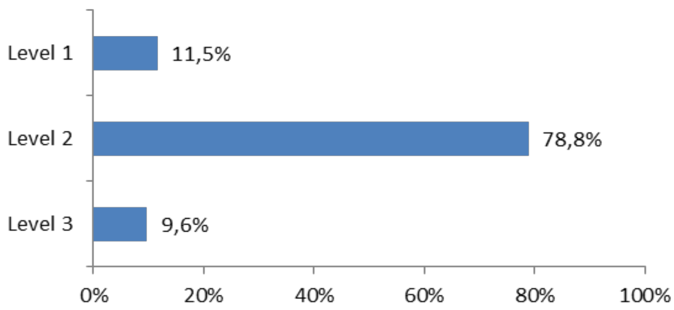

Figure 29: Level of efficiency for VRU (n=52)

The adequate functioning or Vulnerable Road User Protection (VRU) seems very constrained by accident contextual elements as is fully effective in only 11.5% of cases. It was found that in 78.8% of cases it is moderately effective and in 9.6% of cases it is completely ineffective.

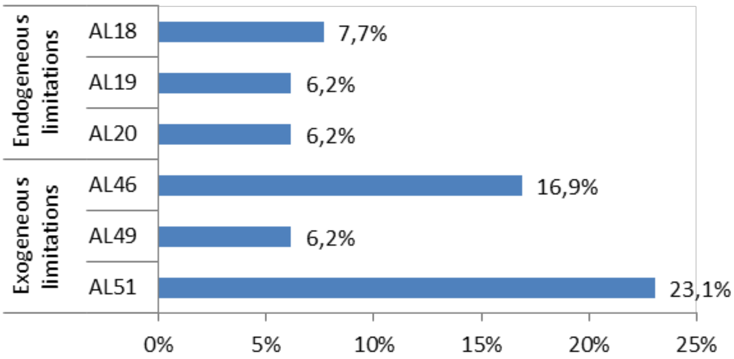

Figure 30: Limiting factors for VRU (n=65)

Mask to visibility generated by a vehicle can disrupt the effectiveness of the aid (23.1% of cases). Furthermore, at an intersection, it is possible that the radar is not wide enough to allow the detection of pedestrians (16.9% of cases). Finally, attention problems: inattention (7.7% of cases), passive distraction (6.2% of cases) and active distraction (6.2% of cases) can modulate the full effectiveness of the aid provided.

- **Intelligent Speed Adaptation (ISA)**

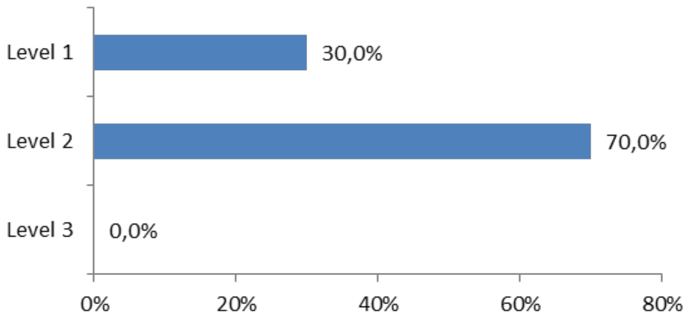

Figure 31: Level of efficiency for ISA (n=10)

This assistance is greatly influenced by contextual factors because in 70% of cases it is only moderately effective and is completely effective in 30% of cases.

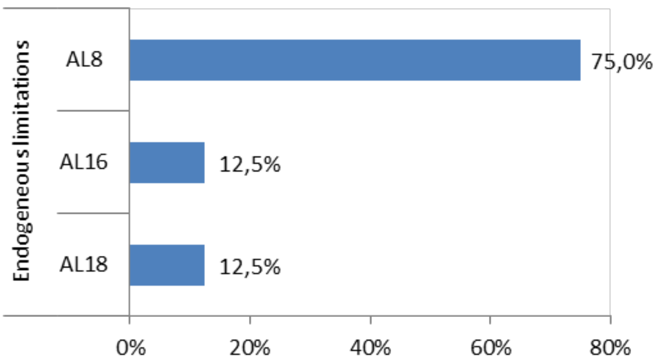

Figure 32: Limiting factors for ISA (n=8)

The main limitation is the potential neglect due to deliberate violation of speed (75% of cases). The influence of alcohol (12.5% of cases) and inattention (12.5% of cases) can also cause an involuntary failure to take account of the message given and thus limit its effectiveness.

3.4. Single vehicle accidents

Single vehicle accidents constitute a specific category of accident insofar as they do not involve an interaction with another road user, but an interaction restricted to a road user, his vehicle and the infrastructure on which he drives. The task being specific, the difficulties connected to it can be assumed to be specific also. For this reason, they have been considered in a separate section, this being done at each phase of the accident process.

The sample studied includes 108 accident cases involving 87 car drivers plus 21 PTW riders.

3.4.1. Pre-accident situations

Before switching to the rupture phase, the majority of drivers, whether car drivers or PTW drivers, involved in single vehicle accidents were in so-called stabilized driving condition, meaning that they were not at an intersection and they were not proceeding to a manoeuvre either. 37.2% of car drivers and 33.3% of PTW drivers were on a straight road. 47.7% of car drivers and 38.1% of PTW drivers were on a bend. However, a non-negligible proportion of PTW riders lost the control of their vehicle at an intersection point (notably when the intersection includes a bend: e.g. at a roundabout).

Table 14: Pre-accident situations

			Car drivers	PTW riders
Stabilised Situation	Going ahead	Straight road	37.2%	33.3%
		Bend	47.7%	38.1%
Intersection	On approach with right of way		3.5%	9.5%
	On approach without right of way		3.5%	9.5%
	Turning across/away from traffic		3.5%	4.8%
Manoeuvre	Overtaking		3.5%	4.8%
	Turning (not a junction)		1.2%	0.0%

3.4.2. Initiating factors

Psycho-physiological condition of the driver is contributing to a paramount number of loss of control for car drivers [93.0%, including alcohol (29.1%); fatigue (24.4%) and emotional state (17.4%)], and in a more limited way for PTW riders (38.1%).

Also contributing to these specific kinds of accidents is risk taking in a same proportion for car drivers and PTW riders. A lack of experience is more specific to PTW riders. Attention disturbance and over experience are more specific to car drivers.

Elements connected to the infrastructure involving Road Condition and Road Geometry are also affecting both car and PTW drivers. Visibility impairment is also a factor of loss of control insofar as it does not allow the road user to anticipate the bend to negotiate.

Table 15: Initiating factors in single vehicle accidents

	Car drivers	PTW riders
Physical/Physiological	4.7%	0.0%
Psycho-physiological condition	93.0%	38.1%
Road user status	14.0%	4.8%
Risk taking	41.9%	38.1%
Little/None Experience	30.2%	47.6%
Over-experienced	25.6%	9.5%
Attention disturbances	31.4%	14.3%
Road Condition	24.4%	23.8%
Road Geometry	25.6%	14.3%
Traffic Condition	3.5%	0.0%
Visibility Impaired	10.5%	19.0%
Traffic Guidance	0.0%	0.0%
Other Environmental Factors	0.0%	4.8%
Electro-mechanical	1.2%	0.0%
Maintenance	4.7%	0.0%
Design	0.0%	0.0%
Load	1.2%	0.0%
Specific factors linked to meeting a PTW	0.0%	-

3.4.3. Car drivers and PTW riders needs at the driving phase

At the driving phase, before switching to breakdown situations, drivers of cars essentially need to get a diagnosis of their internal state, that is to say alcohol level (26.3%), alertness (13.2%) and level of attention (11.8%) or to obtain a diagnosis for their speed to be adapted to the legislation (14.5%) or the characteristics of the road (13.2%). Among PTW drivers, needs mainly concern the estimation of the velocity with respect to legislation (21.4%) or in relation to road characteristics (35.7%). We also note that 14.3% of riders need to estimate their BAC level or detect an unexpected difficulty related to the road.

Table 16: Distribution of drivers and riders needs at the driving phase

		Car drivers	**PTW riders**
Needs in driver internal diagnosis	N01.1	13.2%	7.1%
	N01.2	11.8%	0.0%
	N01.3	26.3%	14.3%
Needs in vehicle internal diagnosis	N02.1	2.6%	0.0%
Needs in detection	N03	10.5%	14.3%
	N05	1.3%	0.0%
	N06	1.3%	0.0%
	N07	0.0%	7.1%
	N10	1.3%	0.0%
Needs in external diagnosis	N11	13.2%	35.7%
	N12	14.5%	21.4%
	N15	1.3%	0.0%
Needs in prognosis	N18	1.3%	0.0%
	N19	1.3%	0.0%

3.4.4. Safety functions adapted to car drivers and PTW riders needs

The four most commonly useful systems to meet car drivers' needs when faced with PTWs are:

- AK (Alcolock Key, 20.2%): this aid is used mainly for drivers who need to estimate their level of blood alcohol (19.1%);
- ISA (Intelligent Speed Adaptation, 9.1%): this system meets with drivers who need to adapt their speed to the legislation (10.6%) or road conditions / characteristics (6.4%);
- TSR (Traffic Sign Recognition (10.6%): this aid is useful when drivers need to adapt their speed to the recommendation (6.4%);
- LoFrctD (Low friction detection, 10.6%): this aid meets four needs, among which the need to detect unexpected situations related to road conditions (rain, ice, gravel, etc.) (4.3%).

Table 17: Distribution of safety functions according to car drivers needs

	AAFLS	ACC	AK	DDS	DrvMon	INFRA AS-1	INFRA AS-3	INFRA AS-4	ISA	LCA	LKA	LoFrctD	RollD	TPMS	TSR	VRU	YK
N01.1			1.1%	9.6%													
N01.2																	1.1%
N01.3			19.1%			1.1%	1.1%										2.1%
N02.1									1.1%			1.1%		2.1%	1.1%		
N03	1.1%				1.1%		1.1%					4.3%	1.1%				
N05																1.1%	
N06									1.1%						1.1%		1.1%
N10						1.1%					1.1%						
N11	1.1%						5.3%		6.4%			2.1%			2.1%		
N12							2.1%	1.1%	10.6%			3.2%			6.4%		2.1%
N15										1.1%							
N18		1.1%															
Total	**2.1%**	**1.1%**	**20.2%**	**9.6%**	**1.1%**	**2.1%**	**9.6%**	**1.1%**	**19.1%**	**1.1%**	**1.1%**	**10.6%**	**1.1%**	**2.1%**	**10.6%**	**1.1%**	**6.4%**

The two most widely useful systems to meet the needs of PTW drivers in single accidents as outlined above are as follows:

- PTW AS-3 (Intelligent Speed Adaptation, 40%): this aid specifically addresses the need to adapt speed, as regard as what is allowed (20%) or in relation to road characteristics (20%);
- INFRA AS-3 (Bend Alert), 33.3%): this system is useful to help meet three types of requirements: to adapt speed to the characteristics of the road (20%), adapt speed to the legal one (6.7%) and detect an unexpected difficulty related to the layout (6.7%).

It should be noted that no technological system has been developed to address the need for PTW riders to diagnose their blood alcohol level, whereas this need remains crucial for motorcyclists.

Table 18: Distribution of safety functions according to PTW riders needs

	AK	INFRA AS-3	INFRA AS-4	PTW AS-1	PTW AS-3
N01.3	13.3%				
N03		6.7%			
N07				6.7%	
N11		20.0%	6.7%		20.0%
N12		6.7%			20.0%
Total	**13.3%**	**33.3%**	**6.7%**	**6.7%**	**40.0%**

3.4.5. Limitations of the most potentially useful systems

2.1.7.3. For car drivers in single vehicle accidents

- **Alcolock Keys (AK)**

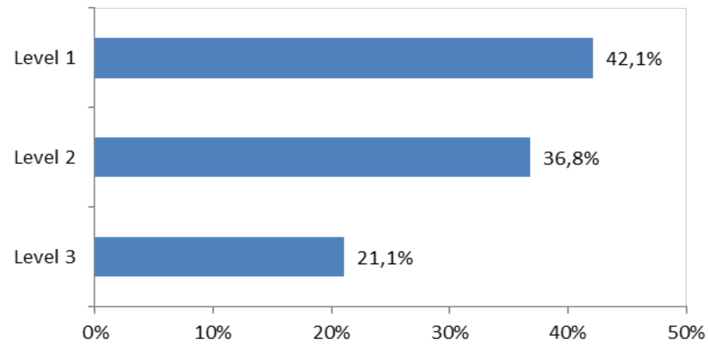

Figure 33: Level of efficiency for AK (n=19)

In 42.1% of cases AK is fully effective and would have prevented the occurrence of the accident. However, in 36.8% of the other cases, the aid effectiveness is limited by the contextual factors that can modulate its efficiency or maybe neutralize its effectiveness in 21.1% of cases.

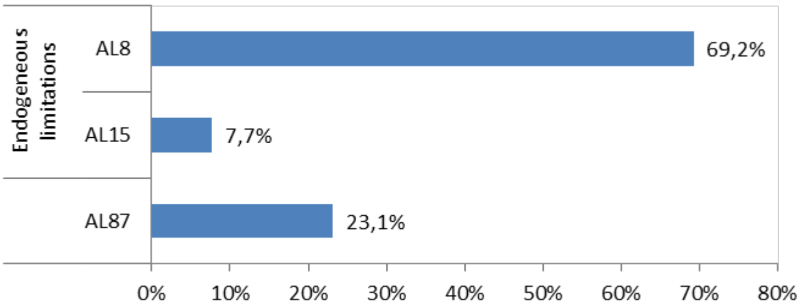

Figure 34: Limiting factors for AK (n=13)

The major limitation to AK effectiveness is the possibility that it is neglected due to deliberate violation (69.2% of cases). Furthermore, in 23.1% of cases, alcohol level is less than or equal to the legal rate and the system would not be activated.

- **Intelligent Speed Adaptation (ISA)**

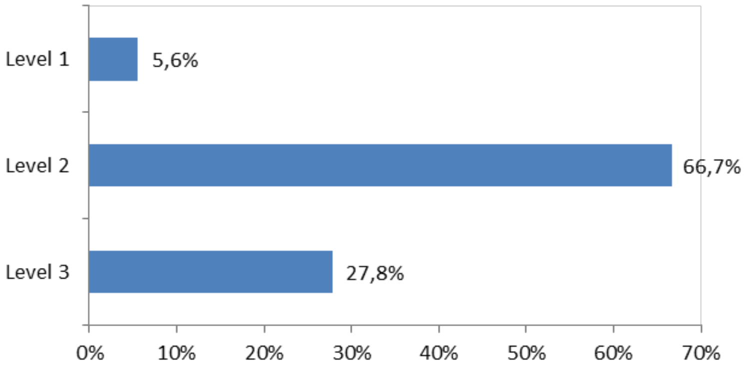

Figure 35: Level of efficiency for ISA (n=18)

ISA efficiency in single vehicle accidents seems particularly dependent on contextual constraints since it is fully effective only in 5.6% of cases. In other cases, efficiency can be modulated by contextual factors (66.7%) or have no effect at all (27.8%)

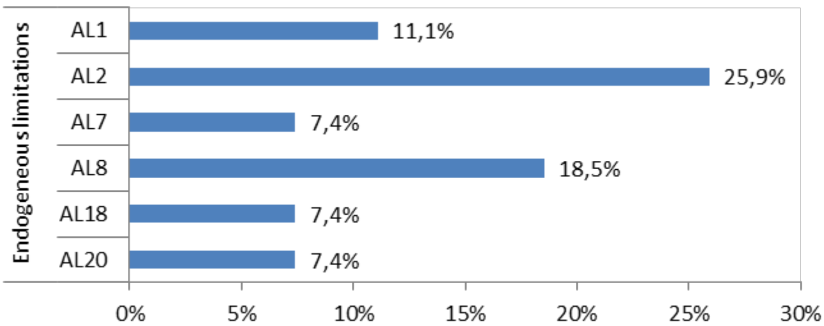

Figure 36: Limiting factors for ISA (n=27)

Factors limiting the effectiveness of ISA at this stage of the process are exclusively endogenous. The majority of factors are referring to voluntary dismissal (85.2%). For example, information is not taken into account due to motivation for speed (25.9%), to deliberate violation (18.5%) or in connection with the motivation for the journey (11.1 %). In addition, there are some parameters weakening attention capacities: inattention (7.4%) and active distraction (7.4%).

- **Low friction detection (LoFrctD)**

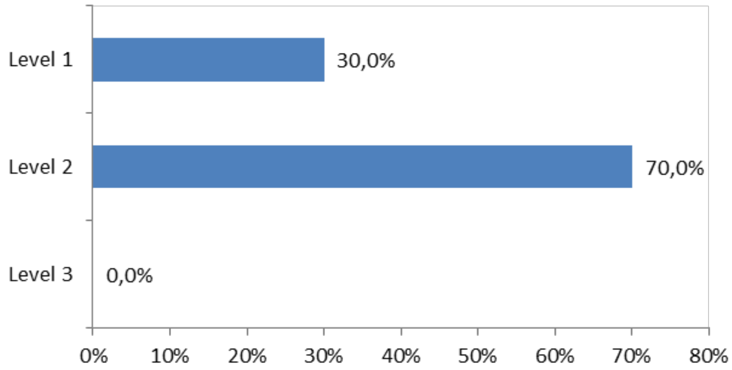

Figure 37: Level of efficiency for LoFrctD (n=10)

This assistance is greatly influenced by contextual factors because in 70% of cases it is only moderately effective. Nevertheless, it is completely effective in 30% of cases.

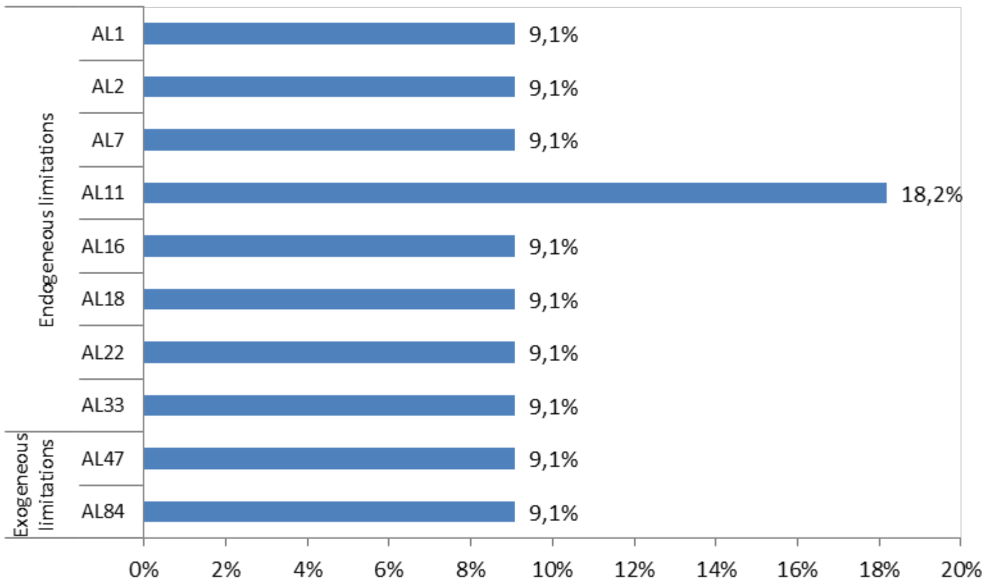

Figure 38: Limiting factors for LoFrctD (n=11)

Limits to the effectiveness of this aid are mainly endogenous. These include psycho-physiological problems such as fatigue (18.2%), the influence of alcohol (9.1%), inattention (9.1%) or the attention focus on a potential hazard (9.1%). Driver's motivations (type of journey or speed) may limit the effectiveness of the aid.

- **Traffic Sign Recognition (TSR)**

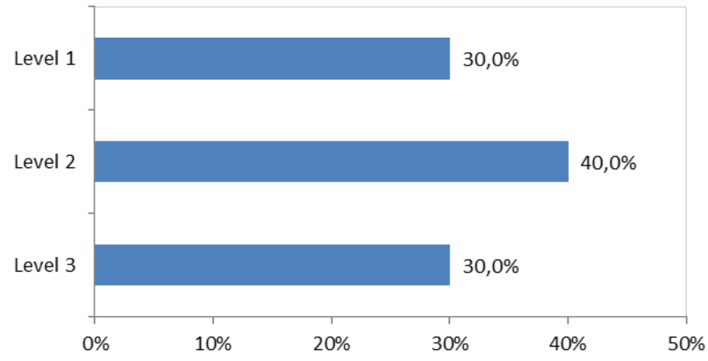

Figure 39: Level of efficiency for TSR (n=10)

In 40% of cases, aid effectiveness is modulated by contextual factors. In 30% of cases, it is even completely ineffective. We note however that in 30% of cases, it is totally effective.

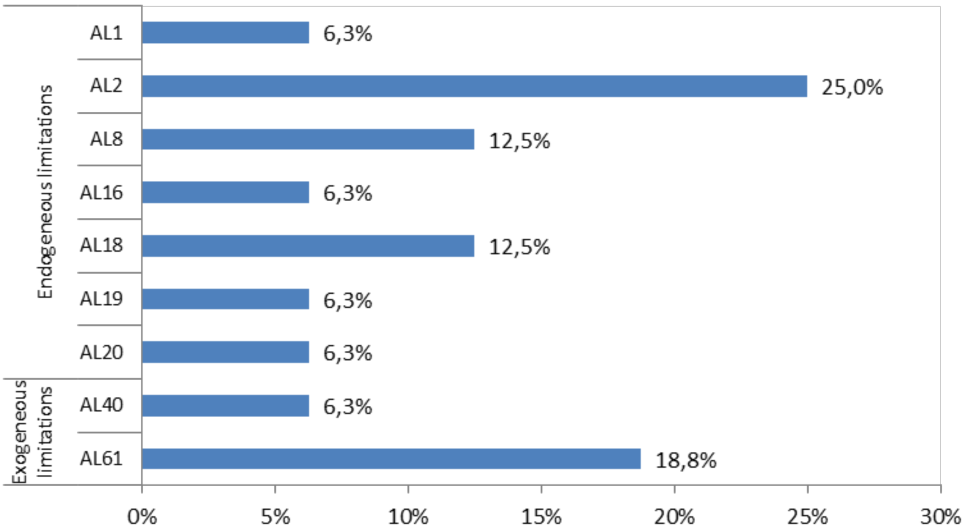

Figure 40: Limiting factors for TSR (n=16)

Most limiting factors are endogenous. They are mainly concerning wilful rejection of information due to deliberate level of speed (25%), intentional violation (12.5%) and inattention (12.5%). In 18.8% of cases, the absence of pre-signalling would reduce the effectiveness of aid.

