

HOLLAND: VRU PARADISE GOES FOR THE NEXT SAFETY LEVEL

Margriet van Schijndel - de Nooij

Stefanie de Hair-Buijssen

Ton Versmissen

TNO

The Netherlands

Rikard Fredriksson

Erik Rosén

Jan Olsson

Autoliv Research

Sweden

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ABSTRACT

In Europe there has been a large focus on increasing pedestrian safety by requiring protection capability of cars, both using regulations and consumer tests, however none of this involved the safety of bicyclists in car crashes. The increasing use of bicycles in many major cities leads to the expectation that the number of cyclist fatalities will increase in the coming years, unless proper actions are taken.

In the Netherlands, a country with many cyclists, there were 720 road fatalities in 2009, of which 69 pedestrians and 185 cyclists. About half of the cyclist fatalities were directly related to an impact by a passenger car. In protection of cyclists and pedestrians, cornerstones are infrastructure, training, visibility/detectability of the vulnerable road user (VRU), and VRU friendliness of the vehicle. The first three cornerstones are dealt with in several (national) projects; the latter so far gained little activity within the Netherlands.

Initiated by the Dutch Cyclists' Union, the Dutch Ministry of Transport commissioned a project on the vehicle VRU friendliness. The overall target is to decrease the number of VRU fatalities and severe injuries. The preparation phase contained experiments and simulations studying cyclists' movements during the last seconds prior to impact. These activities were combined with accident reconstruction tests of a dummy riding a bike that was impacted by a passenger car. A study to the protection potential has been initiated, aiming to determine the number of fatally and severely injured (AIS3+) VRUs potentially saved by different types of countermeasures. This study focuses on the Dutch situation covered by the Dutch BRON database, enriched with GIDAS. While the effectiveness calculations remain to be done, the study shows that cyclists hit the windscreen area on a higher location than pedestrians. For all VRUs, the windscreen area is the main injury source. In the cases studied, ground

impact accounts for 20% of all AIS3+ injuries. AIS3+ survivors sustain in most cases a single AIS3+ injury (80% for cyclists, 70% for pedestrians), while the majority of fatalities suffered from AIS3+ and AIS4+ injuries to more than one body region. Cyclists suffer from leg injuries considerably less than pedestrians.

The current phase of the project is on the development and evaluation of a Proof of Concept of a VRU protection system. The major part of this phase consists of a Sensor Field Test, in which the vision system for classification of cyclists, pedestrians and "other objects", to trigger an airbag and/or automatic braking system, is further developed and tested. This Sensor Field Test runs for a year in order to encounter enough close-to-accident situations needed to develop a system with a high detection rate in combination with a sufficiently low number of false positives. The Proof of Concept will also be evaluated in laboratory tests, in crash and pre-crash situations, using the "Beyond NCAP" protocols of Euro NCAP. When proven successful, a larger Field Test covering several European countries would be an essential step towards further implementation of these types of systems.

INTRODUCTION

In most EU countries bicycles are mainly used for sporty activities. However, in the Netherlands the bike is a widely accepted means of daily transport for distances up to 10-12 km. With the increasing number of both cyclists and passenger cars in a shared environment, the issue of safety becomes increasingly important. For the physical safety of the car driver, accidents with cyclists are normally not catastrophic. On the other hand, the cyclist is much more vulnerable, just like pedestrians. Therefore, passenger car-to-cyclist/pedestrian accidents often cause severe or fatal injuries to the VRU [4]. While a lot of worldwide attention is being paid to the safety of car occupants as well as of motorcyclists

in almost any type of accident, pedestrian and pedal cyclist safety has been lagging behind. With an increasing number of cyclists that use the bike as an environment friendly means of transport [19], e.g. in major cities such as Paris, London, Barcelona and Berlin, cyclist safety starts to gain the attention it deserves. Figure 1 shows that safety of VRUs is at stake in many major European cities.

To improve cyclist safety there is a number of important instruments available, which include:

- Training
- Infrastructure/separation of traffic
- Cyclist visibility, especially at dawn and at night
- Pedestrian & cyclist friendliness of the vehicle.

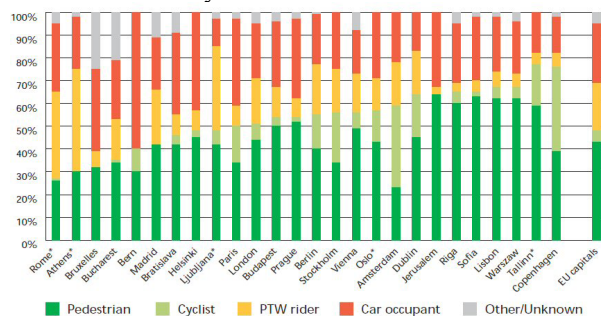


Figure 1. Distribution of road deaths by road user groups (2004 – 2006) [1]

In the Netherlands the number of fatalities in road traffic has been reduced from over 3000 per year in the 1970s to 720 in 2009. However the number of cyclist fatalities has been stable at around 185 per year for a long period [15]. Concerned by this situation the Dutch national government started some years ago to be more active in increasing cyclist safety. This is supported, stimulated and in some areas initiated by interest organisations such as the Dutch Cyclists’ Union.

