Contract no.: 027421

eIMPACT
Socio-economic Impact Assessment of Stand-alone and Co-operative Intelligent Vehicle Safety Systems (IVSS) in Europe

Report type
Deliverable D4

Report name
Impact assessment of Intelligent Vehicle Safety Systems

Version number
Version 2.0

Dissemination Level
PU

Lead contractor
TNO

Due date
M26

Date of preparation
11.08.2008

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Revision and history chart

<table>
<thead>
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<td>01.02.2008</td>
<td>Comments by Kerry Malone incorporated and text added by Isabel Wilmink</td>
</tr>
<tr>
<td>0.3</td>
<td>07.02.2008</td>
<td>Text added by Isabel Wilmink</td>
</tr>
<tr>
<td>0.4</td>
<td>26.02.2008</td>
<td>Complete draft, incomplete conclusions</td>
</tr>
<tr>
<td>0.5</td>
<td>05.03.2008</td>
<td>Comments and contributions from Kerry Malone, Gunnar Lind, Wiel Jansen and Pirkko Rämä incorporated by Isabel Wilmink and Niina Sihvola</td>
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<tr>
<td>0.6</td>
<td>17.03.2008</td>
<td>Second round of comments incorporated</td>
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<td>0.7</td>
<td>31.03.2008</td>
<td>Third round of comments incorporated</td>
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<td>0.8</td>
<td>01.04.2008</td>
<td>Final draft for peer review</td>
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<td>15.04.2008</td>
<td>Peer review comments processed; Report to be sent to the EC for approval. Final check by JKI.</td>
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<td>08.08.2008</td>
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<td>11.08.08</td>
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Executive summary

Introduction to eIMPACT

The eIMPACT project, "Socio-economic Impact Assessment of Stand-alone and Co-operative Intelligent Vehicle Safety Systems (IVSS) in Europe", assesses the socio-economic effects of Intelligent Vehicle Safety Systems (IVSS) and their impact on traffic, safety and efficiency. It addresses policy options and the views and roles of the different stakeholders involved. eIMPACT is part of the EU's Sixth Framework Programme for Information Society Technologies and Media.

eIMPACT supports the three pillars of the EC's Intelligent Car Initiative (ICI), addressing stakeholders, research, and awareness-raising. eIMPACT provides quantitative impacts of twelve IVSS in terms of safety, traffic and cost-benefit effects, making use of an integrated assessment method. These quantitative results provide important building blocks for the potential contribution of Intelligent Transport Systems (ITS) to reduce road fatalities, as described in the EU White Paper on Transport [EC, 2001].

eIMPACT also provides perspectives on the market introduction of IVSS. The results of eIMPACT can be used to provide guidance in the deployment of IVSS. The results support decision making processes for research programmes in terms of focus and funding, as well as awareness, promotion and deployment activities, mainly at the EU, but also on national and regional levels. These results can also be used by policymakers, road operators and driver clubs in terms of strategic orientation, investment, promotion and deployment decisions. Finally, automotive and insurance industries can take the results as needed to develop product and innovation strategies.

Systems Analysed in eIMPACT

The twelve systems selected for analysis in eIMPACT reflect a three-step method, where all potentially beneficial systems were considered, the most promising systems were selected and a balanced choice was finally made. Firstly, eIMPACT developed an overview of the potential systems to be considered, based on the findings of EU projects. Secondly, the systems were ranked in a workshop with stakeholders, external experts and representatives of EU research projects on IVSS, using a multi-criteria assessment. The third and final step made use of the portfolio method to reduce the number of systems. In the portfolio method, eIMPACT chose a set of systems such that the set of systems:

- covers a range of time-to-market (present – 2020);
- covers both stand-alone and cooperative systems;
- covers systems addressing different types of functionality (longitudinal, lateral, etc.);
- reflects the ranking from the workshop;
- chooses the highest ranking systems meeting all of the criteria above.
The following twelve systems met the criteria above (in brackets: the 3-letter abbreviation used in tables and figures throughout this report):

1. Electronic Stability Control (ESC)
2. Full Speed Range ACC (FSR)
3. Emergency Braking (EBR)
4. Pre-Crash Protection of Vulnerable Road Users (PCV)
5. Lane Change Assistant (Warning) (LCA)
6. Lane Keeping Support (LKS)
7. NightVisionWarn (NIW)
8. Driver Drowsiness Monitoring and Warning (DDM)
9. eCall (one-way communication) (ECA)
10. Intersection Safety (INS)
11. Wireless Local Danger Warning (WLD)
12. SpeedAlert (SPE)

Impact assessment of Intelligent Vehicle Safety Systems

This report, “Impact assessment of Intelligent Vehicle Safety Systems”, provides concrete, unified estimates of traffic and safety effects. Together with “Cost-benefit analyses for stand-alone and co-operative intelligent vehicle safety systems” (D6, [Baum et al., 2008]), it forms an integrated estimate of costs and benefits of twelve IVSS. A comprehensive approach was followed to generate the results. The approach made use of scientific and transparent methodologies and state-of-the-art information to generate the results.

The impact assessment provides estimates of effects at realistic penetration rates of the IVSS in 2010 and 2020. For each year, two scenarios were considered: a low scenario, for a ‘business as usual’ situation, and a high scenario, where focused policy incentives are assumed.

The functional and technical descriptions of the systems as specified in the project form the basis for the impact assessment.

Methodology

Many of the IVSS considered in eIMPACT are future systems. Those that are already on the market tend to have low penetration rates. There is, therefore, not much empirical evidence on the effectiveness and efficiency of the systems considered. With more and more systems on the market, there is a clear need for a transparent and scientifically sound approach to the assessment of IVSS (and similar stand-alone and co-operative systems). The impact assessment approach developed and implemented in eIMPACT covers:

- The estimation of penetration rates (passenger cars, goods vehicles), using information on current fleet composition and mileage, as well as information on the year of market
introduction and the (expected) market acceptance of systems.

- The assessment of traffic impacts. The analysis distinguishes between direct and indirect effects:
  - direct traffic effects on the traffic flow, e.g. changes in speeds and headways (analysed using micro-simulation);
  - indirect traffic effects in terms of reduced congestion, due to avoided accidents with fatalities and injuries.

- The assessment of the safety impacts. The innovative approach followed in eIMPACT covers all possible (intended and unintended) effects of IVSS, using insights into system and driver behaviour. The approach looks at the three components of traffic safety analysis (exposure, risk of collision, and risk of a collision to result in injuries or death). The approach does justice to the complexity of the analysis of the effects of IVSS. The method for quantifying the safety effects explicitly takes into account the general accident data available from the CARE database, which is a good basis for relevant accident data (such as numbers of fatalities and injuries in many EU countries).

The approach made use of a “reference case” (in terms of the number of accidents) in the considered future years. This is the situation without IVSS. In order to establish the reference cases, the trend for the autonomous decrease in the number of accidents was investigated, resulting in estimates for the number of fatalities and injuries in 2010 and 2020 in the ‘without IVSS’ case.

The results from the impact assessment are used as input in the cost-benefit analysis (reported in Socio-economic impact assessment of stand-alone and co-operative intelligent vehicle safety systems (IVSS) in Europe, by [Baum et al., 2008]), also carried out in the eIMPACT project. Where needed (for the CBA), results for specific areas or conditions are scaled up to EU-25 level. The results are also used as input for the policy options and stakeholder analysis.

The application of the approach in the eIMPACT impact assessment shows that it is a valuable approach that can be replicated. In the future, actual results can be adjusted based on new insights (e.g. FOT results, regarding driving behaviour, new system specifications, etc.).
Penetration rates

Figure 1 shows the estimated penetration rates of the vehicle fleet in the 2020 high scenario. The penetration rates vary between less than 1% (for Intersection Safety) to 75% (ESC on passenger cars). For ESC, it is assumed that the system will be made mandatory in new vehicles. A similar assumption was made for eCall. The high penetration rate for SpeedAlert was (partly) based on the assumption that enforcement of speed limits will continue to increase in the coming years.

ESC is the only system for which a substantial penetration rate was estimated for 2010. In 2010 and 2020, stand-alone systems generally have higher penetration rates than co-operative systems (such as Intersection Safety and Wireless Local Danger Warning), which also require investments on the infrastructure side.

![Penetration rates (fleet) in the 2020 high scenario](image)

Figure 1: Penetration rates (of vehicles equipped with IVSS) as estimated for the 2020 high scenario.

For the impact assessment, the fleet penetration rates were converted to the share of driven km’s of the equipped vehicles, which are higher than the fleet penetration rates (reflecting that the equipped vehicles are likely to make more km’s than vehicles with no IVSS).
Figure 2: Change in the number of fatalities in the 2020 high scenario (a minus indicates that fatalities are avoided).

Figure 3: Change in the number of injuries in the 2020 high scenario (a minus indicates that injuries are avoided, a plus that the number of injuries has increased).

**Impacts**

For the cost-benefit analysis, the primary impacts are the number of avoided fatalities and injuries in the four scenarios. Figure 2 and Figure 3 show how many fatalities and injuries can be avoided in the 2020 high scenario, i.e. with focused policy incentives.
ESC is expected to prevent by far the most fatalities and injuries: about 3,250 fatalities (-14%\(^1\)), and about 52,000 injuries (-5.7%). SpeedAlert (-5.2% fatalities), eCall (-3.5% fatalities) and Lane Keeping Support (-3.3% fatalities) also have substantial effects. Except for eCall, these systems would also be the most effective in reducing the number of injuries. The other systems’ effects are less pronounced.

Several factors affect the magnitude of the estimates. The effects shown in Figure 2 and Figure 3 are the result of a combination of several parallel impact mechanisms, with intended and unintended impacts. The three main factors affecting the ranking of the systems are:

- The assessed effectiveness of the IVSS to prevent targeted injury accidents, fatalities and injuries.
- The share of relevant accidents in the EU-25 data.
- The assumed fleet penetration of the system.

Some systems could have much more substantial impacts if the penetration rates would be higher. Figure 4 shows the expected potential safety effect for fatalities and injuries, if the system in question would be implemented in all vehicles (i.e. 100% penetration rate). The figure shows the combined effect of effectiveness and the share of relevant accidents.

The potential reductions are in the range of 1.4-16.6% for fatalities. For injuries, the effects range from a very small increase in injuries (0.1%) for eCall to a decrease of 8.9% for Lane Keeping Support. Electronic Stability Control (ESC) has the highest potential safety impact, in terms of avoided fatalities, followed by Lane Keeping Support (LKS) and SpeedAlert (SPE). These systems are all aimed at frequently occurring situations and collision types, and are reasonably to very effective in preventing these. LKS has the highest potential to reduce the number of injuries.

The Emergency Braking system is not expected to have high impacts in 2020, but this is mainly due to the low penetration rate, as the system is assumed to have quite good potential to improve road safety. NightVisionWarn and Driver Drowsiness Monitoring and Warning have quite similar effects: both systems seemingly focus on a significant group of accidents but the systems’ effectiveness to prevent these accidents was estimated to be limited.

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\(^1\) Note that the accident base, the number of fatalities and injuries, is smaller in the scenario years 2010 and 2020 than it is today. The effect of ESC (a system that is already on the market today) has been taken into account in the accident base. A different accident base is used for ESC (see section 2.5). Also, it is noted that the European accident statistics are more reliable and comparable for fatalities than for injuries.
This can be because within the targeted group of accidents, the system is ultimately expected to affect only a small part of the accidents (e.g. NightVisionWarn cannot be expected to prevent the majority of accidents occurring in the dark), or there are unintended effects (modified behaviour, described by mechanisms 3-8) which reduce the total expected effect. Intersection Safety was assessed to be somewhat more effective, but the target accident group of fatalities is relatively small at the EU level, and therefore the system’s safety potential to reduce fatalities is limited. The potential to reduce injuries is much higher.

Full Speed Range ACC (FSR) has the lowest potential impact on fatalities. This system targets only a small share of all accidents (but is expected to be quite effective in preventing those). This is also the case for Lane Change Assistance (LCA) and, to a lesser extent, for Pre-Crash Protection of Vulnerable Road Users (PCV).

eCall does not prevent accidents and is relevant only for mitigating the effects of selected collision types. However, eCall has a high penetration rate in the 2020 high scenario, and thus still has a relatively high impact on the number of fatalities. However, as most of the fatalities are turned into injuries, and not many injuries are avoided, the system will result in a very small increase in the number of injuries.

![Diagram: Potential safety effect of IVSS (at 100% penetration rate)](image)

Figure 4: Potential safety effect (%) for the 12 selected IVSS if all vehicles would be equipped with the system.
The primary traffic effects were the changes in speeds and travel times (resulting from changes in the characteristics of the traffic flows, or from less congestion caused by accidents). Compared to the safety effects, the traffic effects are modest. This is not unexpected, as eIMPACT looks at safety systems, but an important conclusion is that the selected IVSS have no negative impacts on traffic flows and travel times.

Only the SpeedAlert system shows (positive) direct traffic effects in monetary terms substantial enough to be noticed at the EU-25 level. Although slightly increased travel times are expected because of reduced speeds, the environmental benefits of the reduction in speed (reduced emissions) outweigh the negative travel time effects.

At cross-sections, the direct traffic effects such as reduced speeds, earlier braking and longer headways can be expected for a number of systems, but this is not substantial enough at the penetration rates examined to produce significant traffic impacts at the network and EU-level. Those effects have, however, been accounted for in the safety analysis.

Indirect traffic effects, i.e. avoided congestion costs resulting from a reduction in the number of accidents with fatalities and injuries, occur for all systems.

The largest effects are found for systems that are effective in high traffic densities (mostly on motorways, in peak periods). The effectiveness of the system on different road types and in different periods of the day was derived from the safety analysis. The ESC system showed the highest reduction in congestion costs. Intersection Safety showed the lowest reduction (mainly due to the low penetration rate).

It should be noted that the impact assessment focused on safety and traffic impacts (and effects on emissions), and did not consider other aspects such as the increased comfort that some of the IVSS considered can bring.

**Relationship with other work packages in eIMPACT**

The impact assessment provides input for the cost-benefit analysis (CBA). The most important input is the reduction in the numbers of fatalities and injuries. Each avoided fatality and injury is assigned a monetary value. Monetary values were also assigned to the traffic effects: changes in travel times and emissions. In the CBA, the total benefits are compared to the total costs of implementing the systems to obtain the benefit-cost ratios (at the estimated penetration rates in 2010 and 2020).

The results also provide insights for the stakeholder analysis and for policy development.
The impact assessment results also supported the choice of systems analysed in the stakeholder analysis. However, other characteristics of the system were also relevant in that choice: whether systems are co-operative or stand-alone, and what the time to market is.

Note: The assumptions on which the penetration rates and impact assessments were based were obtained from state-of-the-art sources, whether that be literature or discussion with experts. The results presented in the eIMPACT deliverables reflect the knowledge of the partners in the eIMPACT consortium.
1 Introduction

1.1 Background information about eIMPACT

The eIMPACT project, "Socio-economic Impact Assessment of Stand-alone and Co-operative Intelligent Vehicle Safety Systems (IVSS) in Europe", assesses the socio-economic effects of Intelligent Vehicle Safety Systems (IVSS) and their impact on traffic, safety and efficiency. It addresses policy options and the views and roles of the different stakeholders involved. eIMPACT is part of the EU's Sixth Framework Programme for Information Society Technologies and Media.

eIMPACT supports the three pillars of the EC's Intelligent Car Initiative (ICI), addressing stakeholders, research, and awareness-raising. eIMPACT provides quantitative impacts of twelve IVSS in terms of safety, traffic and cost-benefit effects, making use of an integrated assessment method. These quantitative results provide important building blocks for the potential contribution of Intelligent Transport Systems (ITS) to reduce road fatalities, as described in the EU White Paper on Transport.

eIMPACT also provides perspectives on the market introduction of IVSS. The results of eIMPACT can be used to provide guidance in the deployment of IVSS. The results support decision making processes for research programmes in terms of focus and funding, as well as awareness, promotion and deployment activities, mainly at the EU, but also on national and regional levels. These results can also be used by policymakers, road operators and driver clubs in terms of strategic orientation, investment, promotion and deployment decisions. Finally, automotive and insurance industries can take the results as needed to develop product and innovation strategies.

eIMPACT looks forward to the years 2010 and 2020. The project examines two scenarios, "business as usual" and "implementation of policy options "scenarios", for each of those years. Thus, eIMPACT examines a less-than-100% penetration rate. The development of the two scenarios involved defining penetration rates for the selected IVSS in regions of the EU.

1.2 The impact assessment in the eIMPACT project

This report, “Impact assessment of Intelligent Vehicle Safety Systems”, provides concrete, unified estimates of traffic and safety effects, as calculated in WP3000 of the eIMPACT project. WP3000 is composed of 3 tasks:

- WP3100: Scenarios for market acceptance and penetration
- WP3200: Traffic impacts
- WP3300: Safety impacts

Figure 5 shows the tasks in WP3000 and their place in the overall process of the project.

The impact analyses receive input from the system selection and the specification of the twelve selected systems (WP1100). WP3000
partners took part in the system specification because of the need for specific, detailed data for the impact analyses. The impact assessment provides input to the cost-benefit analysis in WP2300, which in turn provides input for the work package on policy options for facilitating market introduction (WP4200) and the stakeholder analysis (WP5000).

Figure 5: WP3000 tasks and relations to other tasks in the eIMPACT project

Table 1 gives a very brief description of the twelve systems selected for analysis. A more extensive description of the functions and components of the systems can be found in Annex 3.

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<tr>
<th>System name</th>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>Electronic Stability Control</td>
<td>ESC</td>
<td>Stabilises the vehicle within the physical limits and prevents skidding through active brake intervention and engine torque control.</td>
</tr>
<tr>
<td>Full Speed Range ACC</td>
<td>FSR</td>
<td>Adaptation of speed and distance to vehicles ahead down to standstill, including Stop and Go.</td>
</tr>
<tr>
<td>Emergency Braking</td>
<td>EBR</td>
<td>Fully automatic system, avoids or mitigates longitudinal crashes (braking only).</td>
</tr>
<tr>
<td>Pre-Crash Protection of Vulnerable Road Users</td>
<td>PCV</td>
<td>Detection of vulnerable road users and fully automatic emergency braking (no passive safety).</td>
</tr>
<tr>
<td>Lane Change Assistant (Warning)</td>
<td>LCA</td>
<td>Warning for nearby vehicles next to or at the rear of the vehicle just before lane change.</td>
</tr>
<tr>
<td>System name</td>
<td>Abbreviation</td>
<td>Description</td>
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<tr>
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<td>-------------</td>
</tr>
<tr>
<td>Lane Keeping Support</td>
<td>LKS</td>
<td>Lane keeping assistance by active steering support (Phase 2)</td>
</tr>
<tr>
<td>NightVisionWarn</td>
<td>NIW</td>
<td>Enhanced vision at night through near or far infrared sensors, including obstacle warning</td>
</tr>
<tr>
<td>Driver Drowsiness Monitoring and Warning</td>
<td>DDM</td>
<td>Warns drivers when they are getting drowsy</td>
</tr>
<tr>
<td>eCall (one-way communication)</td>
<td>ECA</td>
<td>Automatic emergency call for help in case of an accident</td>
</tr>
<tr>
<td>Intersection Safety</td>
<td>INS</td>
<td>Red light warning, right of way information at signalized intersection and stop signs and left turn assistance</td>
</tr>
<tr>
<td>Wireless Local Danger Warning</td>
<td>WLD</td>
<td>Inter-vehicle communication distributing early warnings for accidents, obstacles, reduced friction and bad visibility</td>
</tr>
<tr>
<td>SpeedAlert</td>
<td>SPE</td>
<td>Map and camera based system warning for speed limits by use of a haptic gas pedal and warning module for when speed limit is exceeded</td>
</tr>
</tbody>
</table>

The objectives of work package 3000 are to:

- Create scenarios of market penetration and acceptance of Intelligent Vehicle Safety Systems for the years 2010 and 2020 (step 1 in Figure 6);
- Assess the impacts of the Intelligent Vehicle Safety Systems in these scenarios in terms of safety and traffic (step 2 and 3 in Figure 6);
- Coordinate with the accident causation project TRACE (TRaffic Accident Causation in Europe);
- Provide data for the cost-benefit analysis (CBA) in WP2300 (step 4 in Figure 6).
1.3 Structure of the report

This introduction is followed by a description of the methodology of the impact assessment and the co-operation with the TRACE project (chapter 2). An innovative approach was followed for several aspects of the impact assessment. This will also be discussed in chapter 2.

Chapter 3 discusses the first step in the impact assessment: the estimation of the penetration rates. Scenarios were produced for 2010 and 2020, describing the selected IVSS in terms of penetration rates, application areas, etc. The fleet penetration rates for future vehicle fleets were determined on the basis of current vehicle fleet age distributions from the different EU countries.

The penetration rates formed input for the traffic impact analysis, presented in chapter 4. For each scenario, the effects of IVSS on traffic were quantified in terms of the traffic flow effects (homogenisation, speed differences, travel times), fuel consumption and environmental effects, for the years 2010 and 2020. Three traffic simulation models were used in order to carry out the analysis: the ITS modeller, VISSIM and FARSII Simulator. The models were applied in a coordinated way, making use of each model's strengths.

