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Quantifying the effectiveness of ITS in improving safety of VRUs

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Abstract: This paper presents the results of a safety impact assessment, providing quantitative estimates of the safety impacts of ten Intelligent Transport Systems (ITS) which were designed to improve safety, mobility and comfort of vulnerable road users (VRUs). The evaluation method originally developed to assess safety impacts of ITS for cars was now adapted for assessing safety impacts of ITS for VRUs. The main results of the assessment showed that nine ITS included in the quantitative safety impact assessment affected traffic safety in a positive way by preventing fatalities and injuries. At full penetration the highest effects were obtained for Pedestrian and Cyclists Detection System + Emergency Braking (PCDS+EBR), VRU Beacon System (VBS) and Intersection Safety (INS). The estimates for PCDS+EBR showed the maximum reduction of 7.5% on all road fatalities and 4.4% on all road injuries at full penetration, which comes down to an medium estimate of around 1,900 fatalities saved per year in the EU-28 when applying the 2012 accident data and 100% penetration rate. The results regarding future scenarios showed the highest effects in number of reduced fatalities per system in the EU-28 in 2030 for PCDS+EBR (-200 fatalities), Blind Spot Detection (BSD) (-22 fatalities), INS (-20 fatalities) and VBS (-11 fatalities).

1. Introduction

In recent years both technological developments and research activities in the fields of Intelligent Transport Systems (ITS) have primarily focussed on motorised transport aiming to improve the safety and environmental impacts of transport by developing the equipment of vehicles and infrastructure. The uptake of ITS applications has assisted in the decrease of road traffic fatalities, particularly amongst passenger car occupants [1, 2]. Only a few ITS so far have been designed specifically for vulnerable road users (VRUs), such as pedestrians, cyclists, moped riders and motorcyclists. However, VRUs account for 68% of the all road fatalities in urban areas [3]. To address this, there is a clear need for ITS that address VRUs as an integrated element of the traffic system.

This paper presents the results of a safety impact assessment, providing quantitative estimates of the safety impacts of selected ITS. These are ITS aiming to improve the safety, mobility and comfort of VRUs. The approach is based on the method introduced by Kulmala [4], which was developed for the assessment of safety impacts of ITS for cars. The method has been developed and applied in several previous European projects (see e.g. [5, 6, 7, 8, 9, 10]). The assessment presented in this paper is the first attempt to apply this method to vulnerable road users.

2. Method

2.1 European Risk Calculation tool ERiC

The safety impacts of ITS on vulnerable road users were assessed based on a literature review and expert assessment based on the principles described by Kulmala [4]. Safety impacts were determined in terms of number of fatalities and injuries saved, compared to a baseline. Number of accidents and amount of property damage were not used as indicators because of data limitations. The ERiC (European Risk Calculation) tool was utilised to assess the numerical effects in the European accident data. The assessment follows the generally accepted theoretical background according to which traffic safety consists of three dimensions, which are (1) exposure, (2) risk of a collision to take place during a trip and (3) consequences (= risk of a collision to result in injuries or death) [11]. The framework of Kulmala (2010) emphasises the system nature of transport: when one element of the system is affected, the consequences may appear in several elements and levels of the system. Therefore, the implemented safety measures influence safety by affecting one or several of the factors contributing to any of these three dimensions of safety.

In order to ascertain that all possible impacts (both positive and negative impacts on road safety; direct, indirect and unintended effects of systems) will be covered, and no effects are counted twice, the analysis proposed by Kulmala (2010) utilises a set of nine mechanisms via which ITS can affect road user behaviour and thereby road safety (based ten-point list compiled by Draskóczy et al. [12]):

- Mechanism 1: Direct modification of the task of road users
- Mechanism 2: Direct influence by roadside systems
- Mechanism 3: Indirect modification of user behaviour in many, largely unknown ways
- Mechanism 4: Indirect modification of non-user behaviour
- Mechanism 5: Modification of interaction between users and non users
- Mechanism 6: Modification of road user exposure
- Mechanism 7: Modification of modal choice
- Mechanism 8: Modification of route choice
- Mechanism 9: Modification of accident consequences

The content and detailed description of these mechanisms were modified to be more focused on changes in behaviour of VRUs and the situations they face in traffic [13].

2.2. Accident data

The CARE database (Community Road Accident database) was chosen for the analysis due to it covering accidents on a European wide level. There is variability in the quality of the accident data entered into the CARE database by country. Therefore countries were grouped in three clusters, which were formed based on the prevalent safety situation in each country. Countries with similar safety situations, i.e. low, medium and high safety situations were included in the same cluster. For the countries and criteria where no detailed information in the CARE database was available on the background variables such as road type, weather conditions, lighting conditions, location and age (or when the values were not considered reliable), the average values from the cluster, to which the country belongs, were used.

The total number of fatalities for 2012 (28,126 fatalities) used in the impact assessment calculations for the EU-28 was taken from the statistical pocketbook [14] and the total number of injuries (1,429,888 injuries) was taken from the CARE database since the statistical pocketbook does not include any information on the number of injuries (only on the number of accidents where injuries occurred). The more detailed information on fatalities and injuries for the EU-28 were gathered from the statistics of the CARE database for the year 2012. No accident data for 2012 was available for Belgium, Bulgaria, Estonia, Lithuania, Malta, Slovakia and Sweden and thus the latest available data in the CARE database was used for those countries instead. For Lithuania the total numbers of fatalities and injuries in 2012 were taken from their national statistics. The total number of fatalities and injuries used in the calculations concerned all traffic participants, not just vulnerable road users. The accident numbers for 2020 and 2030 were calculated based on accident trends including separate estimates for accidents related to pedestrians, cyclists, moped riders, motorcyclists and cars (the calculation of accident trends is described in detail later in this manuscript).

2.3. Selection of systems

The system selection process started with a literature search of ITS systems, resulting in a list of 86 systems. Through discussions with stakeholders, the systems were prioritised and a set of 23 systems were selected, which were deemed to have the greatest potential to improve the safety, mobility and/or comfort of VRUs, and covering all VRU groups and the accident scenarios, which were identified to be the most critical [15]. These 23 systems went through a qualitative assessment based on the literature review and iterative discussion processes among the project team. The results of the qualitative assessment were presented in a workshop, in which a set of 10 systems were selected for quantitative assessment by using multi-criteria assessment and portfolio check [16]. The multi-criteria analysis ranked the systems whereas the portfolio check determined whether all important aspects were covered. The multi-criteria selection included issues such as benefits, costs, deployment, targeted vulnerable road user groups and potential impact on safety, mobility & comfort. The portfolio check confirmed, for example, that the set of systems addressed all vulnerable road user groups, covered all impact categories and covered different types of ITS (infrastructure-based, car based, VRU-based and cooperative ITS).