A major Dutch project in the field of cyclist and pedestrian protection, called SaveCAP, was initiated by the Dutch Cyclist Union and the Dutch Ministry of Infrastructure and Environment. The main objective of SaveCAP is the development of an evaluated Proof of Concept for VRU safety systems. A consortium was formed, including also TNO, Autoliv and Dutch insurance company Centraal Beheer Achmea. Since 2008, they cooperate within SaveCAP. The Dutch Ministry of Infrastructure and Environment strives towards less than 500 road fatalities in 2020 and sees this project as an instrument to achieve this, while being its main funder. TNO acts as project leader and development partner, as well as the organizer of the Sensor Field Test and Proof of Concept Evaluation. Autoliv works on the system development, for the sensor and

protection system, including development of new test methods for cyclists based on accident data in Sweden and Germany. Funding has been provided for parts of this work by the Swedish Transport Administration and the Swedish government (FFI; Strategic Vehicle Research and Innovation). Centraal Beheer Achmea and the Dutch Cyclist Union support with project focus and supply real life data on car-to-VRU accidents, and cyclist needs.

The focus of this paper is on the protection potential of countermeasures on the vehicle towards fatally and severely injured cyclists and pedestrians. The paper starts with a short overview of the recent history of pedestrian protection. Many lessons learned here can be used for cyclist protection. This part is followed by case studies found in the Netherlands, enriched with data from the German In-Depth Accident Study (GIDAS). It is followed by an injury study based on GIDAS accident data. This section shows the distribution of severe injuries sustained by cyclists and pedestrians. Furthermore, it includes a description of the injury producing sources, such as ground, bonnet and windscreen. A study on the protection potential of several countermeasures is partially based on this, indicating the potential benefits for road safety in the Netherlands. Countermeasures taken into account are a VRU airbag, a pedestrian airbag, automatic braking and a deployable bonnet. For systems detecting the Vulnerable Road User (VRU) prior to impact, a reliable detection system is necessary. The last technical section will focus on the running Sensor Field Test for development and evaluation of such a detection system.

DEVELOPMENTS IN PEDESTRIAN AND CYCLIST SAFETY

Pedestrian safety research has been conducted since the 1970’s but it was with the introduction of consumer tests (Euro NCAP) in 1997 and legal tests in Japan and Europe 2005 [5] [16] that the development of pedestrian countermeasures gained momentum. Passive solutions for the bumper, headlights, bonnet, wing and scuttle areas have been presented and to some extent been introduced [2] [10]. While later Euro NCAP improved leg test results show that the bumper area has proven feasible to accommodate solutions, the bonnet area is more challenging. To give the energy absorption distance necessary and keep design freedom of the car, deployable bonnets have been developed and introduced in a number of car models (e.g. Jaguar, Citroën, Honda, BMW, Mercedes-Benz, Cadillac, Nissan and Porsche).

While current legal tests do not evaluate the windscreen area, this is included in Euro NCAP tests. This in combination with the recent introduction of combined rating of occupant and pedestrian protection [7] is expected to give increased focus on windscreen area solutions. Different airbags for the lower windscreen and a-pillars have been presented [3] [14] [12].

Another solution to increase the safety for pedestrians is aiding the driver in reducing the impact speed, and in some cases even avoiding the accident completely. Brake-assist, a system which aids the driver to optimize the braking in panic situations, was mandated in Europe 2008. The shortcoming of this system is that the driver needs to initiate the braking action. Since it is common in car to pedestrian accidents that no braking action is taken [11], probably due to that the driver does not notice the pedestrian before the impact; a natural next step is developing automatic braking systems. Automatic braking systems that gently or fully apply the brakes when a pedestrian is detected have been introduced recently [13] [20].

Both automatic braking systems and bonnet/windscreen countermeasures have been estimated to potentially save 27-44% of severely or fatally injured pedestrians when impacted by a car front, and over 60% if these systems are combined in an integrated system [8] [17]. While focus has been on pedestrian protection, less focus has been laid on cyclist safety so far. Within SaveCAP, first tests on accident reconstructions with cyclists have been performed. First, tests with volunteers were done, showing the last-moment moves that cyclist are capable of, in an attempt to avoid an accident. Furthermore, accident reconstruction full crash tests were performed, with a dummy (Hybrid III pedestrian) riding a bike, impacted by a car. Car speeds used were up to 50 kph, the bike speed was ¼ of the vehicle speed, see Figure 2.

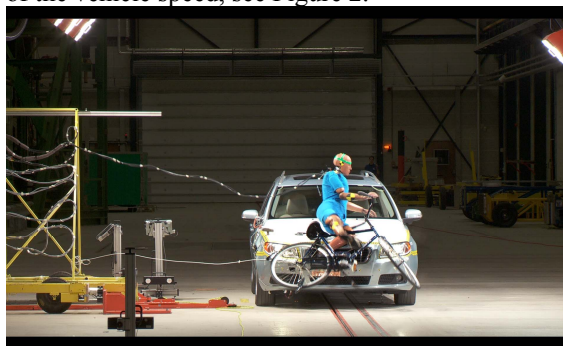


Figure 2. Biking dummy impacted by a car, under lab conditions

ANALYSIS OF VRU SAFETY SITUATION IN THE NETHERLANDS

Method

When starting the project SaveCAP, the first action was to look into the relevant accident information for the Netherlands, to gain deeper insight in the actual numbers of cyclist and pedestrian fatalities and severe injuries, as well as the accident scenarios. In this study, the following data sources were used:

1. Dutch National Accident databases (BRON),
2. German in-depth data bases (GIDAS) [23],
3. Insurance company data (Centraal Beheer Achmea),
4. Results of EU projects eIMPACT [22] and APROSYS [21].