The reduction in the number of fatal and injury accidents affects accident-related congestion and the associated costs, the "indirect traffic effects". Thus, for each system, the "avoided congestion costs due to avoided accidents" were calculated.

Chapter 5 discusses the safety impact analysis. Estimates of safety impacts for the selected IVSS were provided in terms of percent-changes (with ranges) in the numbers of fatalities and injured persons. This was done for different situations (accident type, road
class), circumstances, vehicle types and EU regions, and for the different dimensions of safety (exposure, crash risk, crash consequences). Information was shared with the TRACE\textsuperscript{2} project (a parallel STREP\textsuperscript{3} on accident causation), and in joint workshops with partners from eIMPACT and TRACE, and with the EUCAR working group on safety. TRACE contributed in eIMPACT by providing accident data.

Finally, chapter 6 provides conclusions and recommendations, regarding the results and the impact assessment approach followed.

The annexes contain the keywords for the report, a glossary of terms used in this report, the specification of the twelve selected systems, tables of the penetration rates, an overview of the current market status of the systems and a list of the technical reports produced in WP3100 (penetration rates), WP3200 (traffic impacts) and WP3300 (safety impacts).

\textsuperscript{2} TRACE stand for: TRaffic Accident Causation in Europe.

\textsuperscript{3} STREP stands for: Strategic Targeted REsearch Project.
2 Methodology of the impact assessment

This section gives an overview of the methodologies applied in the impact assessment. After some general aspects, the specific methodologies for estimating the penetration rates, the traffic impacts and the safety impacts, respectively, are discussed.

2.1 General aspects of the impact assessment

Figure 7 depicts the information flows between the analyses carried out for the impact assessment. The impact assessment started with the estimation of the penetration rates for passenger cars, goods vehicles and buses (see glossary in Annex 2 for definitions, note that this report only provides the results for passenger cars and goods vehicles), based on the specification of the twelve selected systems. The system specifications (functional descriptions of how, where and when the systems have an effect) were also the basis for the traffic and safety impact analyses. Also, the penetration rates were used in the cost-benefit analysis (dotted line in Figure 7).

For those systems that can have an effect on the speed and following distances noticeable on the traffic flow level (continuously, not just in rare events), traffic simulations were carried out to investigate what travel time effects can be expected and how the system affects surrogate safety measures, i.e. traffic parameters that give an indication of the effect on traffic safety. These parameters provide input for the safety impact analysis.

The safety impacts assessment was carried out for all systems. It yielded estimates of the changes in the number of accidents with fatalities and injuries, for each selected system. Fewer accidents means less accident-related congestion – another effect on travel times.

Both travel time effects (direct and indirect) and the safety effects were subsequently used as input for the cost-benefit analysis.

All analyses were carried out for the years 2010 and 2020. Most systems were assumed to be the same in both years, but with higher penetration rates for 2020. For some systems, additional functionalities were assumed for 2020.

Two scenarios with respect to the penetration rates were analysed – a low scenario (‘business as usual’, a scenario with no specific incentives to promote IVSS), and a high scenario (with focused incentives to promote roll-out of the systems).

In the safety analysis, three sets of estimates were provided: the most probable estimates, and optimistic and pessimistic values. This was done to show the range in estimates due to uncertainties in the analysis of these, for the most part, future systems.
2.2 Estimation of penetration rates

The estimation of penetration rates of selected systems for the years 2010 and 2020 was conducted in several phases. First, relevant information about market acceptance of IVSS from earlier and ongoing EU projects was compiled. In addition, information about the percentages (volumes of new cars) of different car segments (from small cars to luxury cars) in 2005 was utilised. It was assumed that these market shares do not change until 2020 and the systems will be installed first in most expensive cars. It was also taken into account that it will take several years to reach the target market shares set for transport policy (e.g. for ESC or eCall in EU). For the existing systems, the current market acceptance rates were used as a basis for future rates. For the penetration rates of new goods vehicles, the passenger car estimates were taken as a starting point. Expert judgment and knowledge of e.g. policy measures and regulations on the EU level regarding heavy vehicles were used to determine whether the penetration rates for goods vehicles differed from the penetration rates for passenger cars. In the high scenario, it was also taken into account that some major fleet owners may equip all or most of their new vehicles with the some of the systems if there are clear benefits for them.

Secondly, the estimates for new vehicles were converted to the fleet penetration rates for the whole vehicle fleet in the years 2010 and 2020, on the basis of current vehicle fleet age distributions in each EU member state. This was done assuming that the vehicle age
distributions would remain the same in 2010 and 2020 as in 2005. Fleet data from EU-25 countries were gathered with the support of eIMPACT partners and several other international colleagues. The collected information included the number of vehicles in use by the first year of registration. In case of insufficient data, it was complemented using International statistics [Eurostat, 2007] and [EU, 2005] or estimates were produced as averages from neighbouring countries. The data for the year 2004 data was used when information for the year 2005 was not available. For the estimates of the fleet penetration rates, the information of the first year of market introduction was needed.

The number of new vehicles varies substantially per year as the changes in the economy affect the vehicle fleet age distribution. In order to enable extrapolation to future years, the age distribution numbers were smoothed by an exponential model "vehicleproportion"=a*exp(b*AGE). The smoothed EU-25 vehicle age distribution is shown in Figure 8.

![Vehicle fleet age EU-25, smoothened from 2005](image)

Figure 8: The smoothened EU-25 vehicle age distribution 1985–2005. GV = goods vehicles.

Changes in new vehicle taxation and other policies were not explicitly considered, although they might affect vehicle age distributions especially in 2020. However, expected policy measures are included to some degree in the market penetration estimates for the "High" penetration rates scenario. Specifically, this scenario assumes that incentives, campaigns and other additional measures are undertaken to accelerate the market penetration of the systems.

Thirdly, the penetration rates were converted into the share of the driven mileage by weighing the vehicle age related fleet distribution (as in Figure 8) by the vehicle age distribution of annual vehicle kilometres (as in Figure 9). The reason for this conversion was that the share of vehicles (or roads) equipped is not the same as the share of km’s travelled by equipped vehicles (or the share of vehicle kilometres travelled on roads that are equipped). E.g. IVSS are likely to be introduced first on new vehicles which usually make more km’s than old vehicles and possibly on busy roads.
Annual vehicle kilometres of older vehicles, compared to those driven by the 1-year old vehicles, were available only from Swedish, German and Finnish statistics. As German figures may apply better than Nordic figures, the German statistics were given a double weight in relation to Finnish and Swedish ones. For the EU-25 the annual vehicle kilometres were calculated as follows (Figure 9):

\[(\text{FI} + \text{SE} + 2\times\text{DE}) / 4.\]

![Figure 9: Annual vehicle kilometres compared to those driven by the 1-year old for EU-25. GV = goods vehicles](image)

Share of the driven mileage driven with the system was estimated separately for each three European regions (Northern and Central Europe, Southern Europe and Eastern Europe). The regions are introduced more precisely in section 2.5, Accident data. Typically the share of the driven mileage with the system was higher for Northern and Central Europe than EU-25 and lower for Eastern Europe than EU-25. Differences in driven mileage with the system were done taking into account the combination of market penetration and vehicle fleet age distribution.

The fleet penetration rates were used in the analysis of the safety and traffic impacts and in the benefit cost calculations.

In the process, feedback was sought from project partners and external parties at several stages:

1. The first estimates for new vehicle penetrations were given in co-operation with the researchers and car manufactures involved in eIMPACT. For these figures the acceptance from all eIMPACT partners was requested.

2. After producing the first estimates, a workshop was organised where the scenarios for new vehicle penetrations were discussed with, and vetted and accepted by international experts. Core people from the automotive industry and the EU participated in this so-called Scenario Workshop.

3. The final acceptance for the penetration rates was gathered by email consultation of the participants of the workshop and eIMPACT partners as an iterative process.
4. As the scenarios for 2020 for goods vehicles for FSR, EBR and PCV were not estimated at the Scenario Workshop, these were estimated afterwards and validated by email consultation among eIMPACT partners.

2.3 Traffic impact assessment

The traffic impact analysis distinguishes between direct traffic effects and indirect traffic effects. Direct traffic effects result directly from changes in traffic flow caused by the system (or the driver’s reaction to the advice given by the system). They were analysed using several micro-simulation models. A cross-validation was carried out for the simulation models used, to ensure that results obtained from different models are comparable.

Indirect traffic effects are changes in the amount of congestion, as a result of the implementation of the system. The analysis of the indirect effects is based on the quantitative results from the safety impact analysis (the changes in the number of accidents).

The next sections describe, in more detail, the analysis of the direct and indirect traffic effects and the cross-validation of the micro-simulation models used.

2.3.1 Direct effects

Direct traffic effects are, for instance, changes in speeds, travel times and headways, caused by the way the systems affect vehicle and driver behaviour. Micro-simulation models allow the modelling of these changes in driving behaviour due to the use of IVSS and are therefore suitable for modelling the types of systems selected in eIMPACT. The technical and functional specifications of the selected systems were translated into descriptions of vehicle and driver behaviour, which were implemented in microscopic traffic simulation models. The combined expertise of the eIMPACT project partners was crucial in this process, as the simulations require detailed knowledge of how the systems work.

The models were run for the relevant scenarios. The penetration rates used were the shares of driven mileage. The results from the runs comprise direct traffic effects in terms of changes in the traffic flow, such as changes in speeds and travel times. In the cost-benefit analysis, these data were used to calculate the changes in the travel time costs and environmental costs (fuel consumption and emissions of CO₂, particulate matter and NOx).

Simulations have been carried out only for those of the systems that affect the (longitudinal) movement of a vehicle. Systems that increase safety but do not change the normal movements of the vehicle or the interactions between vehicles have not been modelled, because in that case micro-simulation does not add any information.

The simulations were carried out with two microscopic simulation models, the ITS modeller and VISSIM. Both models are capable of modelling individual vehicles moving through a road network. Table 2

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4 Current micro-simulation models are not capable of modeling lateral interactions with a degree of detail that would allow analysis of the direct traffic effects of systems such as LCA and LKS.
shows which systems are modelled with the ITS Modeller and VISSIM. A third simulator, FARSIM, was used to model in more detail the effects of Wireless Local Danger Warning. The FARSIM model works with a 'moving window', i.e. a vehicle’s trajectory is followed and the interactions with vehicles surrounding it are modelled, but assessments at the network level are not possible. These were therefore carried out with the ITS modeller.

Table 2: Systems modelled (in brackets: years and scenarios considered)

<table>
<thead>
<tr>
<th>model: VISSIM</th>
<th>model: ITS modeller</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intersection Safety (2020 high)</td>
<td>SpeedAlert (2010 &amp; 2020, low and high)</td>
</tr>
<tr>
<td>Full Speed Range ACC (2020 low and high)</td>
<td>Wireless Local Danger Warning (2020 high)</td>
</tr>
<tr>
<td>Night Vision Warn (2020 low and high)</td>
<td></td>
</tr>
</tbody>
</table>

To support the accident analysis in which the safety effects are determined, the micro-simulation runs also yield surrogate safety measures that can be used as indicators for changes in the number of critical situations. Such surrogate parameters are the proportion of small headways or times-to-collision, or the frequency of strong decelerations. Surrogate safety measures cannot directly be linked to changes in the occurrence of accidents; but they can give insight into changes in traffic flow that will have safety effects.

### 2.3.2 Indirect effects

The indirect effects were calculated using the changes in the number of accidents as reported by the safety impact analysis. Avoided accidents can lead to benefits in terms of reduced congestion costs. As effects may depend on the road types and periods of the day that a system is effective, we checked, for each system separately, which reduction in congestion costs can be expected from avoided fatalities and injuries.

Deliverable 3 of the eIMPACT project (Methodological framework and database for socio-economic evaluation of Intelligent Vehicle Safety Systems [Assing et al., 2006]) gives estimates for the average avoided costs per avoided accident (see Table 3). The values are valid for 2010 and 2020.
Table 3: Average avoided costs per avoided accidents [Assing et al., 2006].

<table>
<thead>
<tr>
<th>Accident with</th>
<th>Avoided congestion costs (EUR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fatality</td>
<td>15,500</td>
</tr>
<tr>
<td>Injury</td>
<td>5,000</td>
</tr>
</tbody>
</table>

These are average costs, based on the current distribution of accidents over road types and periods of the day. However, road type and the time of day at which an accident occurs affect the accident cost (Night Vision Warn is an obvious example). Therefore, we take into account where and when the systems are expected to be the most effective.

Figure 10 shows how the indirect effects are calculated and which data are available to do that. For each system, we received data from the safety impact assessment about the changes in the number of accidents with (a) fatalities and (b) injuries, per road type. The safety impact assessment gave no specific information about the distribution of avoided accidents over the day, but assumptions about the effectiveness of the systems in different periods of the day have been made based on the description of the systems and factors identified in the safety impact assessment (e.g. by comparing effectiveness factors for the day and night period). When the avoided accidents are divided over road type and period of the day, the numbers can be multiplied by the average avoided costs per avoided accidents for the relevant road types and periods of the day. As these costs are only available as averages (for accidents with fatalities and accidents with injuries respectively), the costs have been disaggregated to obtain costs per road type and period of the day. Assumptions for that were made based on available statistics on congestion (costs). For instance, a queue caused by a fatal accident generates higher congestion costs in the morning (peak hour) than at night. Also, on motorways congestion costs will be much higher than on rural roads, because of the higher traffic flows.
Avoided congestion costs were defined for twelve different scenarios (4 periods of the day, on 3 road types), for accidents with fatalities, and for accidents with severe injuries.

The costs of a combination of location and time of day must depend on the probability of the occurrence of congestion due to an accident on that road type in that period. The estimations are based on statistics on accident and congestion occurrence over the day, and the following considerations:

- In morning and evening peaks the traffic flows mainly consist of traffic that has high value of times such as commuters, and freight traffic. Economic damage due to considerable time losses is therefore likely to occur. In addition, fatal accidents will lead to considerable congestion on most motorways and some rural roads in peak hours. Also, in city networks high traffic loads will easily fill the area around the accident and consequently block other crossings. Even though most urban networks are quite dense, it is unlikely that traffic can be easily rerouted during busy periods.

- In off-peak hours, congestion may also arise due to fatal accidents. However, traffic in off-peak hours will have lower values of time, and the impact will be less because of lower flows. In city centres, traffic can more easily be rerouted through the dense network, leading to considerably less congestion costs.
- At night traffic volumes are very low, so no significant reduction in congestion is expected then.

These considerations lead to a disaggregation of the average congestion costs as given in Table 4.

Table 4: Congestion costs due to accidents with fatalities and severe injuries over location and time of day.

<table>
<thead>
<tr>
<th></th>
<th>Fatalities</th>
<th>Queuing costs (EUR)</th>
<th>&quot;Share&quot; in average</th>
<th>Injuries</th>
<th>Queuing costs (EUR)</th>
<th>&quot;Share&quot; in average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motorways</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>morning peak</td>
<td>0.9%</td>
<td>103438</td>
<td>925</td>
<td>1.0%</td>
<td>25715</td>
<td>257</td>
</tr>
<tr>
<td>evening peak</td>
<td>1.4%</td>
<td>103438</td>
<td>1478</td>
<td>1.7%</td>
<td>25715</td>
<td>437</td>
</tr>
<tr>
<td>night</td>
<td>1.9%</td>
<td>20688</td>
<td>403</td>
<td>1.8%</td>
<td>5143</td>
<td>93</td>
</tr>
<tr>
<td>rest of the day</td>
<td>3.5%</td>
<td>51719</td>
<td>1808</td>
<td>3.8%</td>
<td>12857</td>
<td>489</td>
</tr>
<tr>
<td>Rural roads</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>morning peak</td>
<td>6.5%</td>
<td>21715</td>
<td>1421</td>
<td>3.8%</td>
<td>8098</td>
<td>308</td>
</tr>
<tr>
<td>evening peak</td>
<td>10.5%</td>
<td>21715</td>
<td>2270</td>
<td>6.5%</td>
<td>8098</td>
<td>526</td>
</tr>
<tr>
<td>night</td>
<td>14.3%</td>
<td>2895</td>
<td>413</td>
<td>6.7%</td>
<td>1080</td>
<td>72</td>
</tr>
<tr>
<td>rest of the day</td>
<td>25.6%</td>
<td>14477</td>
<td>3703</td>
<td>14.5%</td>
<td>5398</td>
<td>783</td>
</tr>
<tr>
<td>Urban roads</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>morning peak</td>
<td>4.1%</td>
<td>13096</td>
<td>534</td>
<td>7.3%</td>
<td>4883</td>
<td>356</td>
</tr>
<tr>
<td>evening peak</td>
<td>6.5%</td>
<td>13096</td>
<td>853</td>
<td>12.5%</td>
<td>4883</td>
<td>610</td>
</tr>
<tr>
<td>night</td>
<td>8.9%</td>
<td>2619</td>
<td>233</td>
<td>12.8%</td>
<td>977</td>
<td>125</td>
</tr>
<tr>
<td>rest of the day</td>
<td>15.9%</td>
<td>9167</td>
<td>1460</td>
<td>27.6%</td>
<td>3418</td>
<td>943</td>
</tr>
</tbody>
</table>
| TOTAL                | 100.0%     | 100.0%              | EUR 15,500 per accident with fatality | EUR 5,000 per accident with injury

1) Based on: [SafetyNet, 2007] and Dutch accident statistics.

The results of the indirect costs analysis were the avoided congestion costs per system, for the four scenarios. This is direct input for cost-benefit analysis.

2.3.3 Cross-validation

A cross-validation was carried out to compare the different simulation models used (ITS Modeller and VISSIM): do they produce similar results, in different situations? In other words: if the same kind of input goes into the models, will the models produce the same kind of results? If this is the case, the assessment of different systems with different models can be expected to be comparable.

Since microscopic traffic simulations are based on stochastic processes, different runs produce different results. This is realistic; in reality the traffic will never be exactly the same, even for two periods with similar traffic demands. Therefore, in order to be able to draw conclusions from the simulations, a number of simulation runs has to be carried out. The required number of runs for statistically significant results depends on the variability between runs. These issues were investigated in this cross-validation study as well.

The following hypotheses were formulated:

1. There is substantial variation between data from two different runs with the same model (different = different random seed, same scenario = set of input), in terms of: average speed and speed distributions, travel times, etc. This depends on the simulation duration (kept constant in this analysis), and traffic demand.
2. Five runs are sufficient to get results with a small enough amount of variation (to be confident about the results), in case of traffic with limited congestion.
3. Similar input to VISSIM and the ITS modeller results in similar output, i.e. similar average/distributions of speeds, flows, etc.
4. The variation between runs from VISSIM and the ITS modeller is similar to the variation between runs from the same model.
5. Variation between data from different days as measured in reality is at least as large as variation between runs from the models.

Cross-validation scenarios

The same scenario (a three-lane motorway with a traffic demand of 4500 vehicles/hour, of which 20% goods vehicles) has been simulated in the ITS modeller and VISSIM for the cross-validation. The following comparisons have been carried out:

- Variability between simulation runs with the same model;
- Comparison between VISSIM and ITS modeller;
- Comparison to real data sets.

Also, similar real-world situations were investigated, using real-world measurements from loop-detectors at motorways in The Netherlands.

Conclusions

Small differences have been found between VISSIM and the ITS modeller. However, the differences found in real traffic data are much larger. Furthermore, the differences between different simulation runs are small if a sufficient sample size, i.e. simulation duration, is applied. This means that a small number of simulations will already be sufficient to get statistically significant results. Also, this shows that the simulations are stable (i.e. do not change substantially when additional runs are carried out). By implementing and simulating a safety system for (a share of) the vehicles in the simulation, it is likely that the differences found in the simulations compared to the reference situation without the safety system can be contributed to the system and not to stochastic traffic behaviour.

Therefore, it can be concluded that VISSIM and the ITS modeller produce sufficiently similar results for the evaluation studies in eIMPACT.

2.4 Safety impact assessment

The aim of the safety impact assessment was to provide estimates of safety impacts for the selected 12 systems in two target years, 2010 and 2020, and in two penetration scenarios – ‘business as usual’ and a scenario with implementation of policy options. The safety impact estimates in terms of percent changes translated into numerical estimates of avoided fatalities and injuries. These estimates provide a central input for the benefit-cost calculations, in which a monetary value for these benefits is assigned.

2.4.1 Approach
The effects of IVSS on traffic safety may appear in many, both intended and unintended ways. It is not possible to define in advance the group of accidents affected by the system, although system developers typically have as a starting point a target group of accidents for a system. Therefore, it is highly important that the analysis of IVSS covers all possible effects in a systematic manner.

The approach was based on 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, both immediately and in the long term, due to behavioural modification. Road safety is regarded as a multiplication of three orthogonal factors: (1) exposure, (2) risk of a collision to take place during a trip and (3) risk of a collision to result in injuries or death [Nilsson 2004].