2.4. Safety impact assessment procedure

The adopted safety impact assessment method followed the steps and applied the calculation tool reported by Kulmala [4] and is presented in Figure 1.

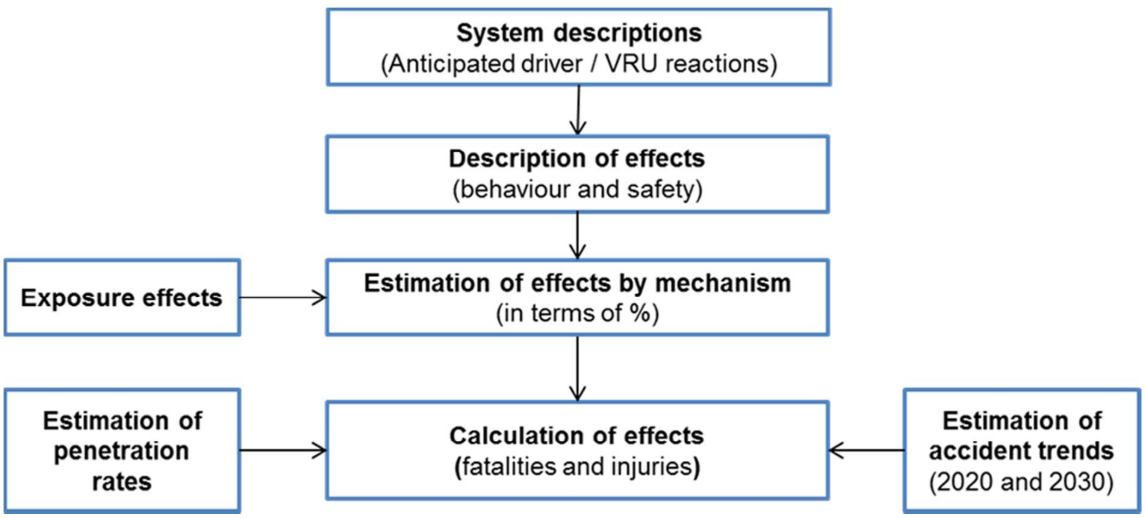

Fig. 1. *Description of the overall safety impact analysis method.*

2.4.1. System descriptions: The process started by writing comprehensive system descriptions in order to have a clear and convergent understanding of the systems under assessment, their functioning, technical limitations and anticipated user reactions and expected effects on safety.

2.4.2. Description of effects: During this step the description of expected changes in driver and VRU behaviour and documentation of the expected effects based on existing literature and other evidence available were done for each relevant safety mechanism.

2.4.3. *Estimation of effects by mechanism (mechanisms 1–5, 9):* In this step the earlier described effects of each safety mechanism were presented in terms of effectiveness i.e. % increase/decrease of relevant accidents. The reference case for the estimates was the situation without any ITS, and a linear development of safety effects was assumed in terms of penetration rate unless stated otherwise. The safety assessments were made step wise typically starting with the definition of target accidents and proceeding by providing estimate of effectiveness (low, medium, high) indicating the medium and lowest/highest possible value. The safety experts involved in this process were partners of the VRUITS project and from four different organisations and countries. The systems under assessment were divided among the four organisations and the first, independent estimates of effects were drawn by these ´responsible partners´ (one per system) who studied the relevant literature and system functioning in detail. The estimates made by the responsible partners were reviewed among all safety experts to crosscheck and independently peer review the estimates for reasonableness. This crosscheck and validation of estimates for each system to reach the consensus of the estimate was led by the responsible partners and was found especially important for assumptions for which there existed no proper literature. Lack of solid results from literature was a significant issue because many of the selected ITS are still in development, and hence little empiric evidence was available. Furthermore, findings may depend significantly on the cultural and legal context, and on other circumstances (like level of urbanization, climate, etc.) and hence it is a challenge to generalize findings across the EU. Literature could often be found on direct effects (mechanisms 1 and 2), albeit typically only for specific countries or situations. The indirect mechanisms (3–5) were found to be much harder to assess, and thus there was a much larger need to rely upon expert judgement and knowledge on general behavioural mechanisms.

In addition, support of external experts (1–13 per system) was used to check whether the assumptions made in the earlier phases of the assessment were correct and as background information when generating the numerical estimates. The external expert estimates were collected via an internet survey which was sent to a predetermined number of experts. Each partner was asked to contribute for finding the suitable external experts to answer the questionnaire. Previous VRU related research projects, VRU related workshops and/or conferences were, for example, considered as good sources to identify suitable experts.

2.4.4. Exposure effects: The results of the mobility and comfort assessment [17] were applied regarding mechanisms 6–8. The effects of the modal change were only included for vulnerable road users. The effects of the modal change of cars, trucks and public transport were estimated to be insignificant. The estimated effects on VRU exposure were transferred to safety effects of exposure (same values for fatalities and injuries) based on the values found from earlier studies. These studies found a “safety in numbers" effect, where the accident risk per kilometre for VRU modes decreases as VRU travel increases – a likely explanation is that other road users learn to expect VRUs on the road when they become more prevalent. This means that the number of fatalities and injuries increases slower than the number of VRU kilometres. The studies modelled this with an exponential model: if the exposure increased by a factor of x, then the number of fatalities and injuries increased by a factor x^y, for some exponent y less than 1. The exponent y was 0.38 for the pedestrians (based on [18]), 0.4 for cyclists and moped riders (based on [19]) and 0.7 for motorcyclists (based on [20] and previous impact assessment studies).

2.4.5. Estimation of penetration rates: For the estimation of the penetration rates for the systems, two questionnaires were developed for involved stakeholders. It was however very challenging for stakeholders to make predictions on the implementation of innovative ITS technologies. The first questionnaire, which targeted input for both 2020 and 2030 and different VRU and vehicle classes, only received a low number of answers. Based on the inputs received, and on feedback retrieved during the workshop with the stakeholders, an estimate for the implementation rate in 2030 was made. A second questionnaire was then sent out to the stakeholders, and 34 replies from 14 countries were received. Based on these replies, low, medium and high ranges for the penetration were estimated. The penetration rates are reported in [21].