BRON and GIDAS (see also Table 1) were used to obtain dedicated figures representative for the Netherlands. BRON was used as the base data source and was enriched with GIDAS data, since some of the important categories are not present in BRON. It was assumed that certain aspects of GIDAS data are representative for the Dutch situation.

Table 1. BRON and GIDAS databases

Topic	BRON (Netherlands)	GIDAS (Germany)
Data sources	Based on police reports	Specialist teams on accident location.
Registration criteria	Accident reported to the police	Accident reported to the police, rescue services and fire department headquarters and involving personal injury.
Coverage	Covers 80% of all cases in entire Netherlands	Covers most cases in regions of Hannover and Dresden, in which a person gets injured. The data is representative for the situation in Germany.
Database owner	SWOV (Dutch institute for road safety research)	GIDAS is a joint project between FAT (Automotive Industry Research Association) and BAST (German Federal Road Research Institute)

Injury level included	AIS1+, no distinction on severity level	All AIS levels included, distinction can be made
Years used in current study	2006-2008	1999-2007
Relevant data for current study	<ul style="list-style-type: none"> • Number of fatalities and severely injured • Age • Road type • Vehicle type • Frontal accident • Weather and lighting conditions 	<ul style="list-style-type: none"> • Ratio AIS1+ : AIS3+ • Head injury level • Impact location • Head impact location • Car braking level

In this study only the severe injuries (fatalities and AIS3+ (Abbreviated Injury Scale)) were taken into account. The AIS3+ and fatality cases are most relevant target groups to be saved by the countermeasures considered. The BRON database contains only figures of severity level AIS 1+ injuries, and beside fatalities no other injury levels are distinguished. The relation AIS1+, AIS3+ and fatal injuries from GIDAS were used to obtain AIS3+ figures representative for the Netherlands.

The ability of VRU safety countermeasures to reduce fatalities and mitigate injuries depends on several factors. The main factors taken into account are:

- type of vehicle,
- whether the VRU strikes the front of vehicle,
- speed of vehicle,
- whether the vehicle brakes or not,
- age of the VRU,
- impact location of head on vehicle,
- lighting conditions,
- weather conditions.

For the Netherlands representative numbers and their interrelation to the above mentioned categories were obtained (using BRON and GIDAS data). The data was handled in two steps.

The first step The data was filtered from the reference group (all accidents in which a VRU is severely or fatally injured) to the target group (those that can potentially be helped by the considered countermeasures). This target group consists of those cases in which a VRU is hit by the front of a moving passenger vehicle on a road with speed limit lower than or equal to 80 km/h (since very few VRU related

accidents occur on these Dutch roads). The resulting target group was used as input for the second step.

The second step A so called data tree was filled. The tree shows the number and cases and due to which combination of main factors the VRU became injured.

Table 2 gives an overview the categories used in the data trees and the origin of data used to fill the data trees. Furthermore it is explained how the data was divided over the different categories.

Table 2. Categories used in the data trees

Road type
The accident data was categorized according to the speed limit of the roads: <ul style="list-style-type: none"> • urban roads: speed limit ≤ 50 kph. All roads with a maximum speed limit of at most 50 kph, • rural roads: speed limit > 50 kph The roads with a maximum speed limit higher than 50 kph, but with a maximum of 80 kph. Roads with higher speed limits were not taken into account, as very few VRU related accidents occur on these Dutch roads.
VRU Age
The accident data was categorized according to the ages of the injured VRUs in BRON. Based on their age the cases were allocated to the appropriate category: <ul style="list-style-type: none"> • child: age ≤ 12, • adult: $12 < \text{age} \leq 65$, • senior: age > 65. The cases in which the age of the VRU was not specified were excluded.
Car braking*enriched
In GIDAS the car deceleration level is registered, a derived parameter, for example from the braking marks on the road and accident reconstruction simulations. This deceleration level was used to make a distinction between the following categories: <ul style="list-style-type: none"> • car is braking • car is not braking (deceleration is zero or the vehicle is accelerating). The GIDAS ratio between braking and not braking was used to enrich the BRON data. The cases with unknown braking levels were excluded.
Severe head injury*enriched
The GIDAS database contains a variable showing the VRU's head injury severity. The level is specified in AIS levels. Two categories are distinct: <ul style="list-style-type: none"> • severe head injury: head injury level is AIS3+ • no severe head injury: no head injury or a head injury of AIS1 or AIS2 The ratio between these two categories was used to enrich the BRON data. The cases with unknown head injury severity were excluded.

Head impact location*^{enriched}

The GIDAS database contains a variable which denotes on which zone of the car the VRU's head strikes the car. The zones are visualised in Figure 3. Zone 4 represents the windscreen. The 'no windscreen' cases were represented by impact to the car by the bonnet zones 1, 2 and 3 and the roof 5 or by cases in which the head does not hit the car (e.g. ground impact). The unknown cases were excluded from the data taken into account.

