eVADER

Electric Vehicle Alert for Detection and Emergency Response
Executive summary

In this report we revise important concepts that are related to the safety management between driver, vehicle and pedestrian. The point that we cover tries to emphasize certain concepts that will affect the concept, design and construction of the acoustic warning device to be implemented in eVADER. The points covered are:

Revision of accident causation

Statistical quantification of the effect of eVADER on accident reduction

Fundamental information for visually impaired (VI) and vulnerable road users

Safety warning sounds. From concept to design

Sensor integration for pedestrian collision warning system

The stereovision system from CONTINENTAL
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1 Introduction

Past European projects like TRACE have studied the current accident causation state at European level. Through an integrated approach, a common methodology was applied over available accident and exposure databases. First, the most relevant accident configurations were selected in order to know which safety problems should be firstly tackled by safety systems. On a second stage, these configurations, particularly for each road user group, were analysed in order to identify the main accident causation factors. This was developed applying the ‘Human Functional Failures’ methodology developed by ‘TRACE– Human Factors’. Therefore, an update of the accident etiology was which is revised here.
2 Revision of accident causation

The identification of the causation mechanisms for each type of road user allows the development of specific safety solutions addressing their particular needs. Although passenger cars represented 87% in 2004 of the total vehicles in use, it can be observed in the following figures that passenger cars do not present the same percentage of road fatalities. According to that, it is worth analysing what are the safety problems encountered by the different road users while performing the driving task.

Passenger cars represent 52% of road fatalities, while vulnerable road users (Powered-two wheels (PTWs), pedestrians and cyclists) account for 42%, while only 5% of fatalities are related to heavy vehicles. It has to be taken into account that due to the typical dimensions and mass of heavy vehicles, that allow them to transmit a huge energy in the event of crash so they can produce severe injuries to other road users and, therefore, their accident causation issues are also considered. Moreover, drivers do not have the same capacities across their driving life and therefore the mechanisms that induce them to commit failures might also be different according to the driver age or even gender specifications. Figures 1 to 5 give an overview of the relevance of each road user group in accident statistics in EU-275:

<table>
<thead>
<tr>
<th>Passenger Cars</th>
<th>Fatalities in the passenger car</th>
<th>24 136</th>
<th>52%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Injured in the passenger car</td>
<td>1 021 273</td>
<td>58%</td>
</tr>
<tr>
<td></td>
<td>Casualties in the passenger car</td>
<td>1 045 409</td>
<td>58%</td>
</tr>
</tbody>
</table>

**Figure 1**

<table>
<thead>
<tr>
<th>Powered Two Wheelers</th>
<th>Fatalities in the PTW</th>
<th>7 084</th>
<th>15%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Injured in the PTW</td>
<td>288 277</td>
<td>16%</td>
</tr>
<tr>
<td></td>
<td>Casualties in the PTW</td>
<td>295 361</td>
<td>16%</td>
</tr>
</tbody>
</table>

**Figure 2**

1 TRACE. Project FP&-2004-IST-4027763. Road users and accident causation
The most important objective for each road user group is to detect the main accident configurations or the main problems.

To summarize this information, Figure 6 provides the evolution of the above figures over the last decades. It can be observed that, although the whole number of fatalities is decreasing,
there is a slight increase of fatalities related to the whole number of vulnerable user groups (pedestrians, mopeds, motorcycles and cyclists).

2.1 Car Drivers

Passenger car accidents represent a big issue for road safety. Indeed, the car is the most popular and used transport mode in Europe compared to bus, coach, and railway transport. The general trend shows an increase of its use of 16% from 1995 in Europe 25. In spite of a significant work done to reduce road fatalities, it is necessary to identify the main problems and their magnitude related to the causation of the accidents involving a passenger car – as road accident is still one of the main causes of fatalities.
eVADER will explore ways of reducing road accidents with visually impaired (VI) and vulnerable road users by developing an exterior acoustic warning system that will be specially tuned for the needs of these people

Accidents situations
Two main groups of accident situations have been studied in the literature references, accounting for a large proportion of traffic accidents fatalities.

- Single vehicle accidents can mostly be related to a loss of control of guidance problems. Due to the accident databases coding criteria, it is not impossible to identify whether or not skidding of loss of control problems were a contributing factor. This would be essential in order to identify the proper countermeasure addressing this accident situation.
- On the other hand, collisions at junctions constitute a relevant accident situation for passenger car drivers and pedestrians. For most of European countries and also for Unites States, to avoid this type of crash is a great challenge in order to enhance road safety. This fact is important in the context of eVADER since in this project new testing protocols for exterior noise assessment of IC and EV are proposed. This new testing arrangements take into account straight driving as well as driving in crossings. The simultaneously recording of vehicle noise and vehicle position and orientation with respect to an hypothetical pedestrian will then allow the investigation of complex acoustic interaction between quiet vehicles and vulnerable road users.
Risk Factors

Different research studies have already analysed possible risk factors related to passenger car accidents. The following is a synthesis of the most representative factors:

- Driving speed.
- Age & sex.
- Alcohol.
- Fatigue. Three high-risk groups have been identified:
  - Young people, particularly males, aged 16–29 years.
  - Shift workers whose sleep is disrupted by working at night or working long, irregular hours.
  - People with untreated sleep apnoea syndrome or narcolepsy.