2.4.6. Estimation of accident trends: An exponential regression analysis of current accident numbers from 2002 to 2012 (from the CARE database) was conducted to forecast the accident numbers in 2020 and 2030 with the assumption that no further deployment of ITS for VRUs had occurred between these dates. These safety trends were separated by country cluster (based on previous safety track record within the EU), vulnerable road user type (pedestrians, cyclists, moped riders and motorcyclists) and accident severity ('fatal' or 'injured'). No distinction was made by accident type; this means that it is assumed that the relative importance of each accident type stays the same. The analysis included the establishment of the ratio of accidents for 2020 and 2030 for every accident which occurred in 2012.

2.4.7. Calculation of effects: The safety effects of the systems were estimated by mechanism, which were used to calculate the overall low, medium and high estimate on the effect of the system. These estimates were applied to the EU-28 road accident data to determine the overall effect on fatalities and injuries by applying the calculation method and tool presented by Kulmala [4]. There were several steps in this calculation, namely:

- *Identification of the main classifying variable*: Different effect estimates can apply in different circumstances. To model this, the method uses a main classifying variable to weigh the estimate. For example, in case the ITS under assessment was estimated to be more effective on preventing pedestrian accidents than cyclists accidents. E.g. the system was estimated to prevent 30% pedestrian accidents and 9% of multi vehicle accidents involving cycles. Then the overall effect was determined by multiplying the share of relevant accidents by these effect estimates, and summing the results. The main classifying variable was usually chosen as the one that was considered to have the strongest or most relevant evidence on the effect size. In our assessment, the accident type was chosen as the main classifying variable for all systems (highlighting the targeted user groups such as pedestrians and cyclists), and other classifying variables were not considered. This means in particular that when other variables were deemed important (e.g. heavy versus light vehicles, or day versus night), then these were taken into account in the estimates per mechanism.
- *Determining the estimates per mechanism:* For each mechanism, the effect of the system on fatalities needed to be determined. This was expressed as a percentage of all road fatalities that will be saved (or created) in relation to this mechanism. The same was done for injuries. The percentages were determined by the experts using all available evidence, as well as expert judgment. Evidence stemmed from literature for example on general road user behaviour or experiences on the use and effects of ITS applications. Empirical findings regarding road user behaviour using the ITS applications in real traffic were preferred (with sound study design). The assessment covered technical aspects (does the system work appropriately? And under which circumstances?) and behavioural aspects (how do the road users respond to the system and adapt their behaviour?). In many cases the numerical estimates were based on expert opinion. For these estimates a range was suggested.
- *Combining the estimates per mechanism into an overall estimate and applying reduction factors for usage and penetration rate:* The overall effects by mechanism were translated into an overall effect of the system on all road fatalities/injuries at 100% penetration. First, the estimates given in percentages were converted to coefficients of efficiency (e.g. a decrease of accidents by 10% means that the target group of accident is multiplied by coefficient 0.90). Secondly, the total effect was computed by multiplying the coefficients for each mechanism and giving this total effect as percentage. The estimated non-usage of systems (e.g. due to annoyance) was taken into consideration together with the penetration rate, as factors reducing the effect.

- *Combining the overall effect with accident data:* The impact of the system in number of fatalities was calculated by multiplying the overall effect expressed as a percentage of all road fatalities that was estimated to be saved or created by the total number of all road fatalities. The safety effects for 100% penetration rate were calculated by exploiting the 2012 accident levels. The safety effects for future scenarios (2020 and 2030) were calculated by multiplying the effect of the system by the estimated number of fatalities of a particular scenario to arrive at the total number of fatalities saved for that scenario. A similar calculation was done for injuries, with different values for the effects.

3. Results

This chapter presents the results by system for 100% penetration rate. After a description of the system, its targeted VRU groups and accident types, the impact per mechanism and the overall impact are given as a percentage of all road fatalities and injuries (so not only the VRU-related ones). The analysis produced low, medium and high impact estimates in terms of effectiveness, but for readability usually only the medium values are shown. Finally, the summary of the quantitative safety impact assessments is presented.

3.1. Blind Spot Detection (BSD)

Targeted vulnerable road user groups: Pedestrians, cyclists, mopeds and motorcyclists

Description: The system uses vehicle sensors to detect pedestrians, cyclists, mopeds and motorcyclists in blind spots near cars, trucks and buses. However, the share of blind spot accidents with pedestrians and motorcyclists is really low and thus these groups were not further considered in our analysis. The system addresses mainly the side areas of the car/truck/bus, but optionally also front and rear of the car/truck/bus. After detection the system provides a warning to the driver. The system does not intervene. The system aims to prevent accidents between cars/trucks/buses and VRUs in the blind spot of the car/truck/bus (blind spot can be either side of the vehicle).

The overall impact of BSD (in relation to all road accidents) per relevant safety mechanism and the assumption used in the calculations are presented in Table 1.

Table 1 Impact of BSD (in relation to all road accidents) on fatalities (F) and injuries (I) per safety mechanism (M) including assumptions, 100% penetration rate

M	Assumptions	Impact (%)	
		F	I
M1	– 13% of fatal cyclist and moped accidents occur at blind spots [22, 23] – The detection rate of VRUs in the blind spot of vehicles is 99% (based on [24])	-0.99	-1.68

	– 90% of fatalities and 94% of injuries occurring at blind spots can be avoided by the system – 89–96% of relevant accidents can be prevented with the help of the system [25]		
M3	– The safety effect is impacted negatively by overreliance by the VRU, overreliance by the driver and distraction of the driver	+0.05	+0.08
M3	– The safety effect is impacted negatively by the annoyance of the driver		
M7	– A small modal shift is expected from car and public transport to cycling	+0.02	+0.02
Overall average impact		-0.93	-1.58
The estimated average non-usage due to annoyance was 37.5%			
Overall average impact including usage		-0.58	-0.99

3.2. Bicycle to car communication (B2V)

Targeted vulnerable road user groups: Cyclists

Description: The system informs and warns the equipped car/truck/bus driver about cyclists on the road in the vicinity of the car/truck/bus, and the equipped cyclists of potential collisions with nearby cars/trucks/buses. Cyclists can receive the information on their mobile device (e.g. smart phone). The system uses wireless communication to transmit information, and a GPS device to determine the relative locations of the equipped road users. The system does not intervene. The system aims to prevent all accidents between cars/trucks/buses and cyclists due to inattention of car/truck/bus driver or cyclists.

The overall impact of B2V (in relation to all road accidents) per relevant safety mechanism and the assumption used in the calculations are presented in Table 2.