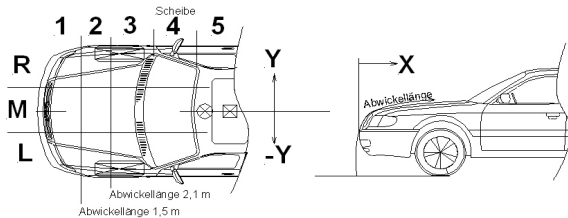


Figure 3. GIDAS definition of head impact location

Given that the victim's head strikes the windscreen, the method needed to distinguish between whether the head strikes the top or the bottom of the windscreen. The GIDAS variable does not make a distinction between the top and the bottom of the windscreen. To obtain this information the GIDAS photo material was used to investigate all cases in which the VRU's head struck the windscreen. On the basis of this information, visualized in Figure 4, a distinction was made between the cases that struck the top or bottom of the windscreen.

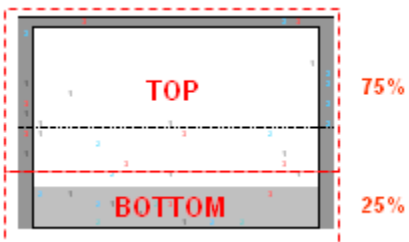


Figure 4. Schematic representation of windscreen containing the definition of windscreen TOP (upper 75%) and BOTTOM (lower 25%)

Lighting conditions

The lighting conditions were taken from the BRON database. The cases were divided over the following categories:

- darkness,
- daylight: meaning daylight and twilight.

The cases in which the lighting conditions were not specified are excluded.

Weather

The BRON data offers the weather conditions. The cases were divided over the following categories:

- normal weather: dry weather and hard wind,
- adverse weather: rain, fog, snow, hail.

The cases in which the lighting conditions were not specified were excluded.

Several data trees were setup taking the following categories into account: severely injured versus fatalities, cyclist versus pedestrians and countermeasure type. The data trees were first filled with available BRON data, complemented by using the relations retrieved from a comparable data tree setup with GIDAS data (see next section on the results). Since the number of relevant cases in GIDAS is very small, there are cells in the data tree without any cases. In these cases the proportion of a representative other subcategory was used. For example, in GIDAS no data was available about fatally injured children in urban areas, whereas in BRON there were. In order to obtain data for the Dutch situation for the braking and no braking cases for this category, overall mean values of the adult category were used to calculate the number of braking and not braking cases.

Results

The first step: determination target group

The resulting target group size was 398 (out of 905 from reference group) severely-injured cyclists and pedestrians for one year, based on detailed information available over the years 2006-2008. For fatalities, the target group was 93 (out of 228 from reference group) cyclists and pedestrians.

Table 3: Filtering from reference to target group

# cases 1 year (cyclists & pedestrians)	Reference group	Target group
Severely injured	905	398
Fatally injured	228	93

The second step: data trees The data tree is structured around braking and severe head injury, based on the assumption that the head injury is the main injury. If head injury could be prevented, the VRU involved could be saved. Based on newest insights (see next section) the structure of the data trees should be extended. Beside head injuries chest injuries should also be taken into account, in order to draw conclusions on the protection potential of the considered countermeasures. The data trees are shown in Table 4 till Table 7.

In these tables, weather and lighting conditions are not included. Each table contains a section on urban cases and a section on rural cases. For both locations, a split is made into three age categories: children, adults and seniors. Thus, Table 4 shows e.g. for severely injured pedestrian children in the urban environment 21,3 cases, of which 6,6 sustained severe head injury. From this number, 3 cases of

severe head injury were caused by a head impact on the bottom of the windscreen. Furthermore, the table shows that out of the 21,3 cases, in 13,3 cases the car was braking before impact.

In the calculations run to fill the tables, the rounding of digits was done in the latest stage possible. This causes the small errors that can be found when adding the final numbers.

Most fatalities sustained a severe head injury, for cyclists in a majority of the cases caused by the top of the windscreen area. In the group fatalities, elderly are overrepresented.

Table 4. Pedestrians - severely injured. Number of cases for 1 year.

Note: No compensation included for under-reporting of AIS3+ injured compared to fatalities

VRU Age group	Severe Head Injury		Head impact location on Windscreen		Braking		
Urban 65,6							
Child	21,3	Y	6,6	Top	0	Y	13,3
				Bottom	3		
				No	3,3		
N		14,6					
Adult	30	Y	17,6	Top	2,6	Y	15,6
				Bottom	6		
				No	2,6		
N		19					
Senior	14,3	Y	2,6	Top	0,3	Y	9
				Bottom	1,6		
				No	0,6		
N		11,6					
Rural 7,6							
Child	1	Y	1	Top	0	Y	0,6
				Bottom	0,3		
				No	0,3		
N		0					
Adult	5,3	Y	0,6	Top	0,3	Y	3,6
				Bottom	0		
				No	0,6		
N		4,6					
Senior	1,3	Y	1,3	Top	0	Y	0,6
				Bottom	0,6		
				No	0,6		
N		0					
Total 73,3							

The results show that cyclists in general hit higher on the windscreen than pedestrians. Most accidents take place in urban area (speed limit ≤ 50 kph). On rural roads, a large majority of the VRUs (severely injured and fatalities) have (also) severe head injury.