In Europe 27 (EU 27), accidents involving at least one passenger car represent 81% of road injury accidents, 71% of the fatalities and 94% of the casualties. Two configurations of injury accidents can be distinguished and cover 40% to 60% of all injury accidents: single passenger car accidents (this accident configuration contributes at least in the 6 national databases to 25% of fatalities in passenger car accidents) and passenger car versus passenger car (no pedestrian and no other vehicle), with special mention to intersection-located collision.

These are the general conclusions of the descriptive analyses performed for the issue of passenger accidents:

- Around 80% of injuries accidents and fatalities in accidents involving at least one passenger car occur in good weather conditions.

- Two thirds of passenger car injury accidents occur inside urban area (no motorway) while more than a half of fatalities are outside urban area (no motorway).

- Three fourth of passenger car injury accidents occur at daytime whereas one third of fatalities are during the night.

- The passenger car accidents at intersection represent 45% of passenger car injury accidents, 42% of the total casualties (fatalities and injured) in passenger car accidents and 21% of the fatalities in passenger car accidents.

- Accidents with vulnerable road users (pedestrians, bicycles, powered two wheeler) are significant. In this respect, eVADER will develop integrated systems to reduce the impact that EV can have on groups of vulnerable road users.

- Young drivers (especially drivers aged from 18 to 25) and elderly drivers (aged from more 65) mainly contribute to road fatality. They represent from 23% to 53% in countries of EU of accidents involving at least one passenger car.
2.2 Powered two wheelers Riders

Motorcycle and moped vehicles owners can greatly differ in the way of driving compared to other more common vehicles like passenger cars. Despite their dimensions (much smaller than other types of vehicles), those who choose to ride a PTW (Powered Two Wheeler) do not always buy it just because they need it. Due to their size they may become not easy to be detected by other users (PTW), they give a freedom feeling to the rider who is much more exposed to the hypothetic collision energy than a passenger car driver. Moreover, because they only have two wheels their dynamics is completely different, most of all in braking manoeuvres and curves approaching. Therefore, relevant questions like When?, How? and Why? a motorcyclist rides different than other road users are essential to address their specific accident causes.

Issues that have proved to be related with these road user group accidents are the following ones:

- Motorcycles and moped low conspicuity.
- Fault of car driver of not giving the right of way to the PTW.
- Alcohol and rider impairment (usually no permanent impairment).
- Road infrastructure hazards (loss of traction of the single track).
- Rider experience and training.
- Vehicle and braking problems.

Moreover, references analysed also looked in the past at the most relevant accident configurations. Accidents at intersections within urban area as well as run off accidents in curve at rural roads showed to be the most important. Nevertheless, there have been studies that have not achieved to prove a relation between some factors and PTW accidents. These factors are:

- Speeding.
- Engine size.
- Rider gender.
- Rider age.

Figure 7 presents a break-down of the main causes of accidents for two-wheelers
2.3 Vans, Bus and Truck Drivers

Accidents in road transport count for a high part of human and material loss, for the individual, for the common, and for the business and welfare. Transport accidents on the road are lower in absolute figure as compared to other modes of traffic participation (such as car, two-wheel-vehicles, etc.), but they usually result in much higher average damage losses, including the responsibility for a good part of traffic congestions, because of temporal total road closings, on Europe’s roads. Truck and van accidents are more destructive against the unprotected, namely pedestrians, cyclists, and small passenger cars. The reasons for that becomes obvious thinking in terms of the biomechanical effects of different mass volumes, standing against each other. Since the goods transport on EU’s roads do, and will increase rapidly, as shown by all economical figures (yearly average ton kilometres), and since the same prognoses see the road with most increase, it is a major challenge for research, business, and politics to improve safety of the road transport industry. Nevertheless, there are substantial differences between the types of vehicles used for people and goods transport. Therefore, this task has analysed this road user group separated in three different areas:

- Vans: goods road vehicles/lorries with a G.V.W. (Gross Vehicle Weight) ≤ 3.5 t.
- Buses or coaches: vehicles with more than 8 seats without driver
- Heavy Goods Vehicles (HGV): goods road vehicle/lorries with a G.V.W. > 3.5 t.

Germany is the country with the highest absolute number of heavy truck accidents followed by United Kingdom, France, Spain, Netherlands and Sweden. On account of Germany’s
central transit position of Europe and the good road network it is clear why Germany has the highest figures. There is not a great difference between rural and urban in Germany. In opposite to Spain, there is a great difference. In France and the United Kingdom, the casualties on the country were also as high as in the city. Therefore, it is clear that on the rural the likelihood of injury is higher as in the city.

Passenger cars are the most frequent accident opponents of trucks. The passenger car was the opponent of the truck in over 50 % of all truck accidents. Nevertheless, crashes with unprotected road users are also frequent and have serious consequences for the weak party. In these kinds of casualties the crossroads and the inlets were the places with the highest accident potential. Especially, right turning accidents have severe consequences for pedestrians and cyclists. These crashes are the result of the dead angle on the right side in the case of trucks (left side for the United Kingdom). Although pedestrians were considered to be at fault in most of the accidents, perhaps the accident could have been avoided with an electronic system installed in the truck. The problem is that most of the cyclists or pedestrians could not estimate the behaviour of the truck. They are not able to know how trucks react in a turning or a crossroad.

It is, thus, important to define what are the most relevant type of collisions. The kind of collisions are different, but the rear-end collision accounts for a high amount of the accidents. Another finding is the heavy injury risk in single truck accidents. Often, the truck is tilting to the side or rollover, because the speed in the bend was too high. The final consequence of the accident is that the cab is seriously deformed. Drivers not wearing safety belt constitute one of the most important problems in terms of injury consequences of the accident. The truck/truck accidents are like the single truck accidents with a high potential of serious injury for the occupant. There are two vehicles, which are big and heavy and the impact could be enormous. The missing crumble zone does not receive the driver and the end would be serious injured people.