Table 2 Impact of B2V (in relation to all road accidents) on fatalities (F) and injuries (I) per safety mechanism (M) including assumptions, 100% penetration rate

M	Assumptions	Impact (%)	
		F	I
M1	– 90% of fatal cyclist-vehicle accidents and 94% of cyclist-vehicle accidents with injuries can be prevented with this system [23] – Inattention plays a role in 30–50% of accidents – System is estimated to make the driver/cyclist aware of the danger in 80–95% of accidents – Driver/cyclist can make an evasive action in 31–61% of accidents	-1.11	-1.78
M3	– The safety effect is impacted negatively by the annoyance of the system user due to false alarms		
M6	– The system use is estimated to increase the length of cycling trips	+0.02	+0.03
M7	– A small modal shift is expected from car and public transport to cycling	+0.02	+0.03
Overall average impact		-1.07	-1.72
The estimated average non-usage due to annoyance was 50%			
Overall average impact including usage		-0.54	-0.86

3.3. Crossing Adaptive Lighting (CAL)

Targeted vulnerable road user groups: Pedestrians

Description: The system is mounted at a zebra crossing, and illuminates the zebra crossing when a pedestrian is observed to approach the crossing. The lighting dims down automatically when there is no one at the crossing. The detection of pedestrians is performed through the use of optical sensors and wireless communication. The system aims to increase the safety of pedestrians by increasing the possibility of car/truck/bus drivers to detect the zebra crossing and thus the pedestrians using the zebra crossing. The assumption is that the crossing will always be lightened before the pedestrian enters the crossing. The system aims to prevent accidents between cars/trucks/buses and pedestrians occurring at non-signalised zebra crossings.

The overall impact of CAL (in relation to all road accidents) per relevant safety mechanism and the assumption used in the calculations are presented in Table 3.

Table 3 Impact of CAL (in relation to all road accidents) on fatalities (F) and injuries (I) per safety mechanism (M) including assumptions, 100% penetration rate

M	Assumptions	Impact (%)	
		F	I
M2	– 28% of pedestrian fatalities and 30% of pedestrian injuries occur at night at urban areas (CARE) – 9.5–22.7% of fatal pedestrian accidents occur at non signalised pedestrian crossings [26, 27] – 6.4%–33.9% of pedestrian accidents resulting in injuries occur at non signalised pedestrian crossings [26, 27] – 60% of crashes (fatalities/injuries) can be prevented with the help of increased intensity of lighting at night [27] – Pedestrian fatalities and injuries occurring outside zebra crossings (18–23% based on [29]) and in night-time and urban areas (28–30% according to CARE) will increase by 6–8% due to the system use because of lowered detectability [30].	-0.48	-0.39
M6	– The system use is estimated to increase the leisure trips of pedestrians	+0.02	+0.01
Overall average impact		-0.46	-0.37

3.4. Green Wave for Cyclists (GWC)

Targeted vulnerable road user groups: Cyclists

Description: The system provides cyclists with speed advice. If they follow the advice they are guaranteed a green light at the next signalized intersection. The traffic light controller provides information on its current state and signal plan via I2VRU wireless communication. The cyclist has a personal device (a smartphone or a bicycle computer) that receives this information and uses it to calculate speed advice, which is presented to the cyclist. The personal device needs to be able to determine the location of the cyclist relative to the signalized intersection, by GPS. If the cyclist’s route information is available, the system will work better because it can more easily determine the next signalized intersection, or even anticipate the intersection(s) thereafter. The system is purely communication based and uses no sensors except for a GPS device to determine location. The system aims to prevent accidents between cars/trucks/buses and cyclists at signalised intersections which occur because of red light violations by cyclists.

The overall impact of GWC (in relation to all road accidents) per relevant safety mechanism and the assumption used in the calculations are presented in Table 4.

Table 4 Impact of GWC (in relation to all road accidents) on fatalities (F) and injuries (I) per safety mechanism (M) including assumptions, 100% penetration rate

M	Assumptions	Impact (%)	
		F	I
M2	– Red light violations of cyclists is a contributing factor to 9% of cyclists fatalities and 6% of cyclist injuries on intersections [23] – 90% of fatalities and 94% of injuries due to red light violations are relevant for this system – The red light arrivals of cyclists are expected to decrease between 4% (actuated traffic light controller) and 20% (static traffic light controller) due to the use of the system [31]. Therefore, the system is expected to be effective in 4–20% of targeted accidents	-0.07	-0.07
M6	– An increase in the number and length of cycling trips is expected because of an increase in infrastructure quality	+0.02	+0.02
M7	– A small modal shift is expected from car and public transport to cycling due to a decrease in travel time for cyclists in certain routes	+0.01	+0.02
M8	– Cyclists may change route from non-signalised to signalised intersections	-0.10	-0.16
Overall average impact		-0.14	-0.18

3.5. Information on Vacancy on Bicycle racks (IVB)

Targeted vulnerable road user groups: Cyclists

Description: The system provides information to cyclists regarding the number of, and closest available, parking facilities for cycles (bicycle racks). The cyclists will receive the information through an application on a mobile device (smartphone) and/or by signs near the parking place. The system concerns only the provision of information on availability of free and safe parking facilities, not the construction of such facilities. The system is suitable to be placed at for example: stations for public transport, parking garages, work places, apartment buildings, shopping centres and hotels. The system is expected to have no direct safety effects.

The overall impact of IVB (in relation to all road accidents) per relevant safety mechanism and the assumption used in the calculations are presented in Table 5.

Table 5 Impact of IVB (in relation to all road accidents) on fatalities (F) and injuries (I) per safety mechanism (M) including assumptions, 100% penetration rate

M	Assumptions	Impact (%)	
		F	I
M6	– An increase in the number of cycling trips is expected due to better and more detailed information on safe parking places	+0.02	+0.04
M7	– A small modal shift is expected from car and public transport to cycling if safe parking possibilities for bicycles are available at the destination	+0.02	+0.04
Overall average impact		+0.05	+0.07

3.6. Intelligent Pedestrian Traffic Signal (IPT)

Targeted vulnerable road user groups: Pedestrians

Description: IPT is a traffic signal control system that uses sensors such as an infra-red cameras to determine the presence of pedestrians and adjusts the traffic signals accordingly. It has two functions: it will request a green light for pedestrians entering a detection zone near the crossing, and provide slower pedestrians (e.g. elderly) or those who started to cross later in their green phase with enough time to cross the road while the lights for conflicting traffic remain red. The system aims to prevent accidents between cars/trucks/buses and pedestrians occurring at signalised pedestrian crossings due to red light violations by both pedestrians and cars/trucks/buses.

The overall impact of IPT (in relation to all road accidents) per relevant safety mechanism and the assumption used in the calculations are presented in Table 6.