For the severely injured VRUs, there is found a large share of non-severe head injuries. The share of children amongst the severely injured pedestrians is three times higher than their share amongst severely injured cyclists. This effect is not found for fatalities.

Table 5. Cyclists - severely injured. Number of cases for 1 year.

Note: No compensation included for under-reporting of AIS3+ injured compared to fatalities

VRU Age group	Severe Head Injury		Head impact location on Windscreen		Braking		
Urban 269							
Child	24,3	Y	9,6	Top	2,3	Y	9,6
				Bottom	0		
				No	7,3		
N		14,6					
Adult	192,6	Y	71	Top	43,6	Y	101
				Bottom	22		
				No	5,3		
N		121,6					
Senior	52	Y	2,6	Top	1,6	Y	9,6
				Bottom	6		
				No	6		
N		38,6					
Rural 55,3							
Child	5,3	Y	5,3	Top	1,3	Y	2,3
				Bottom	0		
				No	4		
N		0					
Adult	38,6	Y	38,6	Top	19,3	Y	19,3
				Bottom	0		
				No	19,3		
N		0					
Senior	11,3	Y	11,3	Top	11,3	Y	4,6
				Bottom	0		
				No	0		
N		0					
Total 324,3							

Table 6. Pedestrians - fatally injured. Number of cases for 1 year

VRU Age group		Severe Head Injury		Head impact location on Windscreen		Braking		
Urban								21
Child	1,3	Y	1,3	Top	0	Y	0,6	
				Bottom	0,6			
				No	0,6			
		N			0	N	0,6	
Adult	9,3	Y	6,3	Top	1,3	Y	4,6	
				Bottom	3,6			
				No	1,3			
		N			3	N	4,6	
Senior	10,3	Y	9	Top	2,6	Y	6,3	
				Bottom	6			
				No	0,6			
		N			1,3	N	4	
Rural								9
Child	1,3	Y	1,3	Top	0	Y	0,6	
				Bottom	0,6			
				No	0,6			
		N			0	N	0,6	
Adult	5,6	Y	4	Top	0,6	Y	1	
				Bottom	2,3			
				No	0			
		N			1,6	N	4,6	
Senior	2	Y	2	Top	0,6	Y	1	
				Bottom	1,3			
				No	0			
		N			0	N	1	
								30

Table 7: Cyclists - fatally injured. Number of cases for 1 year

VRU Age group		Severe Head Injury		Head impact location on Windscreen		Braking		
Urban								38,6
Child	2,3	Y	2	Top	0,3	Y	1,6	
				Bottom	0			
				No	1,3			
		N			0,3	N	0,6	
Adult	17	Y	14,6	Top	11,6	Y	14,3	
				Bottom	3			
				No	0			
		N			2,3	N	3	
Senior	19,3	Y	14,6	Top	7,3	Y	9,6	
				Bottom	7,3			
				No	0			
		N			5	N	9,6	
Rural								24
Child	2,3	Y	2,3	Top	0,6	Y	1,6	
				Bottom	0			
				No	2			
		N			0	N	0,6	
Adult	12,3	Y	12,3	Top	4	Y	8,3	
				Bottom	8,3			
				No	0			
		N			0	N	4	
Senior	9,3	Y	9,3	Top	9,3	Y	6,6	
				Bottom	0			
				No	0			
		N			0	N	2,6	
								62,6

INJURY PATTERN STUDY FOR CYCLIST AND PEDESTRIANS

Method

The GIDAS database from 1999 to 2008 was used to study the injury pattern of cyclists and pedestrians in real-world, road traffic accidents. GIDAS uses the AIS injury classification system (1998 version), dividing the body into eight different body regions: head, face, neck, thorax, abdomen, spine, and upper and lower extremities [2]. In this study, head and face were combined in a new category called “head”. Thorax, abdomen, and spine were combined in a category called “chest”. Further, lower and upper extremities were called “leg” and “arm” respectively.

The AIS scale comprises six levels of injury severity, where AIS1 denotes minor injury, 2 moderate, 3 serious, 4 severe, 5 critical, and 6 maximal injury. The fatality risk from a single injury increases with the AIS score. In this study, injuries with AIS scores equal to or higher than AIS3 (i.e. AIS3+) were considered severe.

The GIDAS database was queried for all severely and fatally injured cyclists and pedestrians struck by the front of a passenger car or van. This yielded a study group comprising 14 fatally and 88 severely injured cyclists together with 41 fatally and 120 severely injured pedestrians. This group of 263 vulnerable road users suffered from a total of 643 AIS3+ injuries. Injury mechanisms for the pedestrians in this study group were analysed by Fredriksson et al [9].

Results

For fatalities, the majority of cyclists and pedestrians in the study group suffered from AIS3+ and AIS4+ injuries to more than one body region. For both cyclists and pedestrians, approximately 80% had AIS3+ head injuries and 80% had AIS3+ chest injuries. Nearly 60% of the pedestrian fatalities had AIS3+ leg injuries, while only 20% of the cyclist fatalities had AIS3+ leg injuries. At the AIS4+ level, head and chest injuries were even more dominating for both groups.