2.1.7.4. PTW riders

- **Bend Alert (INFRA AS-3)**

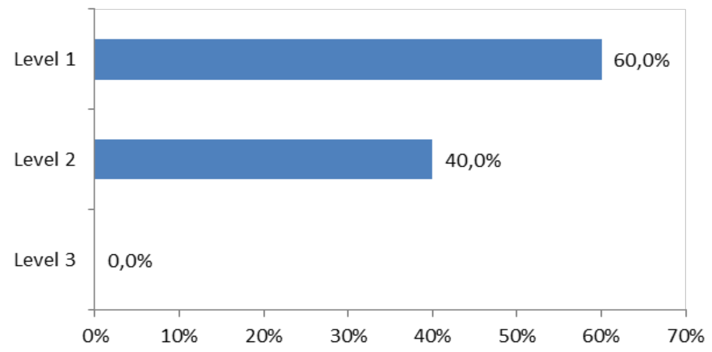

Figure 41: Level of efficiency for INFRA AS-3 (n=5)

This assistance has a very effective potential since in 60% of cases it would permit to avoid the occurrence of the accident. However, in 40% of cases, the contextual elements of the accident could limit its effectiveness.

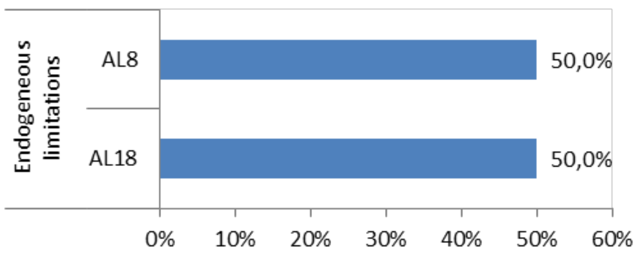

Figure 42: Limiting factors for INFRA AS-3 (n=2)

Only two factors are likely to limit the effectiveness of the system. It is the rejection by deliberate violation (50%) and inattention (50%).

- **Intelligent Speed Adaptation (PTW AS-3)**

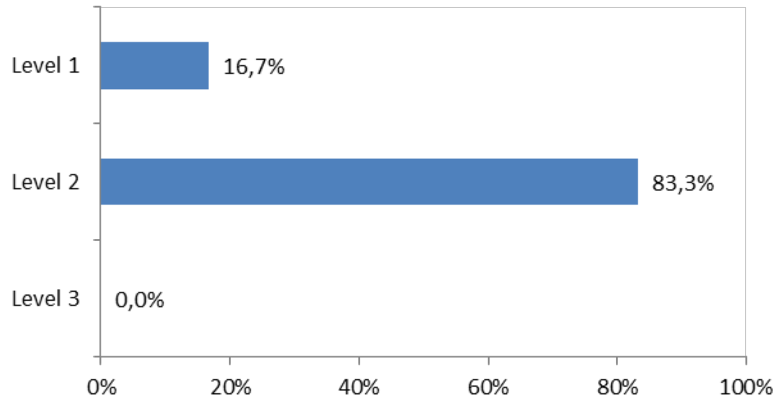

Figure 43: Level of efficiency for PTW AS-3 (n=6)

This aid seems potentially much impeded by contextual elements when addressing PTW riders' needs since it is fully effective in only 16.7% of cases. In other cases, its effectiveness is estimated to be moderate.

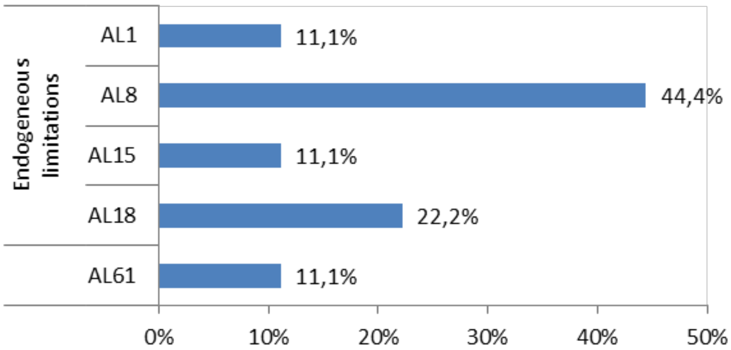

Figure 44: Limiting factors for PTW AS-3 (n=9)

Most limiting factors are linked to the riders themselves. They deal essentially with the risk of a wilful rejection of the aid due to deliberate violation (44.4%) and inattention (22.2%). We also note the intervention of motivations for the trip (11.1%) and the influence of alcohol (11.1%). At last, the lack of pre-signalling could be able to weaken the effectiveness of the aid in 11.1% of cases

4. RUPTURE PHASE

As stated in the introduction, the so-called "rupture" situation consists, along the accident generating process, in the transitional stage between a still controlled situation and an impaired situation. The rupture in this process deals with the meeting of an event unexpected by the road user. This event can be an unforeseen presence or manoeuvre by another user, the advent of an infrastructure configuration which takes the driver by surprise, or provokes a sudden high workload, and so on. The effect of the rupture situation is to switch the system components from a bearable level of demand to a suddenly excessive demand in terms of ability to respond. That is why this situation can be regarded as crucial in terms of prevention, as far as it characterizes the pivotal moment of the accident process.

It should be noted that an 'unexpected event' does not necessarily mean 'unpredictable'. Which raises the question of to what extent it really was unpredictable, and if not, why it was unexpected. Information gained on the driving situation is of considerable use when seeking this explanation.

At this phase will be examined: the pivotal Human Functional Failures (Step 7 of the analysis process), the factors triggering this HFF (Step 8), the pivotal needs (Step 9), the safety functions able to meet the pivotal needs (Step 10), the potential limitations to safety functions meeting the pivotal needs (Step 11) and the response efficiency of safety functions at the rupture phase (Step 12).

4.1.Car versus car accidents

The sample consists of 210 drivers involved in 105 accidents. Within these 210 drivers, 27 are "passive" -did not show any failure- and 19 are indeterminate (not taken into account in the following analysis).

The following section is focused on 164 car drivers with failure identified, involved in an accident in interaction with another car. Of these 164 drivers, a need is identified for 157 of them.

4.1.1. Pivotal human functional failures

As stated above, functional failure features the impairment of one (at least) of the cognitive, sensory-motor or psycho-physiological functions that usually allow the operator to adapt to the difficulties he meets when fulfilling his task. This notion accounts for different levels of human dysfunctions: the error, the violation, the inaptitude. They are the consequence of the factors described above.

Table 19: Distribution of car drivers failures

Failure category	%
Detection	42,7%
Diagnosis	13,4%
Prognosis	22,6%
Decision	11,0%
Execution	6,1%
Overall	4,3%
Total	164

In these car-against-car accidents, perceptual errors are found predominantly (42.7%): the drivers did not see in due time an important aspect of the visual scene (other road user, element of infrastructure, etc.). Then, for almost a quarter of drivers, it is a prognosis failure that originates the breakdown situation: the drivers did not anticipate the evolution of the situation to which they were confronted. The explicative elements behind these failures and the needs in safety systems to which they correspond are described below.

4.1.2. Triggering factors

The factors triggering the pivotal human functional failure were diagnosed on the basis of the overall list of factors already presented for the driving phase. The factors selected here, at the rupture phase of the accident process, are those which directly provoke the HFF. They most of the time combine elements coming from the individual and from the context in which he is behaving.

Table 20: Distribution of the main explicative elements of car driver's functional failures

Physical/ Physiological condition	Fatigue	7,3%
Psychological condition	In a hurry	5,5%
Road user status	Right of way status	17,7%
	Excessive confidence	4,9%
	Identification of potential risk	3,7%
	Trivialization of the situation	12,2%
Risk taking	Illegal Speed	7,9%
	Vehicle positioning	6,7%
	Traffic control	6,1%
Little/None Experience	Driving	4,3%
	Route	11,6%
Over-experienced	Sur experience Route	14,0%
Attention disturbances	Distraction problem	11,0%
	Attention competition problem	14,0%
	Inattention problem	11,0%
Road Condition	Contaminants: Wet/Flood/Snow	3,0%
	Contaminants: Oil/Diesel	0,6%
Road Geometry	Misleading/complex road layout	5,5%
Traffic Condition	Atypical other road users manoeuvres	11,6%
	Illegal other road users manoeuvres	11,6%
Visibility Impaired	Weather	4,9%
	Terrain profile	5,5%
	Other vehicle(s)	4,3%
	Roadside objects	17,1%
Traffic Guidance	Traffic signs/signals – Maintenance	1,8%
	Traffic signs/signals – Inappropriate	1,2%
	Road markings (visual/tactile) - Insufficient	1,2%
	Road markings (visual/tactile) - Maintenance	1,8%
	Road markings (visual/tactile) – Unexpected	0,6%
Other Environmental Factors	Obstacle(s) in road	1,2%

Table 20 presents the main explicative elements of the functional failures committed by car drivers when meeting other passenger cars at this rupture stage. It is shown that the main factors of this type of accident are first, the strong feeling of right of way (17.7%) and the visibility impaired by a roadside object (17.1%). The over experience of the journey, of the road or the manoeuvre the competition is found in 14% of cases. It is interesting to note, on the opposite, that the lack of experience of the journey, the road or manoeuvre contributes to 11.6% of accidents involving two cars. Dealing with factors relating to attention deficiencies, it is shown first the problem of attention competition between tasks (14% of cases), and secondly inattention and distraction are found in 11% of cases for both of them. Factor "trivialization of the situation" is part of the explanatory factors of the accident in 12.2% of cases. Finally, the atypical or illegal manoeuvres on the part of other road users explain 11.6% of car driver's failures when confronted with another car.

4.1.3. Drivers needs at the rupture phase of the accident

For more than one out of two car drivers involved in an accident in interaction with another car, the need is of perceptual type (53%). More specifically, this refers to a need for the detection of another user on a transversal trajectory (24.8%). Another need frequently found refers to the proper evaluation (in time and distance) that another road user is on a collision course (12.1%). For nearly a quarter of car drivers, a prognosis need is identified and more particularly a need in anticipation of the restarting or non-stop by another road user (10.8%), or a need in anticipation of the manoeuvre engaged by another user (8.9%).

Tableau 21: Distribution of car drivers needs at the rupture stage

	Types of needs	n	%
Needs in internal diagnosis	N01.1	3	1,9%
Needs in detection	N03	6	3,8%
	N04	3	1,9%
	N05	7	4,5%
	N06	5	3,2%
	N07	39	24,8%
	N08	6	3,8%
	N09	7	4,5%
	N10	10	6,4%
Needs in external diagnosis	N11	1	0,6%
	N12	2	1,3%
	N13	1	0,6%
	N14	19	12,1%
	N16	3	1,9%
Needs in prognosis	N17	17	10,8%
	N18	2	1,3%
	N19	14	8,9%
	N20	4	2,5%
Needs in control	N21	5	3,2%
Needs in communication	N22	3	1,9%
	Total	157	100,0%

4.1.4. Safety functions meeting drivers' needs

In only 8 cases (out of 157) no safety function met the needs found in the rupture phase of the accident process, meaning that in the huge majority one system at least could have the capacity to address the difficulty met by the car driver in the rupture phase of the accident.

This is undoubtedly a good result in the purpose of road safety. Are mentioned hereafter the functions the most promising in that respect (for an overall view cf. table 4).

The safety systems most often able to meet the needs of drivers are the following:

- CA / CW (Collision Avoidance / Collision Warning) meets 28.6% of the needs found by car drivers in the rupture phase. This is a system with a potentially wide and quite heterogeneous impact in the sense that it can meet 13 different kinds of needs. More specifically, this assistance comes in one of 10 cases when the need N07 (Detecting a user on an intersecting course) appears, and in 5% of cases for the need N14 (Estimating a collision course with another user).

- IC (Intersection Control, 23.6%) meets the needs in detection of another user in a transversal path, which is specifically its purpose, in more than 1 in 2 cases.

- INFRA AS-4 (Intersection Alert, 14.6%). This function meets two main needs: N07 (Detecting a user on an intersecting course) in almost one out of two cases and N17 (Predicting that another user will move off or fail to stop) in almost a quarter of the cases.

- ACC (Adaptive Cruise Control, 5.7%). This system can potentially correspond to different kinds of needs but mainly meet the need N05 (Detecting an obstacle slowly moving).

- LDW (Lane Departure Warning, 5.0%). This can potentially correspond to three kinds of needs but more particularly meet the need in detection of a deviation from the right path, in about 75% of cases.

Table 22: Distribution of safety functions according to the needs covered

	ABS	ACC	Autolight	BA	BS	CA/CW	DDS	ESC	IC	INFRA AS-1	INFRA AS-2	INFRA AS-4	ISA	LCA	LDW	LKA	LoFrctD	NV	PTW - FICA	ROINT	TSR
N01.1							1.1%								1.1%	1.1%					
N03		0.4%							1.8%			1.4%	0.7%								1.8%
N04		0.7%				1.1%															
N05		1.8%				2.5%															
N06						1.4%			0.4%			0.4%									
N07						10.0%			12.5%		0.4%	6.8%									
N08					1.8%									1.4%		0.4%					
N09						2.1%			1.1%			0.4%									
N10						0.4%				0.4%				0.4%	3.6%	2.5%					
N11													0.4%								
N12		0.4%											0.7%								0.7%
N13		0.4%				0.4%															
N14		0.4%			1.1%	5.0%			2.5%			0.7%				0.4%					
N16		0.0%				0.4%			0.7%			0.4%									
N17		0.4%				1.8%			2.9%		0.7%	3.2%									
N18		0.7%				0.7%															
N19	0.4%	0.7%				2.1%			1.4%		0.4%	0.7%						0.7%	0.4%	0.4%	
N20						0.7%		0.4%	0.4%	0.4%		0.4%		0.4%	0.4%	0.4%					
N21	0.4%			0.4%				1.4%				0.4%					0.4%				
N22			0.4%								0.4%										
% of needs by function	0.7%	5.7%	0.4%	0.4%	2.9%	28.6%	1.1%	1.8%	23.6%	0.7%	1.8%	14.6%	1.8%	2.1%	5.0%	4.6%	0.4%	0.7%	0.4%	0.4%	2.5%

4.1.5. Limitations of the most potentially useful systems

- Collision Avoidance / Collision Warning (CA/CW)

As mentioned above, the CA/CW system could be useful for 28.6% of drivers involved in car against car accidents, by meeting different kinds of needs, among which the two connected N07 (Detecting a user on an intersecting course) and B14 (Estimating a collision course with another user).

In 46.3% of cases when CA / CW is able to meet the needs of drivers, it turns out that it would have a very effective role in the sense that the specifications of the system are well suited to the contexts in which the corresponding accidents occur. Thus it can be argued that in these cases the system would prevent the accidents.

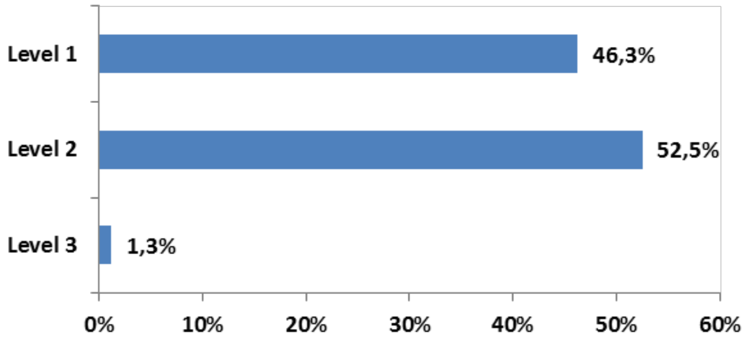

Figure 45: level of efficiency for CA/CW (n=80)

However, in 52.5% of cases, the contextual parameters of the accident may limit the effectiveness of this aid, the reasons why being given below. It may be noted that in very few cases (1.3%), the system is found to be completely ineffective.

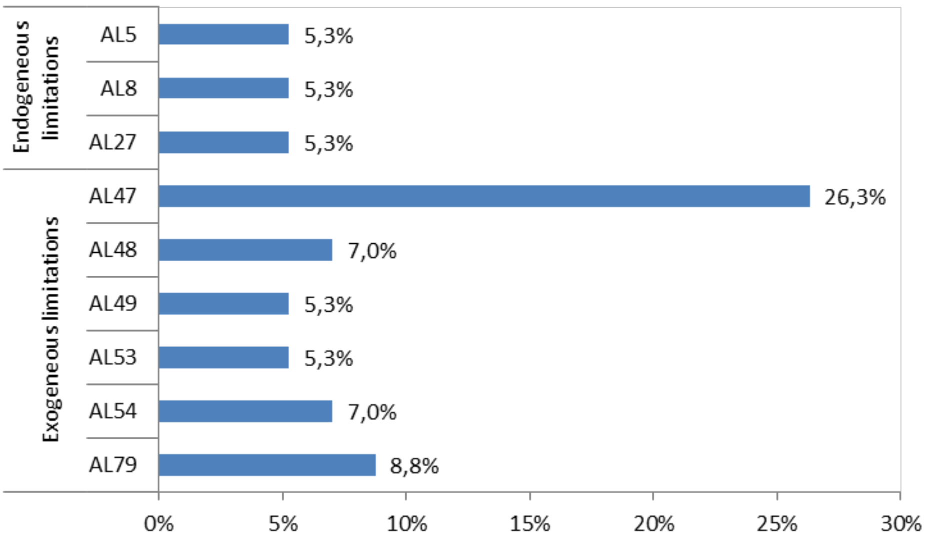

Figure 46: Limiting factors for CA/CW (n=57)

Factors limiting the effectiveness of CA/CW system are predominantly exogenous. They typically do not refer to a problem of interaction with the driver. It is in relation with the physical context of accident production that the difficulties are found. More particularly, because of insufficient width of radar, the aid is not capable of detecting an obstacle when the road is multi-way (26.3%), or this obstacle is located on an opposite lane (7%). In case of low friction (8.8%), the effectiveness of the system could be jeopardized. Indeed, CA / CW is not capable of adjusting the automatic triggering of the emergency braking according to the surface friction and therefore the braking distance required to stop the vehicle.

- Intersection Control (IC)

As mentioned above, IC would be useful for 23.6% of car drivers involved in accidents with other cars, especially to meet the needs B07

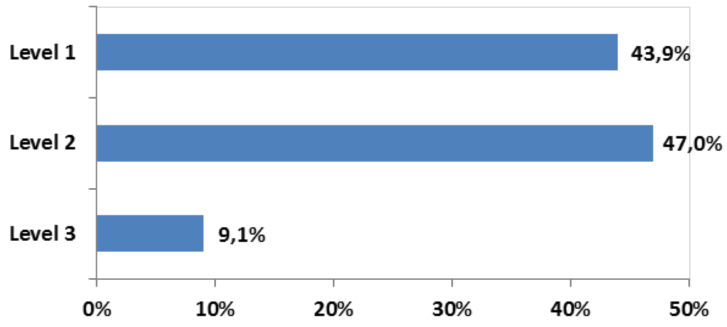

Figure 47: Level of efficiency for IC (n=66)

In 43.9% of cases where the system is potentially useful, it would be very effective considering the context parameters and would therefore have a role in the prevention of the accident. In the other cases, it will be limited by certain factors, to the point of having a zero level of efficiency in 9.1% of cases.

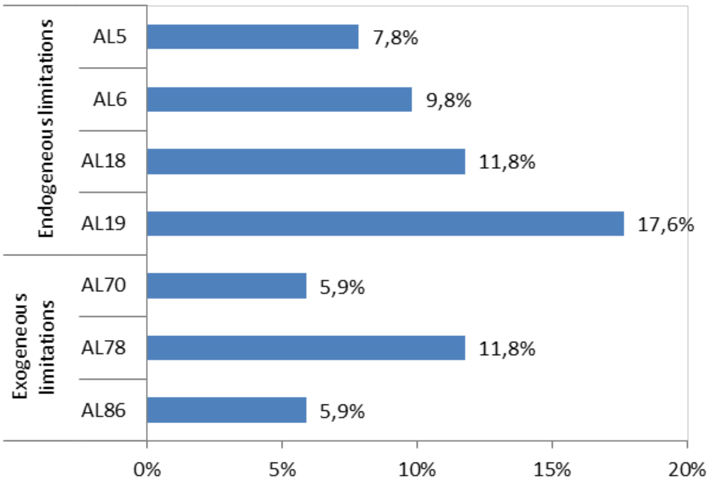

Figure 48: Limiting factors for IC (n=51)

Potential limitations combine driver's endogenous elements and exogenous elements. Attention problems constitute the main limit in the effectiveness of this system, especially the passive distraction (17.6%) and inattention (11.8%). In 11.8% of cases, the signal is given too late in terms of time and space to allow the driver to avoid the crash.

- Intersection Alert (INFRA AS-4)

Aid INFRA AS-4 would be useful for 14.6% drivers, to cover several needs mainly including B07.