In the analyses, the three main factors of traffic safety were covered by nine behavioural mechanisms as first described in [Draskóczy et al., 1998]. The first five mechanisms are mainly connected to the accident risk:

1. Direct in-car modification of the driving task;
2. Direct influence by roadside systems;
3. Indirect modification of user behaviour;
4. Indirect modification of non-user behaviour and
5. Modification of interaction between users and non-users.

The second group deals with exposure:

6. Modification of road user exposure;
7. Modification of modal choice;

Finally, there is the mechanism that deals with changes in accident consequences:


Below, the mechanisms are described briefly and some illustrative examples are given. Every mechanism may result in either positive or negative impacts on road safety.

**Mechanism 1: Direct in-car modification of the driving task**

The driving task is directly modified by giving information, advice, and assistance or taking over part of the task with an in-car system. The system may influence driver attention, mental load, and decision about action (driver choice of speed, for example), or it may take over the gas pedal or vehicle braking system. The criterion for this mechanism is that the effects are direct consequences of the use of the system; they are direct reactions to the system outputs and appear in few milliseconds or seconds. This mechanism covers both intended (e.g. decrease of speed to avoid a collision) and unintended (e.g. driver distraction) impacts.

**Mechanism 2: Direct influence by roadside systems**

Direct influence by roadside systems is typically based on information provision and advice. Without the possibility to control driver action or the vehicle directly, the impact of this influence is
more limited than that of the in-vehicle systems. In other aspects the impacts are similar to the ones described in mechanism 1.

**Mechanism 3: Indirect modification of user behaviour**

Indirect modification of user behaviour appears in many, largely unknown ways. The driver will always adapt to the changing situation. This is often called behavioural adaptation, and will often not appear immediately after taking the system into use but may show up later and is very hard to predict. This is a well-known effect in the road safety research (see e.g. [Elvik and Vaa 2004], [Shinar 2007]). Behavioural adaptation may appear in many different ways, e.g., by change of headway in a car following situation, by change of speed behaviour, by change of expectation of the behaviour of other road users, by reallocation of attention resources etc.

**Mechanism 4: Indirect modification of non-user behaviour**

This type of behavioural adaptation is even harder to study because it is often secondary. Non-equipped drivers may change their behaviour, by imitating the behaviour of equipped drivers, for example driving closer or faster than they should, not having the equipment; or decreasing speed due to the speed decrease of the equipped vehicle ahead. (It is noted that the effect on non user behaviour approaches zero when fleet penetration of a system approaches 100%).

**Mechanism 5: Modification of interaction between users and non-users**

ITS will change the communication between equipped road users. This change of communication may influence the traditional communication with non-equipped road users. To a large extent this problem may appear in the interaction between drivers and unprotected road users. This mechanism emphasises active communication between road users, compared to the more passive imitating behaviour (in mechanism 4). In cooperative systems, drivers are supported by vehicle-to-infrastructure and/or vehicle-to-vehicle communications, on the basis of which they receive warnings of potential risks of collisions with other vehicles. In such cases, it is very likely that drivers tend to learn to pay more attention to the vehicles, being more accustomed to receive warnings about them, and less attention to vulnerable road users. In the case of e.g. intersection safety systems, this results in deteriorating interaction with pedestrians crossing the arms of the intersection while the equipped vehicle is entering the junction. Interaction with vulnerable road users can also improve due to intelligent vehicle safety systems. Results from studies on speed alert show that drivers encouraged to lower speeds by the system are more prepared to pay attention to vulnerable road users and give way to them in their interactions. Interaction effects can also concern other non-users of the systems and not just vulnerable road users.

**Mechanism 6: Modification of road user exposure**
Road user exposure may be modified by for example information, recommendation, restrictions, debiting or increased comfort in car driving. This mechanism covers only changes in the amount of travelling, i.e. whether the road user decides to make more or less, or longer or shorter, trips due to the system. This is certainly an area where introduction of ITS may have a large impact because the impacts are not limited to selected collision types, but typically affect all collision types.

**Mechanism 7: Modification of modal choice**

Mechanism 7 concerns modification of modal choice, by for example demand restraints (area access restriction, road pricing, area parking strategies), supply control by modal interchange and other public transport management measures, and travel information systems. Increased attractiveness of car driving due to the system may result in more car trips compared to public transport. Different travel modes have different accident risks, therefore any measure which influences modal choice, has also impact on road safety. It is noted that in assessing the road safety impacts the whole travel chain, including e.g. the walking trips to the bus station, should be covered.

**Mechanism 8: Modification of route choice**

Modification of route choice can occur because of demand restraints, route diversions, route guidance systems, dynamic route information systems, and hazard warning systems monitoring incidents. Different parts of the road network, i.e. different categories of roads, have different accident risks, therefore, any measure which influences route choice by diverting traffic to roads of a different category, also has an impact on road safety.

**Mechanism 9: Modification of accident consequences**

Modification of accident consequences by intelligent injury severity reducing systems in the vehicle is achieved by quick and accurate crash reporting and call for rescue, and by reduced rescue time. The consequences are also mitigated, or made more severe, by changes in the collision speed. This effect, however, is taken into consideration via other mechanisms (usually 1 and 3) and is not included here to avoid any risk of double counting.

In summary, the analyses aimed to cover not only the direct intended effects of systems but also the indirect and unintended effects, including behavioural adaptation in long term use. In addition, it was taken into consideration that the effects will vary according to road conditions and circumstances. This should ensure that all effects on safety are covered by the analyses.

The starting point for the safety impact assessment were the system specifications, including detailed safety function definitions. Figure 11 presents an overview of the phases in the analysis.
2.4.2 Effects on driver behaviour for relevant impact mechanisms

After describing the safety functions in detail, the relevant safety impact mechanisms were selected for each IVSS. The expected changes in driver behaviour were described. Furthermore, based on existing knowledge, a numerical percentage value for the change in fatalities and injuries was estimated for each mechanism. The reference case for the estimates was the situation without any IVSS, and usually a linear development of effects was assumed. The estimates were motivated with references found in literature and other evidence available. The literature was categorised in three classes:

- Already available empirical evidence on safety impacts
- Expert evaluations of safety impacts (predicted results)
- Indirect evidence on safety impacts, which means more general assessment of the effects based on knowledge of driver behaviour, traffic flow, and effects of comparable systems, e.g. road side telematics (potential results)

The focus in eIMPACT is on future systems. Therefore, the third category of evidence was quite frequently used in the assessments. In central position were e.g. results of the AIDE project [Janssen et al., 2006] and the so-called power model [Nilsson, 2004], which describes the relationship between relative mean speed effects and injury accidents. In the case of expert evaluations when no clear evidence was found in the literature, a range of effect estimates (optimistic/pessimistic) was given in addition to the most probable...
effect. Most direct evidence was available for ESC, which is already on the market. In addition, relatively direct evidence from the field operation tests concerning ACC and SpeedAlert systems were available.

### 2.4.3 Selection of the main accident category

It was expected that the effect of the IVSS would vary according to the following background variables that are also represented in European accident statistics:

1. vehicle type (passenger car/goods vehicles)
2. collision type (8 categories, defined in the accident statistics (see Table 7))
3. road type (motorway/rural/urban)
4. weather conditions (normal/bad)
5. lighting conditions (daylight/night)
6. location (intersection/not intersection)

For each system, one of these background factors was chosen as the main classifying factor, and hence, the basis for the assessments. The selection of this main classifying variable in accident data was based on the reliability of the evidence available. It was assumed that it would be more likely to gain evidence concerning some specific situation, and the total effect estimate could be then be linked to this specific situation. In many cases the main factor was the collision type; it was e.g. known based on previous field tests and literature how effective the system has been estimated to be for different or some specific collision types in a certain area or country in Europe. Also other factors might be most relevant, e.g. road type or location. In fact, all background variables, except vehicle type, were chosen as main classifying factor at least for one safety function.

The numerical effect estimates were produced for the specific situation, e.g. a system targeting especially intersection accidents is assumed to decrease the relevant accidents (accidents at intersections, e.g. 23% of all fatalities; see Table 8 on page 34) by 25%, but has an effect of only 1% outside intersections (where, for instance, 77% of all fatalities occur, see Table 8). The total effect may then be a 7% reduction of all accidents.

### 2.4.4 Calculation of numerical estimates for EU-25

The effect estimates were applied to the EU-25 road accident data, so that the distribution of the main classifying variable weighted the estimate. In weighting, the effect estimate indicated in percent changes was multiplied with the share (%) of relevant accidents.

The estimates were firstly applied to a specific data set on which the estimate and empirical evidence was based. This could be a national data set, but usually it was the so called Cluster 1 accident data including data from the central western and northern European countries (see section 2.4.5 on Accident data). Secondly, the same estimate was applied to other parts of the EU-25 data. An Excel tool was developed for structuring the accident data and effect estimates,
and carrying out the calculations to obtain the changes in the number of accidents.

Table 5 shows an illustrative example of the calculation of the total effect when the effects for the selected mechanisms are available. First, the estimates given in percentages were converted to coefficients of efficiency (e.g. a decrease of accidents by 30% means that the target group of accidents is multiplied by coefficient 0.70). Secondly, the total effect was computed by multiplying the coefficients for each mechanism and giving this total effect as a percentage. N.B. The same procedure should be followed when calculating effects of combinations of systems (note that it is not allowed to simply add up the effects in that case).

Table 5: An illustrative example of calculation of the total effect based on percent coefficients.

<table>
<thead>
<tr>
<th>Mechanism</th>
<th>Effect on injury accidents</th>
<th>Effect, % (EC)</th>
<th>Coefficient of efficiency (EF)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechanism 1</td>
<td>decreases</td>
<td>−30%</td>
<td>0.70</td>
</tr>
<tr>
<td>Mechanism 3</td>
<td>decreases</td>
<td>−0.5%</td>
<td>0.995</td>
</tr>
<tr>
<td>Mechanism 5</td>
<td>increases</td>
<td>+12%</td>
<td>1.12</td>
</tr>
<tr>
<td>Total average effect</td>
<td></td>
<td>−22%</td>
<td>0.70 x 0.995 x 1.12 = 0.78</td>
</tr>
</tbody>
</table>

The effect estimates for 100% fleet penetration were provided in terms of percent changes. The effect estimates were multiplied by the estimated fleet mileage penetrations. In general, a linear development of the effects for different penetrations was assumed.

Based on the previous accident data, the accident trends for the target years were provided (see section 2.5 on Accident data). Finally, the impacts were provided in numbers of accidents, injuries and fatalities (see Figure 11).

The above analysis produced the main safety impact of the system (the number of avoided accidents), and these figures provided input for the benefit cost calculations. In the benefit cost calculations a monetary value is assigned to each avoided fatality and injury.

In addition, the effect was weighted according to all other variable categories (in addition to the main category explained above) (see Table 7 for the definitions of the categories).
2.5 Accident data

2.5.1 Data needs

The collection and compilation of accident data as a basis for the safety impact assessment on the EU-25 level was carried out in close co-operation with the TRACE project. The data needs followed from the approach followed in the safety impact assessment in eIMPACT. Figure 12 shows what accident data was collected, in relation to the safety impact assessment.

![Diagram of accident data collection and compilation]

Figure 12: Need of accident data as input for the safety impact assessment.

2.5.2 Compilation of accident data

In the process of collection and compilation of the accident data, the project had to cope with various challenges:

- The level of accident data disaggregation was determined by the methodology for the safety impact assessment. This meant that quite detailed data (see Figure 12 for the variables and accident classes distinguished) was needed for 25 countries.

- The CARE database offered only limited provision of the needed accident data. The CARE database is limited to EU-14 (EU-15 excluding Germany) plus Estonia, Hungary and Poland, but data were needed for the EU-25. Also, not all variables needed were included in CARE. For instance, the collision type variable had been removed from the database just before the data compilation started. Finally, the level of completeness of the data varied between countries included in CARE. Additional data therefore had to be compiled.
eIMPACT calculated effects for the years 2010 and 2020, but no up-to-date forecast of the safety performance (accidents/casualties) in those years was available for EU-25. Consequently, the project produced its own road safety forecast.

In order to supplement the accident data provided by the CARE database, data were collected directly from individual countries. A national enquiry was set up by BASf in close co-operation with University of Loughborough and VTT, defining the desired variables and categories of accidents. The national enquiry was sent to the respective countries via the TRACE project. For efficiency reasons, the countries of the EU-25 were grouped into different country clusters with a similar level of road safety performance. A selection of representative countries of each cluster was then asked to provide data. The results from these cluster’s representatives were then transferred to all other countries in the same cluster. With this approach, a high degree of accuracy was retained.

Cluster Analysis

The cluster analysis took into account a number of chosen risk variables, based on the number of fatalities in 2005. As a result the countries were grouped into three different clusters (see also Figure 13):

- Cluster 1 (6 countries):
  - Denmark, Finland, Germany, Sweden, The Netherlands, United Kingdom;

- Cluster 2 (8 countries):
  - Austria, Belgium, France, Ireland, Italy, Luxemburg, Malta, Spain;

- Cluster 3 (11 countries):
  - Cyprus, Czech Republic, Estonia, Greece, Hungary, Latvia, Lithuania, Poland, Portugal, Slovakia, Slovenia.

For each country cluster two representative countries were selected to answer the national enquiry (underlined in the list above). Those countries were chosen because of their high share of fatalities within the clusters, but also for reasons of data availability and reliability.

The clustering of the countries was exploited in the assessment of safety impact estimates, and also enables regional discussions of the results.
Data enquiry and resulting categorisation

The structure of the enquiry was designed to match the data needs of the safety impact analysis with the available data. The data were collected, checked for errors, and processed according to eIMPACT requirements.

Two aspects proved to be important for the calculation of the different system’s safety impact:

- The discrimination of different accident classes, based on vehicle types
- The inclusion of relevant background variables.

The accident classes allow for the separate calculation of effects, depending on the number and type of vehicles involved in the accident, equipped with one of the systems under examination. There are several reasons why it is necessary to distinguish different accident classes. First of all, they have to be disjoint to avoid double counting (of victims). Secondly, accidents without “relevant” vehicles have been excluded because there will be no effect on those accidents. More importantly, a discrimination of accidents according to the number of vehicles (possibly equipped with one of the IVSS) is needed, as the effect depends largely on that. For instance, the effect might be a reduction of e.g. 3% if accidents where only one vehicle with IVSS is involved are considered. But if accidents where two vehicles with IVSS are involved are considered, the effect can be greater, e.g. 5%. Therefore, the effects have to be calculated separately.
Both requirements were met by designing a two-dimensional structure with results for all background variables for each accident class. The number of accidents, fatalities and serious and slight injuries were taken as measures.

Table 6 shows the resulting categorisation of accidents distinguished. The definition of the resulting background variables can be found in table 7.

Table 6: Definition of accident classes for the data enquiry.

<table>
<thead>
<tr>
<th>Accident classes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Accidents with one or two vehicles</td>
</tr>
<tr>
<td>2 Accidents with one or two vehicles</td>
</tr>
<tr>
<td>3 Accidents with two vehicles</td>
</tr>
<tr>
<td>4 All other accidents</td>
</tr>
</tbody>
</table>

[Table content continues...]

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Table 7: Definition of variables for the data enquiry.

<table>
<thead>
<tr>
<th>Category</th>
<th>Definition / Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Collision on the road with pedestrian</td>
</tr>
<tr>
<td>2</td>
<td>Collision on the road with all other obstacles</td>
</tr>
<tr>
<td>3</td>
<td>Collision besides the road with pedestrian or obstacle or other single vehicle accidents</td>
</tr>
<tr>
<td>4</td>
<td>Frontal collision</td>
</tr>
<tr>
<td>6</td>
<td>Angle collision</td>
</tr>
<tr>
<td>7</td>
<td>Rear collision</td>
</tr>
<tr>
<td>8</td>
<td>Other accidents with two vehicles</td>
</tr>
<tr>
<td>9</td>
<td>All other collisions</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Road type</th>
<th>Urban roads (no motorway)</th>
<th>Motorway</th>
<th>Rural roads (no motorway)</th>
</tr>
</thead>
</table>

| Weather | Adverse | Includes fog, mist, rain, snow, sleet, hail |
|         | Normal  | Includes dry, strong wind |

<table>
<thead>
<tr>
<th>Light conditions</th>
<th>Darkness</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Daylight or twilight or unknown</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Location</th>
<th>At intersection</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No intersection</td>
</tr>
</tbody>
</table>

Table 8 shows the estimated shares of fatalities and injuries by background variable categories in the EU-25 accident data, summarized over all accident classes. This table gives some insight into the potential for reduction of accidents. For instance, if a system only targets side-by-side collisions (collision type 5), which have a 5%
share in fatalities, the effects of a system that helps prevent these accidents can never exceed 5%, even at very high penetration rates and very high effectiveness of the system.

The totals given in Table 8 are for the year 2005. Accidents not relevant to the assessment of IVSS have been excluded (e.g. bicycle accidents).

Table 8: One-dimensional distribution of background variables over all relevant accident classes, EU-25 (2005).

<table>
<thead>
<tr>
<th></th>
<th>Injury accidents</th>
<th>Fatalities</th>
<th>Seriously injured</th>
<th>Slightly injured</th>
</tr>
</thead>
<tbody>
<tr>
<td>Totals</td>
<td>1,127,057</td>
<td>36,069</td>
<td>282,128</td>
<td>1,206,847</td>
</tr>
<tr>
<td><strong>Collision type</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Collision on the road with pedestrian</td>
<td>11%</td>
<td>13%</td>
<td>13%</td>
<td>8%</td>
</tr>
<tr>
<td>Collision on the road with all other obstacles</td>
<td>6%</td>
<td>7%</td>
<td>6%</td>
<td>6%</td>
</tr>
<tr>
<td>Collision besides the road with pedestrian or obstacle or other single vehicle accidents</td>
<td>13%</td>
<td>22%</td>
<td>16%</td>
<td>11%</td>
</tr>
<tr>
<td>Frontal collision</td>
<td>8%</td>
<td>18%</td>
<td>14%</td>
<td>9%</td>
</tr>
<tr>
<td>Side-by-side collision</td>
<td>5%</td>
<td>2%</td>
<td>3%</td>
<td>5%</td>
</tr>
<tr>
<td>Angle collision</td>
<td>25%</td>
<td>15%</td>
<td>22%</td>
<td>26%</td>
</tr>
<tr>
<td>Rear collision</td>
<td>13%</td>
<td>5%</td>
<td>6%</td>
<td>14%</td>
</tr>
<tr>
<td>Other accidents with two vehicles</td>
<td>6%</td>
<td>3%</td>
<td>4%</td>
<td>6%</td>
</tr>
<tr>
<td>All other collisions</td>
<td>13%</td>
<td>14%</td>
<td>15%</td>
<td>14%</td>
</tr>
<tr>
<td><strong>Road type</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Urban roads (no motorway)</td>
<td>66%</td>
<td>32%</td>
<td>51%</td>
<td>64%</td>
</tr>
<tr>
<td>Motorway</td>
<td>5%</td>
<td>7%</td>
<td>6%</td>
<td>5%</td>
</tr>
<tr>
<td>Rural roads (no motorway)</td>
<td>29%</td>
<td>61%</td>
<td>43%</td>
<td>30%</td>
</tr>
<tr>
<td><strong>Weather</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adverse</td>
<td>13%</td>
<td>13%</td>
<td>13%</td>
<td>14%</td>
</tr>
<tr>
<td>Normal</td>
<td>87%</td>
<td>87%</td>
<td>87%</td>
<td>86%</td>
</tr>
<tr>
<td><strong>Light conditions</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Darkness</td>
<td>26%</td>
<td>39%</td>
<td>30%</td>
<td>26%</td>
</tr>
<tr>
<td>Daylight or twilight or unknown</td>
<td>74%</td>
<td>61%</td>
<td>70%</td>
<td>74%</td>
</tr>
<tr>
<td><strong>Location</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>At intersection</td>
<td>50%</td>
<td>23%</td>
<td>38%</td>
<td>52%</td>
</tr>
<tr>
<td>No intersection</td>
<td>50%</td>
<td>77%</td>
<td>62%</td>
<td>48%</td>
</tr>
</tbody>
</table>

2.5.3 Road safety forecast 2010 and 2020

Method

Within eIMPACT, analyses are carried out for the target years of 2010 and 2020. Consequently, special emphasis has to be laid on the prospective development of road traffic and road safety performance. Since up-to-date forecasts of accidents and/or casualties for these target years were not available on a EU-25 level, it was necessary for eIMPACT to perform its own estimation of road safety indicators for the selected time horizon.

The general approach for the road safety prediction (see Figure 14) is based on the future development of the fatality risk for each country cluster, i.e. the ratio between the total number of fatalities and the
total vehicle-km driven. Data on vehicle-km were not available for some countries, and in that case the ratio between fatalities and the vehicle stock, being one indicator determining road safety, was calculated. Based on this method, time series of the annual number of fatalities and vehicle-km respectively vehicle stock per year for the period 1991 to 2005 were obtained for the 25 countries using the CARE and the IRTAD databases. For each year of this period, the fatality risk was calculated. A time series analysis was carried out using exponential regression to extrapolate the trend of fatality rates to the years 2010 and 2020. In a further step, the number of fatalities in each country cluster was calculated backwards by using values for vehicle-km or numbers of vehicles provided by recent forecasts for the target years.