Clear statements regarding accident causation could not be taken from the literature. Because most reports refer on police data, the real causes are often not mentioned. From presumptions of different literature sources reveals the most frequent causations distraction or inattentiveness and fatigue. For falling asleep at the wheel there are several causes. These are related to a shift-work, too long working hours or driver sleeping lack.

2.4 Pedestrians and Cyclists

Pedestrian fatalities in Belgium, Luxembourg, The Netherlands and France amount to approximately 10% of all road accidents. This number is even higher in the United Kingdom, Ireland, Portugal and Greece where numbers rise to 21%, 19% and 18% for the latter two, respectively. On the other hand, cyclists were representative for 4.5% of road accident fatalities in 2004, during which 1,209 road users riding bicycles were killed during traffic accidents in 14 European Union countries. Across the decade from 1995 to 2004 there was a reduction in this figure by 731 accidents (37%) to the 1,940 fatal accidents that took place in 2005. When looking at EU statistics from 2004, the countries with the highest percentage of bicycle fatalities are Denmark, the Netherlands and Finland; in contrast Greece, Spain and Luxembourg are only representative for a small fraction of the overall accidents.

Three basic aspects can be considered: accident causation factors; development methodologies for safety systems aimed at pedestrian and cyclists; and safety regulations for pedestrians and cyclists.
There have been found few literature documents concerning accident causation. In the technical documents reviewed, the main relevant parameters discussed are location of accidents (i.e. crossings, signalled intersections), visibility and opponent vehicles. There is no clear definition as to the most concurrent scenarios and conditions relating to pedestrian and cyclist accidents. Data from studies focussed on accidents in UK, Japan and Korea has been collected and it is found that pedestrians differ in sizes and biomechanical response during accidents, even behaving differently while crossing the street. In these cases, old people, children and VI people are more likely to have an accident and more specifically from this old people are more likely to result severely injured after these accidents. It is also revealed that most of the vehicle opponents during pedestrian accidents reduce to a certain set of vehicle types.

Typical scenarios for pedestrians accidents normally are:

- Car turning and pedestrian crossing the street (at corners).
- Pedestrian crossing a street with parked vehicles (reduced visibility) and vehicle approaching.
- Scholar area pedestrian accidents (young people).
- Commercial area pedestrian accidents.

Pedestrians most often undergo ‘G2’ failures, meaning they are impaired in their sensor-motor and cognitive abilities. The task they perform is ‘crossing the street’ when the conflict with a vehicle from the side occurs. In most cases the pedestrians have to be regarded as ‘primary active’. The most frequently found explanatory elements for this failure-task-conflict combination is alcohol above the legal limit (as would have been applied to drivers with a value of 0.05% BAC – Blood Alcohol Content).

In the context of eVADER, we analyse the particular problem of vulnerable road users like VI people and the elderly interacting with quiet or EV in urban or extra-urban conditions. It is, therefore, expected that the statements above are not applicable for this special group of pedestrians.

For the opponents, as being the drivers involved in the fatal pedestrian accident the distribution of sex is shifted towards males, and shows an age distribution comparable to the driver population in general. For the drivers most often a ‘P1’ failure (‘Non-detection in visibility constraints conditions’) could be detected. The task they were performing was going ahead on a straight road most frequently when conflicting with a pedestrian crossing the street. In most cases the drivers have to be regarded as ‘secondary active’ as the pedestrian initiated the situation. The explanatory elements found for the drivers comprise visibility constraints like night, other vehicles, weather, and vehicle lighting.

For the case of cyclists, the most representative scenarios are:

- Outside urban areas:
- Straight road, cyclist in the road shoulder and car overtaking the cyclist.
- Sinuous road, car driving and cyclist not visible (blind curve).
- Urban areas:
- Cyclists in the bicycle lane and car invading it.
- Bicycle riding between lanes.
- Illicit turning at an intersection.
The above are considered the most frequent and relevant accident scenarios for both pedestrians and cyclists. National accident databases do not offer enough detailed variables in order to describe accident causation process for these scenarios.

Considering the cyclist accidents from the data available not many conclusions or recommendations could be made regarding the accident causation issues or Human Functional Failures associated. The problem however seems to be linked to a lack of attention and vigilance on the road, therefore drivers should be made to understand the consequences if they do not always look properly, and should be made to pay particular attention to the possibility of vulnerable road users as cyclists appearing unexpectedly. Also danger spots should be identified, sharp bends or slopes lacking clear signalling can become danger zones for cyclists. The main recommendation is that more data collection and consequent analysis is required for cyclists’ accidents.

Figure 8 summarizes the main causes of accidents affecting cars, cyclists and pedestrians.

For the pedestrians...
The 3 most common scenarios regarding pedestrian accidents are:
- Car turning and pedestrian crossing the street (at corners).
- Pedestrian crossing a street
- Pedestrian walking along the road

For the cyclists...
- Urban areas: the vehicle invades the lane used by the cyclist or, even, when a cyclist invades a lane used by other vehicle (intersection – non-intersection)
- Rural areas: the vehicle drives in the same way as the cycle and tries to overtake it or approaches it in a point with reduced visibility, as bends or hill crowns.