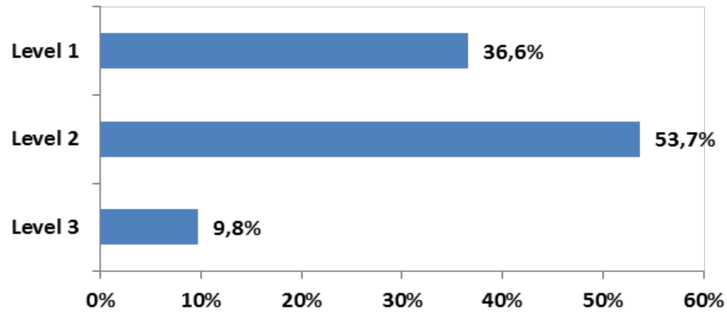

Figure 49: level of efficiency for INFRA AS-4 (n=41)

However, the system INFRA AS-4 shows relatively low level of efficiency when looking at the contexts in which it would intervene. It would thus be fully effective in only 36.6% of cases. This assistance which is appropriate for crossroad situations seems pretty constraint in terms of limits.

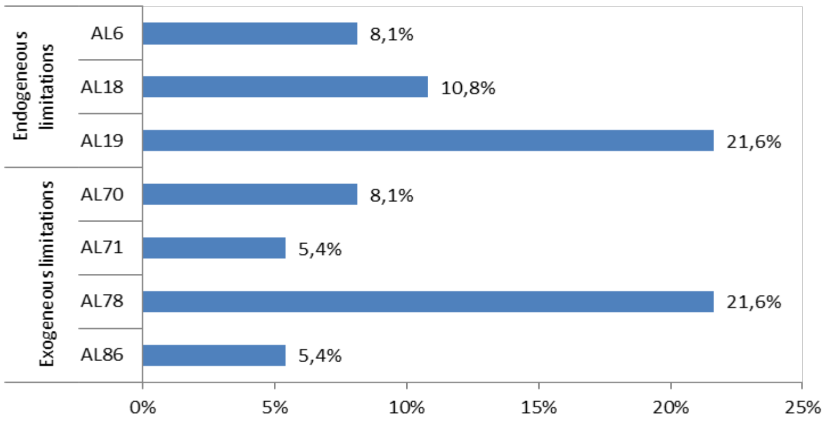

Figure 50: Limiting factors for INFRA AS-4 (n=37)

The main limiting factors are relative to a problem of driver attention (namely passive distraction (21.6%) and inattention (10.8%). These attention problems were at the origin of the accident and would reduce the amount of information given by the system. In 21.6% of cases, time and space are too small after the signal given by INFRA AS-4 to allow the driver to avoid an accident.

- Adaptive Cruise Control (ACC)

ACC assistance would be useful for 5.7% of persons involved in car vs. car accidents.

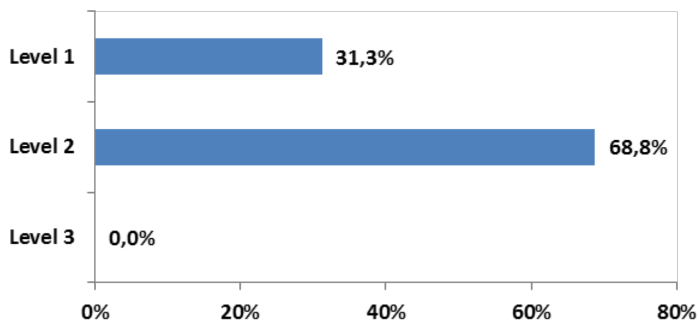

Figure 51: Level of efficiency for ACC (n=16)

In only less than 1 in 3, using ACC is fully effective and thus could avoid the accident. The effectiveness of this aid is strongly constrained by certain factors (68.8%)

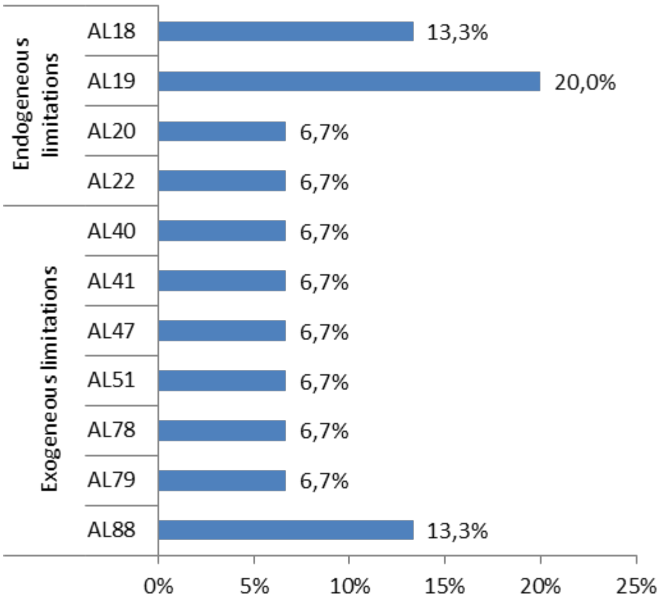

Figure 52: Limiting factors for ACC (n=15)

The main factors limiting the effectiveness of using ACC system are related to attention including passive distraction (20.2%) and inattention (13.3%). In 13.3% of cases, the late braking triggered by the driver would not have allowed to avoid the collision (NB: this aid is able to adapt the inter-distance with the vehicle ahead slowing down, but is not able to apply emergency braking in case of too much important slowdown or complete stop of the preceding vehicle).

- Lane Departure Warning (LDW)

The LDW aid would be useful for 5% of people involved in car-car accidents, especially to meet the need N10 (Detecting a deviation from the path).

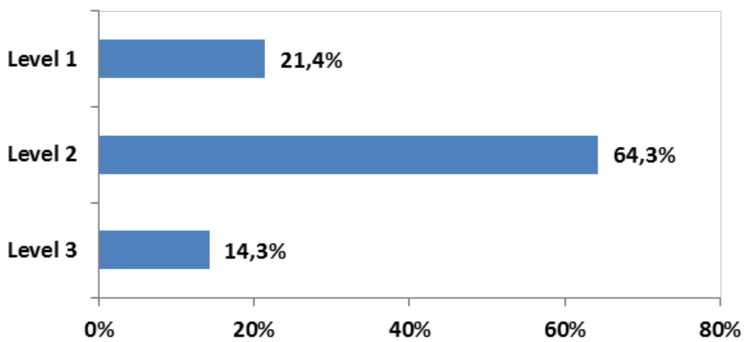

Figure 53: Level of efficiency for LDW (n=14)

This aid seems very constrained by contextual elements because it is fully effective in only 21.4% of cases. It is assumed a limited efficiency in 64.3% and inefficiency in 14.3% of cases.

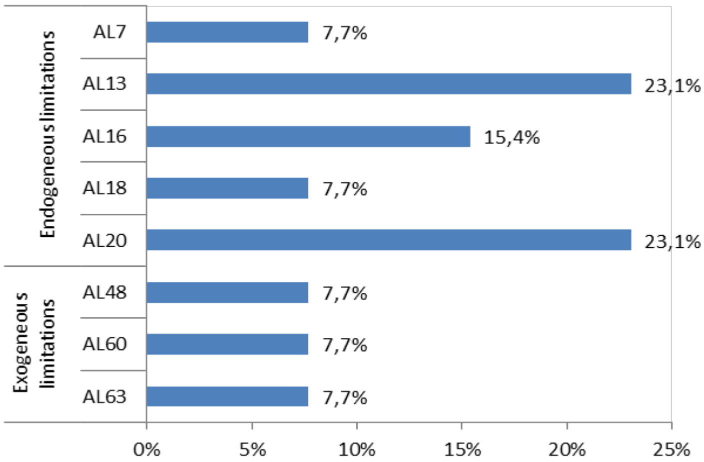

Figure 54: Limiting factors for LDW (n=13)

These are essentially the driver-specific factors that limit the effectiveness of this aid, including psycho-physiological problems such as sleep (23.1%) or the influence of alcohol (15.4%) and of attention problems such as distraction (20%).

4.2. Car versus PTW accidents

An important bulk of literature assumes specific difficulties in driving interactions when meeting a PTW, which accounts both for car drivers and for PTW riders. The following sections describe the specific factors involved for each of these categories of road users in the production of the functional failures resulting for both of them.

The sample consists of 246 drivers involved in cars vs. PTW accidents. Of these drivers, 31 are passive (23 car drivers and 8 PTW riders) therefore did not show any functional failure and 10 are indeterminate (7 cars and 3 PTW) and therefore will not be considered in the following analysis.

Here, we are interested in 93 drivers with an identified failure: 93 car drivers and 112 PTW drivers involved in an accident in interaction (i.e. excluding single vehicle accidents). On these drivers, 202 lead to an identified need (92 car drivers and 110 PTW riders).

4.2.1. Pivotal human functional failures

In these accidents involving car versus PTWs, detection problems are found in the majority (78.5% for drivers of cars and 29.5% for drivers of PTW), which shows the essential implication of perceptive difficulties in this kind of accident. For more than a third of PTW riders a failure in prognosis is the origin of the breakdown situation (35.7%), which is a specific tendency for them to fail in their expectations about the potential evolution of the situation. Another difficulty more characteristic of PTW riders refers the diagnosis of a road difficulty (13.4%).

Tableau 23: Distribution of functional failures for car drivers and PTW riders

Failure category	% cars	% PTW
Detection	78.5%	29.5%
Diagnosis	5.4%	13.4%
Prognosis	4.3%	35.7%
Decision	9.7%	9.8%
Execution	1.1%	1.8%
Overall	1.1%	1.8%
Total	93	112

4.2.2. Triggering factors

The distribution of the main explicative elements of car drivers and PTW riders functional failures presented in table 23 shows some differences between these two kinds of road users when they meet together. Among triggering factors which represent more than 10% of cases are found the following:

Car drivers failures in a rupture situation when confronted with a PTW are most often found to be as a result of the road user being over-experienced with the route on which they are driving (18.3%), leading notably to inattention problems (11.8%). Other attention weakness is related to the problem of competition between several sources of information (12.9%) to survey at the same time, in that case to the detriment of PTW detection. This difficulty to put forward an efficient information gathering is also linked to situational time constraint (11.8%), and is also physically related to visibility impaired by the presence of other vehicles (18.3%) and roadside objects (11.8%). It can be noted that around 18% of car drivers were affected by the specific nature of PTW characteristics (small frontal size, lack of contrast with the environment) and behaviour (filtering).

PTW riders are more sensitive, in the functional failure that they produce, to their strong feeling of right of way (15.2%) which does not lead them to pay attention to the car arriving on the secondary road. At the spot of the accident, they are affected (as car drivers meeting them) by visibility impaired by roadside objects (12.5%). The surprising behaviour consisting in atypical (12.5%) and illegal manoeuvers (19.6%) put forward by the car driver is the element the most often explicative of their failures. Illegal speed practiced by PTW riders is also contributing to their incapacity to adapt (12.5%).

Table 24: Distribution of the main explicative elements of car drivers and PTW riders functional failures

		Car drivers	PTW riders
Road user status	Right of way status	7,5%	15,2%
	Identification of potential risk	5,4%	1,8%
	Situational time constraint	11,8%	0,0%
	Trivialization of the situation	4,3%	8,9%
	Illusion of visibility	0,0%	7,1%
Risk taking	Illegal Speed	3,2%	12,5%
	Legal Speed but inappropriate	1,1%	5,4%
	Traffic control	9,7%	7,1%
	Atypical overtaking	1,1%	8,0%
Little/None Experience	Route	6,5%	2,7%
	Vehicle	0,0%	8,0%
Over-experienced	Route	18,3%	8,9%
Attention disturbances	Distraction problem	8,6%	2,7%

	Attention competition problem	12,9%	7,1%
	Inattention problem	11,8%	3,6%
Traffic Condition	Other road user(s) : Absence of clues to maneuver	1,1%	8,0%
	Other road user(s) : Atypical maneuvers	7,5%	12,5%
	Illegal road user(s) maneuvers	8,6%	19,6%
	Disruptive behaviour of another user	0,0%	5,4%
Visibility Impaired	Day/night	5,4%	1,8%
	Terrain profile	7,5%	4,5%
	Other vehicle(s)	18,3%	12,5%
	Roadside objects	11,8%	8,9%
Design	Visibility	5,4%	0,0%
Specific factors linked to meeting a PTW	Filtering	3,2%	-
	Size of PTW	8,6%	-
	Lack of contrast between PTW and the environment	6,5%	-

4.1.6. Drivers needs at the rupture phase of the accident

In accidents involving car/PTW interactions, in the same way as for accidents involving car/car interactions, the car drivers show a need for detection in the majority of cases (89.1%), especially when the other user (PTW) is on a transversal course (on a crossroad, 40.2% of the cases), or when he is out of the front visual field, i.e. behind, on the side or in blind spots (22.8%), or when the user is on the opposite lane (14.1%). The need for detection of a user on a transverse path is also one of the most important particular needs for PTW drivers (21.8%). However, in general, a need in prognosis is the most frequent cause (45.4%) among PTW drivers, including the prediction of the manoeuvring of others (16.4%), prediction of restart or non-stop cars (14.5%) and prediction of the manoeuvre to be performed (10%).

Table 25: Distribution of car drivers and PTW riders needs at the rupture stage

	Types of need	% cars	% PTWs
Needs in detection	N03	0,0%	0,9%
	N05	1,1%	5,5%
	N06	14,1%	5,5%
	N07	40,2%	21,8%
	N08	22,8%	1,8%
	N09	8,7%	3,6%
	N10	2,2%	0,0%
Needs in external diagnosis	N13	0,0%	1,8%
	N14	1,1%	2,7%
	N15	0,0%	1,8%
	N16	4,3%	0,0%
Needs in prognosis	N17	2,2%	14,5%
	N18	0,0%	4,5%
	N19	2,2%	16,4%
	N20	0,0%	10,0%
Needs in control	N21	1,1%	9,1%
	Total	92	110

4.2.3. Safety functions meeting the needs

In 10 cases, no system was able to meet the drivers' needs.

Table 26: Distribution of safety functions according to car drivers needs covered

Car drivers	ACC	BS	CA/CW	ESC	IC	INFRA AS-2	INFRA AS-4	LCA	PTW AS-1	RO-INT	RS	VRU
N05	0.8%		0.8%									
N06			8.6%		1.6%							
N07			20.3%		11.7%	0.8%	12.5%			0.8%		
N08		15.6%						7.8%			0.8%	
N09			0.8%		2.3%		2.3%					
N10			1.6%									
N14			0.8%									
N16			1.6%		2.3%		2.3%					
N17					0.8%		0.8%					
N19									0.8%			0.8%
N21				0.8%								
Total	0.8%	15.6%	34.4%	0.8%	18.8%	0.8%	18.0%	7.8%	0.8%	0.8%	0.8%	0.8%

The systems most widely used to meet the needs of cars drivers in this type of accident are:

- CA / CW (Collision Avoidance / Collision Warning, 34.4%): this aid can meet seven types of needs. However, it is much used when the driver needs to detect a PTW user on a transversal course (intersection, 20.3%);
- IC (Intersection Control, 18.8%): in 11.7% of cases, it addresses the need for detection of a user on a transversal course (intersection, 11.7%);
- INFRA AS-4 (Intersection Alert, 18%): This system may meet four types of needs, but seems once again especially useful in cases where the car driver needs to detect a PTW on a transversal course (intersection, 12.5%);
- BS (Blind Spot Detection, 15.6%): this aid answers only the need to detect a PTW user out of the frontal visual field that is to say, behind, on the side or in blind spots (while lane changing, left turn, or overtaking: 15.6%)
- LCA (Lane Changing Assistant, 7.8%): such as BS, this system addresses only the need to detect the user out of the frontal visual field that is to say, behind, on the side or in blind spots.

Table 27: Distribution of safety functions according to PTW riders needs covered

PTW riders	ABS	CA/CW	ESC	IC	INFRA AS-2	INFRA AS-4	PTW AS-1	PTW AS-2	PTW AS-4	PTW AS-5	PTW AS-11	PTW AS-12	PTW AS-13	PTW AS-16	PTW AS-19	PTW AS-20	RO-INT	TSR
N03						0.8%												0.8%
N05						0.8%	4.7%	2.3%							0.8%			
N06						0.0%	3.1%											
N07					1.6%	7.0%	17.1%								0.8%		0.8%	
N08										0.8%						0.8%		
N09							0.8%								0.8%			
N13							0.8%	0.8%										
N14							2.3%											
N15							0.8%											
N17				0.8%		5.4%	10.1%											
N18							3.9%	3.1%										
N19		0.8%		1.6%		1.6%	8.5%		0.8%		0.8%							
N20						1.6%	3.9%											
N21	0.8%		0.8%				1.6%				1.6%	0.8%	2.3%	0.8%				
Total	0.8%	0.8%	0.8%	3.1%	1.6%	17.1%	57.4%	6.2%	0.8%	0.8%	2.3%	0.8%	2.3%	0.8%	2.3%	0.8%	0.8%	0.8%

In 25 cases, no system is able to meet the needs of PTW riders.

The systems the most widely used to meet the needs of drivers of PTW, in this type of accident are as follows:

- PTW AS-1 (Forward and intersection collision avoidance, 57.4%): this aid meets many needs (12 in total), in particular the need for detection of a user (car) on a transversal course (intersection, 17.1%) and the need in anticipation of restarting or non-stop of another user (cars, mainly at intersection, 10.1%);
- INFRA AS-4 (Intersection Alert, 17.1%): this system can meet seven needs but seems particularly useful in cases where the PTW driver needs to detect cars transversal course (7%) and predict the restarting or non-stop of another user (cars, mainly at intersection; 5.4%)

4.2.4. Limitations of the most potentially useful systems

4.2.5.1. For car drivers facing PTW

- Collision Avoidance / Collision Warning (CA/CW)

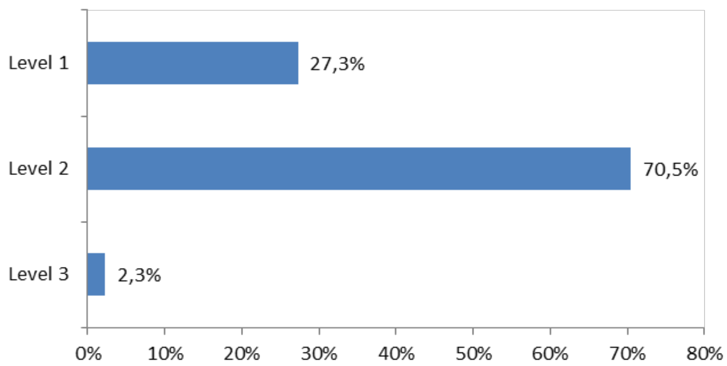

Figure 55: Level of efficiency for CA/CW (n=44)

In 27.3% of cases where CA / CW is used to meet the needs of drivers, it has a very effective role and would permit to avoid accidents. In contrast, in 70.5% of the cases, the contextual elements of the accident may limit the effectiveness of aid. In only 2.3% of cases where the aid is used, contextual factors render ineffective the assistance.

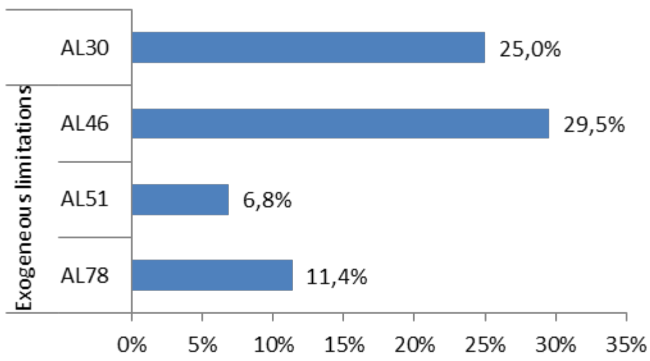

Figure 56: Limiting factors for CA/CW (n=44)

Due to insufficient width of radar, the aid would not be able to detect another user when it intersects (on a transversal path) and would therefore be ineffective (29.5%). A problem of perception of the PTW could also limit the effectiveness of the system (25%).

- **Intersection Control (IC)**

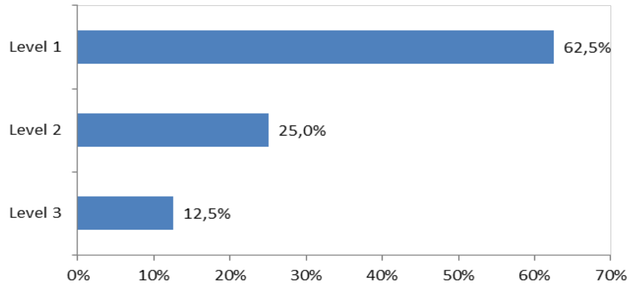

Figure 57: level of efficiency for IC (n=24)

In 62.5% of cases where IC is used, it is very effective and would therefore have a role in the non-occurrence of the accident. In other cases, the aid effectiveness is modulated by contextual factors. These factors may have a moderate effect on the aid (25%) or make it completely ineffective (12.5%).

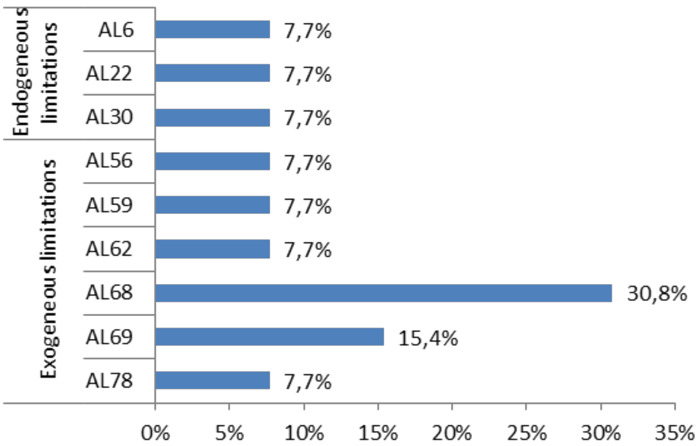

Figure 58: Limiting factors for IC (n=13)

Dealing with such contextual limiting factors, the configuration of intersection: roundabout (30.8%) or private road (15.4%) may limit the effectiveness of the aid, simply because from the description of the system functioning these types of intersection are not equipped with tags allowing traffic control in real time.