Table 6 Impact of IPT (in relation to all road accidents) on fatalities (F) and injuries (I) per safety mechanism (M) including assumptions, 100% penetration rate

M	Assumptions	Impact (%)	
		F	I
M2	– 5.6%–22% of fatal pedestrian accidents and 11.4%–21% of pedestrian accidents resulting in injuries occur at signalised pedestrian crossings [27, 32, 33] – 33% of fatal pedestrian accidents and 22%–38% of pedestrian accident resulting in injuries at signalised pedestrian crossings occur due to red light violations [32, 33, 34] – The system was estimated to prevent between 34–53% of relevant accidents – Red light violations of cars will increase due to longer waiting times for cars (especially during rush hours) → pedestrian accidents during green phase was estimated to increase between 7.5–9.5%	-0.41	-0.20
M6	– An increase in the number and length of walking trips of most vulnerable road users (elderly and people with limited mobility) is expected due to improved subjective safety because of extended green phase	+0.06	+0.04
M7	– A small modal shift is expected from car and public transport to walking due to improved subjective safety because of extended green phase	+0.02	+0.02
Overall average impact		-0.33	-0.15

3.7. Intersection Safety (INS)

Targeted vulnerable road user groups: Pedestrians, cyclists, PTWs (mopeds and motorcycles)

Description: The system warns drivers and VRUs of an imminent collision risk at an intersection. A road side unit (RSU) detects the VRU crossing or approaching the intersection via radar or camera, assesses the risk of collision, and sends a warning of a potential collision to the vehicles via wireless communication. The driver is warned by an on-board unit and the VRU by the RSU via flashing lights and/or sound. The system addresses collision scenarios where the vehicle makes a left or right turn, or where the vehicle drives perpendicular to the VRU. The system does not intervene. The system aims to prevent accidents between cars/trucks/buses and vulnerable road users at signalised and non-signalised intersections.

The overall impact of INS (in relation to all road accidents) per relevant safety mechanism and the assumption used in the calculations are presented in Table 7.

Table 7 Impact of INS (in relation to all road accidents) on fatalities (F) and injuries (I) per safety mechanism (M) including assumptions, 100% penetration rate

M	Assumptions	Impact (%)	
		F	I
M2	– 19% of fatal pedestrian accidents and 32% of pedestrian accidents resulting in injuries occur on intersections (CARE) – 40% of fatal cyclist-vehicle accidents and 65% of cyclist-vehicle resulting in injuries occur on intersections (CARE) – 41% of fatal moped-vehicle accidents and 46% of moped-vehicle accidents resulting in injuries occur on intersections (CARE) – 41% of fatal motorcycle-vehicle accidents and 54% of motorcycle-vehicle accidents resulting in injuries occur on intersections (CARE) – 90% of fatalities and 94% of injuries are relevant for this system – Inattention plays a role in 30–50% of accidents – System can prevent 50–70% of relevant accidents (road user is made aware of the danger and system is expected to be effective)	-2.55	-3.78
M3	– Increasing driving speeds at intersections are expected to lead to 0–6% increase of intersection accidents [6, 35, 36]	+0.33	+0.52
M5	– Early enough provided by the system are estimated to decrease all intersection crashes by 0–0.5% [6]	-0.03	-0.04
M6	– An increase in the number and length of walking and cycling trips is expected because of an increase in perceived safety	+0.04	+0.04
M7	– A small modal shift is expected from car and public transport to pedestrian and cycling trips because of an increase in perceived safety	+0.05	+0.05
Overall average impact		-2.17	-3.23

3.8. Pedestrian and Cyclist Detection System + Emergency Braking (PCDS + EBR)

Targeted vulnerable road user groups: Pedestrians and cyclists

Description: This vehicle based system detects pedestrians and cyclists in front of a forward-moving vehicle via forward-looking sensors. If a collision is likely, the system warns the driver, for instance through sound or visual signals. If the driver fails to respond in time and the collision risk remains, the system can intervene through automatic braking. The system aims to prevent accidents between cars/trucks/buses and pedestrians/cyclists occurring in urban areas due inattention of car/truck/bus driver (or reduce their consequences).

The overall impact of PCDS+EBR (in relation to all road accidents) per relevant safety mechanism and the assumption used in the calculations are presented in Table 8.

Table 8 Impact of PCDS+EBR (in relation to all road accidents) on fatalities (F) and injuries (I) per safety mechanism (M) including assumptions, 100% penetration rate

M	Assumptions	Impact (%)	
		F	I
M1	– 69% of fatal pedestrian accidents and 91% pedestrian injuries occur at urban areas (CARE) – 52% of fatal cyclist-vehicle accidents and 85% cyclist-vehicle accidents resulting in injuries occur at urban areas (CARE) – 76–90% of fatal pedestrians and 63–74% injured pedestrians are struck by the front of the vehicle [37, 38, 39] – 72% of fatal cyclists and 59% of injured cyclists are struck by the front of the vehicle [213 – 50% of pedestrian fatalities and 33% pedestrian injuries can be prevented with the system [37] – 40–45% of cyclist fatalities and 27–30% of cyclists injuries can be prevented with the system	-7.08	-4.26
M6	– An increase in average exposure of pedestrians and cyclists is expected	+0.15	+0.13
M7	– A small modal shift is expected from car and public transport to walking due to increased subjective safety	+0.10	+0.09
Overall average impact		-6.86	-4.05

3.9. PTW oncoming Vehicle information system (PTW2V)

Targeted vulnerable road user groups: PTWs (mopeds and motorcycles)

Description: The system informs both the equipped car/truck/bus driver and equipped PTW rider of each other's presence if they are seen to be on collision trajectory. The system uses wireless communication to ascertain the position and direction of equipped cars/trucks/buses and equipped mopeds/motorcycles in relation to each other. The drivers are warned about the presence of other vehicles on a potential collision course. They are not informed in harmless situations to avoid over informing and annoying the driver or rider. Both parties are warned of the imminent collision so both have the ability to take action and prevent the accident from occurring or at least reduce their speed to mitigate the consequences. The system aims to prevent accidents between cars/trucks/buses and PTWs; especially at intersections.

The overall impact of PTW2V (in relation to all road accidents) per relevant safety mechanism and the assumption used in the calculations are presented in Table 9.