Pedestrians involved in pedestrian accidents:
Decision (D), Overall (O) and Perception (P) failures are the most present in the action of the pedestrians.
Associations:
- →D-failures: generally a pedestrian willing to cross the street.
- →O-failures: can be associated to pedestrians walking along the road or pedestrians crossing the street.
- →D-failures: commonly ‘risk taking – traffic control’.
  ‘Risk taking – economic motives’ has only been marked in a few cases with children involved, violating the safety rule as well.

Drivers involved in pedestrian accidents:
Main Human Functional Failures identified in drivers are P and T-failures.
- →P-failure: most representative is ‘non-detection in visibility constraint conditions’.
- →T-failure: repeatedly present in urban scenarios with traffic lights.
  ‘Expecting no perturbation ahead’ often appears, followed by ‘Expecting another user not to perform a manoeuvre’.

Cyclists and drivers involved in cyclists accidents:
The problem is linked to a lack of attention and vigilance on the road,
- →Drivers should be made to understand the consequences if they do not always look properly, and should be made to pay particular attention to the possibility of vulnerable road users as cyclists appearing unexpectedly.
- →Also danger spots should be identified, sharp bends or slopes lacking clear signalling can become danger zones for cyclists, and at this stage should as a minimum be identified, so that once further studies can consolidate the prediction of this report, action can be taken to improve the safety of these areas.
eVADER opens the type of causes considered here because it also takes into account VI people. This means that for this group of road users, visual information is severely limited or not existent. This fact opens a new world of considerations about how this group of people can interact safely with vehicles in general and, specially, with those particularly quiet, such as EV.
3 Statistical quantification of the effect of eVADER

In this section, we consider the global effect that the implementation of a safety warning system of the type proposed by eVADER. This formulation has been developed as part of the task for deliverable D1.4. First of all, we recall that of the main objectives of eVADER is to reduce the risk of pedestrian accident associated to EV to the one associated to IC vehicles. Keeping this concept in mind the following algebra can be used to calculate the quantitative effect of implementing eVADER approach on the number of accidents involving pedestrians.

\[
N_{ac(IC+EV)} = N_{IC} \cdot P_{ac(IC)} + N_{EV(-eVader)} \cdot P_{ac(EV)} + N_{EC(+eVader)} \cdot P_{ac(EV)(+eVader)}
\]

(1)

taking into account that

\[
P_{ac(EV)} = 1.5P_{ac(IC)}
\]

(2)

then, the second and third term of the equation (1) above can be expanded respectively as

\[
N_{EV(-eVader)} \cdot P_{ac(EV)} = \left( N_{IC} \cdot (\%_{EV}) - N_{IC} \cdot (\%_{EV(EV(+eVader))}) \right) \cdot 1.5 \cdot P_{ac(IC)}
\]

(3)

and,

\[
N_{EC(+eVader)} \cdot P_{ac(EV)(+eVader)} = N_{IC} \cdot (\%_{EV}) \cdot (\%_{EV(EV(+eVader))}) \cdot P_{ac(IC)}
\]

(4)

Substituting equations (3) and (4) into equation (1) gives

\[
N_{ac(IC+EV)} = N_{IC} \cdot P_{ac(IC)} \left[ 1 + (\%_{EV}) \cdot \left( 1 - (\%_{EV(EV(+eVader))}) \right) \cdot 1.5 + (\%_{EV}) \cdot (\%_{EV(EV(+eVader))}) \right]
\]

(5)

and after some algebra, we obtain

\[
N_{ac(IC+EV)} = N_{IC} \cdot P_{ac(IC)} \left[ 1 + 1.5 \cdot (\%_{EV}) - 1.5 \cdot (\%_{EV(EV(+eVader))}) + (\%_{EV}) \cdot (\%_{EV(EV(+eVader))}) \right]
\]

(6)

\[
N_{ac(IC+EV)} = N_{IC} \cdot P_{ac(IC)} \left[ 1 + 1.5 \cdot (\%_{EV}) - 0.5 \cdot (\%_{EV(EV(+eVader))}) \right]
\]

(7)

If no electrical vehicle incorporates the eVader system, then \((\%_{EV(EV(+eVader))}) = 0\) and equation (7) becomes

\[
N_{ac(IC+EV)(-eVader)} = N_{IC} \cdot P_{ac(IC)} \left( 1 + 1.5 \cdot (\%_{EV}) \right)
\]

(8)
Comparing equation (7) and (8) we obtain the ratio

\[
\frac{N_{ac(ICE+EV)}}{N_{ac(ICE+EV)(-eVader)}} = \frac{(1 + 1.5 \cdot (\%)_EV - 0.5 \cdot (\%)_EV \cdot (\%)_EV(+)\Vader)}{(1 + 1.5 \cdot (\%)_EV)}
\] (9)

Note that if we take

\[
(\%)_EV(+)\Vader = 0
\] (10)

and

\[
(\%)_EV = 1
\] (11)

the, equation (9) becomes

\[
\frac{N_{ac(ICE+EV)}}{N_{ac(ICE+EV)(-eVader)}} = 1
\] (11)

as expected, meaning that there is no increment in the number of accidents, regardless on the percentage of EV. In the more general case in which

\[
P_{ac(EV)(-eVader)} = K \cdot P_{ac(IC)}
\] (12)

Then equation (7) becomes

\[
N_{ac(ICE+EV)} = N_{ICE} \cdot P_{ac(ICE)} \left(1 + K \cdot (\%)_EV + (1 - K) \cdot (\%)_EV \cdot (\%)_EV(+)\Vader\right)
\] (12)

and

\[
\frac{N_{ac(ICE+EV)}}{N_{ac(ICE+EV)(-eVader)}} = \frac{(1 + K \cdot (\%)_EV + (1 - K) \cdot (\%)_EV \cdot (\%)_EV(+)\Vader)}{(1 + K \cdot (\%)_EV)}
\] (13)
Figure 9: Reduction of VRU accidents as a function of \( \%_{EV} \) and \( \%_{eVader} \) for \( K = 1.5 \)

Figure 10: Contour plot of figure 9. Reduction of VRU accidents as a function of \( \%_{EV} \) and \( \%_{eVader} \) for \( K = 1.5 \)
Figure 11: Reduction of VRU accidents as a function of $(\%_{EV})$ and $(\%_{eVADER})$ for $k = 2$.