- **Intersection Alert (INFRA AS-4)**

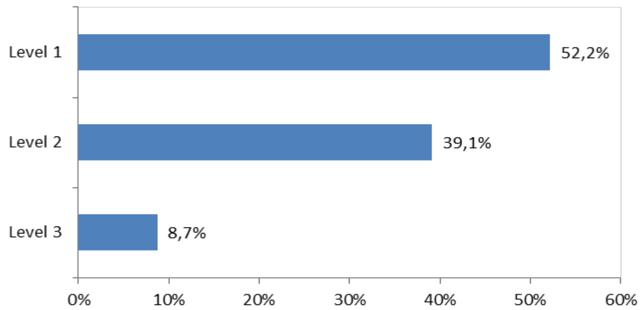

Figure 59: level of efficiency for INFRA AS-4 (n=23)

In this type of accident, this aid seems particularly effective in 52.2% of cases where it is used, allowing preventing the occurrence of the accident. However, in 39.1% of cases, its effectiveness is constrained by contextual elements. In 8.7% of cases, the contextual elements make it ineffective.

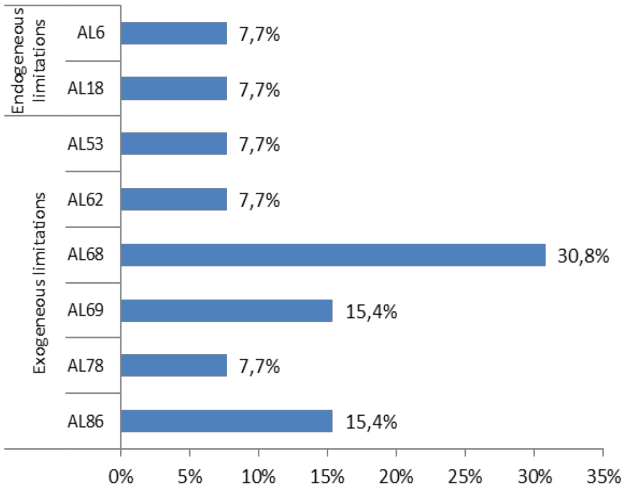

Figure 60: Limiting factors for INFRA AS-4 (n=13)

As for IC the type of intersection: roundabout (30.8%) or private road (15.4%) may limit the effectiveness of the aid. However, another element comes in: if speed is too slow for the car driver or the other (PTW) user, the presence of the vehicle is not detected by the tags (15.4%) (cf. description of the system).

- Blind Spot Detection (BS)

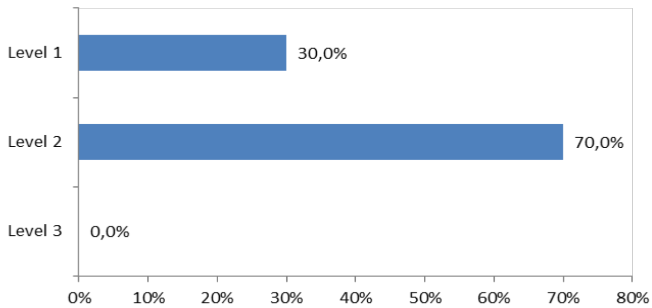

Figure 61: level of efficiency for BS (n=20)

In 70% of cases, the aid effectiveness is limited by contextual factors.

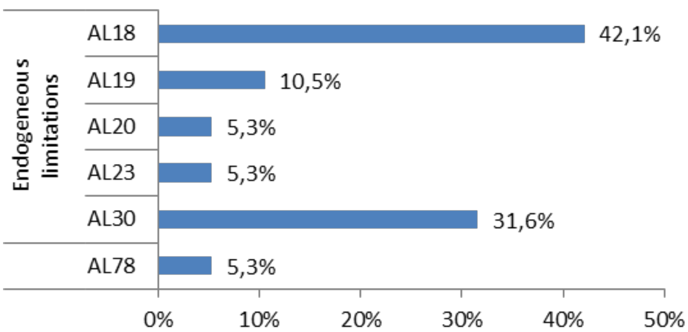

Figure 62: Limiting factors for BS (n=19)

The main factors limiting the effectiveness of aid deal with attention problems: in 42.1% of cases it is limited by inattention and in 10.5% of cases it is limited by the passive distraction. These attention problems could disrupt perception of the visual signal given in the exterior mirror. Moreover, the effectiveness of aid is also limited by problems of perception: the risk for the system to not perceive the PTW would impact negatively on aid effectiveness (31.6%)

- **Lane Changing Assistant (LCA)**

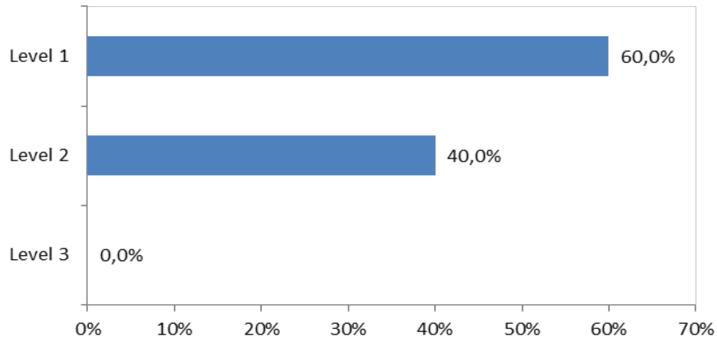

Figure 63: level of efficiency for LCA (n=10)

In this type of accident, LCA seems effective in 60% of cases where it is used; it would have prevented the occurrence of the accident. However, its effectiveness remains sensitive to contextual events (40%).

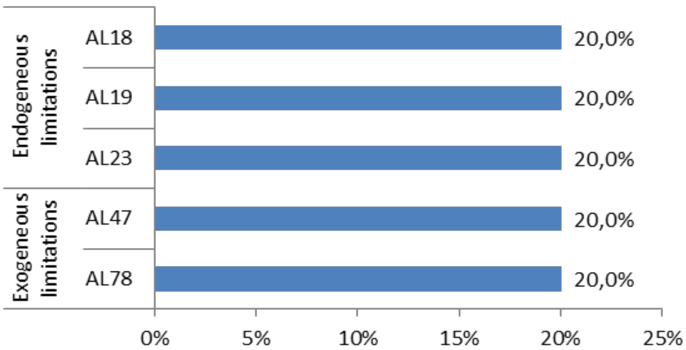

Figure 64: Limiting factors for LCA (n=5)

In 60% of cases attention factors would have limited the effectiveness of aid. More specifically, it deals with inattention (20%), passive distraction (20%) or cognitive capacity exceeded in the case of beginners (20%). In addition, insufficient radar width may limit the effectiveness of the aid, especially when the road includes several ways (20%) (cf. description of the system: 50 m capture area). Finally, in 20% of cases, the driver has neither the time nor the space to avoid the accident once the warning has been given.

4.2.5.2. For PTW riders facing car drivers

- **Intersection alert (INFRA AS-4)**

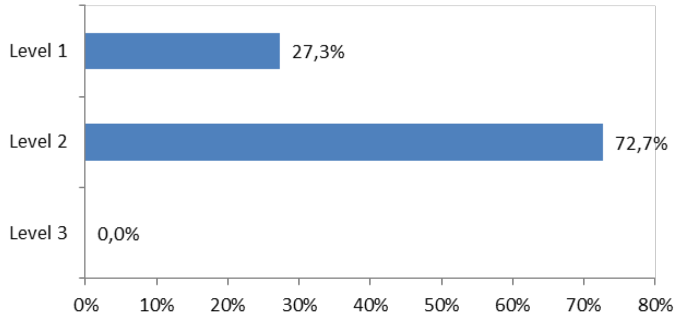

Figure 65: Level of efficiency for INFRA AS-4 (n=22)

The effectiveness of aid seems particularly dependent on contextual factors as in 72.7% of cases its effectiveness is limited, but never to the point of making it completely ineffective. In 27.3% of cases, the aid would prevent the occurrence of the accident.

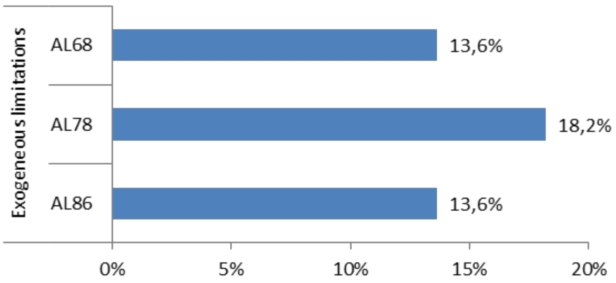

Figure 66: Limiting factors for INFRA AS-4 (n=22)

The effectiveness of aid is limited only by exogenous factors. In 18.2% of cases, the distance and the time required for the driver to react are too small to allow him to avoid the accident with or without the system. A roundabout intersection type may limit the effectiveness of the aid (13.6%), especially because according to the description of the system this type of intersection is not equipped with tags. Finally, if the driver (PTW) or the other user (car) is approaching the intersection at too slow speed, the tags cannot detect their presence (13.6%).

- **Forward and intersection collision avoidance (PTW AS-1)**

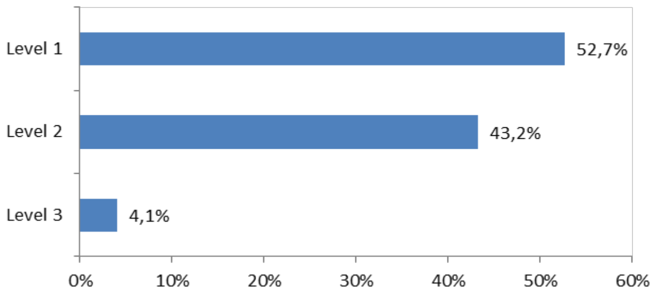

Figure 67: Level of efficiency for PTW AS-1 (n=74)

PTW AS-1 is fully effective in 52.7% of cases. However, this system seems to be quite constrained by contextual factors in 43.2% of cases. We note that in rare cases (4.1%), the contextual elements make it completely ineffective.

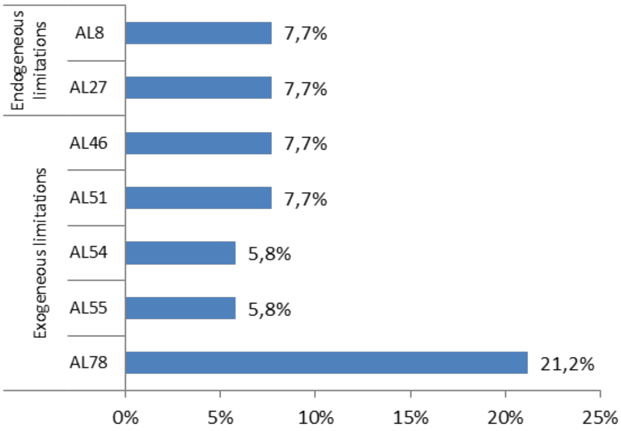

Figure 68: Limiting factors for PTW AS-1 (n=52)

The main limitation to the effectiveness of aid is a too small distance / time ratio (21.2%), that is to say that when the radar can detect the obstacle (cars), the space available to trigger the braking and stop the vehicle is too small. The accident is not necessarily avoided but the consequences can be reduced.

- Adaptive Cruise Control (PTW AS-2)

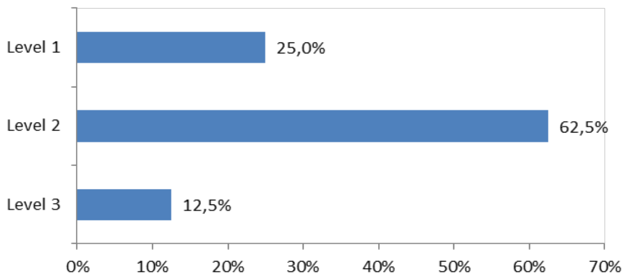

Figure 69: level of efficiency for PTW AS-2 (n=8)

The effectiveness of PTW AS-2 seems particularly dependent on contextual factors involved in the accident, since in 62.5% of cases its effectiveness is limited by them. For only 1 driver of 4, the aid would have prevented the accident. However, for 1 out 8 drivers, the aid would not have been effective and would not have prevented the accident.

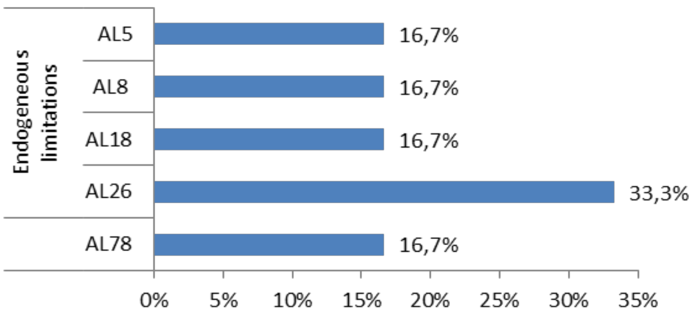

Figure 70: Limiting factors for PTW AS-2 (n=6)

In 33.3% of cases, an erroneous expectation that the vehicle in front will not slow down can modulate the effectiveness of aid (33.3%). It is also the case of a voluntary neglecting a signal due to a deliberate violation or because the driver expected a regulation by the other, of inattention, or the problem of distance / time ratio, all these element limiting the effectiveness of aid in 16.7% of the cases each.

4.3.Car vs. pedestrian accidents

The sample consists of 109 car drivers involved in 109 car vs. pedestrian accidents. Of these 109 drivers, one is passive and therefore does not show any failure and 3 are considered indeterminate and are not taken into account in the following analysis. The focus is put 105 cars drivers with identified failure involved in an accident with a pedestrian. All these 105 drivers show an identified need.

4.3.1. Pivotal human functional failures

In these cars-against-pedestrians accidents, the failures seem to be very specific, involving predominantly perceptual errors (66.7%) and, in a minor proportion, failures in decision making (21.9%).

Tableau 28: Distribution of car drivers' failures

Failure category	% PTW
Detection	66,7%
Diagnosis	4,8%
Prognosis	1,9%
Decision	21,9%
Execution	2,9%
Overall	1,9%
Total	105

4.3.2. Triggering factors

Corresponding to the perceptive failures are found in 42.9% of cases explicative elements involving visibility impairment, specifically those involving the obstruction generated by other vehicles. But are also involved, in quite a frequent way, elements coming from the pedestrian behaviour which was surprising for the driver. Attention problems and the right of way also contribute to car drivers failures when meeting pedestrians.

Table 29: Distribution of the main explicative elements of car drivers functional failures when meeting a pedestrian

Road user status	Right of way status	8.6%
	Identification of potential risk	9.5%
Attention disturbances	Distraction problem	10.5%
	Inattention problem	5.7%
Traffic condition	Surprising other road user behavior	18.1%
	Illegal road user behavior	19.0%
Visibility Impaired	Day/night	7.6%
	Sun glare	8.6%
	Other vehicle(s)	20.0%
	Roadside objects	6.7%

4.1.7. Drivers needs at the rupture phase of the accident

In 38.1% of accidents involving a car and a pedestrian, car drivers need to detect the pedestrian on a transversal trajectory, that is to say a pedestrian who is crossing the roadway or is about to do it. In 20% of cases, drivers have well detected but poorly anticipated his crossing (thinking they will wait). Finally, in 16.2% of cases, drivers need consists in detecting a pedestrian hidden by an object.

Table 30: Distribution of car drivers needs at the rupture stage

Car drivers needs	%
N04	1.9%
N05	1.9%
N06	5.7%
N07	38.1%
N08	4.8%
N09	16.2%
N11	1.9%
N14	4.8%
N19	20.0%
N20	1.9%
N21	2.9%

4.3.3. Safety functions meeting the needs

Table 31: Distribution of safety functions according to car drivers needs covered

	ACC	BS	CA/CW	IC	ISA	NV	RS	TSR	VRU
N04			0.8%						0.8%
N05									1.7%
N06			0.8%		0.8%				4.1%
N07			5.0%	0.8%	0.8%	3.3%			33.1%
N08		2.5%					3.3%		
N09									14.0%
N11	0.8%				1.7%			0.8%	
N14									4.1%
N19			0.8%						16.5%
N20			0.8%						1.7%
N21					0.8%				
Total	0.8%	2.5%	8.3%	0.8%	4.1%	3.3%	3.3%	0.8%	76.0%

The systems most widely used to meet the needs of car drivers in an accident involving a pedestrian are as follows:

- VRU (Vulnerable Road Users Protection, 76%): consistently with the distribution of the needs, this specific aid to pedestrian detection seems particularly useful in cases where the driver needs to detect a pedestrian in a transversal path (crossing or about to cross; 33.1%) to detect a pedestrian hidden by something (14%) or to predict the behaviour of pedestrians already detected (16.5%);

- CA / CW (Collision Avoidance / Collision Warning, 8.3%): this aid dedicated to obstacle detection can meet more particularly the need to detect a pedestrian on a transversal path (5%).

4.3.4. Limitations of the most potentially useful systems

- **Vulnerable Road Users Protection (VRU)**

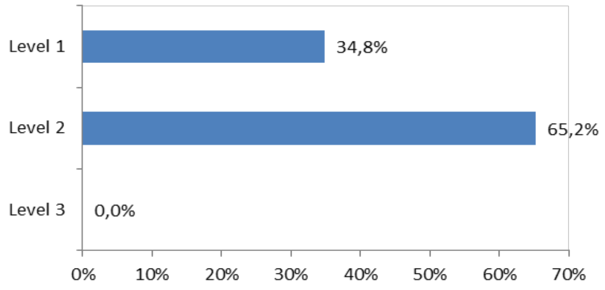

Figure 71: level of efficiency for VRU (n=92)

The effectiveness of VRU seems to depend particularly upon contextual constraints as in 65.2% of cases where it could be useful its effectiveness is moderate. However, in 34.8% of cases, there is no constraint that would impede its efficiency. It would therefore prevent the accident.

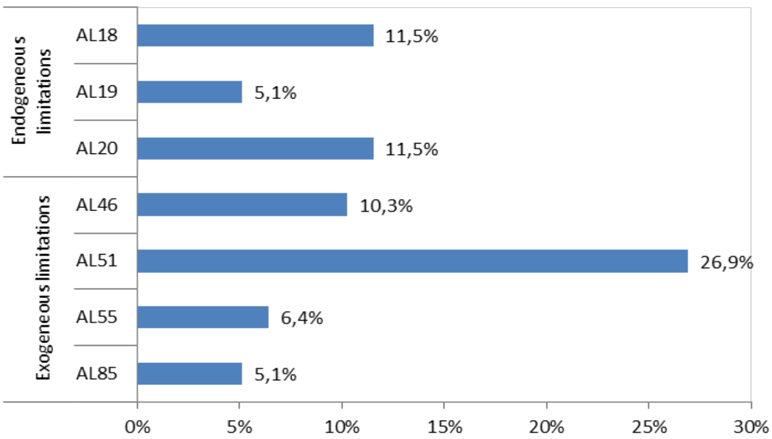

Figure 72: Limiting factors for VRU (n=78)

The main limitation on the effectiveness of this aid consists in visibility hindered by a vehicle (26.9%). Attention problems like inattention and active distraction (11.5%) have less influence, particularly because the aid is capable of triggering automatic emergency braking. Finally, if the accident takes place at intersections, the width of the radar may be insufficient to effectively detect a pedestrian (10.3%).

- **Collision Avoidance / Collision Warning (CA/CW)**

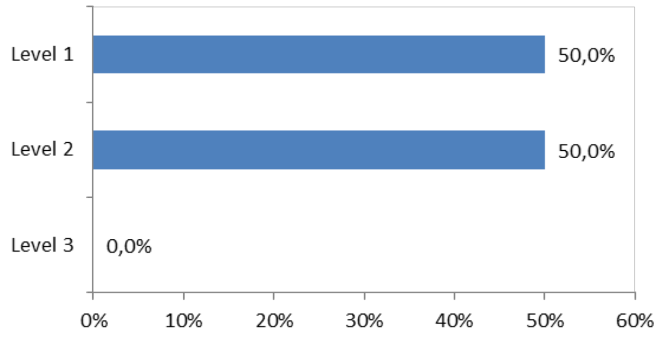

Figure 73: level of efficiency for CA/CW (n=10)

In half of the cases in which it could be useful CA/CW, the system would be completely operating and in the other half its efficiency would be moderated by contextual constraints.

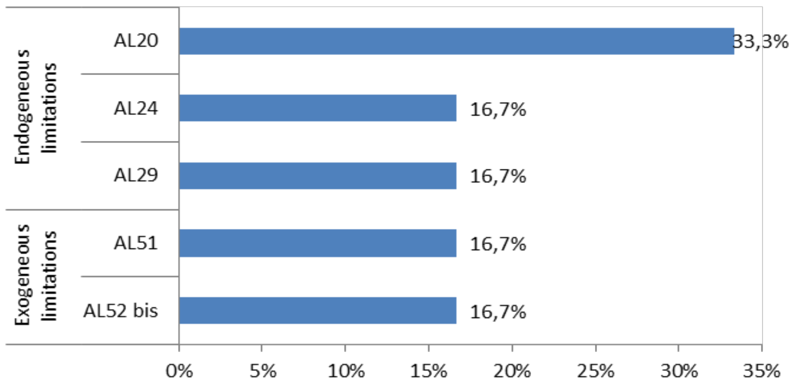

Figure 74: Limiting factors for CA/CW (n=6)

In one third of cases involving a pedestrian and a car, the aid effectiveness is limited by the active distraction of the driver. Other types of problem can come from: an overwhelming of cognitive capacity for some elderly drivers, problems of non-perception of the pedestrian or problems linked to visibility hindered by vehicle or traffic sign which may limit the effectiveness of aid, all these element intervening in an equivalent proportion (16.7%). However, since CA / CW is capable of triggering an automatic emergency braking, the effectiveness of the aid is never completely zero.