Figure 14: Methodological Approach for road safety prediction for 2010 and 2020, EU-25.

Being based on accident data for the period 1991 to 2005, the forecast approach takes into account the effects of all measures taken for the improvement of road safety at any level in the EU within this time period. Hence, it is presumed for the road safety prediction that the measures already implemented (including ESC) will still be effective in the future and that no additional efforts are made to reduce the number of accidents and casualties.
Results
The method for estimating the number of fatalities in the target years 2010 and 2020 allows for fatality data differentiated by the three country clusters which have been introduced for the use in the safety impact assessment. The results of the road safety prediction by cluster are summarized in Figure 15.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Cluster 1</td>
<td>10.596</td>
<td>8.683</td>
<td>81,944</td>
<td>51,247</td>
<td></td>
</tr>
<tr>
<td>Cluster 2</td>
<td>17.505</td>
<td>14.878</td>
<td>84,995</td>
<td>53,033</td>
<td></td>
</tr>
<tr>
<td>Cluster 3</td>
<td>13.203</td>
<td>10.334</td>
<td>78,266</td>
<td>46,029</td>
<td></td>
</tr>
<tr>
<td>TOTAL (Cluster 1-3)</td>
<td>41.304</td>
<td>33.895</td>
<td>82,061</td>
<td>50,336</td>
<td></td>
</tr>
</tbody>
</table>

Figure 15: Results of the road safety prediction for 2010 and 2020, EU-25.

The results of the road safety prediction were compared with other available forecasts. Figure 16 shows the comparison between the forecast outcomes and the targets and predictions of the EC and DG TREN respectively. Due to the chosen forecast approach and the updated accident data used, the number of fatalities predicted within eIMPACT for 2010 are higher (33,900) than the White Paper target (25,000) or even the values of the Midterm Review (32,500).

Figure 16: Comparison of number of fatalities predicted by eIMPACT (2008) and EC road safety forecasts / targets (2001, 2006).
The estimated numbers of fatalities in 2010 (33,895) and 2020 (20,791) form the “accident base”, to which the changes in the number of fatalities are applied (a similar process is followed for the injuries). In the accident base for 2010 and 2020, the effect of the ESC systems currently on the market has been accounted for. Only in the quantification of the effects of ESC itself has a larger accident base been used (to exclude the effects of ESC), in order to show the impact of ESC in a realistic way.
3 Estimation of penetration rates

3.1 Introduction

This chapter contains the penetration rates for passenger cars and goods vehicles, in 2010 and 2020, for:

- the equipped vehicle fleet;
- the mileage driven by the equipped vehicle fleet.

3.2 Vehicle fleet equipment rates

Figure 17 and Figure 18 [Schirokoff, 2008] show the fleet penetration rates (detailed figures are presented in Annex 4). The fleet penetration estimate in 2010 was estimated to be relatively low for each system, except ESC that is already on the market and has been taken into general use. For Lane Keeping Support, Lane Change Assistance and Night Vision Warn, which are systems that are also on the market but not yet very widely available, somewhat higher penetration shares are expected in 2010. The low penetration rates are the result of low vehicle renewal rates. Furthermore, as was concluded in the Scenario Workshop, the implementation of a new system usually takes 5 to 6 years for the new vehicles and an additional 15–20 years are needed to cover the whole fleet.

The European Commission wants ESC to be mandatory in all cars across Europe by 2012. In ESC penetration estimates it was assumed that it will take approximately 5 years from the year of legislation until the system is implemented in the new cars. In addition, it was assumed that before 2020, ESC will not be implemented in trailers, and therefore the new vehicle penetration for goods vehicles will not be 100%. The low penetration figures show the situation without legislative measures.

In the eCall penetration estimations, it was assumed that the system will be installed in all new vehicle models starting in the year 2010. In addition, it was assumed that it will take approximately 5 years until a 100% penetration in new vehicles is reached. The low penetration figures show the situation without legislative measures.

For Lane Change Assistance the Night Vision Warn penetration figures were applied. For Pre-Crash Protection of Vulnerable Road Users, the Emergency Braking penetration figures were applied.

Some of the systems (Lane Keeping Support, NightVisionWarn, Driver Drowsiness Monitoring and Warning, eCall and SpeedAlert) can also be implemented as a retrofit or nomadic system. The share of retrofitted systems varies (low for Lane Keeping Support, high for SpeedAlert) [Schirokoff et al., 2008].

The lowest penetration rates were predicted for the co-operative systems. This is because the implementation of such systems depends not only on the activities of the system and vehicle providers, but also on the activities of those responsible for the necessary infrastructure investments. For vehicle-to-vehicle communications, a critical mass of equipped vehicles would be
needed to have any effects at all. The experts did not assume that the systems would be implemented in the infrastructure on a wide scale before the year 2020.

A share of 1% of equipped passenger cars would mean over 2 million vehicles in EU-25. If penetration rate would be 25%, this would mean that about 55 million passenger cars would have the system.

Figure 17: Estimated penetration rates for the passenger fleet in %, 2010/2020, low and high scenario.

Figure 18: Estimated penetration rates for the goods vehicle fleet in %, 2010/2020, low and high scenario.
3.3 Share of driven mileage

The fleet penetration rates were converted into the share of the driven mileage by weighing the vehicle age related fleet distribution by the vehicle age distribution of annual vehicle kilometres. The share of driven mileages with the system are slightly higher than fleet penetration rates because IVSS are likely to be introduced first on new vehicles, which usually make more km's than old vehicles (e.g. company cars).

These penetration rates are used in the traffic and safety impact analyses. Figure 19 and Figure 20 show the estimated share of the mileage driven with vehicles equipped with each system (see Annex 4 for more detail numbers).

Figure 19: Estimated penetration rates (fleet km’s) for the passenger fleet in %, 2010/2020, low and high scenario.
Penetration rates (fleet km’s) for the goods vehicles

Figure 20: Estimated penetration rates (fleet km’s) for the goods vehicle fleet in %, 2010/2020, low and high scenario.
4 Results of the traffic impact assessment

This chapter contains a summary of the results of the assessment of the direct and indirect traffic effects of all twelve selected systems. First, an overview of the most important direct and indirect effects is given in section 4.1. After the overview of the results, the main aspects of the traffic impacts analysis are discussed per system in sections 4.2-4.13. This includes the assumptions used (e.g. what the system or the driver is expected to do in different situations). The results reported focus on the indicators used in the cost-benefit analysis (changes in travel times, speeds, and avoided congestion costs) and the safety impact analysis (changes in speeds, surrogate safety measures).

The analysis of the indirect effects uses the estimates of the safety effects as input. More information on these estimates and the assumptions on which they are based can be found in chapter 5.

4.1 Overview of traffic impacts

The eIMPACT project analyses safety systems. This explains why only a few systems were expected to have noticeable direct effects on traffic flows, such as choice of speed and following distance. All systems have effects on accident related congestion, but the impacts vary, because of differences in penetration rates and of differences in where and when the system is effective. Systems that are more effective on motorways and in busy (peak-hour) traffic have larger effects in terms of avoided congestion costs.

Expressed in monetary terms, direct effects (changes in speeds/travel times, affecting time costs and environmental costs), when they appear, can be large compared to indirect effects. This is because direct effects (e.g. a 1 km/h change in average speeds) apply everywhere and at any time, to a very large number of km’s travelled, while indirect effects (avoided congestion costs) only occur at times and places with high traffic volumes. However, for the eIMPACT systems, the direct effects found were small to negligible (in monetary terms). The main reason for this is that the travel time changes, on the network level, were mostly very small (in the order of seconds) — hardly noticeable to drivers. As the value of time was considered to be lower for small changes in travel times, the overall effect was negligible for all but one system SpeedAlert.

Table 9 gives the main conclusions that can be drawn from the traffic impact analysis, per selected system.

Table 9: Main conclusions for the selected systems.

<table>
<thead>
<tr>
<th>System name</th>
<th>Abbreviation</th>
<th>Main conclusions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electronic Stability Control</td>
<td>ESC</td>
<td>While some drivers may ‘provoke’ the Electronic Stability Control, it is assumed that the presence of the system does not significantly influence interactions between vehicles and therefore does not have any direct traffic effects.</td>
</tr>
<tr>
<td>System name</td>
<td>Abbreviation</td>
<td>Main conclusions</td>
</tr>
<tr>
<td>-------------------------------------------------</td>
<td>--------------</td>
<td>----------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Indirect effects are high, mainly because of the high penetration rates of ESC.</td>
<td>FSR</td>
<td>The changes in speeds (and with that in travel times) are very small and will not be noticeable to drivers. Equipped vehicles have slightly shorter travel times at low traffic volumes - due to the hypothesis of a 2 km/h increased desired speed (from the same source as in the safety analysis). This effect disappears at high traffic volumes – FSR equipped vehicles keep longer (and safer) minimum headways, thus slowing down earlier for slower predecessors, which reduces the average speeds. The standard deviation of speeds decreases slightly and there is a very small shift of headways: less&lt;1s, more 1s&lt;headways&lt;2s. In some sources, ACC is mentioned to help decrease congestion. This is due to homogenisation of the traffic flow. However, with the penetration rates estimated in eIMPACT, no such effects are expected. The indirect effects are quite high, because the system can be very effective in busy traffic.</td>
</tr>
<tr>
<td>Direct effects are not expected.</td>
<td>EBR</td>
<td>The indirect effects are a bit lower than for FSR, because while Emergency Braking is effective in busy traffic, it is also expected to prevent accidents relatively more often in the dark periods of the day than during daylight hours.</td>
</tr>
<tr>
<td>Direct effects are not expected.</td>
<td>PCV</td>
<td>Indirect effects are modest, because the system only has an effect on collisions with pedestrians (which occur mostly on urban roads).</td>
</tr>
<tr>
<td>Direct effects are not expected.</td>
<td>LCA</td>
<td>Indirect effects are moderate, because the safety effects are moderate. LCA is effective in all periods of the day and in all traffic densities.</td>
</tr>
<tr>
<td>Direct effects are not expected.</td>
<td>LKS</td>
<td>Indirect effects are quite high, because LKS is effective in all periods of the day and in all traffic densities.</td>
</tr>
<tr>
<td>Direct effects were negligible, because NightVisionWarn is most effective in situations with little (car and goods vehicle) traffic. The indirect effects are small for the same reason.</td>
<td>NIW</td>
<td></td>
</tr>
<tr>
<td>Direct effects are not expected.</td>
<td>DDM</td>
<td>Indirect effects are low, because the system is more effective in the late and very early hours of the day, during which traffic volumes are relatively low.</td>
</tr>
<tr>
<td>Direct effects are not expected.</td>
<td>ECA</td>
<td></td>
</tr>
</tbody>
</table>

Deliverable D4 Version 2.0
<table>
<thead>
<tr>
<th>System name</th>
<th>Abbreviation</th>
<th>Main conclusions</th>
</tr>
</thead>
<tbody>
<tr>
<td>communication)</td>
<td></td>
<td>Indirect effects are low, because eCall is more effective in low traffic densities (roads with low traffic volumes, dark periods of the day).</td>
</tr>
<tr>
<td>Intersection Safety</td>
<td>INS</td>
<td>Direct effects were expected but could not be confirmed by the simulations. This is mostly, but not only due to the low penetration rates. For instance, the function leading to vehicles accepting only gaps judged as safe (= with a high safety margin) for left turns did not have an effect on the traffic flow level, even at higher penetration rates. Because of the very low penetration rates, the indirect effects are very low.</td>
</tr>
<tr>
<td>Wireless Local Danger Warning</td>
<td>WLD</td>
<td>Direct effects on the traffic flow level are not expected (though locally there may be substantial effects due to warning messages), because estimated penetration rates in 2010 and 2020 are low. Indirect effects are low, for the same reason.</td>
</tr>
<tr>
<td>SpeedAlert</td>
<td>SPE</td>
<td>Effects on cross-section are clear (lower speed and lower standard deviation of speeds, on urban and rural roads, less speeding on all road types: 7-43%), but effects on network level are very small. For urban roads, this is because delays at intersections can make up a substantial part of travel times, which explains the small effects on network level. For rural roads, a decrease in speeds and a slight increase in travel times can be expected, because there are fewer intersections and traffic volumes are usually low. SpeedAlert is more effective in low traffic volumes. At high traffic volumes, speeds are reduced mainly because of interactions with other vehicles. For motorways, the effects depend very much on the speeds found in the reference case (much speeding vs. little speeding). We assume that the overall effects are negligible. Locally (at measurement cross sections), very small shift of headways: less&lt;1s, more 1s&lt;headways&lt;2s can be found. There are negative direct effects in terms of (increased) travel times (due to a reduced speed on rural roads), but these are more than off-set by the positive environmental effects of the speed reduction, thus resulting in a positive direct traffic effect of 56.3 M EUR in the 2020 high scenario [Baum, 2008]. The indirect effects are quite high, even though SpeedAlert is less effective in busy traffic, because of the quite high safety effects due to high penetration rates of the system.</td>
</tr>
</tbody>
</table>

Table 10 shows the avoided congestion costs at the estimated penetration rates, for the years 2010 and 2020. ESC has the largest effect, followed by Lane Keeping Support, SpeedAlert and Full Speed Range ACC. Emergency Braking and Lane Change Assistant
also have substantial effects. These are systems that have moderate to high safety effects and are (also) effective in busy traffic.

Table 10: Avoided congestion costs for the selected systems (EU-25).

<table>
<thead>
<tr>
<th>System</th>
<th>Avoided congestion costs (M EUR)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2010 (low-high)</td>
</tr>
<tr>
<td>ESC</td>
<td>135 - 157</td>
</tr>
<tr>
<td>FSR</td>
<td>0 - 0</td>
</tr>
<tr>
<td>EBR</td>
<td>0 - 0</td>
</tr>
<tr>
<td>PCV</td>
<td>0 - 0</td>
</tr>
<tr>
<td>LCA</td>
<td>2 - 7</td>
</tr>
<tr>
<td>LKS</td>
<td>8 - 21</td>
</tr>
<tr>
<td>NIW</td>
<td>0 - 1</td>
</tr>
<tr>
<td>DDM</td>
<td>0 - 1</td>
</tr>
<tr>
<td>ECA</td>
<td>0 - 0</td>
</tr>
<tr>
<td>INS</td>
<td>0 - 0</td>
</tr>
<tr>
<td>WLD</td>
<td>0 - 0</td>
</tr>
<tr>
<td>SPE</td>
<td>6 – 9</td>
</tr>
</tbody>
</table>

4.2 Traffic impacts of Electronic Stability Control (ESC)

No direct traffic effects are expected from the Electronic Stability Control (ESC) system: while some drivers may 'provoke' the system it is assumed that this is a very small group and that the presence of the system therefore does not significantly influence interactions between vehicles and therefore does not change traffic flow.

For determining the indirect effects, assumptions have been made based on factors from the safety impact analysis. These assumptions are:

- ESC is more effective in the dark, as the drivers' detection of slippery road conditions is more difficult.
- ESC is most effective on rural roads, where speeds are relatively high and curves may be sharp, followed by motorways. The system is least effective on urban roads.
- ESC is more effective at low traffic volumes, since drivers will then be able to drive faster.

With these assumptions, and the estimated safety effects, the indirect effects (avoided congestion costs in M EUR) are:

<table>
<thead>
<tr>
<th>2010 low</th>
<th>2010 high</th>
<th>2020 low</th>
<th>2020 high</th>
</tr>
</thead>
<tbody>
<tr>
<td>135</td>
<td>157</td>
<td>173</td>
<td>217</td>
</tr>
</tbody>
</table>

4.3 Traffic impacts of Full Speed Range ACC (FSR)

Full Speed Range Adaptive Cruise Control (FSR) is one of the systems that were simulated to analyse its direct effects. With FSR, the vehicle adapts speed and distance to vehicles ahead down to standstill, including Stop and Go. The headway to be kept by the Full Speed Range ACC system (FSR) was set to 1.3s, which was considered to be a good approximation of the preferred setting in the EU-25. An increased intended speed for equipped vehicles was assumed (based on e.g. [Koziol et al., 1999] and [Alkim et al., 2007]). With FSR-ACC, drivers can set their desired speed very accurately,
and it is expected that they will set speeds at or just above the speed limit. Drivers of unequipped vehicles are likely to choose a lower speed to account for their speed variations (which are higher than for FSR vehicles) and with a certain margin of error of the speedometer in mind. Technically, this meant that the desired speed distribution was shifted by 2 km/h (the shape was not altered). For goods vehicles no distinction was made. Note that the desired speed can only be reached if there is no slower predecessor.

This system works in any traffic environment, however, due to sensor technology restrictions some road users such as bicycles or pedestrians will not be detected reliably. The major application areas are therefore motorways, rural road, and urban arterials. Simulations were only carried out for motorway traffic (3 lanes), with low to (very) high traffic densities. On rural and urban roads, no direct traffic effects were expected (although the results found for surrogate safety measures can be expected to be similar). On rural roads the densities are usually low which means the FSR system is not likely to have effects on overall travel times (especially not at low penetration rates). On urban roads, capacities are predominantly restricted by intersections.

Analysis of the network effects found in the simulations showed that in mixed traffic (ACC-vehicles are present), equipped vehicles always have a shorter travel time than non-equipped ones - mostly due to the hypothesis of a 2 km/h increased desired speed (consistent with the safety evaluation) (see Figure 21). Above approximately 4000 veh/h (for three lanes), the ACC vehicles show the same travel times as the unequipped vehicles.

![Figure 21: Travel times as a function of traffic volumes.](image)

All travel time effects are small: the difference between equipped and unequipped vehicles in average travel times is less than 3 seconds (for 3 km).
The standard deviation of speeds decreases slightly and there is a very small shift of headways: less < 1s, more 1s < headways < 2s.

Table 11 shows the changes in speeds and surrogate safety measures. The data in this table result from an aggregation over the simulated traffic volumes. To this end a sample volume over time relation taken from measurements [Heidemann & Wimper, 1982] was used and the parameters (speed, headway shares etc.) aggregated to a weighted average. Therefore, Table 11 shows the results of all simulations combined.

Table 11: Overview of direct effects on motorways for FSR in 2020.

<table>
<thead>
<tr>
<th></th>
<th>Base case (km/h)</th>
<th>Low penetration (%)</th>
<th>High penetration (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average speed</td>
<td>91.25</td>
<td>-0.12%</td>
<td>-0.11%</td>
</tr>
<tr>
<td>change at cross-section (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time Headways &lt; 1s</td>
<td>Base case (%)</td>
<td>21.42</td>
<td>21.36</td>
</tr>
<tr>
<td>change (absolute)</td>
<td>Low penetration (%)</td>
<td>-0.67</td>
<td>-0.67</td>
</tr>
<tr>
<td></td>
<td>High penetration (%)</td>
<td>-2.73</td>
<td>-2.73</td>
</tr>
<tr>
<td>1s &lt; Time Headways &lt; 2s</td>
<td>Base case (%)</td>
<td>31.93</td>
<td>31.85</td>
</tr>
<tr>
<td>change (absolute)</td>
<td>Low penetration (%)</td>
<td>0.63</td>
<td>0.63</td>
</tr>
<tr>
<td></td>
<td>High penetration (%)</td>
<td>2.91</td>
<td>2.91</td>
</tr>
<tr>
<td>Time To Collision &lt; 1s</td>
<td>Base case (%)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>change (absolute)</td>
<td>Low penetration (%)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>High penetration (%)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1s &lt; Time To Collision &lt; 2s</td>
<td>Base case (%)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>change (absolute)</td>
<td>Low penetration (%)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>High penetration (%)</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Although FSR-equipped vehicles have a higher intended speed, the simulation results show a slight decrease in average speeds at the cross-section. This is the result of the aggregation of the effects for a day with varying volumes over time. At low volumes the average speeds are slightly higher with equipped vehicles and at higher volumes the speeds are slightly lower than without FSR vehicles, because FSR vehicles start braking for their predecessors slightly earlier (to maintain the minimum headway). In the weighted aggregation, the decrease mostly comes from the higher number of vehicles travelling at a very slightly lower speed. However, the effects are close to negligible at about 0.1%.

The time headways show a shift from below 1s towards the class of 1 s to 2s. This is the effect of the desired minimum headway of 1.3 s for the equipped vehicles – very relevant for the safety impact assessment. This effect becomes more pronounced as volume increases. For time-to-collision, in no simulation case critical situations with a TTC below 2 s could be found. This could be different in a case with more weaving like in the vicinity of an intersection.

The simulations are based on experiences with today’s systems (e.g. the Dutch FOT [Alkim et al., 2007]), but future systems may show improved system behaviour and have additional effects. Desk research was carried out to investigate whether FSR could, for instance, help prevent congestion. A faster reaction (from the system compared to the driver), could lead to a more “stable” traffic flow and possibly be beneficial for safety and throughput. This faster reaction
was not taken into account in the simulations (because the discussion about this was finalised too late in the project), but it means that an ACC system can control the speed and distance to the preceding vehicle more accurately than human drivers can. It is therefore expected that the system can compensate to some extent for the human behaviour that causes congestion. Drivers, for example, often brake harder than necessary or unintentionally change their speed due to distraction; this behaviour induces traffic jams in dense traffic.