Figure 12: Contour plot of figure 11. Reduction of VRU accidents as a function of $(\%_{EV})$ and $(\%_{EV (+eVADER)})$ for $k = 2$. 
4 Fundamental information for visually impaired and vulnerable road users

In the context of interaction between VI people and EV, the concept of detection of distance is a very important safety parameter. For VI people, this detection is normally based on acoustic information only.

4.1 Detection of distance

In this section, we then consider how acoustic information contributes to the timing of goal-directed human movements, particularly tasks involving relative motion with objects and surfaces in the environment. We begin by considering whether acoustic information can specify time-to-contact (TTC) during relative approach. Later, we evaluate the broader role of acoustic information in interceptive timing and describe an investigation of effects of removing acoustic information on co-ordination. We will conclude that acoustic information has a significant role to play in regulating timing behaviour.

Michaels and Carello (1993) proposed that the auditory perceptual system could be used to regulate action and that information from the acoustic array could lawfully specify motion paths of objects with respect to observers. When an object passes close to an individual it could provide acoustical as well as optical information that can be perceived and used to guide actions such as interception or locomotion. (Schiff and Detwiler, 1979) have termed the use of acoustic information for guiding relative motion between performer and object or surface auditory motion. As we note in this section, a number of research studies have revealed that the sense of hearing is well adapted for localizing and identifying sound sources and for guiding interceptive actions, particularly when there is relative motion between performer and an object or surface (e.g., Kunkler-Peck & Turvey, 2000). However, very little experimental work has examined the use of acoustical and visual information in judging TTC together.

4.2 Acoustic intensity and Time to Contact (TTC)

A prevalent proposal in the literature is that there is a perceptual priority for rising intensity of sound, which has biological salience for animals negotiating complex dynamic environments through locomotion (Neuhoff, 1998). This worker suggested that people might be more sensitive to rising intensity of acoustic information compared to falling intensities because of the well documented facility for perceptual overestimation of intensity change during relative approach. This asymmetry in the perception of egocentric auditory motion was argued to provide an adaptive advantage that facilitates the pick up of looming acoustic information sources. This explanation has found some support in work with human infants who

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5 Perceptual bias for rising tones. Nature, 395, 123-124
demonstrated behavioural signs of preparation for contact with signals of rising intensity (Freiberg 2001)\(^6\)

The *intensity* of a sound wave is the amount of acoustic energy crossing the unit of area normal to the direction of propagation of the wave per unit of time. Therefore, it is expressed in units of power (energy per unit of time) per surface unit, that is, in \(\text{watt/m}^2\). In the case of a flat wave, the acoustic intensity is given by:

\[
I = \frac{p^2}{\rho c},
\]

where \(p\) is the acoustic pressure (r.m.s), \(\rho\) is air density (kg/m\(^2\)) and \(c\) denotes the sound speed (m/s). Figure 13 illustrates the concepts associated with the measurement of intensity. The vector crossing the plane that denotes the unit of area indicates acoustic power and has information about its associated direction. As with the sound pressure, one can talk about the sound intensity level defined as

\[
SIL = 10 \cdot \log \frac{I}{I_{\text{ref}}},
\]

where \(SIL\) is the sound intensity level, \(I\) is the intensity in W/m\(^2\) and \(I_{\text{ref}}\) is the intensity of reference that, in this case, is taken as \(10^{-12}\) watt/m\(^2\). The measurement of sound intensity offers the opportunity to detect *in situ* the area of a vibrating surface that emits more noise. In this context, the expression *emits more noise* suggests that the surface injects acoustic energy into the environment and acts like a loudspeaker. Intensimetry may also reveal those parts of a surface acting as energy drains and subsequently absorbing noise.

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It is of vital importance to keep in mind the vectorial nature of the measurement of intensity, i.e. all measurements of intensity have amplitude and direction. Therefore, it is very useful for the location of sources in acoustically complex spaces to be known. This is also one reason why sound intensity is so valuable for VI people to generate an acoustic image of reality.

According to Schiff and Oldak (1990)\(^7\) TTC of an object with an observer is related to the inverse square law (the intensity of a sound at an auditory perceptual system is inversely proportional to its distance from the source. The role of the rate of intensity change of a sound source in judging TTC is known. The results show that the vast majority of judgements are underestimates (89%). Modality of presentation (visual, auditory-visual or auditory) was a significant factor in the study. Acoustic information alone provided less accuracy in predicting TTC than visual or audiovisual events. The data suggested that for non visually impaired people, the acoustic information does not play a leading role in judging time of arrival, particularly with increasing stimulus trajectories. Obviously, this is not the case for VI people.

When similar experiments are carried out with blind people, blind participants attempted to judge TTC using acoustic information. Blind participants were better than sighted participants in the acoustic conditions only. As with the sighted participants, there was a tendency towards underestimation but the blind participants estimated TTC well even at longer trajectory values.