4.4.Single vehicle accidents

The sample consists of 87 car drivers and 21 drivers of PTW involved in a single vehicle accident. A functional failure was diagnosed for every of them but 1 car driver for who the failure could not be established due to lack of data (not taken into account in the following analysis). The sample studied consists in 107 drivers with failure identified involved in a single vehicle accidents in interaction. Among these 107 drivers, 103 have an identified need.

4.4.1 Triggering factors

The factors triggering the functional failures of road users at the rupture phase of the situation (i.e. when meeting an unexpected event) in single vehicle accidents differentiate very clearly car drivers and PTW riders.

At the origin of their loss of control, car drivers show a lot of problems connected to their psychophysiological condition, notably involving alcohol and fatigue, which is far less the case for PTW riders. Another differentiation between these two kinds of road users when involved in single vehicle accident is the question of risk taking, which is far more represented for car drivers than PTW riders, notably with the problem of speed. A too weak experience of driving is more characteristic of car drivers while the poor experience of the vehicle driven is more representative of PTW riders, showing the importance of this specific adaptation for riding activity. Car drivers are more likely to have attention difficulties, partly in connection with their over experience of the route. Contaminants on the road such appear in nearly twice the case of PTW losses of control than car riders' ones. Road Geometry is a problem for both of them. Problems with the tyres specifically affect riders.

Table 32 : Distribution of the main triggering factors

		Car drivers	Drivers of PTW
Psycho-physiological condition	Substances taken - alcohol	26.7%	9.5%
	Substances taken - Medication	7.0%	4.8%
	Emotional	10.5%	0.0%
	Fatigue	20.9%	4.8%
	Panic	7.0%	0.0%
Risk taking	Illegal Speed	20.9%	9.5%
	Legal Speed but inappropriate	19.8%	0.0%
Little/None Experience	Driving	12.8%	0.0%
	Route	7.0%	4.8%
	Vehicle	5.8%	33.3%
Over-experienced	Route	20.9%	9.5%
Attention disturbances	Distraction problem	16.3%	4.8%
	Attention competition problem	2.3%	9.5%
	Inattention problem	11.6%	4.8%
Road Condition	Contaminants: Wet/Flood/Snow	16.3%	28.6%
	Contaminants: Sand/Gravel/Mud	2.3%	9.5%
	Surface defects	5.8%	0.0%
Road Geometry	Bend(s)	17.4%	14.3%
	Road width	5.8%	0.0%
	Monotonous Layout	9.3%	0.0%
Traffic Condition	Other road user(s) : Atypical maneuvers	7.0%	0.0%
	Disruptive behaviour of another user	7.0%	4.8%
Visibility Impaired	Terrain profile	1.2%	9.5%
Other Environmental Factors	Animals	5.8%	9.5%
Maintenance	Tyre(s)	4.7%	14.3%

4.4.2 Pivotal human functional failures

Consistently with this type of accident, it is mostly execution type errors that origins the accident, whether for car drivers (39.5%) or PTW riders (61.9%). We note however that PTW riders have more executive failure than cars drivers, which is explainable considering the more important intrinsic difficulty of riding (necessity to manage balance, sensibility to road defects, etc.). For PTW riders, it is also found 23.8% of perceptual error which led to their loss of control. In other words, it is because they did not see some elements of the environment they are caught and lose control of their vehicle. Car drivers involved in single vehicle accident show a generalized failure in a quarter of the cases (25.6%), followed by a diagnosis (appraisal or understanding) failure (22.1%)

Table 33: Distribution of car drivers failures

Failure category	% Cars	% PTW
Detection	7.0%	23.8%
Diagnosis	22.1%	4.8%
Prognosis	2.3%	0.0%
Decision	3.5%	0.0%
Execution	39.5%	61.9%
Overall	25.6%	9.5%
Total	86	21

4.1.8. Drivers needs at the rupture phase of the accident

Once again consistently with this type of accident, it is the need in vehicle control which is found in the majority, both in car drivers (35.4%) and among PTW riders (66.7%). 28% of car drivers show the need in detection of a deviation from the trajectory (in line with the fact that 25.6% of the drivers have a generalized failure).

Table 34: Distribution of car drivers needs at the rupture stage

	Car single	PTW single
N01.1	9.8%	0.0%
N01.2	1.2%	0.0%
N03	4.9%	9.5%
N04	1.2%	4.8%
N05	2.4%	0.0%
N06	2.4%	4.8%
N07	1.2%	9.5%
N10	28.0%	0.0%
N11	7.3%	4.8%
N12	2.4%	0.0%
N19	1.2%	0.0%
N20	1.2%	0.0%
N21	35.4%	66.7%
N22	1.2%	0.0%
Total	86	21

4.4.3 Safety functions meeting the needs

The systems most widely useful to meet the needs of car drivers involved in a loss of control are as follows:

- ESC (Electronic Stability Control, 24.4%): this aid primarily addresses a need in the vehicle control (23.1%) but also, to a lesser extent, a need for predicting the manoeuver appropriate to the site (1.3%);
- LKA (Lane Keeping Assistant, 17.9%): this aid is able to meet four requirements, but especially the need for detection of a deviation from the path (12.8%);
- LDW (Lane Departure Warning, 14.1%) as the previous one, this system primarily answers a need in detection of a deviation from the path (12.8%);
- DDS (Drowsy Driver Detection System, 9%): this system can meet 3 needs but mostly a need in diagnosis of the state of fatigue (6.4%).

Tableau 35: Distribution of safety functions according to car drivers needs covered

	CA/CW	DDS	eCall	ESC	IC	INFRA AS-1	INFRA AS-2	INFRA AS-3	ISA	LDW	LKA	LoFrctD	NV	RollD
N01.1		6.4%				1.3%					2.6%			
N01.2											1.3%			
N03					1.3%			2.6%				1.3%		
N04	1.3%													
N05													2.6%	
N06	2.6%													
N07	1.3%													
N10	1.3%	1.3%						1.3%		12.8%	12.8%			
N11								2.6%	1.3%			3.8%		
N12								1.3%	1.3%					
N20				1.3%										
N21		1.3%		23.1%			3.8%		1.3%	1.3%	1.3%			1.3%
N22			1.3%											
Total	6.4%	9.0%	1.3%	24.4%	1.3%	1.3%	3.8%	7.7%	3.8%	14.1%	17.9%	5.1%	2.6%	1.3%

The most widely useful aid to meet the needs of PTW riders losing control are:

- PTW AS-1 (Forward and intersection collision avoidance): 38.5%;
- PTW AS-3 (Intelligent Speed Adaptation): 15.4%;
- INFRA AS-3 (Bend Alert): 15.4%.

Table 36: Distribution of safety functions according to PTW drivers needs covered

PTW riders	ABS	ACC	INFRA AS-2	INFRA AS-3	PTW AS-1	PTW AS-3	PTW AS-11
N03			7,7%	7,7%			
N04					7,7%		
N06					7,7%		
N07					15,4%		
N11						7,7%	
N21	7,7%	7,7%		7,7%	7,7%	7,7%	7,7%
Total	7,7%	7,7%	7,7%	15,4%	38,5%	15,4%	7,7%

4.4.4 Limitations of the most potentially useful systems

4.4.5.1. Car drivers in single vehicle accidents

- **Electronic Stability Control (ESC)**

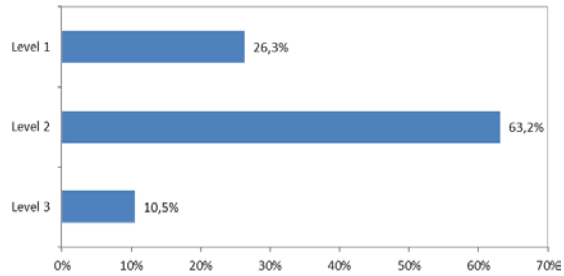

Figure 75: level of efficiency for ESC (n=19)

In 26.3% of cases where ESC is used to meet the needs of car drivers in single accident, it has a very effective role and would permit to avoid accidents. In contrast, 63.2% of cases, the contextual elements of the accident may limit the effectiveness of aid. In some cases (10.5%), the aid is completely ineffective.

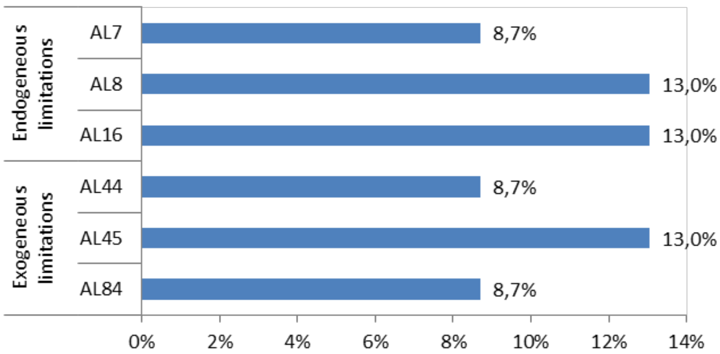

Figure 76: Limiting factors for ESC (n=23)

Endogenous factors such as not taking into account the aid due to over experience of the journey (8.7%) or deliberate violation (13%) as well as the influence of alcohol (13%) may limit the effectiveness of the system. However, exogenous factors may also limit the effectiveness of aid, especially when dynamic constraints are too high because of loading (8.7%) or speed (13 %) or when the tyres are in poor condition (8.7%).

- **Lane Keeping Assistant (LKA)**

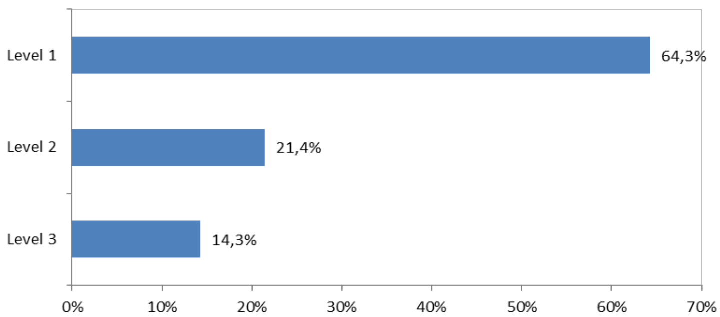

Figure 77: level of efficiency for LKA (n=14)

LKA seems very effective to meet the needs of car drivers in single vehicle crashes. Indeed, in 64.3% of cases where it is used it would have prevented the accident. We note that in 21.4% it would have had a moderate efficiency depending on contextual factors and in 14.3% of cases its effectiveness would be zero.

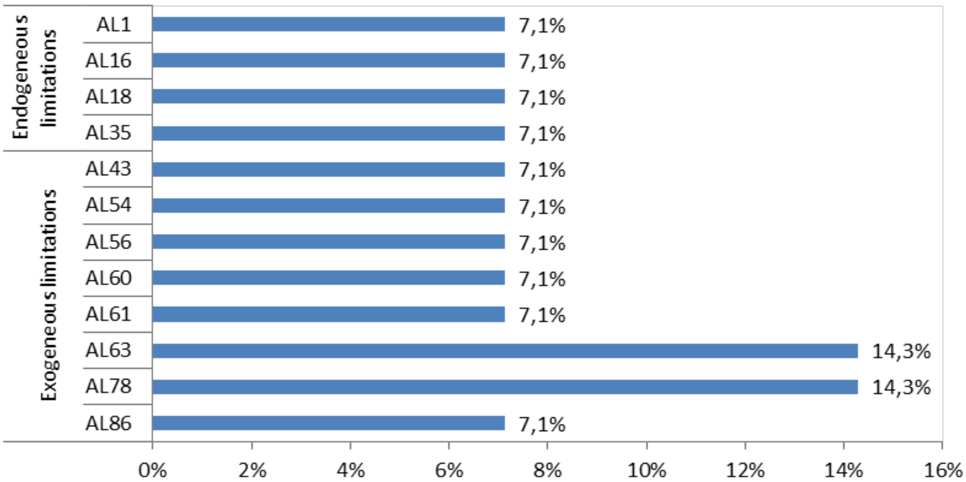

Figure 78: Limiting factors for LKA (n=14)

When contextual factors come into play and limit the effectiveness of aid, it is essentially exogenous factors (71.2%) such as defects of infrastructure design (14.3%), a too small relative distance / time (14.3%), etc.

- Lane Departure Warning (LDW)

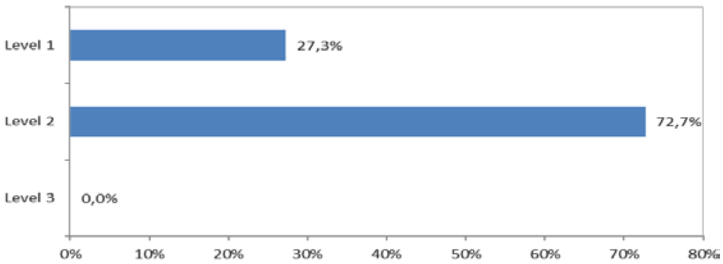

Figure 79: Level of efficiency for LDW (n=11)

LDW seems to be very sensitive to contextual constraints, being totally efficient in only 27.3% of the cases.

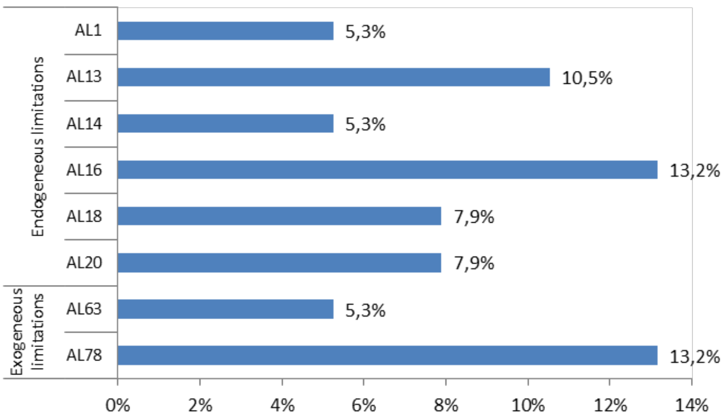

Figure 80: Limiting factors for LDW (n=38)

The main limiting factors of LDW are a too small distance / time after the warning (13.2%), the influence of alcohol (13.2%) and drowsiness (10.5%).

- **Drowsy Driver Detection System (DDS)**

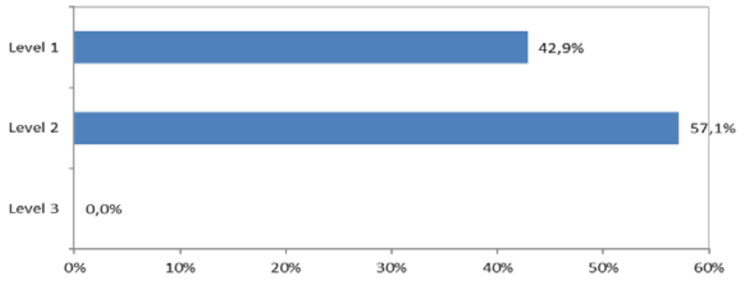

Figure 81: Level of efficiency for DDS (n=7)

In 57.1% of cases where the aid would be used, contextual elements could limit the effectiveness of aid, but in 42.9% of cases it would have prevented the accident.

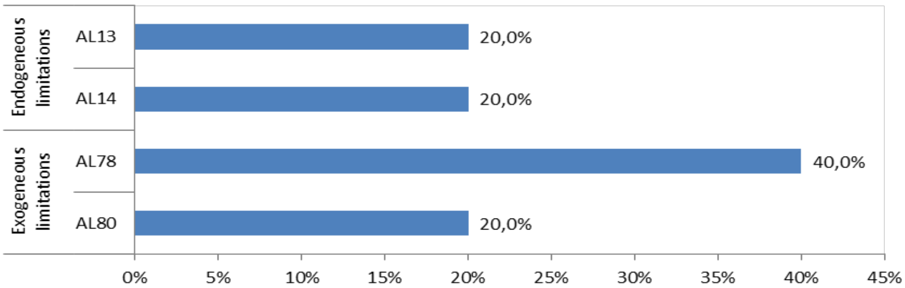

Figure 82: Limiting factors for DDS (n=5)

The main factor that may limit the effectiveness of DDS is the lack of time and space from the moment the signal is given (40%). In addition, psycho-physiological factors such as sleepiness (20%) or disease (20%) may influence the effectiveness of the aid. Finally, an too low alarm sound volume (20%) can default to the effectiveness of aid.

4.4.5.2 PTW riders in single vehicle accidents

The sample of in-depth studies involving single PTW accidents was too small to be able to produce precise results for each safety system considered. In the following are just given some tendencies on the efficiency of these systems as regard to riders' needs.

- **Forward and intersection collision avoidance (PTW AS-1)**

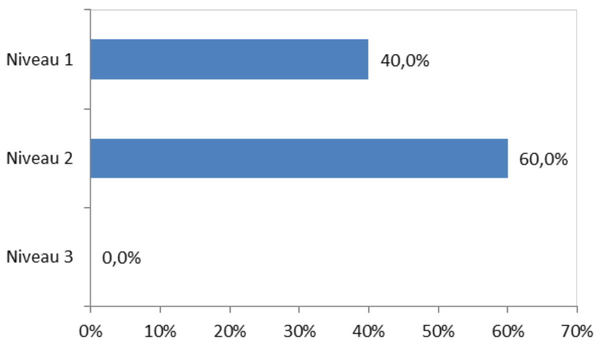

Figure 83: level of efficiency for PTW AS-1 (n=5)

In 40% of cases where the system is used, it would avoid the accident. However, in 60% of cases, contextual factors have modulated its effectiveness.

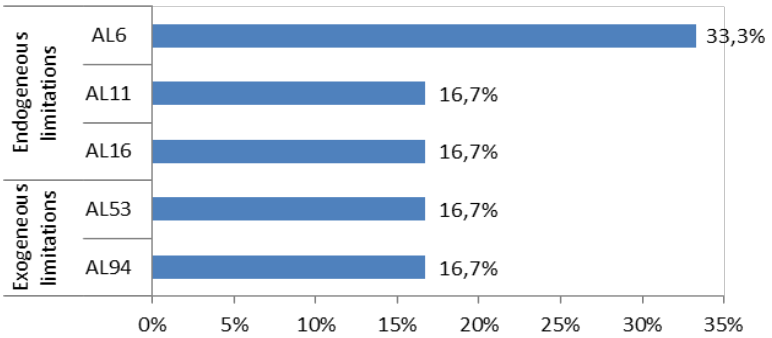

Figure 84: Limiting factors for PTW AS-1 (n=6)

The main parameters potentially weakening the efficiency of Collision Avoidance function for PTW riders refers to their feeling of right of way, hypo-vigilance, influence of alcohol and visibility limited by infrastructure.

- Bend Alert (INFRA AS-3)

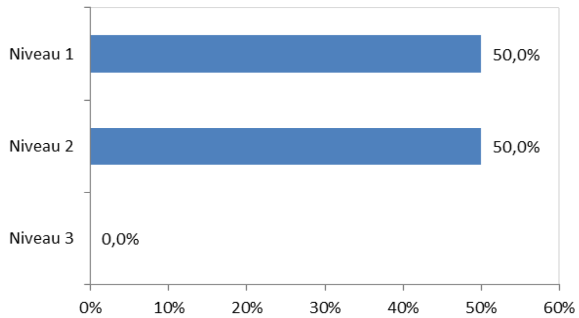

Figure 85: Level of efficiency for INFRA AS-3 (n=2)

In one case out of two, the aid can be fully effective or moderately effective depending on contextual constraints

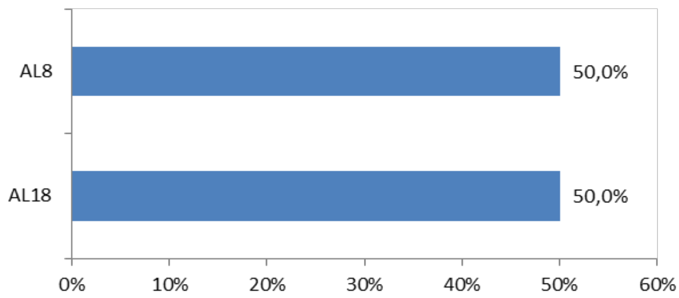

Figure 86: Limiting factors for INFRA AS-3 (n=2)

The 2 limiting factors of efficiency for Bend Alert at the rupture phase in PTW single vehicle accidents are the deliberate violation or inattention of the riders involved.

- **Intelligent Speed Adaptation (PTW AS-3)**

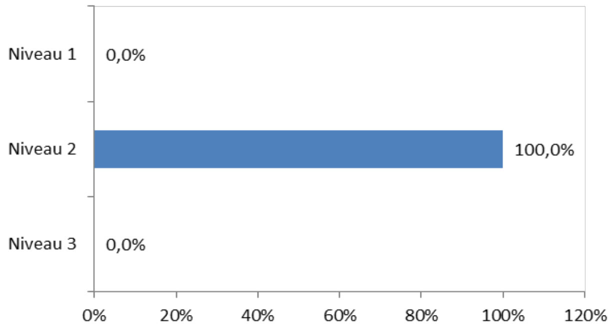

Figure 87: : Level of efficiency for PTW AS-3 (n=2)

In that accident configuration, ISA system for PTWs is considered moderately efficient.

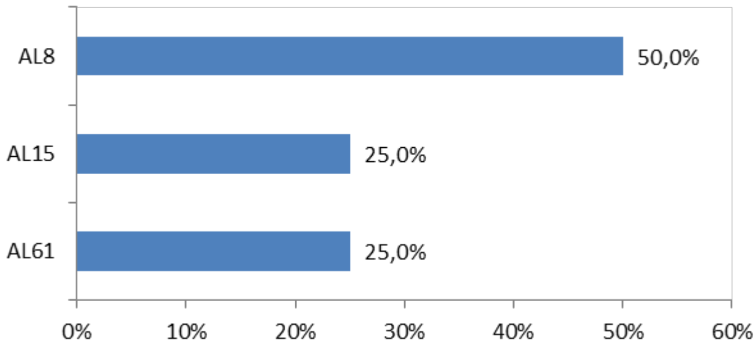

Figure 88: Limiting factors for PTW AS-3 (n=2)

The main elements leading to a lower effectiveness of ISA for PTW riders were in the cases studied: the deliberate violating behaviour of the rider, influence of a drug and a defect of road design.

