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Are Intelligent Transport Systems effective in improving the safety of vulnerable road users?

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Abstract

This paper presents the results of safety impact assessment, providing quantitative estimates of the safety impacts of ten ITS which were designed to improve safety, mobility and comfort of 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 services 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 the systems PCDS+EBR, VBS and INS. The estimates for PCDS+EBR showed the maximum reduction of 7.5% on all road fatalities and 5.8% on all road injuries, which came down to an estimate of over 2,100 fatalities and over 62,900 injuries saved per year in the EU-28 when exploiting the 2012 accident levels adjusted with the estimated accident trends.

Keywords: ITS, vulnerable road users, safety assessment

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. Only 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 (CARE, 2009). 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 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 (2010), which was developed for the assessment of safety impacts of ITS for cars. The method has been developed and applied at in several previous European projects (see e.g. Scholliers et al., 2007; Wilmink et al., 2008; Kulmala et al., 2008; Wimmershoff et al., 2011; Fuerstenberg & Boehning, 2012; Malone et al., 2014). 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 literature review and expert assessment based on the principles described by Kulmala (2010). 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 the 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) (Nilsson, 2004). 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., 1998):

- 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 nonusers
- 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 (van Noort et al. 2014).

2.2. Accident data

The CARE 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 CARE by country. Countries were grouped in three clusters, which were formed based on the prevalent safety situation in each country. Countries with similar safety situation, i.e. low, medium respectively high safety situation were included in the same cluster. For the countries and criteria where no detailed information in CARE 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, to were used.

The total number of fatalities for 2012 used in the impact assessment calculations for EU-28 was taken from the statistical pocketbook (EC, 2014) and the total number of injuries was taken from CARE database since statistical pocketbook does not include any information on the number of injuries (only on the number of injury accidents). The more detailed information on fatalities and injuries for the EU-28 were gathered from the statistics of 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 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.

2.3. Selection of systems

The 10 systems for the quantitative safety impact assessment were selected from a list of 23 systems. The list consisted of systems as having the most potential to improve safety and mobility of VRUs (Scholliers et al., 2014). These 23 systems went through a qualitative assessment. The results of the qualitative assessment were presented in a workshop, in which a set of 10 systems was selected for quantitative assessment by using multi-criteria assessment and portfolio check (Kruijff & Malone, 2014). 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 and users whereas 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 (infra-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 (2010) and is presented in Figure 1.

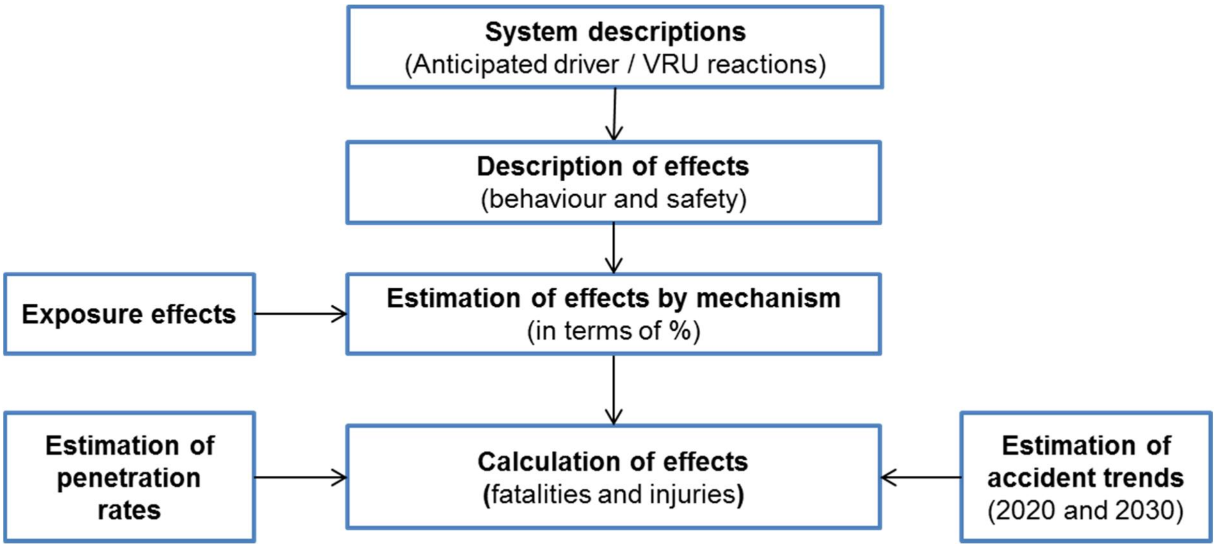

Figure 1 –Description of the overall safety impact analysis method.