Table 9 Impact of PTW2V (in relation to all road accidents) on fatalities (F) and injuries (I) per safety mechanism (M) including assumptions, 100% penetration rate

M	Assumptions	Impact (%)	
		F	I
M1	– 41% fatal moped-vehicle accidents and 46% of moped-vehicle accidents resulting in injuries occur at intersections (CARE) – 41% fatal motorcycle-vehicle accidents and 54% of motorcycle-vehicle accidents resulting in injuries occur at intersections (CARE) – Inattention plays a role in 33% of accidents [40] – 94–99% of drivers/riders obey the warning (motorcyclists) – 94–100% of drivers/riders obey the warning (mopedists)	-1.65	-2.01
M3	– The safety effect is impacted negatively by the annoyance of the system user due to false alarms		
M6	– An increase in the number and length of PTW leisure trips is expected due to increased comfort	+0.08	+0.06
M7	– A small modal shift is expected from car and public transport to PTW riding due to increase in perceived (and actual) safety and comfort	+0.03	+0.03
Overall average impact		-1.55	-1.93
The estimated average non-usage due to annoyance was 35%			
Overall average impact including usage		-1.01	-1.25

3.10. VRU Beacon system (VBS)

Targeted vulnerable road user groups: Pedestrians, cyclists, PTWs (mopeds and motorcycles)

Description: For the VRU Beacon system, the VRU wears a tag or device that sends out a signal that can be received by a device installed in cars/trucks/buses. The system calculates the trajectories of the detected VRU in relation to the car/truck/bus trajectory and assesses the possibility of a collision. The driver is then warned about the possible collision. The VRU end can be either a simple tag transmitting only ID, requiring additional location equipment in the vehicle, or a more complex device, which can transmit messages compliant to C-ITS standards, requiring only C-ITS compliant devices in the car. The system does not intervene. The system aims to prevent accidents between cars/trucks/buses and vulnerable road users.

The overall impact of VBS (in relation to all road accidents) per relevant safety mechanism and the assumption used in the calculations are presented in Table 10.

Table 10 Impact of VBS (in relation to all road accidents) on fatalities (F) and injuries (I) per safety mechanism (M) including assumptions, 100% penetration rate

M	Assumptions	Impact (%)	
		F	I
M1	– 68% of fatal pedestrian accidents and 91% of pedestrian accidents resulting in injuries occur in urban areas (CARE) – 52% of fatal cyclist-vehicle accidents and 85% of cyclist-vehicle accidents resulting in injuries occur in urban areas (CARE) – 52% of fatal moped-vehicle accidents and 84% of moped-vehicle accidents resulting in injuries occur in urban areas (CARE) – 40% of fatal motorcycle-vehicle accidents and 73% of motorcycle-vehicle accidents resulting in injuries occur in urban areas (CARE) – 46% of pedestrian fatalities 43% of pedestrian injuries occur due to non-detection [41] – 19% of bicycle accidents occur due to non-detection [42] – 33% of PTW accidents occur due to non-detection [43] – 85–90% of drivers obey the warning and react on time	-7.96	-8.83
M3	– The safety effect is impacted negatively by overreliance by the VRU and overreliance by the driver	+2.23	+2.48
M3	– The safety effect is impacted negatively by annoyance of driver		
M6	– An increase in the number and length of all vulnerable road users is expected due to improved safety perception	+0.19	+0.17
M7	– A small modal shift is expected from car and public transport to walking and cycling due to improved safety perception	+0.11	+0.10
Overall average impact		-5.62	-6.32
The estimated average non-usage due annoyance was 25%			
Overall average impact including usage		-4.22	-4.74

3.11. Summary of the quantitative safety impact assessments

The overall impacts of the ten selected ITS on all road fatalities and the overall impact on systems in number of fatalities in the EU-28 at 100% penetration rate (vehicle, infrastructure and road user penetration) are summarised in Figure 2 whereas Figure 3 presents the same results by VRU type.

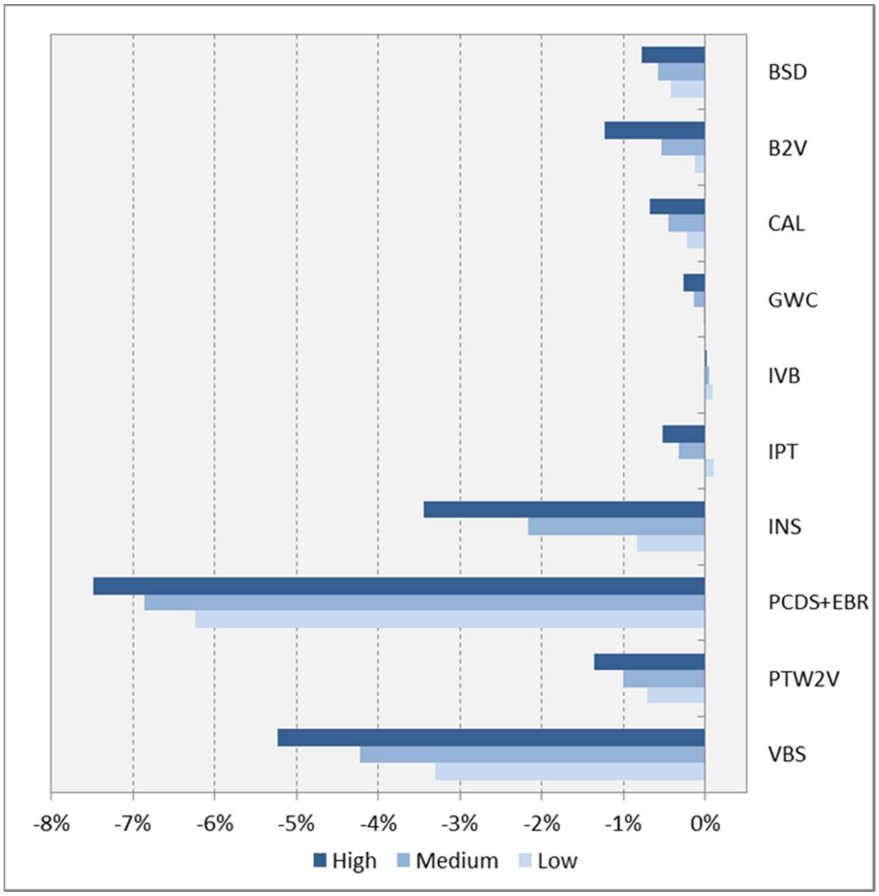

Fig. 2. *The overall impact (%) of systems on all road fatalities in the EU-28, 100% penetration rate. High/medium/low indicate the range of the estimate.*