5. EMERGENCY PHASE

It is the period during which the driver tries to return to the normal situation by carrying out an emergency manoeuvre. A particular feature of this stage is that the driver faces very severe constraints (both temporal and dynamic) with regard to the options open to him.

The emergency phase covers the space and time between rupture and impact. If the rupture situation gives a statement of the problem in hand, the emergency situation defines the space-time 'credit' available in which to solve it. This 'credit' is, by definition, extremely limited.

The emergency situation can be determined in relation to the driving situation by the sudden excessive demand level imposed on the system components. The driver must solve, within a given time, a problem that is, in principle, entirely new to him. The range of solutions depends on the environment in terms of hostile obstacles or the space available for evasive action. The capacity of the vehicle to perform the required manoeuvre depends not only on its design and state of repair but also, when referring to vehicle-ground liaison, on the state of the infrastructure. The emergency situation reveals the insufficiencies or defects in one or another of the system components, weaknesses that remain tolerable when faced with normally moderate driving situation demands.

The emergency manoeuvre is an attempt to find a solution to a problem. It sometimes succeeds, but in accident databases this manoeuvre has failed. So the emergency situation is followed by the crash phase.

At this emergency phase will be defined: the Emergency failure (Step 7) and the emergency Impeding factors (step 8).

5.1. Car vs. car accident

5.1.1. Emergency failures

For 40.6% of car drivers involved in an accident with another car driver, the crash was diagnosed inevitable considering the parameters characterizing the emergency situation, and notably the lack of time and / or space to react (no emergency manoeuver) or to react properly (the manoeuver performed was not efficient enough). Moreover, 36.7% of drivers were unable to avoid the accident because they even did not detect the emergency situation.

Table 37: Distribution of car drivers failures at the emergency stage

ND	36,7%
D	10,6%
E	12,1%
Unavoidable	40,6%
Total	207

5.1.2. Emergency impeding factors

The factors having contributed to the failure of the emergency manoeuvre or to the fact it was not even attempted are to be defined for every road user involved, whether they refer to the human part, the vehicle and the layout. These factors were looked for in the overall list of factors, with the possibility to retain 1 to 5 of them.

When considering car v. car accident, the elements that put the drivers in a difficult condition to realize an emergency manoeuvre are more often found the physiological and attention state of the driver, their risk taking attitude, their feeling of right of way, etc., those elements leading them to put forward appropriate manoeuvre later than it could have been. Visibility impairment was also a factor often delaying the capacity to react on time. Traffic condition and in a lesser proportion the road condition limited the capacity to put forward the optimal efficiency avoiding manoeuvre

Physical/Physiological	0.6%
Psycho-physiological condition	14.0%
Road user status	24.4%
Risk taking	18.9%
Little/None Experience	5.5%
Over-experienced	2.4%
Attention disturbances	24.4%
Road Condition	12.8%
Road Geometry	4.9%
Traffic Condition	28.7%
Visibility Impaired	20.1%
Traffic Guidance	1.2%
Other Environmental Factors	0.0%
Electro-mechanical	0.0%
Maintenance	4.3%
Design	1.2%
Load	1.8%

5.1.3. Drivers needs in emergency situation

33 drivers have no identified needs in emergency situation, 2 drivers needs remain undetermined. Most car drivers (45.1%) were in need of assistance for emergency braking. On the other hand, in accordance with the above distribution of the failures, 28.6% of drivers are in need of an early diagnosis of the emergency aspect of the situation in hand.

Tableau 38: Distribution of car drivers needs at the emergency stage

NE.1	10.9%
NE.2	45.1%
NE.3	0.6%
NE.4	14.9%
NE.5	28.6%
Total	175

At the emergency stage of the accident process, the systems most widely useful to meet the needs of drivers are:

- CA / CW (Collision Avoidance / Collision Warning, 42.8%): this seems to help fulfil four types of needs. However, given its characteristics (able to trigger automatic emergency braking), it is particularly useful when drivers need a brake assist (21.8%) or need to detect earlier the emergency situation (13.6%);

- PBA (Predictive Braking Assist, 18.9%): this is logically mainly useful to help meet a brake assistance need (17.7%), this being the primary function of such a system;

- BA (Braking Assist, 11.5%): once again logically, this system is mainly useful to meet a need in brake assistance (11.1%).

Table 39: Distribution of safety functions according to the needs

	ABS	ACC	BA	BS	CA/CW	CBS	ESC	IC	INFRA AS-1	INFRA AS-2	INFRA AS-4	LCA	LDW	LKA	PBA
NE.1			0.4%		2.1%		3.3%			0.4%				2.9%	0.4%
NE.2	6.6%	1.2%	11.1%		21.8%	0.4%	0.4%								17.7%
NE.3										0.4%					
NE.4		0.4%		0.4%	5.3%		0.8%	1.6%			0.4%				0.4%
NE.5	0.4%	1.2%		1.2%	13.6%			2.5%	0.4%		0.0%	0.4%	0.4%	0.4%	0.4%
	7.4%	2.9%	11.5%	1.6%	42.8%	0.4%	4.5%	4.1%	0.4%	0.8%	0.4%	0.4%	0.4%	3.3%	18.9%

5.1.4. Potential limitations of the systems

- **Collision Avoidance / Collision Warning (CA/CW)**

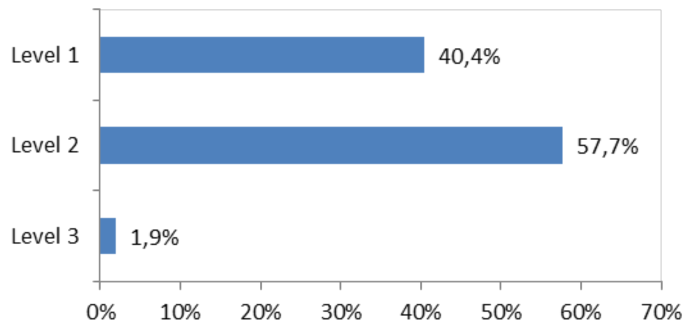

Figure 89: Level of efficiency for CA/CW (n=104)

CA / CW seems quite effective in emergency stage of the accident process. Indeed, it is fully effective in 40.4% and moderately effective in 57.7% of cases, depending on contextual constraints. It is not at all effective in only 1.9% of cases.

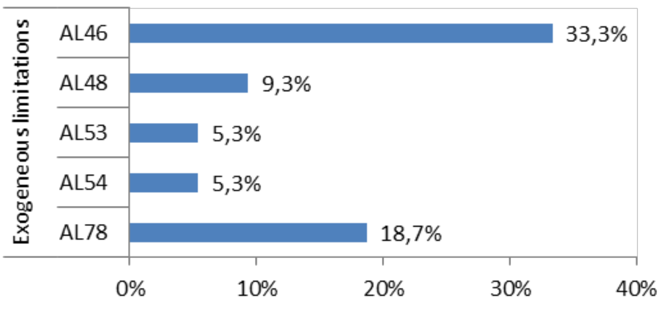

Figure 90: Limiting factors for CA/CW (n=75)

For this system the potential limiting factors are exclusively of exogenous origin. For a third of accidents, it is possible that the width of the radar is insufficient to detect an obstacle (a car) on an intersection. On the other hand, once the radar has detected an obstacle, in 18.7% of cases the system does not have enough time and space to apply an efficient emergency braking.

- **Predictive Braking Assist (PBA)**

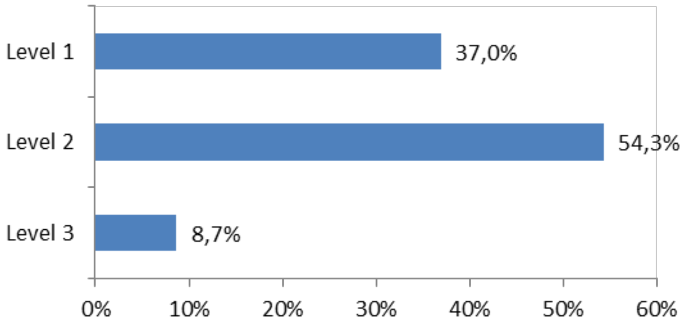

Figure 91: Level of efficiency for PBA (n=46)

PBA aid seems also quite effective. Although the contextual elements of the accident modulate its efficacy in 54.3% of cases, it is fully effective in 37% of cases. Note that for only 8.7% of accidents effectiveness of aid is zero.

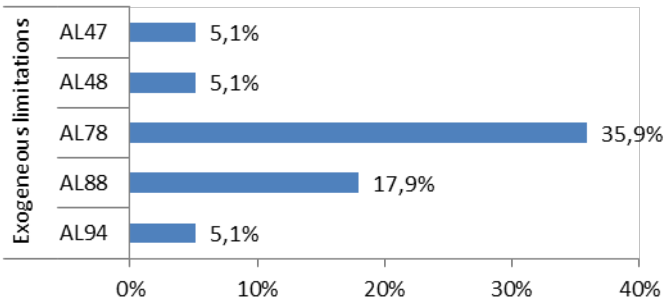

Figure 92: Limiting factors for PBA (n=39)

The limiting factors are exclusively of exogenous origin. Effectively, 35.9% of drivers do not have enough time and space to avoid accidents even with the help of PBA. Nevertheless, the consequences of the accident could be reduced as a result of its triggering. On the other hand, since the system is not automatic, in 17.9% of cases, late braking by the driver causes a late onset of the PBA system which can reduce the consequences of the accident but may be unable to avoid accidents.

- **Braking Assist (BA)**

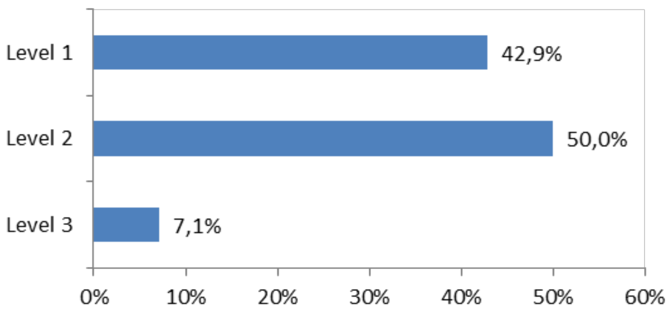

Figure 93: Level of efficiency for BA (n=28)

BA seems quite effective. For half of car drivers involved in an accident with another car driver, contextual factors are such that that aid is moderately effective. However, it is completely effective in 42.9% of cases. Efficiency is zero in 7.1% of cases.

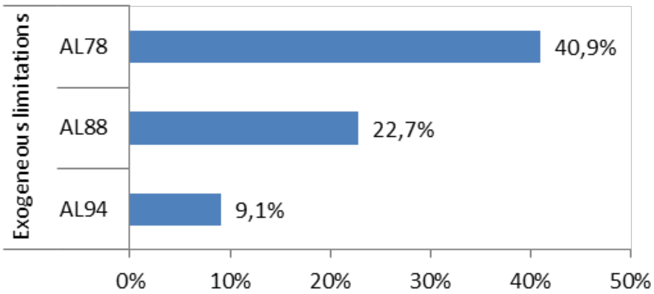

Figure 94: Limiting factors for BA (n=22)

The factors limiting the effectiveness of the system are exclusively of exogenous origin. The main limitation remains a relative distance / brake reaction time too small to allow the driver to avoid accidents (40.9% of cases). Nevertheless, the consequences of the accident can be reduced. In addition, a late braking action by the driver (22.7%) or no braking at all (9.1%) necessarily limits the aid effectiveness.

5.2.Car vs. PTW accident

5.2.1. Emergency failures

For eleven drivers the functional failure remains undetermined due to lack of data (8 car drivers, 3 PTW riders).

In these accidents involving a car driver and a PTW rider, 67% of car drivers did not detect the emergency situation, against 15% of PTW riders. This is most likely related to the difficult perception of PTW (by not noticing the PTW, the drivers did not notice in the same way the consecutive emergency). It is also noted that 50.8% of PTW riders could not avoid the accident (because of time and space, and linked to the intrinsic difficulty of performing an emergency maneuver on a PTW), against 20.9 % for car drivers. In addition, it is found that 28.3% of PTW drivers adopted a proper emergency manoeuver but with a poor execution of it (too sudden braking, wheel lock...).

Table 40: Distribution of car drivers and PTW riders emergency failures

	% Cars	% PTW
ND	67.0%	15.0%
D	7.8%	5.8%
E	4.3%	28.3%
Unavoidable	20.9%	50.8%
	115	120

5.2.2. Emergency impeding factors

The emergency manoeuver performed at the emergency stage of accident processes involving a car and a PTW were partly differently weakened according to the factors involved. The factor more specifically affecting PTW riders is risk taking, whereas car drivers are more affected by attention disturbances. However traffic condition and visibility impairment constitute common explicative elements for the failure of the emergency manoeuver for both of these users.

Table 41 : Distribution of the main emergency impeding factors

	Cars	PTW
Physical/ Physiological	0.0%	2.7%
Psycho-physiological condition	7.5%	5.4%
Road user status	7.5%	12.5%
Risk taking	7.5%	27.7%
Little/None Experience	1.1%	8.0%
Over-experienced	2.2%	1.8%
Attention disturbances	28.0%	11.6%
Road Condition	4.3%	9.8%
Road Geometry	0.0%	1.8%
Traffic Condition	16.1%	27.7%
Visibility Impaired	32.3%	21.4%
Traffic Guidance	0.0%	1.8%
Other Environmental Factors	0.0%	0.0%
Electro-mechanical	0.0%	3.6%
Maintenance	0.0%	2.7%
Design	3.2%	-
Load	2.2%	-
Specific factors linked to meeting a PTW	9.7%	-

5.2.3. Drivers needs in emergency situation

For 40 drivers no needs were identified in emergency situations (29 cars 11 PTWs) and for 8 drivers the need remain indeterminate due to lack of data (4 cars and 4 PTWs).

In a parallel way to failures distribution outlined above, 68.9% of car drivers have a need for emergency diagnosis, against 12% for PTW drivers, and 72.2% of PTW drivers have a need braking assistance, against 17.8% for car drivers. So these two categories of motorized road users can be considered as significantly different.

Tableau 42: Distribution of car drivers and PTW riders needs at the emergency stage

	% Cars	% PTW
NE.1	3.3%	6.5%
NE.2	17.8%	72.2%
NE.3	0.0%	2.8%
NE.4	10.0%	6.5%
NE.5	68.9%	12.0%
Total	90	108

Safety functions adapted to car drivers needs

At the emergency stage of the accident process, the aid most widely used to meet the needs of car drivers are:

- CA / CW (Collision Avoidance / Collision Warning, 50.6%): this aid can meet three types of needs. However, given its characteristics (can trigger automatic emergency braking), it is particularly useful when drivers need to detect the emergency situation (39%) or brake assistance (10.4%);

- PBA (Predictive Braking Assist, 15.6%): is not surprisingly mainly useful to meet a need in a more efficient braking (14.3%);

- BA (Brake Assist, 11.7%): is also essentially useful to meet needs in a more efficient braking (11.7%).

Table 43: Distribution of safety functions according car drivers needs covered

	ABS	ACC	AFU	BA	BS	CA/CW	ESC	IC	LCA	PBA	RS	PTW AS-11
NE.1							1.3%					1.3%
NE.2	1.3%		1.3%	11.7%		10.4%				14.3%		
NE.4						1.3%				1.3%		
NE.5		1.3%			6.5%	39.0%		3.9%	3.9%		1.3%	
	1.3%	1.3%	1.3%	11.7%	6.5%	50.6%	1.3%	3.9%	3.9%	15.6%	1.3%	1.3%

Safety functions adapted to PTW riders needs

For PTW facing an emergency situation when meeting a car, the systems most widely useful to the riders are:

- PTW AS-13 (Combined Brake Systems, 37%): this aid addresses three needs but essentially a need in braking (35.8%). This would allow to compensate for poor execution in emergency manoeuver, notably by distributing the braking when it is triggered on one wheel only;

- PTW AS-12 (Anti-Lock Brake Systems, 23.5%): this aid meets two needs, but more specifically, it is used when drivers need a braking assistance (22.8%). Again, this system would allow to compensate for poor execution of emergency manoeuver by preventing the wheels from locking in case of strong braking;

- PTW AS-1 (Forward and intersection collision avoidance, 15.4%): this system seems able to meet three types of needs. However, given its characteristics (able to trigger automatic emergency braking), it is particularly useful when drivers need a brake assistance (6.8%) or to detect emergency situation (5.6%).

Tableau 44: Distribution of safety functions according PTW riders needs covered

	BA	CBS	PBA	PTW AS-1	PTW AS-5	PTW AS-11	PTW AS-12	PTW AS-13	PTW AS-15	PTW AS-16	PTW AS-20
NE.1						3.7%	0.6%	0.6%			
NE.2	1.2%	3.7%	1.2%	7.4%		3.7%	25.3%	35.8%	3.7%	2.5%	
NE.4				3.1%							
NE.5				5.6%	0.6%			0.6%			0.6%
	1.2%	3.7%	1.2%	16.0%	0.6%	7.4%	25.9%	37.0%	3.7%	2.5%	0.6%

5.2.4. Potential limitations of the systems

5.2.4.1. For car drivers when confronted with PTWs

- Collision Avoidance / Collision Warning (CA/CW)

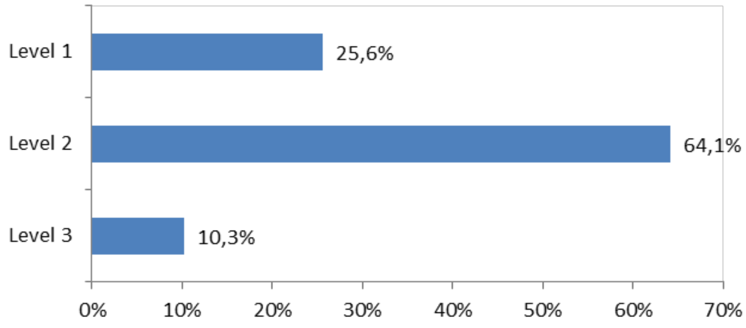

Figure 95: Level of efficiency for CA/CW (n=39)

In a quarter of cases, this aid is entirely effective. Nevertheless the effectiveness of the system seems most often relativized by contextual elements as in 64.1% of cases it is moderately effective, and in 10.3% of cases its effectiveness is nil.

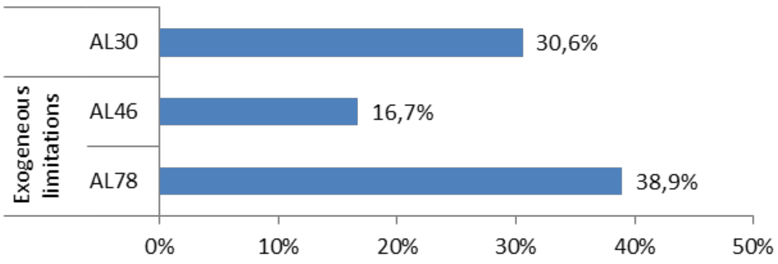

Figure 96: Limiting factors for CA/CW (n=36)

Three main factors are potentially limiting the effectiveness of CA/CW. In 38.9% of cases where the aid could be useful, the braking distance is too short from the obstacle detection to enable it to be fully effective. In 30.6% of cases it is a problem of late perception of the motorcyclist. Finally, in 16.7% of cases, the width of the radar is insufficient to detect an obstacle on an intersection.

- Predictive Braking Assist (PBA)

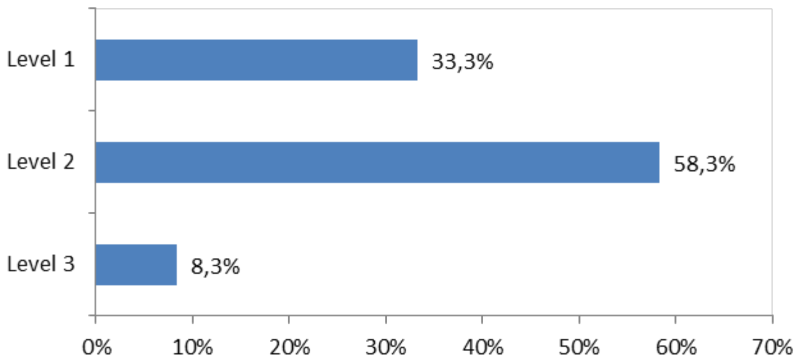

Figure 97: Level of efficiency for PBA (n=12)

PBA seems to be moderately effective when confronted to accident situations. For 58.3% of car drivers involved in an accident with PTW, the contextual constraints modulate the full effectiveness of the system. However, in one third of the cases, the use of this aid could have avoided the accident. For 8.3% of drivers, aid is ineffective.

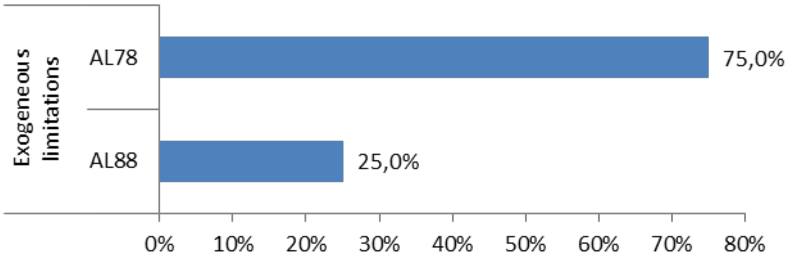

Figure 98: Limiting factors for PBA (n=8)

For 3 car drivers out of 4, the relative distance / brake reaction time is too small to allow them to avoid the accident. However, this does not mean that the consequences of the accident are not reduced at all. A quarter of drivers, a late braking action could limit the effectiveness of aid.