With an ACC system, traffic can be more evenly spaced, with no risky headways. In theory, this could reduce the number of shockwaves and the average headways (as there are always headways larger than needed in current traffic) and increase road capacity. Various studies have been done on the effect of (cooperative) ACC on traffic flow, see [Driel, 2007] and [Arem, 2006]. Conclusions from these studies are that a low-penetration level of ACC (as we assume in eIMPACT) does not have much effect on traffic flow. With penetration levels of about 40%, gains in the density (10%) and throughput (15%) were found.

For determining the indirect effects, assumptions have been made with respect to division of avoided accidents over period of the day (morning peak, evening peak, night and rest of the day). The distribution over road types has also been taken into account. Assumptions were based on factors from the safety impact analysis. Assumptions for FSR are:

- The system is more effective in dark conditions, as the drivers’ estimation of headway is more difficult then.
- The system is more effective in busy traffic.
- Most avoidable accidents are on motorways.

With these assumptions, and the estimated safety effects, the indirect effects (avoided congestion costs in M EUR) are:

<table>
<thead>
<tr>
<th></th>
<th>2010</th>
<th>2020 low</th>
<th>2020 high</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>27</td>
<td>70</td>
</tr>
</tbody>
</table>

### 4.4 Traffic impacts of Emergency Braking (EBR)

No direct traffic effects are expected from the Emergency Braking (EBR) system, a fully automatic system that avoids or mitigates longitudinal crashes by braking only; the presence of the system does not influence choice of speed, following distance etc.

For determining the indirect effects, assumptions have been made based on factors from the safety impact analysis. These assumptions are:

- EBR is more effective in the dark.
- EBR is more effective on motorways and rural roads than on urban roads.
- EBR is very useful in high traffic densities, and therefore more effective during peak hours.

With these assumptions, the indirect effects (avoided congestion costs in M EUR) are:
4.5 Traffic impacts of Pre-Crash Protection of Vulnerable Road users (PCV)

The system Pre-Crash Safety of Vulnerable Road Users (PCV) detects vulnerable road users and enforces fully automatic emergency braking. No direct traffic effects are expected: the presence of the system does not influence choice of speed, following distance etc.

For determining the indirect effects, assumptions have been made based on factors from the safety impact analysis. These assumptions are:

- The system is far more effective on urban roads than on rural roads (since the probability of a collision with a pedestrian is largest in urban areas). The system is not effective on motorways.
- The system is more effective in dark conditions.
- The system is more effective at low traffic volumes.

With these assumptions, and the estimated safety effects, the indirect effects (avoided congestion costs in M EUR) are:

<table>
<thead>
<tr>
<th>Year</th>
<th>2020 low</th>
<th>2020 high</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>2020</td>
<td>21</td>
<td>53</td>
</tr>
</tbody>
</table>

4.6 Traffic impacts of Lane Change Assistant (Warning) LCA

No direct traffic effects are expected for Lane Change Assistant (Warning) (LCA), a system that gives warning for nearby vehicles in the back or next to the vehicle just before a lane change is started: the presence of the system does not influence choice of speed, following distance etc.

For determining the indirect effects, assumptions have been made based on the safety impact analysis. These assumptions are:

- The system will predominantly be used on motorways and rural roads. It is therefore far less effective on urban roads.
- Lighting conditions and traffic volume have no special effects on effectiveness.

With these assumptions, the indirect effects (avoided congestion costs in M EUR) are:

<table>
<thead>
<tr>
<th>Year</th>
<th>2010 low</th>
<th>2010 high</th>
<th>2020 low</th>
<th>2020 high</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>2</td>
<td>7</td>
<td>19</td>
<td>48</td>
</tr>
</tbody>
</table>

4.7 Traffic impacts of Lane Keeping Support (LKS)

No direct traffic effects are expected for Lane Keeping Support (LKS), which gives lane keeping assistance by active steering support: the
presence of the system does not influence choice of speed, following
distance etc.

For determining the indirect effects, assumptions have been made
based on factors from the safety impact analysis. These assumptions
are:

- The system is most effective on rural roads, followed by
  motorways. LKS is far less effective on urban roads.
- Lighting conditions and traffic volume have no special effects
  on effectiveness.

With these assumptions, and the estimated safety effects, the indirect
effects (avoided congestion costs in M EUR) are:

<table>
<thead>
<tr>
<th></th>
<th>2010 low</th>
<th>2010 high</th>
<th>2020 low</th>
<th>2020 high</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>8</td>
<td>21</td>
<td>28</td>
<td>96</td>
</tr>
</tbody>
</table>

### 4.8 Traffic impacts of NightVisionWarn (NIW)

NightVisionWarn (NIW) aims at conditions with reduced visibility,
mostly darkness. The system enhances vision at night through near
or far infrared sensors, and includes obstacle warning. In the traffic
simulations, the system’s impact was simulated by assuming an
increased maximum distance for driver reaction. This, of course,
yields effects that seem to be traffic effects, e.g. by changed headway
distributions or changes in the speed-flow relationship. However, it
must be noted that the system is designed to help drivers avoid
critical situations with other road users or obstacles. These are most
likely to occur in low traffic densities – in higher densities, visibility
would be better through other vehicles’ lights (or there would be
street lights). Therefore, while the system will influence the behaviour
of individual vehicles, direct traffic effects on traffic flows (in terms of
travel times and average speeds) do not arise from NightVisionWarn.
A traffic effect through an improved interaction between vehicles, like
with Full Speed Range ACC, does not arise from NIW; any change in
traffic dynamics leading to a higher capacity can be safely excluded.

For the traffic simulations no changes in desired speeds were
assumed. In situations for which NIW is designed, low traffic density,
a change in travel times consequently does not arise. If, however, the
desired speeds are higher for equipped vehicles, a travel time
decrease and thus a positive direct effect could arise. Such an
increase in speed was, in fact, assumed in the safety impact analysis.
However, at the estimated penetration rates, only a small share of all
traffic experiences shorter travel times, and only for a small share of
their km’s travelled (as the system only works in the dark and
predominantly on quiet roads). Therefore, the effects on the EU level
will be negligible.

For determining the indirect effects, assumptions have been made
based on factors from the safety impact analysis. These assumptions
are:

- NightVisionWarn is most effective on rural roads, followed by
  motorways. The system is generally not needed on urban
  roads.
- The system only works when it is dark.
• The system is most effective in low traffic densities.

With these assumptions, and the estimated safety effects, the indirect effects (avoided congestion costs in M EUR) are:

<table>
<thead>
<tr>
<th>Year</th>
<th>2010 low</th>
<th>2010 high</th>
<th>2020 low</th>
<th>2020 high</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>3</td>
<td>7</td>
<td></td>
</tr>
</tbody>
</table>

### 4.9 Traffic impacts of Driver Drowsiness Monitoring and Warning (DDM)

No direct traffic effects are expected for Driver Drowsiness Monitoring and Warning (DDM), which gives drivers a warning when they are about to fall asleep: the presence of the system does not influence choice of speed, following distance etc.

For determining the indirect effects, assumptions have been made based on factors from the safety impact analysis. These assumptions are:

• The system is far more effective in evening and night period.
• The system is more effective on motorways and rural roads than on urban.

With these assumptions, and the estimated safety effects, the indirect effects (avoided congestion costs in M EUR) are:

<table>
<thead>
<tr>
<th>Year</th>
<th>2010 low</th>
<th>2010 high</th>
<th>2020 low</th>
<th>2020 high</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>8</td>
<td></td>
</tr>
</tbody>
</table>

### 4.10 Traffic impacts of eCall (one-way communication) (ECA)

No direct traffic effects are expected for eCall: the presence of the system, which provides an automatic emergency call for help in case of an accident, does not influence choice of speed, following distance etc.

For determining the indirect effects, assumptions have been made based on factors from the safety impact analysis. These assumptions are:

• On rural roads there is less traffic and therefore it is more probable that accidents happen without eyewitnesses. Furthermore, it will take more time before a third party will come to the accident site. Therefore, the system is most effective on rural roads, less effective on motorways and hardly effective on urban roads.
• eCall is more effective at low traffic volumes and in the dark (when accidents are more likely to go unnoticed), so it is effective for reaching accidents more quickly in the night and during off-peak hours.

With these assumptions, and the estimated safety effects, the indirect effects (avoided congestion costs in M EUR) are:

<table>
<thead>
<tr>
<th>Year</th>
<th>2020 low</th>
<th>2020 high</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>5</td>
<td>7</td>
</tr>
</tbody>
</table>
4.11 Traffic impacts of Intersection Safety (INS)

The traffic effects were analysed for the three Intersection Safety subsystems, which all aim to assist the driver in avoiding common mistakes which may lead to typical intersection accidents: Traffic light assistance (giving a warning when the driver appears to ignore a red light); Right-of-way assistance (warning the driver if he seems to violate a right-of-way, but also if somebody else is expected not to give the right-of-way to the case vehicle); and Left turn assistance (warning the driver about unsafe gaps in left turns).

The red-light running function was not simulated, because the assumptions for the number of red-light running vehicles and the number of avoidings would directly provide the result. Micro-simulation models of traffic generally do not model 'exceptional' situations, which red-light running is considered to be. Hence, the simulations do not include any explicit or implicit information on red-light running and there is not enough information available about how often red light running occurs to be able to implement that behaviour in the model (although there is information about how often it plays a role in accidents, see the safety impact analysis). Also, it is unknown what the consequences are for interactions of the vehicle violating the red light with other vehicles on the intersection.

The other two functionalities are very similar in the sense that they both tackle the problem of gap-acceptance; one in the situation of crossing a prioritized stream, the other in merging into a prioritized stream. Due to this similarity only the case of crossing an on-coming vehicle stream was simulated.

The results from the simulations did not show any significant changes. Given the very low penetration rates (less than 1%), this was not unexpected. However, even when (much) higher penetration rates were modelled, no significant changes were found. An explanation for this lies in the fact that the gaps in a discharging queue (the on-coming stream) are generally too small to be accepted by a left-turning vehicle, whether equipped or not. The first possibility is the gap after the queue has passed. This gap is generally large enough even for unequipped vehicles. Furthermore, the travel times as direct traffic effects will hardly be influenced on the network level (or an individual journey) by accepting or rejecting one individual gap.

It can be concluded that Intersection Safety does not lead to changes in traffic flow. Possible decreases in discharge rate do not occur at these low penetration rates (possible increases, due to cautious drivers accepting smaller gaps with the system, are not expected either). It can further be expected that situations in which the capacity of turning relations play a major role, appropriate infrastructure measures, like separated turning streams, are provided. Traffic effects in terms of changes in travel time and similar are therefore be expected from Intersection Safety.

For determining the indirect effects, assumptions have been made based on factors from the safety impact analysis. These assumptions are:

- Intersection Safety is more effective in off-peak hours (especially for the left-turn function), since the likelihood of a preceding vehicle is lower and drivers may have a lower
attention level if the traffic volumes are low; hence the accident probability at intersections is higher then.

- Lighting conditions have no special effects on effectiveness.
- The system is not effective on motorways.

With these assumptions and the estimated safety effects, the indirect effects (avoided congestion costs in M EUR) are:

<table>
<thead>
<tr>
<th>Year</th>
<th>2020 low</th>
<th>2020 high</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>2020</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

### 4.12 Traffic impacts of Wireless Local Danger Warning (WLD)

The analysis of Wireless Local Danger Warning (WLD) was partly based on the PReVENT-system elaborated in the subproject WILLWARN. Additional analysis was carried out to analyse the system’s effect at the penetration rates estimated in eIMPACT. Two functions were analysed: warnings for stopped vehicles (obstacles), and warnings for reduced friction and poor visibility.

The effect of Wireless Local Danger Warning depends on several things:

- The warning messages have to be generated successfully in relevant situations.
- The messages have to arrive at the equipped vehicles. This requires a certain density of equipped vehicles.
- The drivers of the equipped vehicles receiving the messages have to react in an appropriate way.

**Message generation**

In eIMPACT, we assume that the messages (for accidents, obstacles, reduced friction and bad visibility) are generated successfully.

**Message spreading**

The combination of speed, vehicle density, penetration rate and network characteristics determines the effectiveness of communication and thus the system. Calculations making use of typical densities, road geometry, network layout and the desired message validity time (i.e. the time until the warning message expires) reveal that urban situations, where vehicle density is high and the road network is dense, need only a low penetration rate (5%) to be effective. At this rate, over 90% of all equipped vehicles in the target area will receive a warning message in time [BMW, 2006], [Noecker et al., 2007].

Rural roads are often isolated from other roads and have a very low vehicle density. At such roads the penetration rate may be a bottleneck. At a penetration rate of 5%, typically 50-80% of all equipped vehicles will be warned in time. At 10% penetration, typically 85-95% of all equipped vehicles will be warned in time (source: working paper). On motorways, which have a high vehicle density and high speeds, very low penetration rates (well below 5%) suffice to warn all vehicles.

**The driver reaction**
The driver reaction to WILLWARN has been investigated in a driving simulator study by Daimler [Vollmer at al., 2007]. The study considered two hazard scenarios (fog on motorway, and an obstacle behind a curve on a rural road) and showed that the system influences braking behaviour: equipped drivers typically choose a moment before the hazard area to slow down. Unequipped drivers slow down in the hazard area. Hard braking occurs significantly more for unequipped than for equipped drivers. There is no significant speed difference after the deceleration phase.

**Direct traffic effects**

As indicated in the previous sections, even at low penetration rates, effective communication is possible. This means that equipped vehicles are warned and can (and are likely to) take action. This has direct safety effects, but not necessarily noticeable direct traffic effects at the EU-25 level.

The effect of the system is that drivers react a few seconds earlier to certain types of hazards like fog or obstacles. The driving simulator tests found no change in driving behaviour outside the hazard area. A traffic simulation study shows that, for 10% equipped vehicles, the total time delay near the hazard increases by 5-20%, depending on traffic density and the hazard scenario. At 100% penetration rate, this delay would increase by 20-80% [Malone et al., 2007]. At higher penetration rates, equipped vehicles slowing down may also influence other vehicles following them, thus inducing a positive safety effect for nonusers. However, at low penetration rates, those ‘rare’ equipped vehicles that are warned may brake hard and unexpected for following vehicles (resulting in a possible negative safety effect at low penetration rates for nonusers).

With the WLD specifications used in eIMPACT, it is assumed that warnings will arrive approximately 10 seconds before the hazard (corresponding to 200-500 meters), which means that, certainly in combination with the expected low penetration rates, no significant rerouting effects are expected.

Combined with the knowledge that the hazards that WLD warns for are rare, and only cause early braking at the hazard location, we conclude that the effect on the total travel time is negligible and thus that at the expected 2010 and 2020 penetration rates, no direct traffic effects are expected.

**Indirect traffic effects**

For determining the indirect effects, assumptions have been made based on factors from the safety impact analysis. These assumptions are:

- WLD is most effective on rural roads.
- WLD is more effective when it is dark, but only when the traffic density is high enough. The system is most effective during peak hours, because of communication efficiency.

With these assumptions, and the estimated safety effects, the indirect effects (avoided congestion costs in M EUR) are:

<table>
<thead>
<tr>
<th>Year</th>
<th>2010</th>
<th>2020 low</th>
<th>2020 high</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Deliverable D4
Version 2.0
56
4.13 Traffic impacts of SpeedAlert (SPE)

SpeedAlert, which is a map and camera based warning system that alerts the driver when the speed limit is exceeded, by use of haptic gas pedal and warning module, was modelled in a network of the Eindhoven (NL) region, comprising all road types (motorways, rural roads, urban roads). Penetration rates for 2010 were low. Therefore, simulations were only carried out for the 2020 scenarios.

The SpeedAlert system was modelled by changing the intended speed of drivers of vehicles equipped with the system. This meant in general that they would drive less often at speeds over the speed limit. Another effect of SpeedAlert can be that cautious drivers are more confident to drive at speeds close to the speed limit. Both effects together are reflected in a narrower distribution of the intended speeds in the runs with SpeedAlert equipped vehicles: more vehicles drive between 10 km/h under the speed limit and the speed limit, fewer vehicles exceed the speed limit and fewer vehicles drive more than 20 km/h under the speed limit.

The main conclusions from the simulations and an additional investigation into speed- and speeding data for different European countries are:

- Overall, the SpeedAlert system performs as expected in the simulations, given the assumptions that were made. Effects found on cross-sections are clear: lower speed and lower standard deviation of speeds, on urban and rural roads. On motorways, however, speeds were not reduced, see the explanation below. The number of vehicles exceeding the speed limit in the 2020 high scenario was reduced by 12% (urban roads) to 43% (motorways).

- Travel time effects on the network level are very small for rural roads and negligible for urban roads and motorways. At higher traffic densities, travel time effects cannot be expected; in that case, other traffic determines the speeds, not the SpeedAlert system.

- On urban roads, the network effects are negligible because delays at intersections are responsible for a relatively large part of the travel times.

- On rural roads, a decrease in speeds and a slight increase in travel times on the network level is more likely, because there are fewer intersections and traffic volumes are usually low. Also, speeding is not uncommon on rural roads [ICF Consulting, 2003] [Ellinghaus, 2000] [André, 1999]. SpeedAlert is more effective in low traffic volumes. At high traffic volumes, speeds are reduced mainly because of interactions with other vehicles.

- On motorways, the network effects depend very much on the speeds found in the reference case (much speeding vs. little speeding). In the simulations, based on Dutch data, initial speeds on the motorways were not very high and there was little speeding. Because of the assumed effect of some people
driving a little faster, closer to the speed limit, this meant a small increase in speeds and therefore a decrease in travel times. However, in the literature there were as many examples of motorways with relatively low speeds as examples of motorways where speeding is common [ICF Consulting, 2003] [Ellinghaus, 2000] [André, 1999]. Therefore, even though small effects were found in the eIMPACT simulations, we conclude that the overall travel time effects on the EU level are negligible.

- There were no substantial, consistent effects in surrogate safety measures, such as time to collision and time headways. Locally, very small shifts of headways were found: less<1s, more 1s<headways<2s can be found. A substantial shift can be found in the high penetration scenario for rural roads. This implies a reduction in potentially dangerous following situations, and is probably the result of SpeedAlert equipped vehicles approaching their slower predecessors at lower speeds than without the system. This effect also occurs, to a lesser extent, on motorways, but not on urban roads.

Table 12 gives an overview of the results of the simulations, for a selection of links, for situations with low and high demand.

Table 12: Overview of direct effects (cross-section measurements) for SpeedAlert in 2020.

<table>
<thead>
<tr>
<th></th>
<th>Motorways</th>
<th>Motorways</th>
<th>Rural roads</th>
<th>Rural roads</th>
<th>Urban roads</th>
<th>Urban roads</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low demand</td>
<td>High demand</td>
<td>Low demand</td>
<td>High demand</td>
<td>Low demand</td>
<td>High demand</td>
</tr>
<tr>
<td>Average speed change (%)</td>
<td>88.7</td>
<td>83.5</td>
<td>75.0</td>
<td>74.4</td>
<td>49.9</td>
<td>49.9</td>
</tr>
<tr>
<td></td>
<td>+0.8%</td>
<td>+0.5%</td>
<td>-0.5%</td>
<td>-0.9%</td>
<td>-1.1%</td>
<td>-1.2%</td>
</tr>
<tr>
<td></td>
<td>+1.1%</td>
<td>+0.6%</td>
<td>-1.0%</td>
<td>-0.9%</td>
<td>-1.4%</td>
<td>-1.7%</td>
</tr>
<tr>
<td>Standard deviation speed change (absolute)</td>
<td>11.7</td>
<td>12.2</td>
<td>6.8</td>
<td>28.0</td>
<td>6.0</td>
<td>16.5</td>
</tr>
<tr>
<td></td>
<td>-0.2</td>
<td>+0.8</td>
<td>-0.3</td>
<td>-2.6</td>
<td>0</td>
<td>+2.8</td>
</tr>
<tr>
<td></td>
<td>-0.4</td>
<td>+1.0</td>
<td>-0.1</td>
<td>+4.5</td>
<td>-0.2</td>
<td>+1.1</td>
</tr>
<tr>
<td>Time Headways &lt; 1s change (absolute)</td>
<td>36.3</td>
<td>55.5</td>
<td>16.0</td>
<td>24.0</td>
<td>9.1</td>
<td>21.6</td>
</tr>
<tr>
<td></td>
<td>-0.8</td>
<td>-0.4</td>
<td>+0.3</td>
<td>+0.5</td>
<td>+1</td>
<td>+0.4</td>
</tr>
<tr>
<td></td>
<td>-1.5</td>
<td>-0.6</td>
<td>-0.7</td>
<td>-3.8</td>
<td>+1</td>
<td>+0.5</td>
</tr>
<tr>
<td>1s &lt; Time Headways &lt; 2s change (absolute)</td>
<td>7.9</td>
<td>10.5</td>
<td>12.5</td>
<td>18.9</td>
<td>4.9</td>
<td>11.7</td>
</tr>
<tr>
<td></td>
<td>+0.1</td>
<td>+0.2</td>
<td>-0.1</td>
<td>+0.9</td>
<td>+0.2</td>
<td>-0.1</td>
</tr>
<tr>
<td></td>
<td>+0.2</td>
<td>+0.6</td>
<td>-0.1</td>
<td>+2.9</td>
<td>+0.2</td>
<td>+0.2</td>
</tr>
<tr>
<td>Time To Collision &lt; 1s change (absolute)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1.2</td>
<td>0</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>-0.2</td>
<td>0</td>
<td>+0.2</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>+0.4</td>
<td>0</td>
<td>+0.1</td>
</tr>
<tr>
<td>1s &lt; Time To Collision &lt; 2s change (absolute)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2.0</td>
<td>0</td>
<td>0.7</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>-0.4</td>
<td>0</td>
<td>+0.4</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>+0.7</td>
<td>0</td>
<td>+0.2</td>
</tr>
</tbody>
</table>
For determining the indirect effects, assumptions have been made based on factors from the safety impact analysis. These assumptions are:

- SpeedAlert is most effective on urban roads, followed by rural roads. It is least effective on motorways.
- More accidents are avoided with SpeedAlert in the non-peak hours (night, rest of the day), because of low traffic volumes making it possible to drive fast.