1. System descriptions

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

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.

3. Estimation of effects by mechanism (mechanisms 1–5, 9)

In this step the earlier described effects of each safety mechanisms were presented in terms of % increase/decrease of relevant accidents. The reference case for the estimates was the situation without any ITS, and in most cases a linear development of effects was assumed. The first estimates of the effects (low, medium, high) were drawn by the responsible partners (one per system) who studied the relevant literature and system functioning in detail. Next, the estimates were reviewed among all safety partners to crosscheck and validate the estimates. 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 drawing the numerical estimates.

4. Exposure effects
The results of separate mobility assessment study conducted parallel with the safety estimates (Johansson et al. 2014) 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 formulas presented in earlier studies (pedestrians = Jonsson, 2005; cyclists and mopedists = Jacobsen, 2003 and motorcyclist = Marizwan et al., 2014 and previous impact assessment studies).

5. Estimation of penetration rates
The calculations presented in this paper assume 100% penetration rate.

6. Estimation of accidents trends
A regression analysis of current accident numbers from 2002 to 2012 (from CARE database) was conducted to forecast the accident numbers in 2020 and 2030 with the assumption that no system intervention 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’). The analysis included the establishment of the ratio of accidents for 2020 and 2030 for every accident which occurred in 2012.

7. Calculation of effects
The effect estimates per mechanism (from steps 3 and 4) were combined into an overall low and high estimate for each system, and subsequently applied to the EU-28 road accident data, so that the distribution of the main classifying variable (collision type) weighted the estimate i.e. it was assumed that the ITS under assessment was more effective e.g. on preventing the pedestrian than cyclists accidents. In weighting, the effect estimate which indicated in percent changes was multiplied with the share (%) of relevant accidents. The calculations to obtain the changes in number of accidents were carried out by an calculation tool which was applied from the tool reported by Kulmala (2010) for structuring the accident data and effect estimates. As the final result, the number of prevented road traffic fatalities and injuries concerning vulnerable road users per system in the EU-28 were calculated for 100% penetration rate (for relevant road users, vehicles and infrastructure) by taking into consideration the estimated non-usage of the systems (e.g. due to annoyance). The overall impact in percentages was calculated related to all road fatalities or injuries.

3. Results

This chapter presents the results by system. 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, but for readability 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 motorcyclist is really low and thus these groups were no 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 (SWOV, 2012 & BRON database, 2014) – The detection rate of VRUs in the blind spot of vehicles is 99% (Sotelo & Barriga, 2008) – 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 (Hoedemaeker, 2010)	-0.99	-1.68
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 (BRON database, 2014) – Inattention plays a role in 30–50% of accidents – System is estimated to make the driver/cyclist aware of the danger in 80–	-1.11	-1.78

	95% of accidents – Driver/cyclist can make an evasive action in 31–61% of accidents		
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 in the crossing. The detection of pedestrians is done by means 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 (STRADA, 2012; Statistics Finland, 2014) – 6.4%–33.9% of pedestrian accidents resulting in injuries occur at non signalised pedestrian crossings (STRADA, 2012; Statistics Finland, 2014) – 60% of crashes (fatalities/injuries) can be prevented with the help of increased intensity of lighting at night (Rettig et al., 2003) – Pedestrian fatalities and injuries occurring outside zebra crossings (18–23% based on Eurotest, 2008) 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 (Lundqvist & Nygårhs, 2007).	-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 a speed advice. In case 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 a 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) after that. 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 of 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 (BRON database, 2014) – 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 (van Egmond, 2013). 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 in 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 camera to determine the presence of pedestrians and adjusts the traffic signals accordingly. It has two functions: it will request green 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 of 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 (Statistics Finland, 2014; Koh & Wong, 2014; Austroads, 2000) – 33% of fatal pedestrian accidents and 22%–38% of pedestrian accident resulting in injuries at signalised pedestrian crossings occur due to red light violations (Koh & Wong, 2014; Langbroek et al., 2013; Austroads, 2000) – The effectiveness of the system is assumed to be between 34–53% – 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 in case of collision risk at intersections. A road side unit (RSU) detects the VRU crossing or approaching the intersection via radar or camera, assesses the risk of collision, and sends warning of potential collision to vehicle 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 (Rosén & Sander, 2009; Rosén et al, 2011; Wilmink et al., 2008)	+0.33	+0.52
M5	– Early enough provided by the system are estimated to decrease all intersection crashes by 0–0.5% (Wilmink et al., 2008)	-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 (Rosen et al., 2010, Yanagisawa et al., 2014, Edwards et al., 2014) – 72% of fatal cyclists and 59% of injured cyclists are struck by the front of	-7.08	-4.26

	the vehicle (BRON database, 2014) – 50% of pedestrian fatalities and 33% pedestrian injuries can be prevented with the system (Rosen et al., 2010) – 40–45% of cyclist fatalities and 27–30% of cyclists injuries can be prevented with the system		
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 in 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 (Phan et al., 2010) – 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: In 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 11.