- **Brake Assist (BA)**

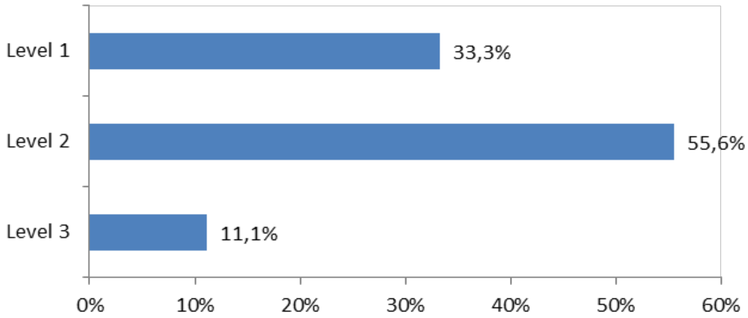

Figure 99: Level of efficiency for BA (n=9)

BA is moderately effective for 55.6% of car drivers involved in an accident with a PTW, contextual constraints modulating its effectiveness. These constraints of the situation would make the use of the system ineffective in 11.1% of drivers. However, a third of drivers using this aid, the accident could have been avoided.

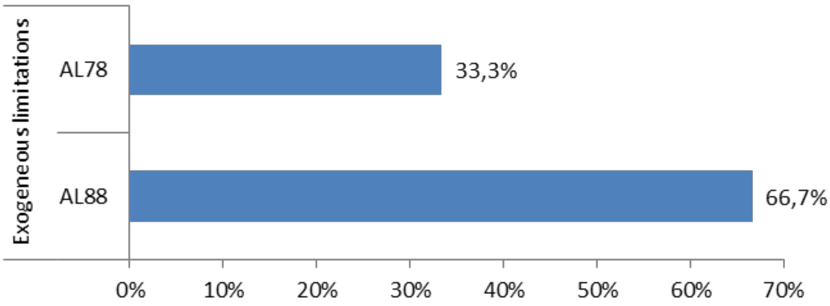

Figure 100: Limiting factors for BA (n=6)

The limitations are the same as above but in different proportions. In 2 out of 3 cases, the late braking by the driver may impede the aid effectiveness and in the other third it is a too short distance / brake reaction time ratio.

5.2.4.2. For PTW riders confronted with cars

- **Anti-Lock Brake Systems (PTW AS-12)**

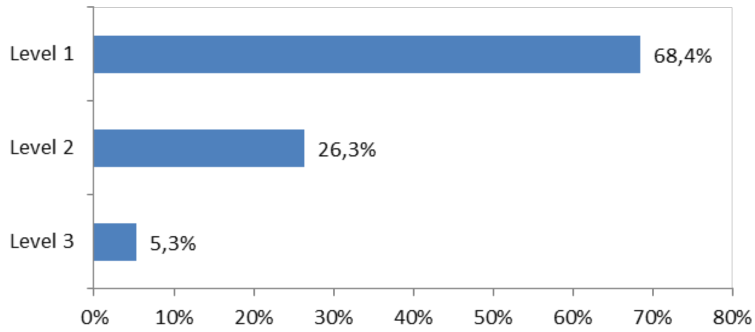

Figure 101: Level of efficiency for PTW AS-12 (n=42)

This aid seems really effective for PTW riders as in 68.4% of cases where it is used to meet their needs, it would have prevented the accident. Contextual factors would limit its effectiveness in 26.3% of cases or make it ineffective in only 5.3% of cases.

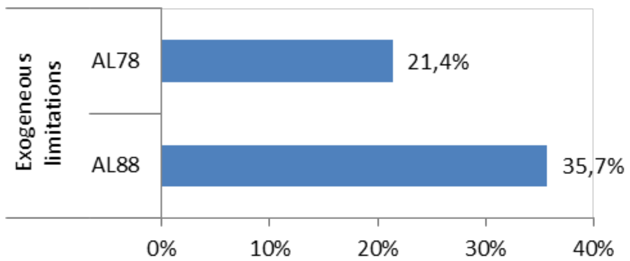

Figure 102: Limiting factors for PTW AS-12 (n=14)

The limiting factors are exclusively of exogenous origin. The effectiveness of this assistance may be limited by a late braking action by the rider (35.7%) or a relative distance / brake reaction time is too small (21.4%).

- **Combined Brake Systems (PTW AS-13)**

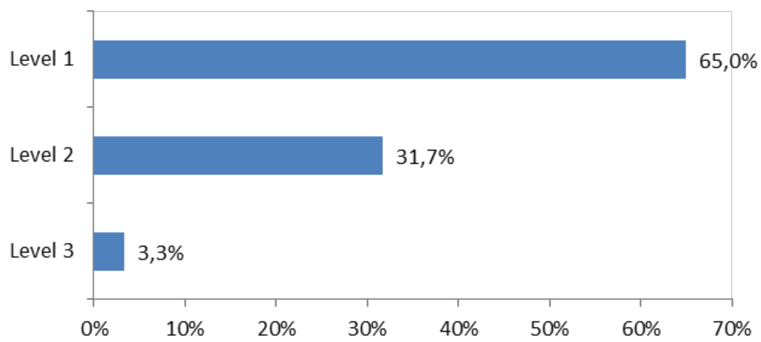

Figure 103: Level of efficiency for PTW AS-13 (n=60)

This system also seems to work efficiently as for 65.0% of cases where it is used to meet the needs of PTW riders, it would have prevented the accident. Contextual factors would have limited its effectiveness in 31.70% of cases but nearly no accident case show no benefit from the system.

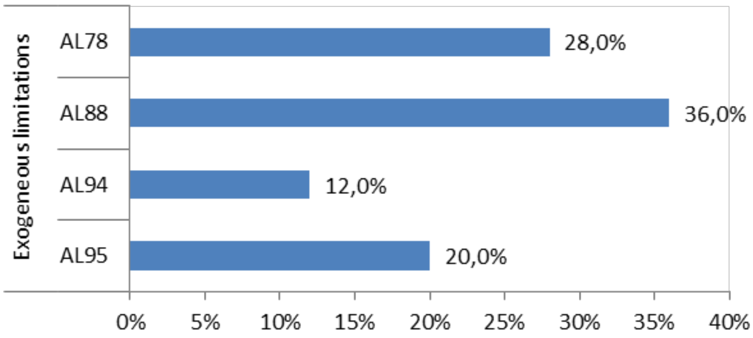

Figure 104: Limiting factors for PTW AS-13 (n=25)

The limiting factors are largely exogenous origin. In 36% of cases, aid effectiveness could be limited by a late braking action or reduced adhesion (by gravel in 20% of cases, the road surface in 20% of cases). In addition, deliberate violation behaviour may hinder the effectiveness of aid in certain cases.

- Forward and intersection collision avoidance (PTW AS-1)

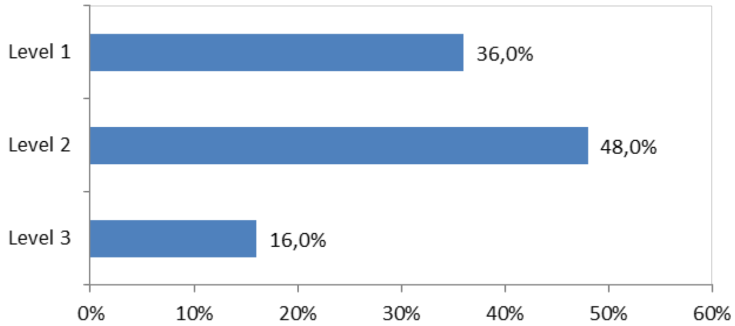

Figure 105: Level of efficiency for PTW AS-1 (n=26)

In 36% of cases where the aid is useful to meet the needs of PTW riders, it would have prevented the accident. However, its effectiveness would have been limited by the contextual constraints in 48% of cases, leading to no gain in 16% of cases.

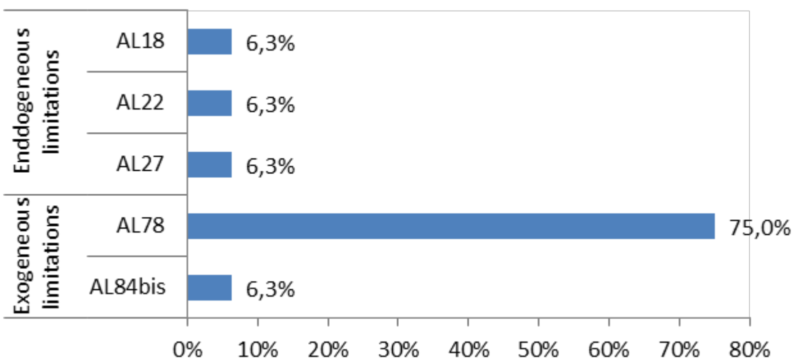

Figure 106: Limiting factors for PTW AS-1 (n=16)

The main limiting factor is a ratio distance / time too small to allow aid to be effective and to avoid the accident. In other words, from the detection of the obstacle, the system would not have enough time and space to initiate emergency braking efficient (up to immobilization of the PTW).

5.3.Car versus pedestrian accidents

5.3.1. Emergency failures

For 61% of car drivers involved in an accident with a pedestrian, the accident could not be avoided, either because the driver did not have the time or space to react or because the emergency manoeuver performed could not result in an efficient avoidance. In addition, 35.2% of drivers did not perceive the emergency situation, so they could not react on time.

Table 45: Distribution of car drivers emergency failures

ND	35.2%
D	1.9%
E	1.9%
Unavoidable	61.0%
Total	105

5.3.2. Emergency impeding factors

Three essential factors seem to specifically affect the capacity of car drivers to put forward an efficient emergency maneuver for car drivers confronted to a conflict situation with a pedestrian. The first one deals with so-called "traffic condition" referring in that case to the surprising "manoeuver" undertaken by the pedestrian which impeded the driver to react on time. Then there is the problem of visibility impairment which did not give the possibility to the car driver to detect the pedestrian and by such to act on due time. And contributing to that is the problem of attention disturbances.

Table 46: Distribution of car drivers emergency impeding factors

Physical/Physiological	0.0%
Psycho-physiological condition	4.8%
Road user status	8.6%
Risk taking	2.9%
Little/None Experience	0.0%
Over-experienced	0.0%
Attention disturbances	**15.2%**
Road Condition	1.9%
Road Geometry	0.0%
Traffic Condition	**37.1%**
Visibility Impaired	**25.7%**
Traffic Guidance	0.0%
Other Environmental Factors	0.0%
Electro-mechanical	1.9%
Maintenance	5.7%
Design	2.9%
Load	0.0%

5.3.3. Drivers needs in emergency situation

Most car drivers (57.1%) show a need of assistance in emergency braking. On the other hand, in accordance with the above distribution of the failures, 35.2% of drivers in need of a right diagnosis of the emergency situation.

Tableau 47: Distribution of car drivers needs at the emergency stage

NE.1	3.8%
NE.2	57.1%
NE.2	1.0%
NE.4	2.9%
NE.5	35.2%
Total	105

In an emergency situation, the most widely useful aid to meet the needs of drivers are:

- PBA (Predictive Brake Assist, 34.4%): this system is logically more useful to meet drivers needs in braking assistance (31.2%);
- BA (Brake Assist, 32.8%): this system is also more useful to meet drivers needs in braking assistance (29.6%);
- VRU (Vulnerable Road Users Protection, 18.3%): this assistance can detect pedestrians and trigger automatic emergency braking, it essentially responds to the need to provide drivers with a diagnosis of emergency (14.5%).

Table 48: Distribution of safety functions according to the needs

	RS	ABS	BA	CA/CW	ESC	PBA	VRU
NE.1					2.2%		
NE.2		5.4%	29.6%	2.2%		31.2%	2.7%
NE.2			0.5%			0.5%	
NE.4			0.5%			0.5%	1.1%
NE.5	1.6%	0.5%	2.2%	2.7%		2.2%	14.5%
	1.6%	5.9%	32.8%	4.8%	2.2%	34.4%	18.3%

5.3.4. Potential limitations of the systems

- **Predictive Brake Assist (PBA)**

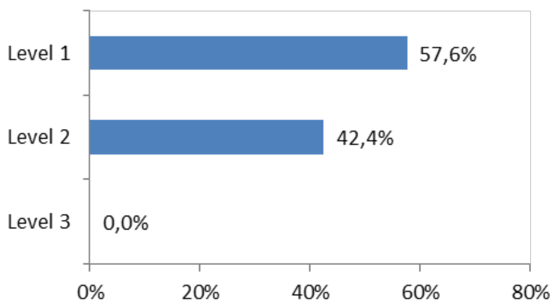

Figure 107: Level of efficiency for PBA (n=66)

This seems to work well because in 57.6% of cases where it is used, it would have prevented the accident. Contextual elements could limit its effectiveness in 42.4% of cases.

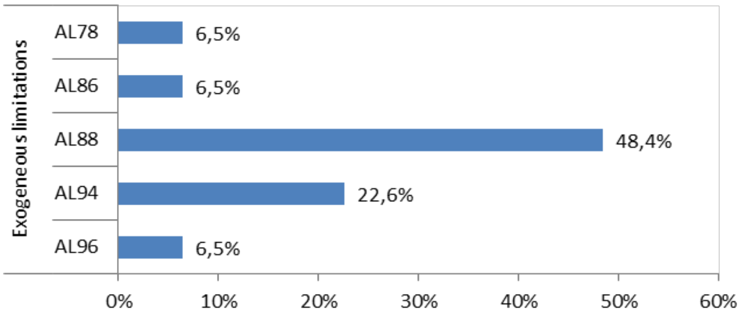

Figure 108: Limiting factors for PBA (n=31)

The limiting factors are exclusively of exogenous origin. The main limitations relate to the driver's late braking (48.4%) or no braking (22.6%). Indeed, this aid is potentially able to detect emergency braking situations, but for that it is still necessary that the driver releases the accelerator pedal and press the brake pedal to trigger the system.

- **Brake Assist (BA)**

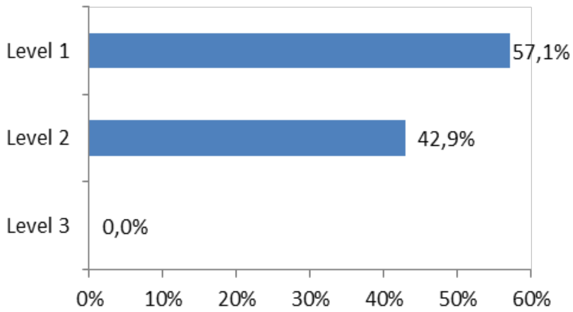

Figure 109: Level of efficiency for BA (n=63)

This aid seems to work in 57.1% of cases where it is useful, and would have prevented the accident. Contextual elements could limit its effectiveness in 42.9% of cases.

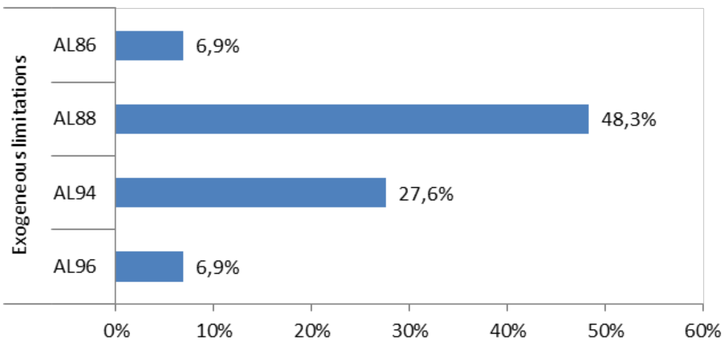

Figure 110: Limiting factors for BA (n=29)

Late braking (48.3%) or no braking (27.6%) are the main limitations to the effectiveness of aid.

- **Vulnerable Road Users Protection (VRU)**

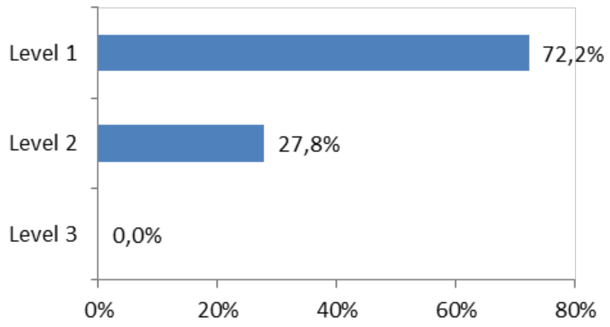

Figure 111: Level of efficiency for VRU (n=36)

This assistance is very efficient since in 72.7% of cases where it is useful to meet the needs of car drivers confronted to pedestrian, and would have a major role in the non-occurrence of the accident. In only 27.8%, its effectiveness would have been limited by contextual factors.

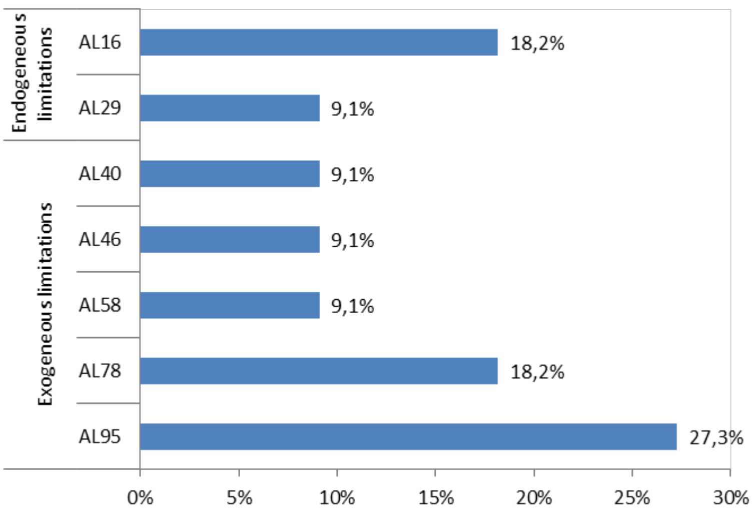

Figure 112: Limiting factors for VRU (n=11)

Among the main factors limiting the effectiveness of the aid are included driving speed (27.3%), the limited ratio distance / time (18.2%) and the influence of alcohol (18.2%).

5.4.Single vehicle accidents

5.4.1.Emergency failures

In this type of accident, the main failure in the emergency phase of the crash process is originally linked to problem of control of action, that is to say that the emergency manoeuver is appropriate but the motor execution fails. This is the case for 43% of car drivers and 60% of PTW riders. On the other hand, for 35% of PTW riders the accident is inevitable because of lack of time and space. Finally, 23.3% of car drivers have made a bad decision on their choice of emergency manoeuver.

Table 49: Distribution of car drivers and PTW riders failures

	% Cars single	% PTW single
ND	19.8%	5.0%
D	23.3%	0.0%
E	43.0%	60.0%
Unavoidable	14.0%	35.0%
Total	86	20

5.4.2.Emergency impeding factors

The most impeding factor of emergency manoeuvre in single vehicle accidents consist for car drivers in the problem of risk taking. For PTW riders it is the road condition; but this is also a factor which plays an important role on the capacity of car drivers to put forward an emergency manoeuver. The road geometry seems surprisingly to affect more car drivers than PTW riders during the emergency phase of the accident. The problems linked with experience are a little bit more concerning PTW riders.

Table 50: Distribution of emergency impeding factors for car drivers and PTW riders in single vehicle accidents

	Cars	PTW
Physical/Physiological	5.8%	0.0%
Psycho-physiological condition	70.9%	19.0%
Road user status	2.3%	0.0%
Risk taking	39.5%	14.3%
Little/None Experience	15.1%	23.8%
Over-experienced	1.2%	0.0%
Attention disturbances	14.0%	4.8%
Road Condition	37.2%	47.6%
Road Geometry	19.8%	4.8%
Traffic Condition	1.2%	0.0%
Visibility Impaired	2.3%	4.8%
Traffic Guidance	1.2%	0.0%
Other Environmental Factors	4.7%	4.8%
Electro-mechanical	3.5%	9.5%
Maintenance	11.6%	4.8%
Design	0.0%	0.0%
Load	2.3%	0.0%

5.4.3.Drivers needs in emergency situation

The majority of car drivers in single vehicle accident need assistance in trajectory control (57.6%). Regarding PTW riders, their needs are more heterogeneous. 44.4% need braking assistance, as it seems that a wrong braking dosage was causing the failure of the emergency manoeuver. In addition, 27.8% of PTW riders need assistance in trajectory control. Finally, for 22.2% of PTW riders, the need is relative to the infrastructure.

Tableau 51: Distribution of car drivers and PTW riders needs at the emergency stage

	% Cars single	% PTW single
NE.1	57.6%	27.8%
NE.2	7.1%	44.4%
NE.3	2.4%	22.2%
NE.4	18.8%	0.0%
NE.5	14.1%	5.6%
Total	85	18

At this stage, the most widely useful systems to meet the needs of car drivers are:

- ESC (Electronic Stability Control, 49.4%): This helps avoiding slippage and is particularly useful to meet the need for assistance in trajectory control (46.8%). It is sometimes used to meet a need in decision making (2.6%) in the sense that it may have helped to correct a decision error (notably in case of braking on a wet road leading the vehicle to skidding);
  - LKA (Lane Keeping Assistance, 14.3%): the aid addresses three needs but is primarily useful when the driver needs assistance in trajectory control (7.8%) or diagnosis of emergency (such as when the deviation from the path is due to sleep; 5.2%).