For AIS3+ injured survivors, it was more common to sustain a single AIS3+ injury compared to the fatalities: 80% of the cyclist and 70% of the pedestrian survivors had only a single AIS3+ injury.

Combinations of AIS3+ injured body regions for fatalities and severely injured survivors are shown in Figure 5 and Figure 6. The fatalities were associated

with AIS3+ injuries to more than one body region, whereas the survivors most often had AIS3+ injuries to only one body region. As many as 70% (17 of 24) of the VRUs with AIS3+ injuries to both head and chest (but no other body regions) died (the average fatality rate for the five injury combinations in the top of Figure 6 (all including head and chest) was 80%). This can be compared to the fatality rate of 11% (7 of 61) for the VRUs with only AIS3+ head injuries and fatality rate of 3% (1 of 31) for those with only AIS3+ chest injuries.

The full meaning of this finding has yet to be investigated. However, it indicates that a countermeasure able to protect from either AIS3+ head injuries or AIS3+ chest injuries would offer a substantial reduction of the fatality risk. On the other hand, cases with AIS3+ injuries to both head and chest were associated with higher maximum AIS, car impact speed and VRU age compared to cases with AIS3+ injuries to only head or chest.

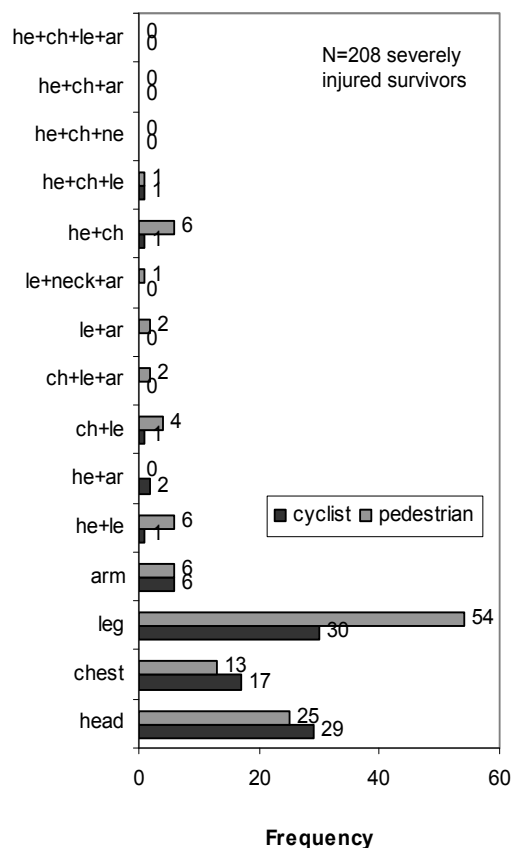


Figure 5. AIS3+ injury combinations for the 208 (88 cyclists, 120 pedestrians) severely injured VRU survivors. The horizontal axis shows the frequency of severely injured survivors with the particular injury combination

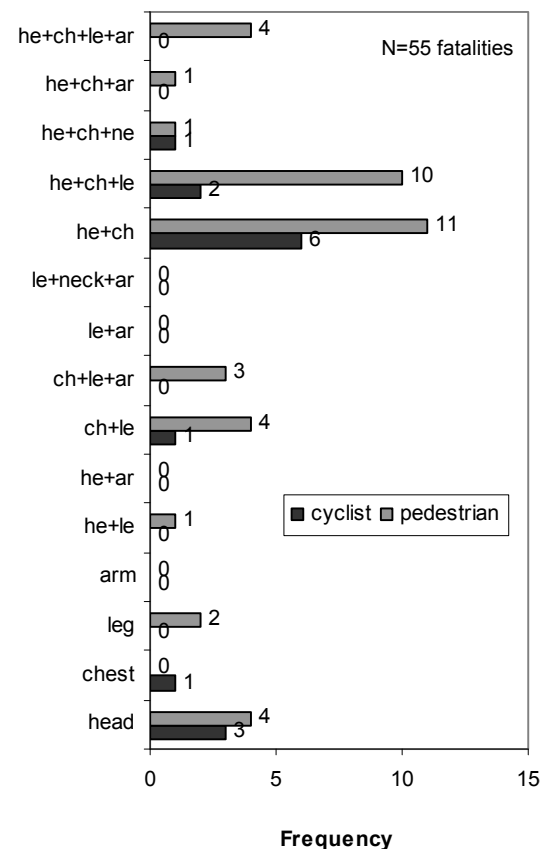


Figure 6. AIS3+ injury combinations for the 55 (14 cyclists, 41 pedestrians) VRU fatalities. The horizontal axis shows the frequency of fatalities with the particular injury combination

Figure 7 shows the distribution of AIS3+ injuries for the total study group (i.e., cyclists and pedestrians as well as survivors and fatalities treated together). Furthermore, Figure 7 shows injury causing parts for each body region. For all VRUs, the windscreen area is the main injury source. In fact, it can be seen that countermeasures for the bonnet and the full windscreen area would have addressed a little over 60% of all AIS3+ head and chest injuries. This in turn made up 45% of all AIS3+ injuries in the study group. Finally, we note that impacts to the ground constituted 20% of all AIS3+ injuries.