With these assumptions, and the estimated safety effects, the indirect effects (avoided congestion costs in M EUR) are:

<table>
<thead>
<tr>
<th></th>
<th>2010 low</th>
<th>2010 high</th>
<th>2020 low</th>
<th>2020 high</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010 low</td>
<td>6</td>
<td>9</td>
<td>66</td>
<td>94</td>
</tr>
</tbody>
</table>
5 Results of the safety impact assessment

This chapter contains a summary of road safety impacts for the safety functions studied. First, the overview in 5.1 sums up the safety impacts, allowing comparison between the systems. In sections 5.2–5.13 the more detailed safety impact analysis (assumptions, descriptions of mechanisms and results) are presented for each system. The presentation of the results in sections 5.2-5.13 follows the flow chart presented in Figure 11. More detailed calculations and motivations are presented in the technical report of WP3300 [Kulmala et al., 2008], an internal deliverable of eIMPACT.

5.1 Overview of safety impacts

Figure 22 and Figure 23 show the safety impacts (fatalities and injuries, respectively) in the four scenarios for each selected system. The variation between the impacts of the systems studied was large: in the high penetration scenario for 2020 the estimated reduction in fatalities ranged from 7 to about 3,250 avoided fatalities.

![Safety effect on fatalities by system and penetration rate](image)

Figure 22: The effect of the 12 systems on fatalities in 2010 and 2020.
Figure 23: The effect of the 12 systems on injuries in 2010 and 2020.

Figure 22 and Figure 23 show small effects for many of the 12 systems. One main reason for this is the low penetration rates for many systems. Nevertheless, for fatalities Electronic Stability Control (ESC), SpeedAlert (SPE) and eCall (ECA) show significant effects, especially in 2020. Lane Keeping Support (LKS) also scores well in the high penetration scenario.

The effects on injuries (in % changes) are smaller than the effects on fatalities for ESC and for Lane Keeping Support, and a small increase in the number of injuries was found for eCall. For SpeedAlert, the effects on injuries are in the same order of magnitude as the effects on fatalities.

The effect estimates indicated in terms of percent changes were applied to EU-25 accident data, giving the absolute numbers of avoided fatalities and injuries for the four scenarios (see Figure 24 and Figure 25). For instance, ESC, in the assumed high penetration in 2020, would contribute to avoiding about 2900 fatalities and 50,000 injuries.

The effect in absolute numbers of avoided fatalities and injuries depends on the assumed accident trend for the years 2010 and 2020. The accident trend for the years 2010 and 2020 assumed a very positive development even without any IVSS. Consequently, the systems will then target a smaller group of accidents and the effects, in numbers of saved injury accidents, injuries and fatalities, are less than might have been expected for systems with significant penetration rates in the year 2020. The figures presented here are, however, the ones to be used to determine monetary values in the cost-benefit analysis. This is quite critical for the results of eIMPACT’s benefit cost analyses.
Safety effect on fatalities by system and penetration rate

Figure 24: The change in the number of fatalities for the 12 systems in 2010 and 2020 (a minus indicates a decrease, i.e. avoided fatalities).

Safety effect on injuries by system and penetration rate

Figure 25: The change in the number of injuries for the 12 systems in 2010 and 2020 (a minus indicates a decrease, i.e. avoided injuries).
Several factors affected the magnitude of the safety impact estimates. The three main factors affecting the ranking of the systems are:

- The assessed effectiveness of the IVSS to prevent targeted injury accidents, fatalities and injuries.
- The share of relevant accidents in the EU-25 data.
- The assumed fleet penetration of the system.

The 12 selected systems varied in how the reductions in fatalities and injuries were achieved. Common to SpeedAlert and ESC, the most effective systems, is that both systems target several accident types in the accident data with significant shares of all accidents. In addition, the effectiveness to prevent target accidents was estimated to be good and fleet penetrations in 2020 were estimated to be significant.

Lane Keeping Support was assessed to be very effective, but the target group of accidents is smaller than for SpeedAlert and ESC, and the assumed fleet penetration was quite small. For eCall, considerable fleet penetration was assumed but the system’s potential to improve safety is quite limited; the system is relevant only to mitigate the consequences of a crash for selected collision types.

Emergency Braking did not show good effects in 2020, but this was mainly due to the low penetration. The system was assumed to have quite a good potential to improve road safety.

Night Vision Warning and Driver Drowsiness Monitoring and Warning have quite similar effects: both systems focus on a significant group of accidents, but the systems’ effectiveness to prevent these accidents is estimated as limited. Intersection Safety was assessed to be somewhat more effective but the target accident group of fatalities is relatively small in the EU-25 data, and therefore the system results in only a small number of avoided fatalities.

For many systems the target year 2020 may be too early to reach any significant penetration rates and thus safety benefits. Examples of these are Intersection Safety, Wireless Local Danger Warning, Full Speed Range ACC, Pre-Crash Protection of Vulnerable Road Users and Lane Change Assistance. In addition, the target accident groups (fatalities and injuries) for these systems are quite small; very small for Lane Change Assistance and Full Speed Range ACC.

The estimated penetration rates may be boosted by future policy measures. It would be the most interesting to do this for IVSS with a high potential. Figure 26 and Figure 27 show the potential for all 12 selected IVSS to improve road safety at full (100%) penetration. According to the estimates, ESC and Lane Keeping Support (LKS) would be the most powerful in preventing fatalities, showing decreases of nearly 17% and 15% respectively. The effects of SpeedAlert (SPE), Emergency Braking (EBR), eCall (ECA), and Driver Drowsiness Monitoring and Warning (DDM) would vary between 5% and 9%.

5 a possible situation, in an unspecified, future year – which will be different for each system.
Lane Keeping Support is the most powerful system in preventing injuries (-9%). Intersection Safety (INS) and Emergency Braking come next (-7%).

**Figure 26**: The effect of the 12 systems on fatalities in full penetration. SpeedAlert has two versions: SPE1 is for fixed speed limits, SPE2 is dynamic and takes into consideration variable speed limits.

**Figure 27**: The effect of the 12 systems on injuries in full penetration. SpeedAlert has two versions: SPE1 is for fixed speed limits, SPE2 is dynamic and takes into consideration variable speed limits.

As indicated in the methodology description in chapter 2, the data structure with three clusters allows regional discussions of the results. For most of the systems, the effect estimates for the three clusters did not differ from each other; the variation was between 1-2 percentage
points. Lane Keeping Support and Intersection Safety system are the exception to the rule. Both systems would be more effective (by 9 to 5%, respectively) to prevent fatalities in Cluster 1 countries—the northern and central European countries—than in other parts of Europe, due to the distribution of the target accidents. For Intersection Safety this concerns also the prevention of injuries.

Note that the safety effects of the twelve systems shown in Figures 22-27 cannot be added up, because each of the assessments assumed that no other systems would be deployed at the same time. If systems would be bundled in a single vehicle, the total effect is not the sum of the effects of the individual systems. For instance, Electronic Stability Control and Lane Keeping Support affect the same types of accidents. If all cars already had Electronic Stability Control, the accident effect of Lane Keeping Support would be much smaller than indicated in the Figures above (or vice versa).

5.2 Safety impacts of Electronic Stability Control (ESC)

The relevant safety mechanisms of Electronic Stability Control (ESC) are described below.

Mechanism 1: Direct in-car modification of the driving task

ESC stabilises the vehicle within the physical limits and prevents skidding through active brake intervention and engine torque control. The driver's ability to control the movements of the vehicle is significantly improved as the driver maintains the control of the vehicle also in cases where the control would have been lost without the system. Collision speed will in many cases be lower than without ESC. As a consequence, the collision impacts will be reduced.

Based on the literature, Loss-of-control accidents are assumed to be most ESC-sensitive. In Tingvall et al [2005] these are defined as single, overtaking and oncoming accidents. Different studies [National Agency for Automotive Safety & Victims' Aid, 2005][Aga & Okada, 2003][Langwieder, 2005][Thomas, 2006][Page & Cuny, 2006] investigate different kinds of accidents and do not give numbers for all accidents. 40-80% of single accidents and 25-50% of all accidents are supposed to be ESC-sensitive. The higher figures apply to adverse road conditions. Japanese data [National Agency for Automotive Safety & Victims’ Aid, 2005] indicate a factor of 1.5 (50% higher effectiveness in accident prevention) for single vehicle accidents compared to frontal collisions. UK data [Thomas, 2006] indicate a factor of 0.7 for lateral compared to frontal collisions.

A comparative analysis of the Swedish [Tingvall et al., 2005], German [Sferco et al, 2001], [Grömping et al, 2004][Langwieder, 2005] and UK [Thomas, 2007] studies resulted in a probable direct effect on all injury accidents in these countries of around 12%. As more recent studies show somewhat lower values than the earlier studies, the average figure has been slightly adjusted downwards. The resulting estimates for the individual collision types in Table 13 have been used in the calculations for the EU-25.

Many but not all studies indicate higher figures for fatalities than for injury accidents. As the forces causing the accidents (relative velocity and direction) are reduced with ESC it can be assumed that the...
Nilsson power model [Nilsson 2004] can be used. An additional reduction of fatalities of 9% is assumed. These are fatalities that will be turned into severe and light injuries.

For mechanism 1, the effects on fatalities and injuries were estimated for the collision types distinguished in the EU-25 accident data (Table 13).

Table 13: Effect estimates of mechanism 1 on different accident categories.

<table>
<thead>
<tr>
<th>ESC</th>
<th>Mechanism 1</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fatalities</td>
</tr>
<tr>
<td>Collision on the road with pedestrian</td>
<td>-25.0 %</td>
</tr>
<tr>
<td>Collision on the road with all other obstacles</td>
<td>-25.0 %</td>
</tr>
<tr>
<td>Collision besides the road with pedestrian or obstacle or other single vehicle accidents</td>
<td>-35.0 %</td>
</tr>
<tr>
<td>Frontal collision</td>
<td>-20.0 %</td>
</tr>
<tr>
<td>Side-by-side collision</td>
<td>0.0 %</td>
</tr>
<tr>
<td>Angle collision</td>
<td>-12.5 %</td>
</tr>
<tr>
<td>Rear collision</td>
<td>0.0 %</td>
</tr>
<tr>
<td>Other accidents with two vehicles</td>
<td>-12.5 %</td>
</tr>
</tbody>
</table>

The synthesis between different studies also resulted in a probable effect for Loss of control-accidents in dry conditions of 22%, in wet conditions of 42% and in slippery conditions (snow, ice) of 56%. This information is used to set a value of 2:1 for the effectiveness in adverse conditions compared to normal conditions.

Applied to the shares of target collisions (see distribution of collisions in Table 8), for mechanism 1 this means a reduction of approximately 19% (the first bar in Figure 28) in fatalities (8% for injuries).

Mechanism 3: Indirect modification of user behaviour

- Drivers with ESC may in the long run use slightly higher speeds relying on ESC to maintain the controllability of the vehicle in any case. A few drivers may drive more recklessly than before. These forms of behavioural adaptation will probably be strongest in adverse road and weather conditions.

A long-run effect has not yet been proven, but is probable. It is assumed that the average speed is increased by 2 km/h in adverse road conditions. The resulting effect is an increase in fatalities of 2.5% and in injuries of 1.5%.

Mechanism 4: Indirect modification of non-user behaviour, and Mechanism 6-8: Modification of road user exposure, modal choice and route choice

- Small negative effects are also expected in Mechanism 4 and Mechanisms 6-8. Some non-ESC equipped drivers may copy higher speeds of ESC drivers. Some drivers may drive slightly more in adverse road conditions and on lower level roads, relying on ESC.

The expected percentage changes shown above for each mechanisms were multiplied with the relevant accident data proportions in EU-25 data. The estimates for this system were based
on collision type (see Table 8). Figure 28 shows the effects of all relevant mechanisms and the total effect for 100% fleet penetration.

![Figure 28: ESC's effect on fatalities with 100% fleet penetration (veh km). The total effect of all relevant mechanisms is indicated in green.](image)

Finally, the full penetration estimates were applied to the fleet penetrations estimated for the target years 2010 and 2020 (Table 14). The table also shows the range of estimates for full penetration.

<table>
<thead>
<tr>
<th>Table 14: The effect of ESC on fatalities and injuries for full penetration and four scenarios. For full penetration, the range (low/high) is given. (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ESC</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Impact most probable1</td>
</tr>
<tr>
<td>Impact low1</td>
</tr>
<tr>
<td>Impact high1</td>
</tr>
<tr>
<td>Impact 2010 low</td>
</tr>
<tr>
<td>Impact 2010 high</td>
</tr>
<tr>
<td>Impact 2020 low</td>
</tr>
<tr>
<td>Impact 2020 high</td>
</tr>
</tbody>
</table>

1 These figures represent the expected impact if all vehicles were equipped, regardless of the year.

2 Fleet vehicle km equipped

The high estimate for the year 2020 would mean 3,253 avoided fatalities and 52,182 avoided injuries. N.B. For ESC, the accident base used is larger than for the other systems.

### 5.3 Safety impacts of Full Speed Range ACC (FSR)

The relevant safety mechanisms of Full Speed Range ACC (FSR) are described below.

**Mechanism 1: Direct in-car modification of the driving task**

+ Full Speed Range ACC (FSR) maintains a constant safe distance to the vehicle in front, automatically reduces speed if the vehicle in front slows down. Reaction will be faster as the brake control is
automatic up to a certain level of braking. The system will contribute to a reduction in the exposure of very small time-gaps and time-to-collision events during car following processes.

+ In case of unexpected obstacles or lack of attention, the system starts braking automatically. Therefore the collision speed would be lower than without the system and the collision impacts will be reduced.

According to the Dutch FOT of ACC [Alkim et al, 2006] ACC was used 50% of the time during free flow conditions, 35% in heavy traffic and 8% during congestion. The extension from ACC to FSR ACC will increase the use of ACC, but we do not know how much. It is here assumed that FSR is used 80% of the situations where rear-end accidents are frequent. That means that FSR also is used extensively on most urban arterials.

In the Dutch FOT of ACC, dangerous headways below 0.7 seconds decreased with 70% during free flow conditions, 50% in heavy traffic and 30% during congestion. Average achieved minimum headway was increased 0.2 sec with ACC in busy traffic. We assume that these results also are valid for FSR. These figures can be compared to the results in the Traffic Impact Analysis (Table 15). 11% penetration results in a 13% drop of small headways below 1 sec. They seem to be in line with each other.

Based on these indicative results, it is estimated that a 45% reduction of rear-end fatalities is possible (Table 15).

Table 15: Effect estimates of mechanism 1 on different accident categories.

<table>
<thead>
<tr>
<th>FSR</th>
<th>Mechanism 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collision on the road with pedestrian</td>
<td>0.0 %   0.0 %</td>
</tr>
<tr>
<td>Collision on the road with all other obstacles</td>
<td>0.0 %   0.0 %</td>
</tr>
<tr>
<td>Collision besides the road with pedestrian or obstacle or other single vehicle accidents</td>
<td>0.0 %  0.0 %</td>
</tr>
<tr>
<td>Frontal collision</td>
<td>0.0 %   0.0 %</td>
</tr>
<tr>
<td>Side-by-side collision</td>
<td>0.0 %   0.0 %</td>
</tr>
<tr>
<td>Angle collision</td>
<td>0.0 %   0.0 %</td>
</tr>
<tr>
<td>Rear collision</td>
<td>-45.0 % -30.0 %</td>
</tr>
<tr>
<td>Other accidents with two vehicles</td>
<td>0.0 %   0.0 %</td>
</tr>
</tbody>
</table>

Applied to the shares of target collisions, for mechanism 1 this means a reduction of approximately 2% in fatalities (4% for injuries).

**Mechanism 3: Indirect modification of user behaviour**

- There are potential negative effects on safety in the long run: Drivers start trusting the system too much and less attention is paid to other traffic. Drivers may be more inclined to perform secondary tasks, although mostly in free-flow conditions. As long as a SpeedAlert function is not integrated in FSR, it is probable that the desired speed will be slightly higher with FSR.

- It is assumed that drivers with FSR will have a 2 km/h higher desired speed than non-FSR drivers [Koziol et al., 1999]. According to the traffic simulation a speed difference remains in
free-flow and busy traffic conditions up to 5000 veh/h on motorways. It is estimated that the overall effect on all roads will be an increase in fatalities of 1.0% and in injuries of 0.5%.

**Mechanism 8: Modification of route choice**

- Potential positive effects on safety in the long run: FSR makes motorways more appealing. There is a tendency that motorways are used more and provincial roads less with ACC in the Dutch study.

It is assumed that motorways are used 1% more and provincial roads less for vehicles equipped with FSR ACC.

The expected percentage changes shown above were multiplied with the relevant accident data proportions in EU-25 data. The main effect estimates for this system were based on collision type (see Table 8). Figure 29 shows the effects of all relevant mechanisms and the total effect for 100% fleet penetration.

**Figure 29: FSR’s effect on fatalities with 100% fleet penetration (veh km). The total effect of all relevant mechanisms is indicated in green.**

Finally, the full penetration estimates were applied to the fleet penetrations estimated for the target years 2010 and 2020 (Table 16). The table also shows the range of estimates for full penetration.

**Table 16: The effect of FSR on fatalities and injuries for full penetration and four scenarios. For full penetration, the range (low/high) is given.**

<table>
<thead>
<tr>
<th>FSR</th>
<th>Penetration rate for light/heavy vehicles (%)</th>
<th>Reduction in</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Fatalities (%)</td>
</tr>
<tr>
<td>Impact most probable</td>
<td>100 / 100</td>
<td>-1.4</td>
</tr>
<tr>
<td>Impact low</td>
<td>100 / 100</td>
<td>-0.3</td>
</tr>
<tr>
<td>Impact high</td>
<td>100 / 100</td>
<td>-3.0</td>
</tr>
<tr>
<td>Impact 2010 low</td>
<td>0.01 / 0.01</td>
<td>0.0</td>
</tr>
<tr>
<td>Impact 2010 high</td>
<td>0.01 / 0.01</td>
<td>0.0</td>
</tr>
<tr>
<td>Impact 2020 low</td>
<td>4 / 15</td>
<td>-0.2</td>
</tr>
<tr>
<td>Impact 2020 high</td>
<td>13 / 25</td>
<td>-0.5</td>
</tr>
</tbody>
</table>

1 These figures represent the expected impact if all vehicles were equipped, regardless of the year.
2 Fleet vehicle km equipped
The high estimate for the year 2020 would mean 101 avoided fatalities and 9,774 avoided injuries.

5.4 Safety impacts of Emergency Braking (EBR)

Emergency Braking (EBR) uses several functions to assist the driver to avoid or mitigate longitudinal crashes: Predictive Brake Assist, Predictive Collision Warning and Predictive Emergency Braking. The relevant safety mechanisms of Emergency Braking are described below.

Mechanism 1: Direct in-car modification of the driving task

- In case of a detected critical rear end collision situation, the Predictive Brake Assist (PBA) automatically pre-fills the brake system. Additionally the brake assist function is highly sensitive - making braking faster and stronger. Reaction will be twice as fast as during normal braking.
- Predictive Collision Warning (PCW) gives the driver a noticeable activation of brakes (optional with additional HMI) to warn the driver and lead his/her attention to the critical situation.
- Predictive Emergency Braking (PEB) automatically fully activates brakes if the accident is unavoidable.
- EBR reduces impact speed in case of immediate danger, which increases passive safety and reduces accident consequences.

EBR mitigates the equipped vehicle’s accident consequences in longitudinal accident situations. Fully addressed are rear-end-collisions between two vehicles and collision against fixed obstacles. Mitigation is greater for medium than for higher speeds. Studies on Brake Assist Systems indicate that the number of fatalities and injuries directly saved in EBR pertinent collisions may be in the same magnitude.

70% of drivers do not brake at all or do not reach full braking (7 m/s²) according to Page et al [2005]. Brake activation time is reduced from 0.7 sec to 0.35 sec with EBR. EBR works partially in lateral cases but the system is not designed to work there. Additionally addressed are about 15% of collisions as front to side junction and non-junction collisions between two cars.