In the literature, there is growing evidence in support of the rate of change of acoustic intensity as a key variable for perceiving motion, based on the inverse variation with distance of sound pressure at the point of hearing (sound pressure is related to intensity by distance of a source. Velocity can be perceived by a rate of intensity growth or loudness of an approaching object.

The great range of acoustic variables that are proposed as candidates for specifying TTC is notable. For example, Jenison (1997)\(^8\) argued that observer motion structures the ambient acoustic array demonstrating that higher order variables such as position, velocity and TTC, are measured from observations of interaural time delays. A number of acoustical dimensions, which are modulated with changing distance, can potentially support anticipatory looming judgements, including intensity and the overall pattern of spectral change, with the higher frequency portion of the sound spectrum changing at a disproportionally faster rate during approach. Figure 14, shows the simulated diffraction pattern around a human head produced by a plane wave (yellow arrow) impinging from the left hand side. One notes that the complexity of this diffraction pattern increases considerably with frequency. These patterns change as the moving vehicle approaches the pedestrian due to the change in sound frequency and to the relative orientation and distance between the vehicle and the pedestrian. This fact is one of the motivations why the testing protocols proposed in eVADER measure simultaneously vehicle noise (using a binaural system) and vehicle position and orientation.

In general pedestrians are more accurate and consistent in the acoustic location of a source in walking towards a target when they heard the sound during approach compared to when they were stationary. During stationary listening participants tended to overshoot the target. Moving when listening resulted in lower constant error to shorter target distances.

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Figure 14: Diffraction pattern produced by a spherical rigid body representing a head when a plane wave impinges on it at two different frequencies (500 Hz, left; 1 kHz, right)
5 Safety warning sounds. Concepts for design

The reaction of people to safety acoustic warning sounds is an important aspect of eVADER. This aspect has two sides, the perception of drivers and the perception of pedestrians; basically VI people. It is clear that the understanding of the perception of VI people to warning signals is one of the objectives of eVADER in WP2. However, at this stage, it is important to revise known aspects of the perception of people, and in particular drivers, to warning sounds. This will help us, on the one hand, to introduce us into the activities of WP2 and, on the other, to take into account aspects that will also be applicable in the context of eVADER when dealing with possible recommended warning signals for drivers of EV.

This section revises the characteristic of drivers to warning sounds based on their age and their emotional preference in a simulated driving situation to suggest a range of appropriate warning sounds. The assessment of physical response is based on elapsed times for acceleration release and brake response (see figure 15). These dependent variables can be examined for differences due to the frequency, tempo, and intensity of safety warning sounds. The emotional preferences of drivers is assessed based on perceived danger level and driver preference. These variables are assessed for differences due to the frequency, tempo, and intensity of safety warning sounds.

5.1 Physical Response Assessment
The accelerator response time and brake response time of the drivers depends on driver’s age, frequency, tempo, and intensity of the safety warning sounds. The accelerator response time is defined as the time from the moment when warning sound goes off to the time that driver starts to release the accelerator (see figure 15). The brake response time is defined as the time from the moment when driver released the accelerator to the time the driver applied the brake at least 10%.

5.2 Emotional Characteristic Assessment
The drivers’ preference and perceived level of danger can be assessed for each age group according to the frequency, tempo, and intensity of the safety warning sounds. The emotional characteristic assessment was conducted in the same environment (i.e., in the driving simulator) as the physical characteristic assessment with the driving simulator on autopilot mode.

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9. Man Ho Kim, Yong Tae Lee and J. Son, Age-Related Physical and Emotional Characteristics to Safety Warning Sounds: Design Guidelines for Intelligent Vehicles, IEEE Transactions on systems, man and cybernetics – Part C: Applications and Reviews
Figures 16 to 18 show the relationship between the frequency, tempo and sound pressure level of an acoustic warning signal and the accelerator and brake response times. The influence of the driver's age is also shown.

Figures 19 to 21 show the relationship between frequency, tempo and sound pressure level of the warning sound on the perception of the associated danger in the close-to-accident situation. The preference aspect as a function of tempo and frequency is depicted in figures 22 and 23.
Title Safety Management between driver / vehicle and pedestrian

Public

Figure 16

Figure 17
Figure 20

Figure 21
Figure 22

Figure 23
In this section we, therefore, suggest an appropriate range of safety warning sounds based on an analysis of physical and emotional characteristics of drivers of various ages. The response of older drivers to varying frequencies, tempos, and intensities can thus be evaluated to establish guidelines for appropriate warning sounds. In addition, a qualitative analysis of driver response time as a function of age provides useful data for designing a vehicle safety system based on driver age. The results found in the literature suggest that, first, older drivers were significantly statistically different in the way they perceived warning sounds, depending especially on the frequency, but also on the tempo and intensity; second, older drivers showed differences in accelerator and brake response times compared to drivers in their twenties. More specifically, senior drivers responded to warning sounds about 160 and 320 ms later in releasing the accelerator and applying the brake, respectively, independent of the warning sound characteristics. These differences should be considered in the design of safety systems and in particular, in the design of the eVADER concept. Finally, consideration of the physical and emotional characteristic of senior drivers is required when selecting safety-warning sounds. Safety warning sounds should have a frequency of 3–4 kHz and a tempo of 200 ms\textsuperscript{10}.