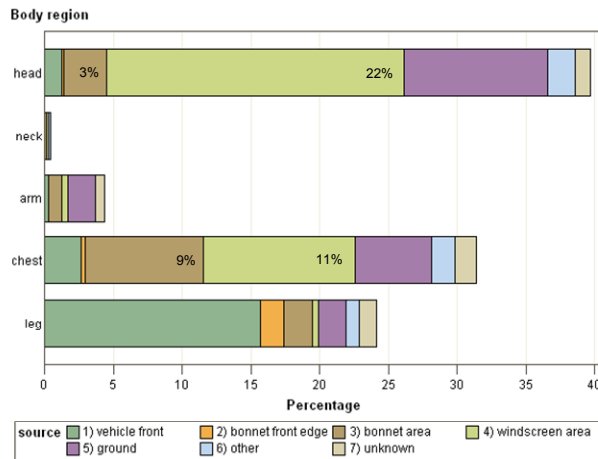
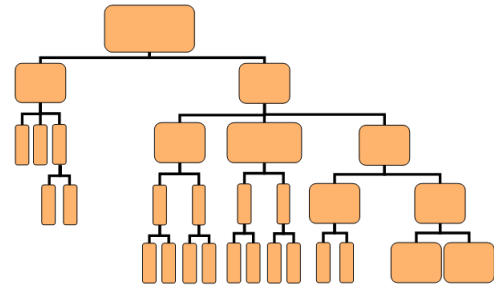


Figure 7. Distribution of AIS3+ injuries for fatally and severely injured cyclists and pedestrians struck by the front of a passenger car or van. Note that a combination of the injuries could be attributed to a single person

Protection potential of vehicle countermeasures

The data analysis described in the previous sections is the first step to get insight in the protection potential of VRU protection countermeasures. A next and future step will be an effectiveness calculation. In this calculation an objective, realistic estimation will be made on the effectiveness of the considered countermeasures (automatic braking, pedestrian airbag, VRU airbag, and deployable bonnet) based on available information (like risk curves, accuracy, airbag geometry, robustness, velocity distributions). This section describes the methodology which can be used to calculate the effectiveness of the considered countermeasures. The reference scenario used to determine the effectiveness potential is the current situation, based on the average of three years of Dutch accident data (2006-2008).



$$\begin{aligned} \text{Number (Data trees)} &= \# \times \# \\ \text{Effectiveness (Effectiveness trees)} &= \# \times \# \\ \text{Reduction of \# Fatalities or MAIS3+} &= \Sigma (\dots\dots\dots) \# \# \end{aligned}$$

Figure 8. Schematic representation of the procedure to determine the effectiveness

The basis of the effectiveness methodology is a tree structure capturing all relevant accident conditions. The structure of the tree is explained before.

The procedure to determine the effectiveness is:

1. The relevant conditions are placed in different levels of the tree. The levels of the tree correspond to the factors determining the effectiveness of the considered countermeasures. Based on the newest insight the tree structure will be extended.
2. Information from databases (BRON & GIDAS) is used to fill the tree with casualty data. This shows under which condition the most injuries/fatalities are inflicted.
3. The extent to which the countermeasure will be effective for VRU protection are estimated and put in the tree, where effectiveness is defined to be the percentage of the VRUs who did NOT die or VRUs who did NOT get injured as a result of the considered countermeasure. The percentages are based on injury risk curves such as illustrated in Figure 9.

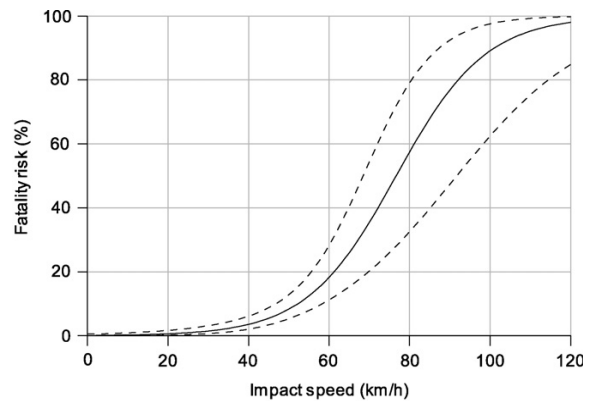


Figure 9. Pedestrian fatality risk curve [18]

4. By multiplying the numbers of step 2 with the percentages of step 3 (at each level) the reduction of the number of fatalities or severely injured VRUs is estimated. This step assumes independence between the levels in the tree.

The outcome of the effectiveness study will show:

- the potential reduction of fatalities among pedestrians and cyclists by the various measures,
- the potential reduction of severely injured pedestrians and cyclists by the various measures;
- a comparison between the various measures.

SENSOR FIELD TEST

Intelligent VRU protection systems are in many cases still in a development phase. The road towards implementation of these systems includes field testing, starting with a small group of test vehicles, which can later on be extended. It has to be ensured that these systems undertake their actions only in case there truly is an imminent risk of impact. This means that the triggering of the system should include an absolute minimum of False Positives.