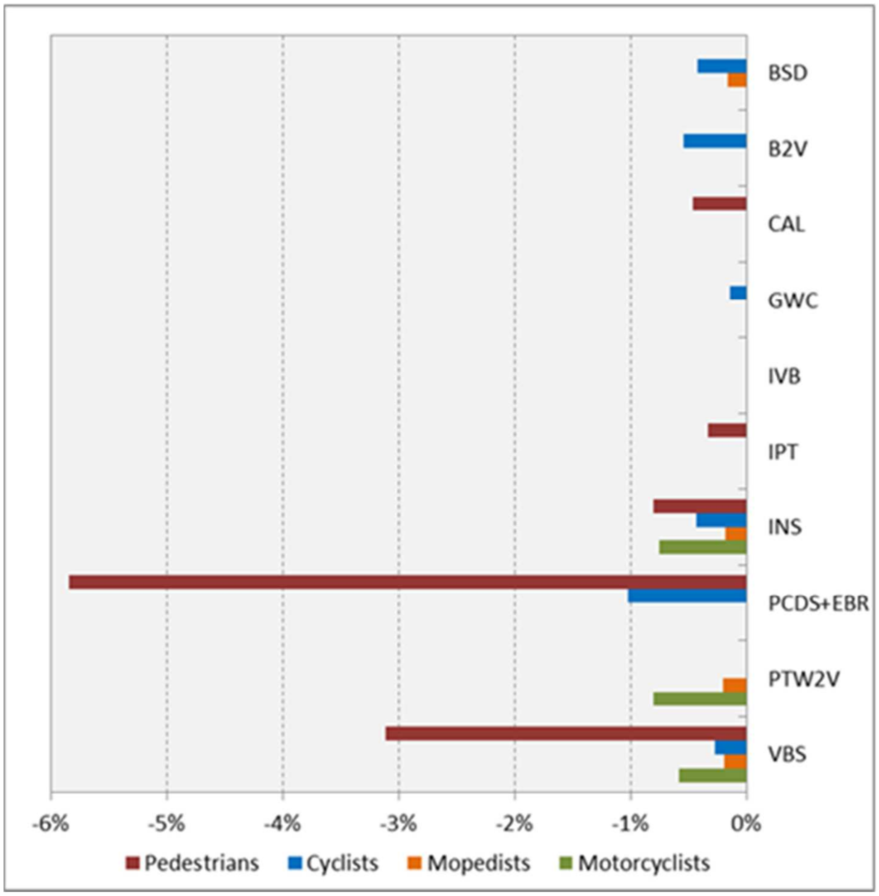

Fig. 3. *The medium overall impact (%) of systems by VRU type on all road fatalities in the EU-28, 100% penetration rate.*

The main results of the assessment show that nine out of ten ITS included in the quantitative safety impact assessment affect traffic safety in a positive way by preventing fatalities and injuries. The estimates considering full penetration show that Pedestrian and Cyclist Detection System + Emergency Braking (PCDS+EBR) and VRU Beacon system (VBS) are estimated to be the most effective systems in preventing traffic fatalities focusing especially on pedestrians. Specifically, the estimates for PCDS+EBR showed the maximum reduction of 7.5% on all road fatalities which comes down to an medium estimate of around 1,900 fatalities saved per year when considering the 2012 accident data and 100% penetration rate. For cyclists the most effective systems are PCDS+EBR and Bicycle-to-vehicle communication (B2V), while for moped riders and motorcyclists the most effective system is Powered Two Wheelers oncoming Vehicle information (PTW2V), followed by Cooperative Intersection safety (INS) and VBS. The differences between VRU groups largely reflect the target groups of the systems. The smallest effects are obtained by GWC, IVB and IPT.

The overall medium impacts of the ten ITS in EU-28 for the future scenarios (2020 and 2030) in number of fatalities and in number of injuries are presented in Figure 4. The forecasts for 2020 and 2030 provide a more realistic view about the expected effects since these numbers take into consideration the estimated accident trends and penetration rates. Quite low penetration rates were assumed based on questionnaire responses from authorities and manufacturers of ITS described in section 2.4.5. The results showed the highest effects in number of fatalities per system per year in the EU-28 in 2030 for PCDS+EBR (-200 fatalities), Blind Spot Detection (BSD) (-22 fatalities), INS (-20 fatalities) and VBS (-11 fatalities).

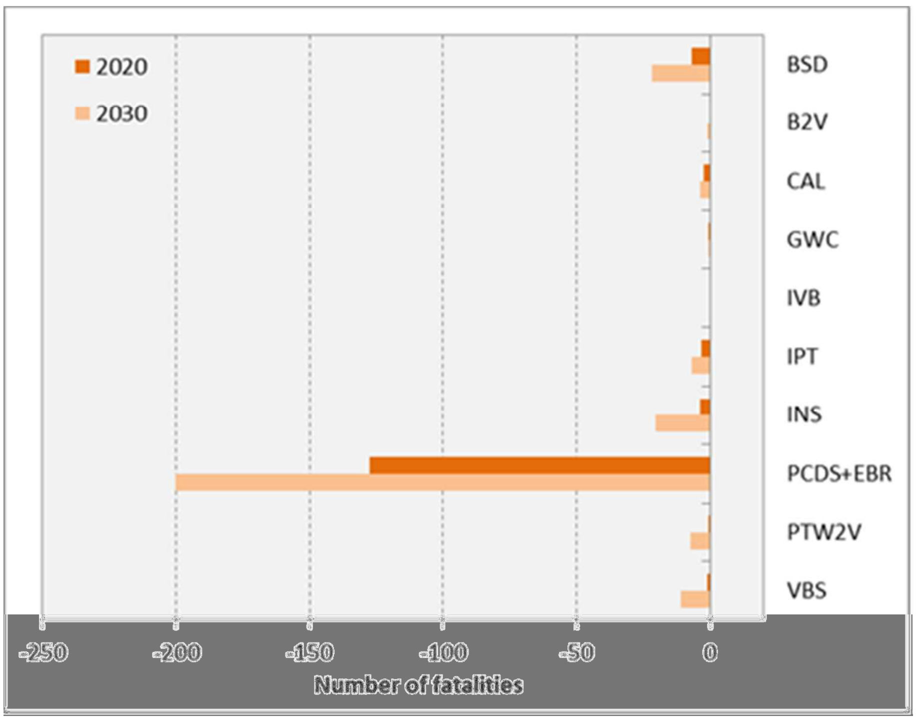

Fig. 4. *The overall medium impact of systems in number of fatalities in the EU-28 when considering the estimated accident trends and penetration rates.*

The results of the safety impact assessment for a 100% penetration rate indicate the full potential of the systems when all relevant road users, vehicles and infrastructure are equipped with the system. Furthermore, 100% usage and 100% reliability of the system is assumed where this can reasonably be expected. The results for 2020 and 2030 scenarios take into consideration the estimated accident trends and system penetration rates.