\textsuperscript{10} M.H. Kim et al, ‘Age related physical and emotional characteristics to safety warning sounds’, IEEE transactions on systems, man and cybernetics
6 Sensor integration for pedestrian collision warning system

Sensor integration is one of the challenges in eVADER. This is because the acoustic warning device to be developed has to be controlled by an ECU which will receive information from a pedestrian detection and positioning system and other sensors like acoustic background and humidity conditions affecting the breaking distance. Therefore, we can foresee that the definition of the pedestrian collision warning system is a dominant point to be addressed.

In this section we discuss some aspects of a pedestrian collision warning system with crosswalk detection feature based on sensor fusion of a monocular camera and a millimetre wave radar. The method to decide about the presence of a pedestrian is based on the assumption that objects moving along a crosswalk can be interpreted as pedestrians under certain circumstances. The advantage of the described solution is its robustness and effectiveness since it is limited to crosswalks. The camera can be used to detect the crosswalk. Data from both sensors can then be used to infer about the presence of a pedestrian. The system can have a warning concept which provides auditory alarm and visual information about the presence of a crosswalk as well as pedestrians to a driver, depending on the estimated collision probability.

To detect pedestrians, existing researches make use of stereo camera, monocular camera, infrared camera and LIDARs as described in the survey by Gandhi and Trivedi. Cameras have advantages of wide view range and high resolution power, so cameras can recognize attributes of objects by image processing. However, there are some problems of image processing that the algorithm is so complex, the computational cost is high, and the distance to target might be inaccurate. On the other hand, a LIDAR is not suitable to recognize attributes of objects, but it can measure the distance accurately. For development of pedestrian protection system in the situation of car-to-pedestrian accidents, it needs calculation of the collision probability, therefore it is important for the system to measure the pedestrian position accurately. Therefore, a sensor fusion of camera and radar is a good solution in order to get high reliability of the system.

6.1 Pedestrian detection and warning system design

The architecture of a possible pedestrian collision warning system is shown in Figure 24. This system consists of three algorithms: a crosswalk detection algorithm, a sensor fusion algorithm of camera and millimetre wave radar, and an algorithm for calculation of the probability of pedestrian collision. A warning can be provided to the driver when the pedestrian collision reaches a certain level.

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6.2 Sensor fusion algorithm

The flow diagram of the sensor fusion algorithm and the example of the information processing by this algorithm are shown in Figure 25. The algorithm is based on the assumption that the vehicle is running straight and the vehicle direction is perpendicular to the crosswalk. The pixel coordinates of the boundary of the crosswalk detected from the image processing unit and the forward object position data with respect to the host vehicle obtained from the millimeter wave radar are used to detect moving objects near a crosswalk. The following procedures of the sensor data fusion algorithm are conducted for pedestrian detection task.
This algorithm provides a visual and an auditory warning in real time to a driver depending on a collision risk to the pedestrian. The warning algorithm estimates the collision risk from the predicted position of the pedestrian, and the host vehicle velocity and the crosswalk information explained in the previous section. Conventional warning system like the one proposed in 12 used a simple index such as Time-to-Collision (TTC) as a criterion whether the warning should be issued or not. However, TTC is the index which considers the relative speed between two vehicles in identical directions, so TTC may not be suitable to indicate the risk when the object approaches to the host vehicle in lateral direction. Until now, the systems based on the current pedestrian longitudinal position have been proposed to estimate the collision risk 13. Therefore, the systems based on TTC index might give inappropriate warning to drivers since they do not take the lateral position of the pedestrian into account. Herein it is shown a collision risk estimation which combines TTC with the prediction of pedestrian position for critical warning to driver. The pictorial diagram is shown in Figure 26. First, the pedestrian motion direction is defined, and then the predicted time \( T_p \) for the host vehicle to reach this axis is calculated. Predicted pedestrian position is the position that a pedestrian moves for the time \( T_p \). The following assumptions are made for the calculation.

Pedestrians and the host vehicle will continue moving with constant velocity \( V_{ped} = const \) and \( V_{car} = const \). The host vehicle is running straight and the vehicle direction is perpendicular to the crosswalk \( (Y_{car}) \). The pedestrians move along the moving axis defined

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above with a constant average walking speed \(X_{ped} \) \((\text{const})\). The predicted time \(T_p\) according to these conditions can be expressed as follows:

\[
T_p(t) = \frac{X_{ped}(t) - X_{car}(t)}{V_{car}}
\]  

(14)

and the predicted pedestrian position can be:

\[
Y_{ped}(t + T_p(t)) = Y_{ped}(t) + V_{ped}(t) \cdot T_p(t)
\]  

(15)

where, \(X_{ped}(t) - X_{car}(t)\), \(Y_{ped}(t)\) are position measured by millimetre wave radar. The pedestrian crossing speed \(V_{ped}\) is calculated by the differentiated value of the lateral position \((Y_{ped})\) and then the smoothing preprocessing for the differentiated signal are conducted by moving average filter.

From the pedestrian current position and the vehicle speed acquired by sensors, the pedestrian predicted position can be calculated in real time. The system can then utilize the position, the lateral velocity of the detected pedestrian in the design of the visual indication, in order to inform the driver about the presence of a crosswalk or a pedestrian. The interest region for detection is determined as shown in Figure 27. The top border of the interest region is set to be proportional to the vehicle speed. \((T_v)\) indicates the parameter for setting the range of longitudinal top in the pedestrian detection which is equivalent to time-to-collision, and \(car V\) indicates the vehicle speed. The proportional relationship between the vehicle and longitudinal range \((T_v)\) is set to the constant value of 4.0 seconds. This value is based on Ueda’s report which addresses that the warning of pedestrian protection algorithm is effective at time-to-collision of 4.0 seconds\(^4\). Visualized hazardous region is separated into the probability of pedestrian collision by every 1.0 seconds. Then, to check the data processing output of the system, a red/yellow/green light indicator in a vehicle–mounted can be built up to show the presence of crosswalk or a pedestrian.