The possibility of the radar system to detect imminent crashes is best for moving objects, which addresses rear-end-accidents. Accidents with fixed objects are also addressed, but detection is more difficult as the system has to distinguish more accurately between vehicles and other objects (if they are static). On the other hand, it can be assumed that the awareness of the driver is lower in situations with fixed objects than in situations with moving objects in busy traffic.

Table 17 shows the estimated effects on fatalities and injuries for different collision types.

Table 17: Effect estimates of mechanism 1 on different accident categories.

---

6 10 m/s² is the maximum on dry road, with good tires.
Applied to the shares of target collisions, for mechanism 1 this means a reduction of approximately 7 % in fatalities (also 7% for injuries).

**Mechanism 3: Indirect modification of user behaviour**

Behavioural compensation effects (mechanism 3) are assumed to be very limited as EBR intervenes only in extremely dangerous situations and much later than the braking of a normal driver.

The expected percentage changes shown above were multiplied with the relevant accident data proportions in EU-25 data. The estimates for this system were based on collision type (shown in Table 8). Figure 30 shows the effects of all relevant mechanisms and the total effect for 100% fleet penetration.

![Effect on number of fatalities for EBR (%)](image)

Figure 30: EBR’s effect on fatalities with 100% fleet penetration (veh km). The total effect of all relevant mechanisms is indicated in green.

Finally, the full penetration estimates were applied to the fleet penetrations estimated for the target years 2010 and 2020 (Table 18). The table also shows the range of estimates for full penetration.

Table 18: The effect of EBR on fatalities and injuries for full penetration and four scenarios. For full penetration, the range (low/high) is given.
### Safety Impacts of Pre-Crash Protection of Vulnerable Road Users (PCV)

The relevant safety mechanisms of Pre-Crash Protection of Vulnerable Road Users (PCV) are described below.

**Mechanism 1: Direct in-car modification of the driving task**

+ The system detects vulnerable road users and takes over control from the driver in case the driver does not brake at all or not sufficiently. Pedestrians are detected within a distance of 40 meters. In case of an emergency, when the driver is not able to avoid an accident with a pedestrian, PCV will help the driver by automatically applying the brakes with the purpose to mitigate the accident consequences. Brakes are automatically pre-filled, making braking faster and stronger. PCV reduces impact speed in case of immediate danger, which reduces accident consequences.

According to literature [Fuerstenberg, 2005], collision speeds of over 30 km/h account for 38% of car-to-pedestrian serious injury accidents. 80% of these (total 30%) car-to-pedestrian accidents are in the region 30-50 km/h where PCV is most efficient. 70% of car-to-pedestrian accidents are frontal. 94% of pedestrians are moving. These two thirds can be detected by PCV. Relevant serious injury accidents that can be mitigated with PCV are therefore approximately 20% of car-to-pedestrian accidents.

There are still indications of detection problems with hidden pedestrians and false alarms. We assume that these problems are solved before 2020 and almost all potential collisions are detected in time and accurate action is taken. We assume that at least 2/3 of the detected serious injury accidents will be taken to a lower injury class (light injury). Many of the light injuries will be avoided. The resulting estimate is a 15% reduction of all injuries.

The efficiency of a system that can mitigate collisions in the region 30-50 km/h is limited for fatalities. Only 15% of fatalities occur in the region 0-60 km/h. A reduction of the impact speed of these from for instance 50 to 30 km/h will result in a reduced fatality rate of two thirds (from 66% to 22%) based on Meinecke & Obojski [2005]. In many cases the accident consequences also of fatal accidents in the higher speed regions will be mitigated. In [Lawrence et al., 2006] the

### Table: Penetration Rate and Reduction in Fatalities and Injuries

<table>
<thead>
<tr>
<th>EBR</th>
<th>Penetration rate for light/heavy vehicles (%)</th>
<th>Reduction in Fatalities (%)</th>
<th>Reduction in Injuries (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Impact most probable</td>
<td>100 / 100</td>
<td>-7.0</td>
<td>-7.3</td>
</tr>
<tr>
<td>Impact low</td>
<td>100 / 100</td>
<td>-3.1</td>
<td>-3.0</td>
</tr>
<tr>
<td>Impact high</td>
<td>100 / 100</td>
<td>-8.8</td>
<td>-8.9</td>
</tr>
<tr>
<td>Impact 2010 low</td>
<td>0 / 0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Impact 2010 high</td>
<td>0 / 0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Impact 2020 low</td>
<td>4 / 3</td>
<td>-0.3</td>
<td>-0.5</td>
</tr>
<tr>
<td>Impact 2020 high</td>
<td>11 / 7</td>
<td>-0.9</td>
<td>-1.3</td>
</tr>
</tbody>
</table>

1 These figures represent the expected impact if all vehicles were equipped, regardless of the year.
2 Fleet vehicle km equipped

The high estimate for the year 2020 would mean 193 avoided fatalities and 10,925 avoided injuries.
estimated efficiency of a Brake Assist system is up to 10% for fatalities and 20% for injuries. As PCV is a more advanced system, we estimate a potential of reducing fatalities of 10%. The direct effects on fatalities and injuries are shown in Table 19.

Table 19: Effect estimates of mechanism 1 on different accident categories.

<table>
<thead>
<tr>
<th>PCV</th>
<th>Mechanism 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collision on the road with pedestrian</td>
<td>-10,0 %</td>
</tr>
<tr>
<td>Collision on the road with all other obstacles</td>
<td>0,0 %</td>
</tr>
<tr>
<td>Collision besides the road with pedestrian or obstacle or other</td>
<td>-5,0 %</td>
</tr>
<tr>
<td>single vehicle accidents</td>
<td>-8,0 %</td>
</tr>
<tr>
<td>Frontal collision</td>
<td>0,0 %</td>
</tr>
<tr>
<td>Side-by-side collision</td>
<td>0,0 %</td>
</tr>
<tr>
<td>Angle collision</td>
<td>0,0 %</td>
</tr>
<tr>
<td>Rear collision</td>
<td>0,0 %</td>
</tr>
<tr>
<td>Other accidents with two vehicles</td>
<td>0,0 %</td>
</tr>
</tbody>
</table>

Applied to the shares of target collisions, for mechanism 1 this means a reduction of approximately 2% in fatalities (2% for injuries).

Mechanism 3: Indirect modification of user behaviour and Mechanism 5: Modification of interaction between users and non-users

- Small compensation effects may occur as some drivers might be inclined to drive more aggressively. Delegation of the responsibility to the system may also result in less communicating between road users.

The expected percentage changes shown above were multiplied with the relevant accident data proportions in EU-25 data. The estimates for this system were based on collision type (shown in Table 8). Figure 31 shows the effects of all relevant mechanisms and the total effect for 100% fleet penetration.

![Figure 31: PCV's effect on fatalities with 100% fleet penetration (veh km). The total effect of all relevant mechanisms is indicated in green.](image-url)
Finally, the full penetration estimates were applied to the fleet penetrations estimated for the target years 2010 and 2020 (Table 20). The table also shows the range of estimates for full penetration.

Table 20: The effect of PCV on fatalities and injuries for full penetration and four scenarios. For full penetration, the range (low/high) is given.

<table>
<thead>
<tr>
<th>PCV</th>
<th>Penetration rate for light/heavy vehicles (%)</th>
<th>Reduction in</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Fatalities (%)</td>
</tr>
<tr>
<td>Impact most probable</td>
<td>100 / 100</td>
<td>-1.8</td>
</tr>
<tr>
<td>Impact low</td>
<td>100 / 100</td>
<td>-1.3</td>
</tr>
<tr>
<td>Impact high</td>
<td>100 / 100</td>
<td>-2.3</td>
</tr>
<tr>
<td>Impact 2010 low</td>
<td>0.1 / 0.1</td>
<td>0.0</td>
</tr>
<tr>
<td>Impact 2010 high</td>
<td>0.4 / 0.1</td>
<td>0.0</td>
</tr>
<tr>
<td>Impact 2020 low</td>
<td>5 / 8</td>
<td>-0.1</td>
</tr>
<tr>
<td>Impact 2020 high</td>
<td>13 / 14</td>
<td>-0.2</td>
</tr>
</tbody>
</table>

1 These figures represent the expected impact if all vehicles were equipped, regardless of the year.

2 Fleet vehicle km equipped

The high estimate for the year 2020 would mean 39 avoided fatalities and 1,918 avoided injuries.

5.6 Safety impacts of Lane Change Assistant (Warning) (LCA)

The relevant safety mechanisms of Lane Change Assistant (Warning) (LCA) are described below.

Mechanism 1: Direct in-car modification of the driving task

+ The system supports the driver to allocate attention resources according to the driving task by warning for vehicles besides or at the rear when starting a lane change. When a collision happens, the severity will be less because evasive action has already started. It is assumed that the (warning) HMI is not confusing to the driver. Some (but very little) potential will be lost because drivers will not switch system on all the time, for instance, not in situations in which they think they do not need the system at all. Since these will, indeed, most likely be the less critical situations, the loss will be minimal.

The leading categorization is that according to accident type. The potential estimate derived here comes from estimating the percentage for each of the relevant types of accidents that will be affected. Prominent among these are sideswipes and a small part of all rear end collisions. The estimate of the potential fatality reduction is hard to get. The literature offers wildly varying estimates (see for instance [Bayly et al., 2007]). The lane change assistance system is often considered in combination with a Lane Keeping (LKS) system; not much information exists for Lane Change Assist only. The direct effect estimates are shown in Table 21.
Table 21: Effect estimates of mechanism 1 on different accident categories.

<table>
<thead>
<tr>
<th>LCA</th>
<th>Mechanism 1</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fatalities</td>
</tr>
<tr>
<td>Collision on the road with pedestrian</td>
<td>0,0 %</td>
</tr>
<tr>
<td>Collision on the road with all other obstacles</td>
<td>0,0 %</td>
</tr>
<tr>
<td>Collision besides the road with pedestrian or obstacle or other single vehicle accidents</td>
<td>0,0 %</td>
</tr>
<tr>
<td>Frontal collision</td>
<td>0,0 %</td>
</tr>
<tr>
<td>Side-by-side collision</td>
<td>-90,0 %</td>
</tr>
<tr>
<td>Angle collision</td>
<td>0,0 %</td>
</tr>
<tr>
<td>Rear collision</td>
<td>-3,0 %</td>
</tr>
<tr>
<td>Other accidents with two vehicles</td>
<td>0,0 %</td>
</tr>
</tbody>
</table>

Applied to the shares of target collisions, for mechanism 1 this means a reduction of approximately 2% in fatalities (5% for injuries).

**Mechanism 3: Indirect modification of user behaviour**

- There will be effects on both driver behaviour and overall alertness level because drivers will experience the presence and the activity of the system frequently and directly in everyday driving.

Expected effects on behaviour are more sloppy driving (i.e., less accurate lane keeping), as well as a decrease in drivers’ overall level of alertness.

**Mechanism 6: Modification of road user exposure**

A tiny amount of extra exposure will be generated.

**Mechanism 7: Modification of modal choice**

A slight amount of modal shift from public transport to the car is to be expected as drivers know that the system is there to support them.

The expected percentage changes shown above were multiplied with the relevant accident data proportions in EU-25 data. The estimates for the system were based on collision type (shown in the Table 8). Figure 32 shows the effects of all relevant mechanisms and the total effect for 100% fleet penetration.
Finally, the full penetration estimates were applied to the fleet penetrations estimated for the target years 2010 and 2020 (Table 22). The table also shows the range of estimates for full penetration.

Table 22: The effect of LCA on fatalities and injuries for full penetration and four scenarios. For full penetration, the range (low/high) is given.

<table>
<thead>
<tr>
<th>LCA</th>
<th>Penetration rate for light/heavy vehicles (%)</th>
<th>Reduction in</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Fatalities (%)</td>
</tr>
<tr>
<td>Impact most probable</td>
<td>100 / 100</td>
<td>-2.2</td>
</tr>
<tr>
<td>Impact low</td>
<td>100 / 100</td>
<td>-1.8</td>
</tr>
<tr>
<td>Impact high</td>
<td>100 / 100</td>
<td>-2.5</td>
</tr>
<tr>
<td>Impact 2010 low</td>
<td>0.2 / 0.03</td>
<td>0.0</td>
</tr>
<tr>
<td>Impact 2010 high</td>
<td>0.9 / 0.6</td>
<td>0.0</td>
</tr>
<tr>
<td>Impact 2020 low</td>
<td>4 / 4</td>
<td>-0.2</td>
</tr>
<tr>
<td>Impact 2020 high</td>
<td>10 / 15</td>
<td>-0.4</td>
</tr>
</tbody>
</table>

1 These figures represent the expected impact if all vehicles were equipped, regardless of the year.

2 Fleet vehicle km equipped

The high estimate for the year 2020 would mean 86 avoided fatalities and 8,596 avoided injuries.

## 5.7 Safety impacts of Lane Keeping Support (LKS)

The relevant safety mechanisms of Lane Keeping Support (LKS) are described below.

**Mechanism 1: Direct in-car modification of the driving task**

- Single-vehicle accidents will be reduced if the driver obeys the active steering wheel signal. If designed properly, this signal will not confuse the driver, so there is no inherent ergonomic problem. Some initial loss of potential is expected because drivers will not always switch the system on (see e.g. the results of the first Dutch FOT on LDWA systems [Ridder & Hoedemaeker, 2003]).
The accident severity of relevant accidents will decrease because the driver will, in a number of cases, already be in the middle of an evasive action.

The leading categorization is that according to accident type (Table 23).

Table 23: Effect estimates of mechanism 1 on different accident categories.

<table>
<thead>
<tr>
<th>LKS</th>
<th>Mechanism 1</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fatalities</td>
</tr>
<tr>
<td>Collision on the road with pedestrian</td>
<td>0,0 %</td>
</tr>
<tr>
<td>Collision on the road with all other obstacles</td>
<td>0,0 %</td>
</tr>
<tr>
<td>Collision besides the road with pedestrian or obstacle or other single vehicle accidents</td>
<td>-70,0 %</td>
</tr>
<tr>
<td>Frontal collision</td>
<td>-7,0 %</td>
</tr>
<tr>
<td>Side-by-side collision</td>
<td>-20,0 %</td>
</tr>
<tr>
<td>Angle collision</td>
<td>0,0 %</td>
</tr>
<tr>
<td>Rear collision</td>
<td>-7,0 %</td>
</tr>
<tr>
<td>Other accidents with two vehicles</td>
<td>0,0 %</td>
</tr>
</tbody>
</table>

Applied to the shares of target collisions, for mechanism 1 this means a reduction of approximately 18% in fatalities (11% for injuries).

**Mechanism 3: Indirect modification of user behaviour**

- Effects are expected on both behaviour (lane keeping will become more sloppy) and on general alertness (driver will become less attentive because he knows system watches over him, and initiates action if needed). Both of these exist because the driver will experience system actions directly and relatively often, even in everyday driving.

Some loss of potential can be expected from drivers switching off the system, as has become apparent in several Field Operational Tests (e.g., [Alkim et al., 2007]) on lane-keeping related systems.

**Mechanism 6 Modification of road user exposure**

- Some increase in exposure is expected because drivers will go out more often under relatively bad conditions.

The expected percentage changes shown above were multiplied with the relevant accident data proportions in EU-25 data. The estimates for the system were based on collision type (shown in Table 8). Figure 33 shows the effects of all relevant mechanisms and the total effect for 100% fleet penetration.
Finally, the full penetration estimates were applied to the fleet penetrations estimated for the target years 2010 and 2020 (Table 24). The table also shows the range of estimates for full penetration.

Table 24: The effect of LKS on fatalities and injuries for full penetration and four scenarios. For full penetration, the range (low/high) is given.

<table>
<thead>
<tr>
<th>LKS</th>
<th>Penetration rate for light/heavy vehicles (%)</th>
<th>Reduction in Fatalities (%)</th>
<th>Reduction in Injuries (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Impact most probable</td>
<td>100 / 100</td>
<td>-15.2</td>
<td>-8.9</td>
</tr>
<tr>
<td>Impact low</td>
<td>100 / 100</td>
<td>-5.7</td>
<td>-3.9</td>
</tr>
<tr>
<td>Impact high</td>
<td>100 / 100</td>
<td>-21.8</td>
<td>-13.6</td>
</tr>
<tr>
<td>Impact 2010 low</td>
<td>1.1 / 0.3</td>
<td>-0.2</td>
<td>-0.1</td>
</tr>
<tr>
<td>Impact 2010 high</td>
<td>2.9 / 1.4</td>
<td>-0.4</td>
<td>-0.3</td>
</tr>
<tr>
<td>Impact 2020 low</td>
<td>6 / 6</td>
<td>-0.9</td>
<td>-0.6</td>
</tr>
<tr>
<td>Impact 2020 high</td>
<td>21 / 23</td>
<td>-3.3</td>
<td>-2.0</td>
</tr>
</tbody>
</table>

1 These figures represent the expected impact if all vehicles were equipped, regardless of the year.

2 Fleet vehicle km equipped

The high estimate for the year 2020 would mean 678 avoided fatalities and 17,296 avoided injuries.

5.8 Safety impacts of NightVisionWarn (NIW)

The relevant safety mechanisms of NightVisionWarn (NIW) are described below.

Mechanism 1: Direct in-car modification of the driving task

NightVisionWarn gives the driver enhanced vision at night through near or far infrared sensors. Present day high quality on-dash display permits sufficient and easy-to-interpret obstacle detection, as well as guidance with respect to the road’s edges. The severity of relevant accidents will decrease because drivers will, in a number of cases, already have started evasive action.
Potential to improve road safety is based on European, US and Japanese estimates [Gayko & Tsuji, 2006] [Owens & Sivak, 1996] [Tsimhoni et al., 2004] [Tsimhoni et al., 2005] [Tsuji et al., 2006] [Uhler, 2006] of the proportion of vulnerable road user fatalities at the night time. The centre of the range of estimates is at about 20%.

The main classifying factor in the analyses was whether the accident would take place in daylight or in night time. The effect estimates for the direct effects are shown in the Table 25.

Table 25: Effect estimates of mechanism 1 on different accident categories.

<table>
<thead>
<tr>
<th>NIW</th>
<th>Mechanism 1</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fatalities</td>
</tr>
<tr>
<td>Day light</td>
<td>0,0 %</td>
</tr>
<tr>
<td>Night</td>
<td>-20,0 %</td>
</tr>
</tbody>
</table>

Applied to the shares of target conditions (see Table 8), for mechanism 1 this means a reduction of approximately 7% in fatalities (5% for injuries).

**Mechanism 3: Indirect modification of user behaviour**

- When driving in the dark, drivers will increase their speed if they get better guidance. The exact amount depends on other conditions, like display quality. (If the display is low-quality, their workload increases instead of their speed.) This will not just increase the risk of targeted accidents (collisions with vulnerable road users), but all types of accidents.

**Mechanism 6: Modification of the exposure**

- A small amount of extra exposure will be generated because drivers will now go out once in a while to make a trip (in the dark) they would not have made otherwise.

**Mechanism 7: Modification of modal choice**

- A tiny amount of modal shift will be induced. Some people disliking driving in the dark try to avoid that and use bus, train or other travel mode instead in their journeys. With NIW, driving in the dark becomes easier and more comfortable. Hence, some of the aforementioned people will drive by car also in the dark and not use the former other travel mode. As the proportion of such people in the first place is quite small, this effect will not be large.

**Mechanism 8: Modification of route choice**

- A tiny amount of route choice modification will be induced, as shortcuts will be taken over more risky (i.e., darker) roads. Some people dislike driving in the dark and tend to use in the dark only routes equipped with road lighting as much as possible. The roads with road lighting tend to be also otherwise safer roads than those without. With NightVisionWarn, some of these people dare to take shortcuts without road lighting. Unfortunately, the crash risk increase due to higher accident rate on unlit roads will not be compensated by the shorter distance driven. As the proportion of such people in the first place is quite small, this effect will not be large.

The expected percentage changes shown above were multiplied with the relevant accident data proportions in EU-25 data. The estimates for the system were based on lighting conditions (shown in Table 8).
Figure 34 shows the effects of all relevant mechanisms and the total effect for 100% fleet penetration.

![Effect on number of fatalities for NIW (%)](image)

Figure 34: NIW's effect on fatalities with 100% fleet penetration (veh km). The total effect of all relevant mechanisms is indicated in green.

Finally, the full penetration estimates were applied to the fleet penetrations estimated for the target years 2010 and 2020 (Table 26). The table also shows the range of estimates for full penetration.

Table 26: The effect of NIW on fatalities and injuries for full penetration and four scenarios. For full penetration, the range (low/high) is given.