The analysis of safety effects only considers the effects of the systems on vulnerable road users (i.e. accidents between vehicles and vulnerable road users). However, it is likely that some systems (such as INS and PCDS+EBR) will be made available as add-ons to systems that affect vehicle-vehicle collisions, but those effects are not considered in this assessment.

4. Discussion and conclusions

The aim of the safety impact assessment was to determine the impact mechanisms through which the ITS services affect the safety of vulnerable road users, describe the effects, and to provide quantitative estimates for the safety impacts of the selected ITS in the EU-28. Three scenarios were provided: full penetration and two selected future scenarios (2020 and 2030). The safety impact assessment provided estimates on how the selected ITS affect the number of fatalities and injuries of vulnerable road users, by comparing the penetration scenarios to a scenario where the system is not present. Material damage was not considered. The results showed that the safety effects of the nine systems are considerable and suggest that some of the selected systems will be able to make a significant contribution to a reduction in vulnerable road user fatalities and injuries.

There are large differences in overall impact between the “best” (PCDS+EBR, VBS and INS) and “worst” (IVB, GWC) systems. There are three main factors which explain how powerful systems are in contributing to traffic safety:

1. Targeted vulnerable road user groups: three of the systems target all vulnerable road users (BSD, INS and VBS) whereas three of the systems target only cyclists (BSV, GWC and IVB) and two systems only pedestrians (CAL and IPT). The remaining two are PCDS+EBR which targets pedestrians and cyclists, and PTW2V which targets mopeds and motorcycles.
2. Extent of the safety problem the systems targets: As mentioned earlier IVB is not expected to have any direct safety effects and it is instead expected to increase the mobility and comfort of the cyclists. Some of the systems (BSD, CAL, GWC and IPT) are targeting very specific situations and thus it is expected that their safety effects are more limited than the safety effects of systems targeting all accidents (or a large proportion) between cars/trucks/buses and relevant vulnerable road users (B2V, INS, PCDS+EBR, PTW2V and VBS).
3. Degree of intervention: The Pedestrian detection and Emergency braking system (PCDS+EBR) is the only system which intervenes if the driver is not reacting to the warning and hence it was expected to have a relatively high impact on safety.

Furthermore, systems which target all vulnerable road users and all accidents (such as VBS) can be expected to have a high impact, whereas systems like IPT or GWC will have a limited impact because they target only specific groups and accident types. However, even the small safety effects can be significant when, as assumed in the future, the systems will be introduced as combinations or bundles of systems. This is especially a case when the individual systems in the bundle target different type of accidents. Furthermore, it is likely that some systems (such as INS and PCDS+EBR) will be made available as add-ons to systems that affect vehicle-vehicle collisions, but those effects were not considered in this assessment.

It must be noted that the safety impact assessment estimates the effect of future systems in future scenarios and there is uncertainty in the estimates for the numbers of avoided fatalities and injuries in the EU-28. In general, we can have uncertainty related to a) the assumed effectiveness of the system to prevent an accident (they depend on the findings from literature and results of expert assessment), b) accident data (for some systems we have better data for accident types the system aims to prevent than for some other ones), and c) estimated accident trends, and d) estimated penetration rates. The uncertainty in the safety effects were addressed by providing low, medium and high values for all the estimates related to each relevant safety mechanism. Similarly, the estimates of penetration rates included low, medium and high values. Uncertainties in accident data and accident forecasts were not addressed. During the assessment process it became clear that the yearly number of injuries reported to the CARE database and to national databases does not correctly reflect the situation in reality. The underreporting of injuries is common and the extent of this problem varies between countries. For fatalities, the data are of better quality but not perfect either. Therefore, the results in this paper concern only fatalities.

Moreover, when interpreting the results for future scenarios it is important to note that the difference between the impacts in 2020 and 2030 is partly due to the fact that the current trend of year-by-year reductions in the number of fatalities and injuries is expected to continue into the future in the EU. This trend is due to all kinds of safety enhancements (e.g. improvements in infrastructure, vehicles, driver and traveller training, etc.) other than the systems under consideration in this project. The consequence of this trend is that there will be fewer fatalities and injuries in 2020 and 2030 in the EU, hence a system that saves the same fraction of fatalities and injuries in 2020 as in 2030 will have lower savings in 2030 than in 2020 in absolute numbers. However, on the other hand, cycling and walking can increase in cities e.g. due to policy measures to support sustainable mobility which would influence the accident trends and thus increase the number of VRU accidents in respect to the estimate. The trends have been determined separately for the different vulnerable road user groups and cars, because the historic trend shows large differences, but further subdivision (e.g. by accident type) has been deemed unnecessary and unpractical.

In summary, the results of the safety impact assessment show that the selected ITS have a high potential to improve the safety of vulnerable road users. It should be noted, however, that the impacts are directly dependent on the penetration rates. Therefore, in order to realise the potential safety effects (or to obtain even higher safety benefits than estimated in this study), the deployment of the most promising systems should be supported by different stakeholders and decision makers. In our assessment, quite a low level of penetration rate was assumed based on questionnaires assigned to authorities and manufacturers of ITS. The respondents were not specifically asked to provide promoted scenarios (e.g. policy actions of EC) and therefore the responses can be regarded as conservative (business as usual scenarios). An additional reason for relatively low penetration rates is that many of the investigated systems such as the cooperative VBS, B2V, PTW2V and GWC require that both VRU and vehicles are equipped with the system and the cooperative INS requires that both the infrastructure and vehicles are equipped. It is acknowledged that even for a short term period after the questionnaires were completed several European Commission (e.g. C-ITS Platform) and other promotion activities have taken place (for example the discussion on automated driving) and therefore the estimated penetration rates could be higher if asked now. For in-vehicle systems, the average life time of vehicles has to be taken into account, which is about 9.7 years in Europe [44]. It can be assumed that ITS applications will be first made available on high-end products and introduced to the vehicles used for professional driving (e.g. trucks, buses and taxis) and later come to the mass market available to the whole vehicle fleet. Specifically, the additional cost of ITS applications is more important for personal cars than for professional vehicles, and is a very important aspect for vulnerable road users. Therefore, the introduction of ITS applications to VRUs – and to get them to adopt and use the systems − can be rather challenging. Moreover, for VRU devices, issues such as privacy and usability are important, especially if the device cannot be integrated as an always-on application in smart phones.

As indicated earlier, our estimates include some uncertainty. Therefore, in order to improve the accuracy of the estimates, there is a need for better accident data (on number and details of the accidents; including also hospital records) and trials to test the functioning of the systems and their effect on road user behaviour.

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