Table 52: Distribution of safety functions according to car drivers needs

Car drivers	ABS	ACC	BA	CA/CW	DDS	ESC	INFRA AS-1	LDW	LKA	PBA	VRU
NE.1	0.0%	0.0%	2.6%	1.3%	0.0%	46.8%	0.0%	0.0%	7.8%	2.6%	0.0%
NE.2	2.6%	0.0%	2.6%	2.6%	0.0%	0.0%	0.0%	0.0%	0.0%	3.9%	0.0%
NE.3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.3%	0.0%	1.3%	0.0%	0.0%
NE.4	1.3%	0.0%	1.3%	0.0%	0.0%	2.6%	0.0%	0.0%	0.0%	0.0%	0.0%
NE.5	0.0%	1.3%	0.0%	3.9%	2.6%	0.0%	0.0%	3.9%	5.2%	0.0%	2.6%
Total	3.9%	1.3%	6.5%	7.8%	2.6%	49.4%	1.3%	3.9%	14.3%	6.5%	2.6%

In a single accident emergency situation, the systems most widely useful to meet the needs of PTW riders are the following. However, the small numbers of cases can only give uncertain figures:

- PTW AS-13 (Combined Brake Systems): this aid is useful to meet PTW riders needs in 38.9% of the cases.
- PTW AS-12 (Anti-Lock Brake Systems) is useful to 33.3%of the riders of the sample at the emergency phase of the accident process

Tableau 53: Distribution of safety functions according to PTW riders needs

PTW riders	PTW AS-1	PTW AS-11	PTW AS-12	PTW AS-13	PTW AS-15	PTW AS-16
NE.2	0.0%	11.1%	33.3%	38.9%	5.6%	5.6%
NE.5	5.6%	0.0%	0.0%	0.0%	0.0%	0.0%
	5.6%	11.1%	33.3%	38.9%	5.6%	5.6%

5.4.4. Potential limitations of the systems

5.4.4.1. For car drivers in single vehicle accidents

- **Electronic Stability Control**

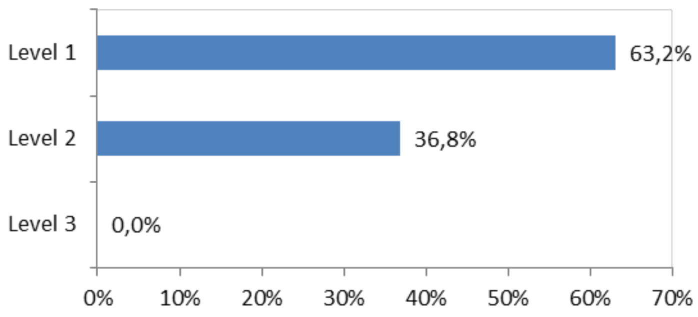

Figure 113: Level of efficiency for ESC (n=38)

ESC seems to constitute a very effective aid in emergency situations. In 63.2% of cases where the system meets the needs of drivers, it would have prevented the accident. In 36.8% of cases, its effectiveness would be modulated by contextual factors.

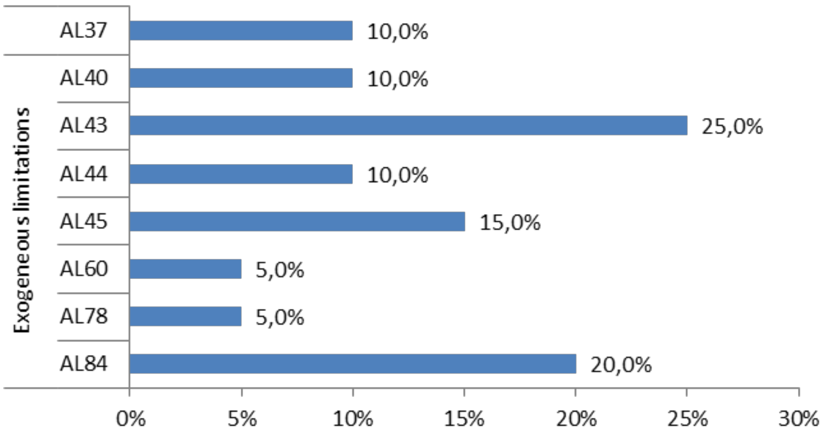

Figure 114: Limiting factors for ESC (n=20)

Factors limiting the effectiveness of ESC are linked to strong dynamic solicitations during loss of control (25%) or in connection with the speed (15%) or tyre problems (20%).

- **Lane Keeping Assistance (LKA)**

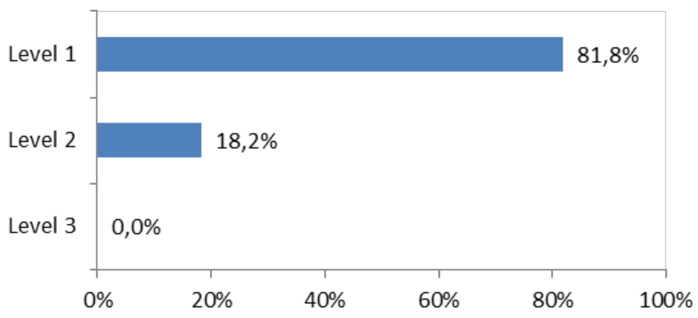

Figure 115: Level of efficiency for LKA (n=11)

LKA also seems very effective aid in emergency situations. In 81.8% of cases it would avoid the accident. In only 18.2% of cases, its effectiveness would be modulated by contextual factors.

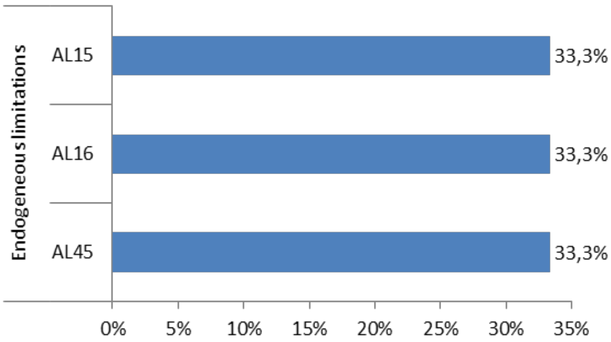

Figure 116: Limiting factors for LKA (n=3)

The influence of alcohol (33.3%) or illicit drug (33.3%), or high dynamic loads due to the speed (33.3%) are the main limitations to the effectiveness of LKA.

5.4.4.2. For PTW riders in single vehicle accidents

The two most represented among aid for riders involved in a PTW accident are PTW AS-13 (= CBS) and PTW AS-12 (= ABS), which both of them show have a potential efficiency of 100%, that is to say, we no limitations were found to these aids in emergency situations.

6. DISCUSSION

Nothing is less easy than giving a general overview of the results developed in the report, first because of the richness of the data coming from in-depth analysis and secondly because accident processes are complex and sequential, which is reflected in the drivers needs and in the capacity of safety functions to address these needs. Everything must at least be analyzed relatively to:

- The accident configuration

The context of the accidents and the drivers' failures are different depending on the whether the accident scenario concerns passenger cars, PTWs, pedestrian or involve single vehicle accidents. Reflecting this difference, the drivers' needs to fulfill and the situational constraints to cope with are different depending on the configuration considered.

- The moment of the accident process

Depending on that fact that the aid system is able to intervene at the approach / rupture / emergency phase, the required functionalities are necessarily different. That is why it is necessary, not only to evaluate the capacities and weakness of the system as a whole, but as a function of their moment of intervention.

The main results delineated along the reports are summarized below for the different accident configurations at the different moments of the accident process.

6.1. Car versus car accidents

6.1.1. Approach driving situation

At this pre-accident phase, what must be reminded is that:

- For nearly 43% of these drivers, there is no need diagnosed during this phase. This means that these drivers were still in a well mastered situation while approaching the accident spot and no impeding factors were characterizing them.

- When a need is diagnosed, it refers in nearly 44% of the cases to a problem of detection in general and more particularly a need in the early detection of a vehicle on a transversal way (15%).

- The system most widely useful to meet the needs of the drivers (if there is one) at this early stage of the accident process is Intersection Control. This means that more than 30% of drivers have their needs addressed by IC, but it doesn't necessarily mean that accidents would be avoided: potential limitations to the efficiency of the system application are still to consider (see below). Also useful are Intelligent Speed Adaptation and Traffic Signal Recognition (more than 14% each).

- In more than 52% of cases where aid would be used, it is considered potentially having an efficient effect (up to 61%) with respect to using Intersection Control insofar as the systems are well addressing the situational constraints characterizing the accidents studied.

- The potential limitations to most driving aid systems at the approach driving situation are those that can cause willfully disregarding assistance (50%), especially as a result of the motivation for the journey (e.g. playful driving) and deliberate speed.

6.1.2. Rupture Situation

At the rupture situation, which can be considered as the pivotal moment of the accident process, the main results are following:

- A need is identified in 95 % of the drivers at this crucial phase of the accident process. This is directly relating to the fact that most of the drivers were subject to a functional failure which prevented them from managing the conflict encountered.

- Once again, the need most often identified refers to a general need for help in detection (53% of the drivers for which a need is diagnosed), and more typically the need in detecting a user on an intersecting course (25%). Two other needs emerge, not dealing with detection, consisting first in estimating a collision course with another user (12%) and secondly in predicting that another user will move off or fail to stop (11%).

- Dealing with the safety functions, the most useful aid to meet the needs of drivers at the rupture phase are Collision Avoidance / Collision Warning (29%), Intersection Control (24%) and Infrastructure Intersection Alert (15%).

- In 44% of cases where the safety functions are addressing the drivers' pivotal needs, they are considered fully effective to cope with situational constraints (46% for Collision Avoidance / Collision Warning, 44% for Intersection Control and 37% for Intersection Alert).

- In 29% of cases, the limits for these drivers are related to attention problems, including active distraction (12%) and passive distraction (9%). Another limitation very often represented in the accident context deals with the reduced conditions of time and space at the moment when the conflict emerges and which necessarily limit the capacity of the systems to overcome the problem.

6.1.3. Emergency situations

At the emergency phase of the accident, the question is no more to prevent but to counteract the difficulty in hand, which leads to radical consequences on the needs of the drivers and on the capacity of safety functions to cope with the difficulty. Dealing with car drivers, the following points are most important to consider:

-For more than 80 % of the car drivers involved in a collision with another car, a need is diagnosed.

- For 45% of car drivers, the need for more optimal braking is the one most represented, followed by a need in diagnosis of the emergency character of the situation (29%).

- For 43% of these drivers Collision Avoidance / Collision Warning would have been the most useful to meet their needs, and to a lesser extent Predictive Brake assist (19%).

- Dealing with the efficiency of the systems applying to the needs of the drivers, in 46% of cases they would have had a maximum impact (40% for Collision Avoidance / Collision Warning and 37% for using Predictive Brake assist).

- The two main limitations involved in the non-maximum aid effectiveness are reduced conditions of time and space (28%) and insufficient width of the detection system (19%).

6.2. Car vs. PTW accident

Road accidents confronting car drivers and PTW riders occur in specific conditions and lead to specific failures. In the same way, they result in specific drivers' needs for help to which safety functions have to answer at the different phases of the process.

6.2.1. Approach driving phase

- For nearly 53% of car drivers and more than 51% of PTW riders, no need is identified during this phase.

- When a need is identified, it refers for car drivers in nearly 80% of cases to a need in detection, especially the needs in detecting a user on an intersecting course (32%) and detecting an oncoming user (26%). PTW riders needs are rather dealing with external diagnostic (45%), including adapting speed to road legislation (27 %) and adapting speed to road conditions (17%). These differences in needs between car drivers and PTW riders reflect differences in the difficulties experienced by each user in accidents they face.

- The safety function most widely useful to meet the needs of car drivers (if there is one) is Intersection Control (almost 60% of drivers). For PTW riders the aids Intelligent Speed Adaptation (40%) and Intersection Alert (25%) are the most represented.

- In less than 30% of cases for which assistance meets the needs of car drivers, it is optimal (33% with respect to using Intersection Control). For PTW riders, the average level of aid optimum efficiency is only 26% (26% for Intelligent Speed Adaptation and 35% for Intersection Alert).

- The two main limitations encountered for car drivers are low visibility of motorcycles (19%) and Inattention (16%). For PTW riders limitations to the potential aid efficiency are the desire for speed (22%) and defect in the road design (notably: atypical intersection) (11%).

6.2.2. Rupture phase

- For nearly 99% of car drivers and more than 98% of PTW riders, at least one need is identified during this accident phase.

- In nearly nine out of ten cases, the need for car drivers is a need for detection, particularly in detecting a user on an intersecting course (40%) and detecting a user outside the frontal field of vision (behind, on the sides, or in blind spot) (23%). PTW riders mainly show needs in prognosis (46%) with predicting the manoeuver of another user (17%) and predicting that another user will move off or fail to stop (15%), but the detection needs are still represented (39%), particularly detecting a user on an intersecting course (22%) .

- The most useful aid to meet the needs of car drivers are aid Collision Avoidance / Collision Warning (34%), Intersection Control (19%) and Intersection Alert(18%). For PTW riders, using Collision Avoidance would have been useful for more than 57% of cases, using Intersection Alert would be useful in 17% of cases.

- When a safety function is able to meet a need at the rupture phase, it is fully effective in 42% of cases for car drivers and 45% of cases for drivers of motorcycles.

- The three most stringent limits for driving aids are the low visibility of motorcycles (20%), insufficient width of the radar at intersection (13%) and inattention (12%) for car drivers, and reduced conditions of time and space (21%) for PTW riders.

6.2.3. Emergency phase

- For nearly 78% of car drivers and more than 90% of PTW riders, at least one need is identified during this accident phase.

- For car drivers, the need most identified is for diagnosis (69%) while for PTW riders it refers to more optimal braking (72%).

- For 51% of car drivers the function Collision Avoidance / Collision Warning would be the most useful, and to a lesser extent Predictive Brake Assist (16%). Regarding PTW riders, Combined Brake Systems (37%), Anti-Lock Brake Systems (26%) and Collision Avoidance (16%) are most useful functions to meet their different needs.

- In 27% of cases, the useful safety functions would have had a maximum effect to compensate for the situational constraints of car drivers (26% with Collision Avoidance / Collision Warning and 33% for using Predictive Brake Assist). For PTW riders, this figure rises to an average of 59%, and more particularly 65% for Combined Brake Systems, 67% for Anti-Lock Brake Systems and 35% for Forward and Intersection Collision Avoidance.

- The main limitations to driving aids efficiency for car drivers are reduced conditions of time and space (44%) and low visibility of motorcycles (19%). For PTW riders, it is the reduced conditions of time and space (38%) and assistance triggering threshold (late braking by the driver) (25%).

6.3. Car versus pedestrian accidents

6.3.1. Approach driving phase

- In one third of cases, car drivers have no need diagnosed yet at this early stage of the accident process.

- When a need is identified, in nearly 80% of cases it is a need for detection, including the needs for detecting a user on an intersecting course (45%) and detecting a user outside the frontal field of vision (masked by an object) (15%).

- The most useful functions to meet the needs of drivers (if there is one) are Vulnerable Road Users Protection (59%) and Intelligent Speed Adaptation (11%).

- Such functions act optimally in only ¼ of cases (12% for Vulnerable Road Users Protection and 30% using Intelligent Speed Adaptation).

- The main limitations encountered are of exogenous origin, including visibility limited by a vehicle (18%) and insufficient width of the radar at intersection (13%).

6.3.2. Rupture phase

- For nearly 100% of car drivers, at least one need is identified during this accident phase.

- When a need is identified, in 69% of cases it is for the car driver a need in detection of the pedestrian, including the need in detecting a road user on an intersection course (38%) and detecting a road user outside the frontal field of vision (masked by an object) (16%). For 20% of drivers, the need identified for the car driver is dealing with predicting the manoeuver of the pedestrian.

- In 76% of cases, the safety function Vulnerable Road Users Protection would have been helpful to meet driver's needs.

- In 37% of cases, the action of the safety functions would have been totally effective.

- The limits to the effectiveness of safety functions are in 34% of cases linked to attention problems, including Active distraction (12%) and Inattention (11%). The other kind of element the most represented is relative to Visibility limited by a vehicle (22%).

6.3.3. Emergency phase

- For nearly 100% of car drivers, at least one need is identified during this accident phase.

- For 57% of car drivers the need for more efficient braking is most represented at the emergency phase of accidents involving a pedestrian, and secondly comes the need for a better diagnosis of the situation (35%).

- The three most represented safety functions able to meet these needs are the functions Predictive Brake Assist (34%), Brake Assist (33%) and Vulnerable Road Users Protection (18%).

- For all of these aids, the optimum efficiency is 61% (72% for Vulnerable Road Users Protection, 58% for Predictive Brake Assist, 57% for Brake Assist).

- The two main limitations to the efficiency of these functions are the problem of the triggering threshold of the device, in relation to late braking by the driver (40%) or no braking at all (20%).

6.4. Single vehicle accidents

Single vehicle accidents only involve an interaction between the driver (motorist or motorcyclist) and no interaction with the traffic. This implies specific road users failures and, as a consequence, road users' needs. It also implies specific contextual constraints that safety functions have to cope with.

6.4.1. Approach driving phase

- A characteristic of this kind of accident is that even at this early phase of the malfunction process the drivers are already in a degraded state, showing a need in 87 % of the cases when car drivers are concerned, and 67 % when it comes to PTW riders.

- The needs identified at the approaching phase of the accident are for car drivers: 54% a need for internal diagnosis, including the need in evaluating the catching up on a slower road user (26%) and adapting speed to road conditions (13%). For PTW riders, these are needs in external diagnostic, especially dealing with adapting the speed to road conditions (36%) and adapting the speed to road legislation (21%).

- The most widely used aids to meet the needs of car drivers (if there is one) are the functions Intelligent Speed Adaptation and Alcolock Keys (respectively 20% and 19%). For PTW riders the functions adapted are once again Intelligent Speed Adaptation (40%) and Bend Alert (33%).

- In 29% of cases where a safety function is answering the need for the car drivers, it is optimal to compensate for situation constraints (42% with respect to using Alcolock Keys and only 6% for Intelligent Speed Adaptation). For PTW drivers, the optimal level of aid effectiveness was 33% (17% for Intelligent Speed Adaptation and 60% for Bend Alert).

- Limits the most represented to driving aids effectiveness are those that can cause willfully disregarding the assistance provided (53% for car drivers and 58% for PTW riders). The most important limitations for car drivers consist in deliberate infringement by the driver (17%) and notably the desire for speed (16%). For PTW the limits are also linked to deliberate violation (44%) and at a minor degree Inattention (19%).

6.4.2. Rupture phase

- For 80% of car drivers and 100% of PTW riders, at least one need is identified during this accident phase in single vehicle crashes.

- For 35% of car drivers the need is related to better controlling the vehicle, which is represented by up to 67% of PTW drivers. The need to detect a trajectory deviation is identified for 28% of car drivers (linked to vigilance problems).

- In 24% of cases, using Electronic Stability Control would have been helpful for car drivers, followed by aid Lane Keeping Assistant (18%) and Lane Departure Warning (14%). For PTW drivers, it is Collision Avoidance (39%); Intelligent Speed Adaptation (15%) and Bend Alert (15%) that would have been useful to meet the needs identified.

- When applying, the aid effectiveness is optimal in 44% of cases for car drivers (26% for Electronic Stability Control, 64% for Lane Keeping Assistant and 27% for Lane Departure Warning). For PTW riders the average rate of efficiency of the useful safety functions is 54%

(50% for Bend Alert, 40% for Forward and intersection collision avoidance, but 0% for Intelligent Speed Adaptation).

- The limits to the aids efficiency the most represented among car drivers involved in single vehicle accidents are Influence of alcohol (14%) and reduced conditions of time and space (10%). For PTW drivers, it is more a question of Deliberate infringement (25%) and strong Feeling of right of way (17%), two parameters that should take 'voluntarily not taken' into account with regards to the assistance provided by the safety functions.

6.4.3. Emergency phase

- For nearly 99% of car drivers and more than 90% of PTW riders, at least one need is identified during this accident phase.

- For 58% of car drivers the need that is most represented deals with controlling the trajectory, against 28% for PTW drivers. For the latter, the needs most represented at the emergency phase in single vehicle accident are dealing with braking requirements.

- Regarding safety functions, Electronic Stability Control (49%) and Lane Keeping Assistant (14%) are most useful for car drivers. For PTW riders, Combined Brake Systems (39%) and Anti-Lock Brake Systems (33%) are the most appropriate for their needs.

- For PTW riders the optimum efficiency is got for about 89% of all the applying functions (100% efficiency for optimal Combined Brake Systems and PTW AS-12). For car drivers this figure comes to 51% (63% for Electronic Stability Control and 81% with Lane Keeping Assistant).

- The main limitations for car drivers are reduced conditions of time and space (13%) and influence of alcohol, strong dynamic solicitations and speed, up to 9% each. For PTW drivers, only 3 limitations are identified: influence of alcohol, reduced adherence (fine gravels) and no braking action by the rider.

7. CONCLUSION

The analysis conducted in the frame of WP5 "e-safety" of the European DaCoTa project constitutes a specific contribution to the studies dedicated to the evaluation of safety functions efficiency. This contribution presents the specificity to be directed toward road user's needs, the particularity to be based on a methodology taking into account attested human safety difficulties (functional failures) an accident reality (context parameters).

The work conducted allows defining:

- Safety needs for different kinds of drivers, reflecting their accident-generating failures at the different stage of the process;

- The potential capacity of safety functions to meet these needs;

- The potential lacks in the functions efficiency.

Such results allow estimating the more or less appropriateness of the current safety systems, but also their weaknesses when considering real accident situations constraints. They also give some clues on the needs which are still not covered by the present devices. As such, these results can be considered as a contribution to the prospective ergonomics of safety systems, allowing their improvement for a better adequacy to the needs shown by drivers in accident situations and to the contextual constraints found in these situations.

Of course, the sample on which this study is based should be extended in order to gain in representativeness. This could be one of the interests of a European in-depth accident database as developed within WP 2 of the DaCoTa Project.

Other aspects are still to be explored in further studies, notably dealing with the acceptance of safety systems and the capacity of their future users to master them appropriately.

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