Depending on the condition of the pedestrian position and the walking speed, the collision warning which consists of auditory warning, the colour of the visual warning on the vehicle display can be changed according to certain rules, and an auditory warning is issued to the driver when the situation becomes more critical as shown in Figure 28

\(^4\) S. Veda et al, ‘A study on effectiveness of the pedestrian warning at inattentive driving’, JSAE transactions, Vol 38, N 2 March, p 231-236
Figure 26

Figure 27
6.3 The stereovision system from Continental

As mentioned in the previous section the vision system for pedestrian detection is of paramount importance.

The Stereo Camera System provided by Continental inside the EVADER project is a One-Box solution incorporating all technology specific components and the complete processing power for stereo functions.

The size of the One-box design is mainly defined by the required range resolution for stereo reconstruction (base width) that aims about 20 cm between the two sensing devices. In addition, due to the processing and accuracy requirements, the Continental stereo camera has a metal housing. This specific housing is able to guarantee a good EMC shielding for emission and radiation but also to handle of power dissipation and preserve robustness and long term stability of optical paths alignment.

The implementation of the stereoscopic box inside the vehicle needs a specific calibration process involving dedicated tools specially developed by Continental but also some specific information from the vehicle like for example vehicle speed. The information about detected obstacles and their path is provided onto a CAN bus.

The stereoscopic module must be integrated behind the windshield in an area that is cleaned by the wipers in order to avoid any field of view blockage due to rain or dust.
The algorithm for pedestrian detection implemented into the stereo module are running without any model assumptions required they provide a direct, accurate and stable distance measurement (esp. in near range). Furthermore, this generic detection approach does not require knowledge of appearance / size / shape of object class. The detection is based on local feature-based combination of motion (optical flow) and distance measurements (disparity estimation) that allow a robust target separation.

The main specifications of the Stereoscopic systems to be used in eVADER are presented in the following table.
<table>
<thead>
<tr>
<th><strong>Dimensions (W x H x D):</strong></th>
<th>275 x 34 x 100 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Protection class:</strong></td>
<td>IP5K0</td>
</tr>
<tr>
<td><strong>Temperature range Operating / Storage:</strong></td>
<td>-40°C...+85°C (at night -40°C...+60°C) / -40°C...+105°C</td>
</tr>
<tr>
<td><strong>Self diagnostics / self monitoring:</strong></td>
<td>yes - contamination, imager function, CPU</td>
</tr>
<tr>
<td><strong>Interfaces:</strong></td>
<td>1 x CAN  maximum 500 kb/s</td>
</tr>
<tr>
<td><strong>Main power supply:</strong></td>
<td>7.0...16 V DC (typical 14.0 V), 120 s protection against wrong polarity</td>
</tr>
<tr>
<td><strong>High system voltage – response time:</strong></td>
<td>&lt; 10 ms (disable main circuit elements)</td>
</tr>
<tr>
<td><strong>Shock mechanical:</strong></td>
<td>50 g</td>
</tr>
<tr>
<td><strong>Vibration mechanical:</strong></td>
<td>20 m/s² peak@10Hz , 0.14 m/s² peak@1000Hz</td>
</tr>
<tr>
<td><strong>Field of view</strong></td>
<td>53 x 30 (h x v) deg</td>
</tr>
<tr>
<td><strong>Cycle time</strong></td>
<td>60 ms</td>
</tr>
<tr>
<td><strong>Image sensor</strong></td>
<td>CMOS – Color sensor</td>
</tr>
<tr>
<td><strong>Distance Range</strong></td>
<td>2 – 40 m</td>
</tr>
<tr>
<td><strong>Detectable objects</strong></td>
<td>Stationary and moving objects, seen from all sides</td>
</tr>
<tr>
<td><strong>Detection constraints</strong></td>
<td>No essential constraints - Detection even possible for partially occluded pedestrians</td>
</tr>
</tbody>
</table>
The use cases and main scenarios for pedestrian accidents are provided within the GIDAS data analysis. Among them, the most current are concerned with pedestrian crossing the road from left and right side that represents about 75% of the total. The Continental pedestrian detection system has been designed to cover these scenarios.

Figure 11: GIDAS data analysis
7 Conclusion

This report covers various of the important point that have to be addressed in eVADER regarding the interaction between the car, the driver and the pedestrian. The analysis suggests that it is possible to design EV so that their impact in the total number of accidents involving pedestrians would be the same as IC vehicles. The combination of exterior and interior warning signals is probably the best solution to warn both pedestrians and drivers in close-to-accident situations.

WP2 is an important work package in eVADER because it will give us a better understanding of the acoustic detection mechanism used by VI people near public roads. The detection of EV by this special group will be investigated in terms of detection distance and influence of acoustic level evolution. The physical response and emotional characteristics of the warning sounds for both pedestrians and drivers will be considered since it has been shown that is noticeable for drivers.

On the other hand the physical device producing the warning sound will have to be directional in some way. A sensor integration combining visual and acoustic information will have to be developed improving current systems. In this field, the partner CONTINENTAL will have an important role integrating its stereovision system with other sensors that will be available in the vehicle.