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 (Jermakian & Zuby, 2011) – 19% of bicycle accidents occur due to non-detection (Schramm et al., 2008) – 33% of PTW accidents occur due to non-detection (McCarthy et al., 2007) – 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 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 (Figures 2–3).

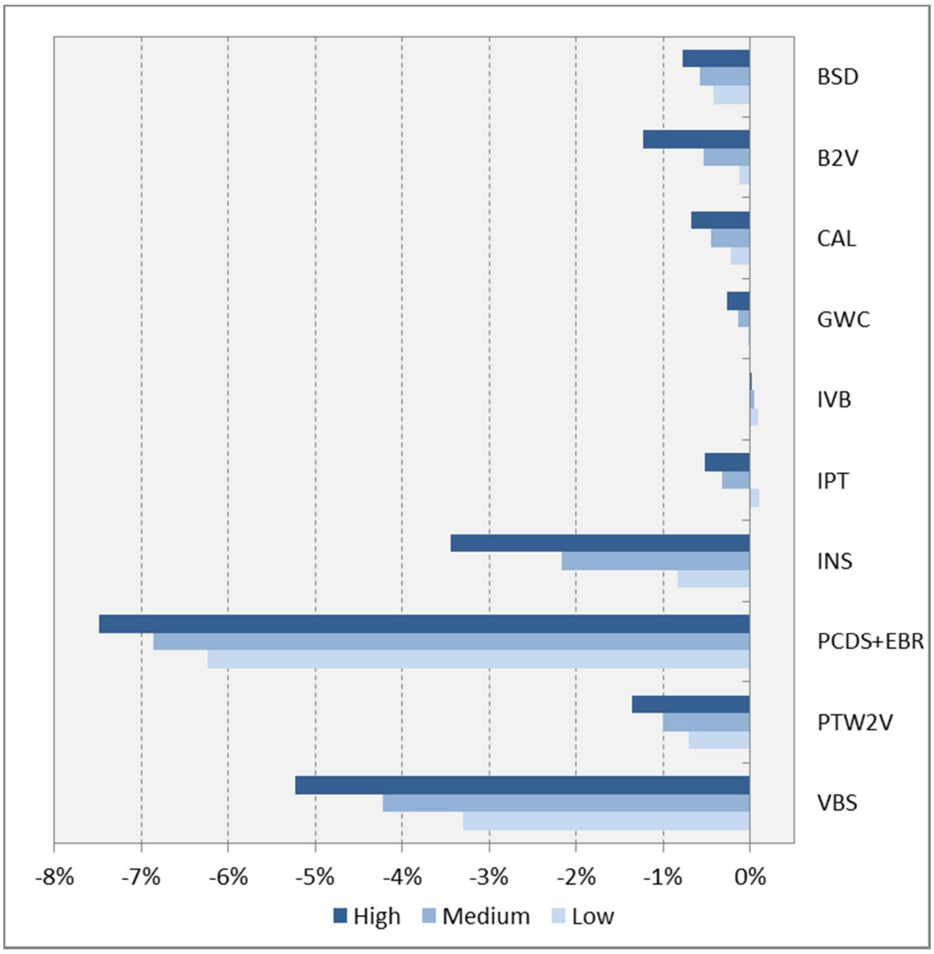

Figure 2 – The overall impact (%) on all road fatalities in the EU-28, 100% penetration rate.