The SaveCAP consortium has recently started a Sensor Field Test (SFT), in which five identical vehicles are equipped with a system for cyclist and pedestrian detection and recognition. The objectives of this SFT are:

- Reduce number of false alarms by improving sensor algorithm
- Capture realistic near-accident situations for further sensor system development
- Speed up the development from testing in laboratory environment to test drives with VRU protection system on the road
- Make major step in VRU protection system development process towards a mature product.

In this Sensor Field Test (SFT), five vehicles are driving in two large Dutch cities. Two vehicles drive in The Hague, with many different types of traffic situations, while three vehicles are driving in Utrecht, where mixed traffic and narrow streets are common situations, and where there is a lot of student traffic. The Sensor Field Test will run for a full year, thus meeting many different traffic situations, as well as all possible weather conditions. The vehicles are used by service technicians of a Dutch telecomm company, KPN. They follow their normal routine and do not have to perform additional tasks. Accident situations are not needed to have a successful SFT.



Figure 10: Overview of SFT test vehicles

The SFT is about improving the activation capacity of the sensor systems for VRU protection countermeasures. Therefore the main component of the system is the sensor itself: a stereo vision camera. Since the focus of the SFT is on false positives, the contact sensor is not included, nor are the VRU protection countermeasures (deployable bonnet, airbag, active braking system). An overview of the SFT equipment incorporated in the vehicle is visualized in Figure 11.

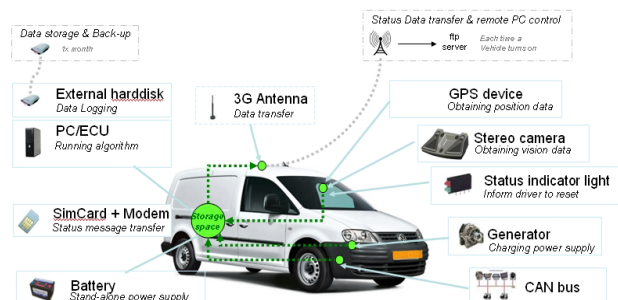


Figure 11: Equipment used in the Sensor Field Test

The stereo camera is positioned at the front windscreen close to the rear view mirror and the vehicle is equipped with data logging equipment, GPS and a 3G antenna for transferring status messages. Furthermore, information from the vehicle CAN bus and an additional ESP sensor is recorded: vehicle speed, yaw rate, braking actions and

windscreen wiper status. Hard discs are used for storing the data. In order to comply with the privacy legislation the data is anonymised.

The SFT system logs only data of potential impacts or critical situations. An interesting situation is defined as a situation in which an object is within a time-to-collision of 0.9s from the test vehicle. The recorded time frame is 16 seconds before estimated impact and 4 seconds after that moment. Per day about 30 events are estimated. A screen shot showing a situation of interest, recorded during the SFT, is given in Figure 12.



Figure 12: Image of real life situation, captured in the SFT

Every three months, the sensor software will be updated, based on the analysis of the measurements in the previous period. Thus, the number of False Positives (FP) will be decreasing during the project, based on real life information. This is essential to come to a properly working system. The sensor system cannot be optimized for a low FP rate only by laboratory tests, or by tests using professional test drivers. A minimized number of False Positives is essential for implementation of systems like this in the vehicle fleet.

DISCUSSION AND CONCLUSIONS

The SaveCAP project aims at improving safety for both cyclists and pedestrians in impacts with passenger cars. In doing so, it is important to understand which areas of the car impose most frequent and most severe injuries. This has been studied for the actual road situation in the Netherlands. In the study presented here, some assumptions needed to be made, such as appointing head injury as main injury in some of the data trees. In future studies, it would be good to verify these assumptions.

It was seen that as many as 80% of the VRUs with AIS3+ injuries to both head and chest died. This can be compared to the fatality rate of 11% for the VRUs with only AIS3+ head injuries and fatality rate of 3%

for those with only AIS3+ chest injuries. The full meaning of this finding has yet to be investigated. However, it indicates that a countermeasure able to protect from either AIS3+ head injuries or AIS3+ chest injuries would offer a substantial reduction of the fatality risk. This can be achieved by several of the vehicle-side countermeasures studied. On the other hand, cases with AIS3+ injuries to both head and chest were associated with higher maximum AIS, car impact speed and VRU age compared to cases with AIS3+ injuries to only head or chest.

Most probably due to the higher location with which cyclists impact the car, they suffer in far less cases from severe leg injury than pedestrians (AIS3+, 20% of the fatalities vs. 60% of the fatalities). This can also explain the finding that cyclists hit the windscreen area on a higher location than pedestrians. For all VRUs, the windscreen area is the main injury source. In the cases studied, ground impact accounts for a minor share of all AIS3+ injuries.

Continuing work like the Sensor Field Test and the Proof of Concept evaluation will lead to a large amount of (real life) close-to-accident information which is worldwide missing so far. This information will have a positive impact on future developments for VRU protection.

After the Sensor Field Test is finalized, the sensor system will be combined with a VRU airbag as test case, and evaluated according to the Beyond NCAP protocols. This will be done in several pre-crash and crash scenarios. Based on the outcomes of these tests as well as the outcomes of the Sensor Field Test, it will be decided how to proceed the drafted developments. Most probably, the scale of testing will be enlarged to a Field Operational Test in several countries, as a step towards implementation of this kind of live saving systems.

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