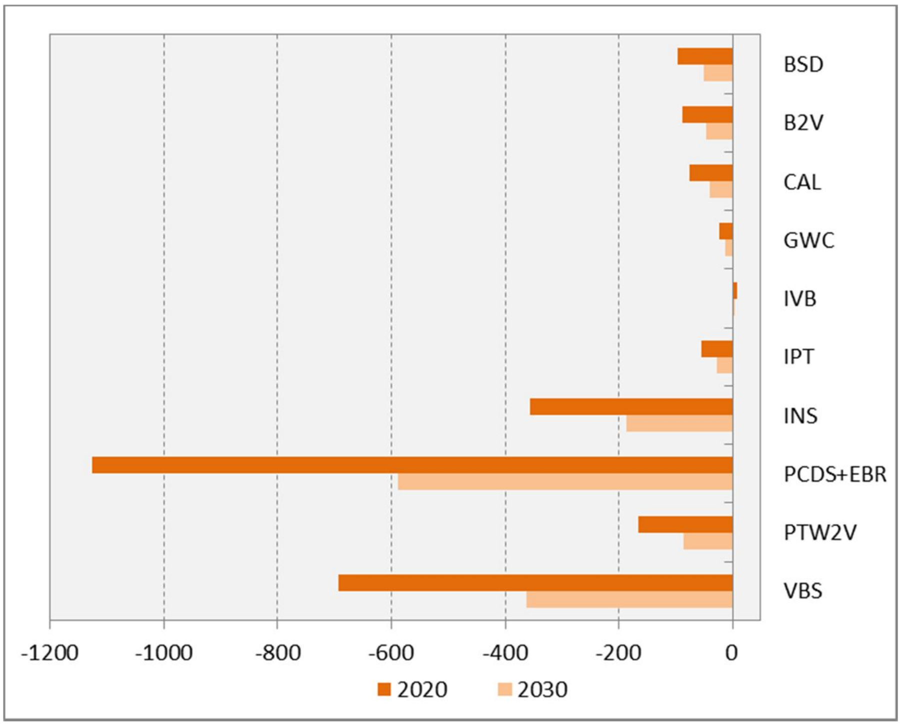

Figure 3 – The overall impact in number of fatalities in the EU-28, 100% penetration rate.

The estimates considering full penetration showed that the highest effects could be obtained by the implementation of PCDS+EBR, VBS and INS. The estimates for PCDS+EBR show the maximum reduction of 7.5% on all road fatalities and 4.4% on all road injuries, which comes down to an estimate of over 2,100 fatalities and over 62,900 injuries saved per year when considering the 2012 accident data adjusted with the estimates accident trends. These effects 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.

The results of safety impact assessment for 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 consider only 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 when fully deployed. The safety impact assessment determined how the selected ITS affect the number of fatalities and injuries experienced by vulnerable road users in traffic accidents, by comparing the full penetration scenario to a scenario where the system is not present.

There are large differences in overall impact between the “best” (PCDS+EBR, VBS and INS) and “worst” (IVB, GWC) systems. There are two main reasons to explain on how powerful the systems are in contributing to traffic safety: 1) the targeted vulnerable road user groups; three of the systems target all vulnerable road users whereas several systems target only one or two road user groups, and 2) the extent of the safety problem the systems targets; some systems are targeting very specific situations and some are targeting all accidents (or large proportion) between cars/trucks/buses and relevant vulnerable road users. The Pedestrian and Cyclists Detection and Emergency braking system (PCDS+EBR) is the only system which intervenes if the drivers are not reacting to the warning and hence it was expected to have a relatively high impact on safety. This means for example that VBS or INS which target all vulnerable road users and all accidents 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.

It is important to be noted that the results indicate the effects of future systems and hence there is uncertainty in the numbers of avoided fatalities and injuries in the EU-28. Specifically, we can have uncertainty related to a) estimates of safety effects (they depend on the results of expert questionnaire and findings from literature), 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. The uncertainty in the safety effects are addressed by providing low, average and high values for all the estimates and each relevant safety mechanism. Uncertainties in accident data and accident forecasts are not addressed.

The results show a difference between the impacts in 2020 and 2030. This 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. 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 paper. The consequence of this trend is that there will be fewer fatalities and injuries in 2030 and 2020, and hence a system that saves the same fraction of fatalities and injuries in 2030 as in 2020 will have lower savings in 2030 than in 2020 in absolute numbers. However, on the other hand, cycling and walking for example can increase in cities due to different reasons which would influence the accident trends and thus increase the number of VRU accidents in respect 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.

During the assessment it became clear that the yearly number of injuries reported to 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 among countries. Therefore, the results regarding injuries should be treated with caution and considered rather as indicative than the exact estimate of the effect. For fatalities the data are of better quality but not perfect either.

Next, the safety effects of selected ITS will be calculated for future scenarios (2020 and 2030) by taking into consideration the estimated penetration rates by system. The consideration of penetration rates will provide a more realistic view about the expected effects. At the end, the calculated safety, mobility and comfort impacts of selected ITS on vulnerable road users will be translated into socioeconomic indicators as part of cost benefit analysis.

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