<table>
<thead>
<tr>
<th>NIW</th>
<th>Penetration rate for light/heavy vehicles (%)(^2)</th>
<th>Reduction in</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Fatalities (%)</td>
</tr>
<tr>
<td>Impact most probable(^1)</td>
<td>100 / 100</td>
<td>-2.9</td>
</tr>
<tr>
<td>Impact low(^1)</td>
<td>100 / 100</td>
<td>0.6</td>
</tr>
<tr>
<td>Impact high(^1)</td>
<td>100 / 100</td>
<td>-6.2</td>
</tr>
<tr>
<td>Impact 2010 low</td>
<td>0.2 / 0.03</td>
<td>-0.01</td>
</tr>
<tr>
<td>Impact 2010 high</td>
<td>0.9 / 0.6</td>
<td>-0.03</td>
</tr>
<tr>
<td>Impact 2020 low</td>
<td>4 / 4</td>
<td>-0.1</td>
</tr>
<tr>
<td>Impact 2020 high</td>
<td>10 / 15</td>
<td>-0.4</td>
</tr>
</tbody>
</table>

\(^1\) These figures represent the expected impact if all vehicles were equipped, regardless of the year.

\(^2\) Fleet vehicle km equipped

The high estimate for year 2020 would mean 73 avoided fatalities and 2,542 avoided injuries.
5.9 Safety impacts of Driver Drowsiness Monitoring and Warning (DDM)

The relevant safety mechanisms of Driver Drowsiness Monitoring and Warning (DDM) are described below.

**Mechanism 1: Direct in-car modification of the driving task**

+ The system warns drivers when they are inattentive or fall asleep. There are no major inherent problems with the HMI, i.e., the warning given, to be expected with the design specified in eIMPACT. However, there are reliability problems in the diagnostic performance of the system. Some missed alarms (as well as false alarms) are expected, which will reduce the potential.

The estimate of the potential is from the AWAKE project (Final report, [AWAKE, 2004]), and already takes into account the non-perfect diagnostic power of the system. This estimate happens to be around the midrange of estimates given by other sources as well, e.g. [Ecorys, 2006].

The main classifying factor in the analyses was whether the accident would take place in daylight or in night time. The effect estimates for the direct effects are shown in Table 27.

Table 27: Effect estimates of mechanism 1 on different accident categories.

<table>
<thead>
<tr>
<th>DDM</th>
<th><strong>Mechanism 1</strong></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Fatalities</td>
<td>Injuries</td>
</tr>
<tr>
<td>Day light</td>
<td>-1,0 %</td>
<td>-1,0 %</td>
<td></td>
</tr>
<tr>
<td>Night</td>
<td>-21,3 %</td>
<td>-21,3 %</td>
<td></td>
</tr>
</tbody>
</table>

Applied to the shares of target conditions, for mechanism 1 this means a reduction of approximately 8% in fatalities (6% for injuries).

**Mechanism 3: Indirect modification of user behaviour**

- Availability of system will bring down the general level of driver alertness, the most so under critical conditions (i.e., in darkness and after long periods of driving). Behaviour under these same conditions will also be slightly sloppier, lane keeping in particular.

It is known that changes in drivers’ alertness level have major effects on his accident risk. For example, the AIDE project has concluded that accident risk will double if a driver’s overall alertness drops form ‘excellent’ to ‘poor’ [Janssen et al., 2006]. For the present system, however, it is not to be expected that such a dramatic drop in overall alertness will occur in addition to the ‘natural’ curve of developing fatigue after several hours of driving. Alertness will by itself already be so low after an extended period of driving – which is when the DDM system starts noticing that something is the matter - that there is little room left for the driver to adapt by allowing himself to get even drowsier. The most probable estimate given here, for the basic ‘darkness’ condition, is therefore based on no more than a modest extra drop in overall alertness (i.e., on top of the ‘natural’ curve).
Mechanism 6: Modification of road user exposure

− Extra exposure will be generated, because drivers will drive on in some conditions – which will be the more critical ones – in which they would formerly have stopped driving.

There is concern that driver vigilance monitoring systems will actually encourage users to continue to drive even when impaired, due to over-confidence in the system [OECD, 2003]. Indeed, the AWAKE Project itself reported that a considerable number of interviewed said they would probably drive on longer if they had the system (between 11-38%, the extremes of the range depending on other factors, like the type of driver).

[Vincent et al., 1998] completed a test track evaluation of a fatigue warning system that measured ocular and face monitoring, vehicle speed, steering position and lane position. They found the users of the system did not take more or longer breaks, and did not show different fatigue levels to controls.

Mechanism 7: Modification of modal choice

− An amount of modal shift towards the DDM-vehicle will be induced from other transportation modes.

The expected percentage changes shown above were multiplied with the relevant accident data proportions in EU-25 data. The estimates of direct effects were based on lighting conditions (shown in Table 8). Figure 35 shows the effects of all relevant mechanisms and the total effect for 100% fleet penetration.

![Effect on number of fatalities for DDM (%)](image)

Figure 35: DDM’s effect on fatalities with 100% fleet penetration (veh km). The total effect of all relevant mechanisms is indicated with green colour.

Finally, the full penetration estimates were applied to the fleet penetrations estimated for the target years 2010 and 2020 (Table 28). The table also shows the range of estimates for full penetration.
Table 28: The effect of DDM on fatalities and injuries for full penetration and four scenarios. For full penetration, the range (low/high) is given.

<table>
<thead>
<tr>
<th>DDM</th>
<th>Penetration rate for light/heavy vehicles (%)</th>
<th>Reduction in Fatalities (%)</th>
<th>Reduction in Injuries (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Impact most probable 1</td>
<td>100 / 100</td>
<td>-5.0</td>
<td>-3.8</td>
</tr>
<tr>
<td>Impact low 1</td>
<td>100 / 100</td>
<td>-1.5</td>
<td>-1.0</td>
</tr>
<tr>
<td>Impact high 1</td>
<td>100 / 100</td>
<td>-7.0</td>
<td>-4.9</td>
</tr>
<tr>
<td>Impact 2010 low</td>
<td>0.2 / 0.3</td>
<td>-0.01</td>
<td>-0.01</td>
</tr>
<tr>
<td>Impact 2010 high</td>
<td>0.4 / 1.1</td>
<td>-0.04</td>
<td>-0.03</td>
</tr>
<tr>
<td>Impact 2020 low</td>
<td>1 / 6</td>
<td>-0.1</td>
<td>-0.08</td>
</tr>
<tr>
<td>Impact 2020 high</td>
<td>5 / 15</td>
<td>-0.5</td>
<td>-0.3</td>
</tr>
</tbody>
</table>

1 These figures represent the expected impact if all vehicles were equipped, regardless of the year.

2 Fleet vehicle km equipped

The high estimate for the year 2020 would mean 94 avoided fatalities and 2,715 avoided injuries.

5.10 Safety impacts of eCall (one-way communication) (ECA)

The relevant safety mechanisms of eCall (one-way communication) (ECA) are described below. eCall is an atypical system because it only works after an accident has occurred. This means that mechanism 9 is the most important mechanism (instead of mechanism 1, which is the most important mechanism for the other systems).

**Mechanism 8: Modification of route choice**

- Drivers may rely on the system to make the emergency call after an accident and know the location. This may encourage them to drive more in remote rural areas where there are no other people around and where they do not know their exact location all the time. However, this effect is expected to be small.

**Mechanism 9: Modification of accident consequences**

+ The system decreases the number of traffic fatalities because swifter arrival of help should prevent some traffic fatalities. E.g. the fatalities in which the delay between the time of accident and the time of emergency call has been unusually long or the accident has been located incorrectly can be partly avoided.

+ The system decreases the injury levels in some degree: swifter arrival of help alleviates the injuries of some accident victims.

+ In addition, the swifter arrival of help and more exact location provided by the system will make the road operator’s incident management more efficient and reduce the impacts of the incident (accident) as well as the number of traffic incidents resulting from the original incident. The faster arrival of rescue teams enables the accident scene to be cleared more quickly which has also a positive impact on traffic congestion decrease, which was estimated to be 5% by E-MERGE [Geels, 2004] and even 10–25% by the SEIJS study [Abele et al., 2005].

The number of cases on which eCall may produce benefits is lower than the total number of fatalities and injuries because only in some
injury crashes a rescue time reduction could increase the likelihood to save a life or to reduce injuries.

The E-Merge project, eCall Driving Group and the SEISS Study have all come to the same conclusion that a full-scale deployment of an automatic emergency call system could lead to a 5-15% decrease in fatalities and severe injuries. For light injuries no positive effects have been foreseen. A Swedish study suggested that the potential for Sweden is much lower. According to the study the potential in Sweden is 2–4% of the number of the road fatalities. The portion of seriously injured with permanent problems was expected to be reduced by 3–4% [Abele et al. 2005][Bouler 2005][Geels 2004] [Lindholm 2004].

A Finnish study estimated that an eCall system could be able to reduce 4–8% of all road fatalities in Finland in 2001–2003. The evaluation was based on an in-depth analysis of empirical data of actual accidents that had occurred in Finland in 2001–2003. [Virtanen et al., 2006.]

The expected percentage changes on different accident categories (Table 29) were mostly based on a study by [Virtanen et al., 2006]. As this study was done with Finnish accident data, the results obtained with Finnish data were transferred in to EU-25 accident data. Based on distribution of collisions in the EU-25 data (see Table 8) the overall effect estimate for the eCall system was -5.8% for fatalities (Figure 36) and +0.1% for injuries.

Table 29: Effect estimates of mechanism 9 on different accident categories.

<table>
<thead>
<tr>
<th>ECA</th>
<th>Mechanism 9</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fatalities</td>
</tr>
<tr>
<td>Collision on the road with pedestrian</td>
<td>-0.5 %</td>
</tr>
<tr>
<td>Collision on the road with all other obstacles</td>
<td>-10.0 %</td>
</tr>
<tr>
<td>Collision besides the road with pedestrian or obstacle or other single vehicle accidents</td>
<td>-20.0 %</td>
</tr>
<tr>
<td>Frontal collision</td>
<td>-1.5 %</td>
</tr>
<tr>
<td>Side-by-side collision</td>
<td>-1.0 %</td>
</tr>
<tr>
<td>Angle collision</td>
<td>-1.0 %</td>
</tr>
<tr>
<td>Rear collision</td>
<td>0.0 %</td>
</tr>
<tr>
<td>Other accidents with two vehicles</td>
<td>-1.0 %</td>
</tr>
</tbody>
</table>

Figure 36 shows the effects of all relevant mechanisms and the total effect for 100% fleet penetration.
Finally, the full penetration estimates were applied to the fleet penetrations estimated for the target years 2010 and 2020 (Table 30). The first row of the table shows the total impact estimate found in Figure 36, and also the range for this estimate. In addition, the table includes the estimated penetration rates and the effect estimates on fatalities and on injuries for the low and high penetrations. The last row indicates that the high penetration scenario in 2020 assumes that eCall decreases the number of fatalities by 3.5%. This would mean 728 avoided fatalities in 2020. (eCall shows about the same increase in injuries, because most of the prevented fatalities are expected to turn into injuries.)

Table 30: The effect of ECA on fatalities and injuries for full penetration and four scenarios. For full penetration, the range (low/high) is given.

<table>
<thead>
<tr>
<th>eCall</th>
<th>Penetration rate for light/heavy vehicles (%)</th>
<th>Reduction in</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Fatalities (%)</td>
</tr>
<tr>
<td>Impact most probable</td>
<td>100 / 100</td>
<td>-5.8</td>
</tr>
<tr>
<td>Impact low</td>
<td>100 / 100</td>
<td>-3.6</td>
</tr>
<tr>
<td>Impact high</td>
<td>100 / 100</td>
<td>-7.3</td>
</tr>
<tr>
<td>Impact 2010 low</td>
<td>0.2 / 0.2</td>
<td>-0.01</td>
</tr>
<tr>
<td>Impact 2010 high</td>
<td>0.5 / 0.6</td>
<td>-0.03</td>
</tr>
<tr>
<td>Impact 2020 low</td>
<td>43 / 51</td>
<td>-2.6</td>
</tr>
<tr>
<td>Impact 2020 high</td>
<td>59 / 70</td>
<td>-3.5</td>
</tr>
</tbody>
</table>

1 These figures represent the expected impact if all vehicles were equipped, regardless of the year.
2 Fleet vehicle km equipped
5.11 Safety impacts of Intersection Safety (INS)

Two safety functions of the Intersection Safety system were assessed in the eIMPACT project: traffic light assistance (INS TL) and right-of-way support (INS RoW). The relevant safety mechanisms of these two functions are described below. The mechanism descriptions and the results of the third Intersection Safety function, the left turn function, are described briefly in this report; they are more extensively reported in the PReVAL project [Scholliers et al., 2008].

Mechanism 1 (and 2): Direct in-car modification of the driving task by giving information, advice

+ The system supports the driver to perceive other road users - vehicles, pedestrians, bicycles – with a collision course when approaching an intersection. The system makes the driver better and earlier aware of potential hazards, giving more time for evasive actions, like reduction of speed, and therefore prevents collisions with other road users.

+ The system reduces the number of situations where the driver recognises a red light at a very late stage or does not recognise the light at all and violates the red light.

+ The system reduces the number of situations where the driver misjudges the gap (with an oncoming vehicle) for a left turn, by estimating the velocity of and distance to oncoming vehicles.

+ The consequences are mitigated due to lower speeds in collision situations at the intersections due to earlier warnings.

− The driving task is changed because the driver may at times glance at the device which provides the warnings. The task becomes a divided attention task. The driving task becomes more complex when there is important visual information both inside and outside the car.

The main classifying factor for the analyses was chosen to be the location of potential collisions. Accident data includes a variable indicating whether accidents have taken place at an intersection or not. It was, however, assumed that some minor effects may appear outside the intersections, due to inaccuracies and inconsistencies in the definition of intersection in accident statistics.

For the numerical estimate of traffic light support, the share of signalised intersection accidents out of all intersection accidents was estimated in urban and rural area (based e.g. on [Kulmala, 1995]. Information about the share of red signal running [Retting et al., 1995]: 22%) as a cause of urban crashes was taken into consideration, as well as the driver interviews [Garder 2004] indicating that a quarter of drivers had been unaware that there was a red signal in about 25% of the crashes caused by red-light running violations. It was estimated that red signal violation crashes could be reduced by approximately 35% with the system. For the numerical estimate of distraction, the situation with and without a device was compared: assumptions were made about an average number of

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7 eIMPACT refers to PReVAL project’s results in benefit cost calculations concerning the third function ‘left turn’.
glances, the duration of one glance (0.2 second [Luoma, 1984]), and the increase of risk during a glance by 90% [Janssen et al., 2006].

Table 31 shows the effect estimates for the traffic light support function for full penetration. The effect on fatalities is higher due to lower speed [Nilsson 2004].

Table 31: Effects of mechanism 1 of ‘traffic light support’ on accidents in and outside intersections.

<table>
<thead>
<tr>
<th>INS - TL</th>
<th>Mechanism 1</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fatalities</td>
</tr>
<tr>
<td>No intersection</td>
<td>-0.7 %</td>
</tr>
<tr>
<td>Intersection</td>
<td>-6.7 %</td>
</tr>
</tbody>
</table>

Applied to the shares of target conditions, for mechanism 1 this means a reduction of approximately 2% in fatalities (2% for injuries).

For the numerical estimate of right-of-way support, it was assumed that 50% of accidents at junctions are related to right-of-way situation [Kulmala, 1995]. Literature shows that approximately 80% of all accidents are related to lack of attention [Dingus et al., 2006], and at junctions 40% of crashes involve a perceptual error [Hakamies-Blomqvist 1994]. Consequently, it was assumed that in all, 50% (with a margin of ± 20%) crashes in intersections are related to perception errors. In addition, an assumption was made that the warning right-of-way assistance system would prevent 60% (with a margin of ± 20%) of perception errors contributing to right-of-way crashes at intersections. The numerical effect of distraction was quite similar than for the traffic light assistance. Table 32 shows the effect estimates for mechanism 1. The range for fatalities was -4.6 to -26.6% and for injuries -7.6% to -29.6%.

Table 32: Effects of mechanism 1 of ‘right-of-way information’ on accidents in intersection and link.

<table>
<thead>
<tr>
<th>INS - RoW</th>
<th>Mechanism 1</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fatalities</td>
</tr>
<tr>
<td>No intersection</td>
<td>0.0 %</td>
</tr>
<tr>
<td>Intersection</td>
<td>-16.6 %</td>
</tr>
</tbody>
</table>

Applied to the shares of relevant conditions, this means a reduction of approximately 3% in fatalities (6% for injuries).

The numerical estimate of the left turn assistance function was carried out in the PReVAL project [Scholliers et al., 2008]. The left turn assistance supports the driver to estimate velocity and distance of oncoming vehicles. Table 33 shows the effect estimates for mechanism 1.

Table 33: Effects of mechanism 1 of ‘left turn assistance’ on accidents in intersection and link.

<table>
<thead>
<tr>
<th>INS - LT</th>
<th>Mechanism 1</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fatalities</td>
</tr>
<tr>
<td>No intersection</td>
<td>0.0 %</td>
</tr>
<tr>
<td>Intersection</td>
<td>-4.1 %</td>
</tr>
</tbody>
</table>

Applied to the shares of relevant conditions, this means a reduction of approximately 1% in fatalities (2% for injuries).

Mechanism 3: Indirect modification of user behaviour
Several changes in behaviour can occur:

− A well-working system provides warnings in a reliable manner and the driver learns to trust and rely on the system, i.e., the driver delegates the responsibility to the system. However, the system reliability is not 100% and the system may not always detect and warn in all situations.

− After the driver has learnt to trust the system, this will affect his strategy for approaching intersections. For example drivers might learn to approach the intersections at higher speeds than before relying on the system to warn them in time. These effects are affected by the way in which the messages are provided to the driver; especially the message concerning ‘drive ahead’.

− The higher speeds also result in more severe crash consequences.

The effects due to system malfunction are assumed to be very small for all three Intersection Safety functions, as the system reliability is expected to be very good. The effect due to a new strategy for approaching signalized intersections is estimated to be approximately 2% on all intersection crashes, assuming that the average speed increase in intersections is 1%. The severity of an accident is increased with higher speeds, therefore, an additional effect on fatalities due to increased speeds is taken into consideration.

**Mechanism 4: Indirect modification of non-user behaviour**

± The user becomes a non user when having a non equipped vehicle. Without the system he is used to, he may be poor in detecting other road users. It is also possible that the system has a positive transfer effect; the system may guide the driver to direct his attention adequately. These are however, assumed to be minor effects.

**Mechanism 5: Modification of interaction between users and non-users**

+ The driver perceives other road users earlier, and therefore anticipates the need to stop better, for example. Supported by the system, the driver is able to show his or her intentions to other drivers earlier than without the system. However, this assumes that the warning is provided in time.

This effect is estimated to be -0.5% on all intersection crashes.

**Mechanism 6: Modification of road user exposure**

− It is assumed that the system increases driving comfort in such a way that some additional trips will be made.

**Mechanism 7: Modification of modal choice**

− The system probably increases driving comfort and therefore increases the passenger car exposure by shifting drivers from public transport to person car.

**Mechanism 8: Modification of route choice**

+ Drivers are more likely to choose the routes with equipped signals, because the routes with equipped signals will have more fluent traffic due to less abrupt stops at signals and hence,
become more attractive to drivers. This effect concerns the system owners and at large penetration rates all drivers.

- Due to the right-off-way assistant driver may choose routes that are more complex, not signalised, and are located on the lower road network with higher average accident rates.

The expected percentage changes shown above were multiplied with the relevant accident data proportions in EU-25 data. The estimates for this system were based on whether the collision had taken place in an intersection or outside the intersection. In the EU-25 accident data, the respective shares are 77% of fatalities on a link, and 23% at intersections (see Table 8). However, some minor effects apply to all accidents (mechanism 6, 7, 8).

The result for 100% fleet penetration is shown in Figure 37.

![Effect on number of fatalities for INS (%)](image)

Figure 37: INS's effect on fatalities with 100% fleet penetration (veh km). The total effect of all relevant mechanisms is indicated in green. The figure includes the reduction of fatalities by Intersection Safety Left turn assistance function (estimation carried out in the PReVAL project).

Finally, the full penetration estimates were applied to the fleet penetrations estimated for the target years 2010 and 2020 (Table 34). The first row of the table shows the total impact estimate on fatalities found in Figure 37, also the effect on injuries and the range of estimates is given. In addition, the table includes the estimated penetration rates and the effect estimates on fatalities and on injuries for the low and high penetrations. The last row indicates that in the high penetration scenario in 2020 it is assumed that the effects of Intersection safety system still are very small. This estimate would mean 7 avoided fatalities and 670 avoided injuries.
Table 34: The effect of INS on fatalities and injuries for full penetration and four scenarios. For full penetration, the range (low/high) is given. Figures include also reduction of fatalities by Intersection Safety Left Turn function (estimation done in the PReVAL project, [Scholliers et al., 2008]).

<table>
<thead>
<tr>
<th>Intersection Safety total</th>
<th>Penetration rate for light/heavy vehicles (%)</th>
<th>Reduction in</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Fatalities (%)</td>
</tr>
<tr>
<td>Impact most probable¹</td>
<td>100 / 100</td>
<td>-3.9</td>
</tr>
<tr>
<td>Impact low¹</td>
<td>100 / 100</td>
<td>-1.0</td>
</tr>
<tr>
<td>Impact high¹</td>
<td>100 / 100</td>
<td>-7.5</td>
</tr>
<tr>
<td>Impact 2010 low</td>
<td>0 / 0</td>
<td>0</td>
</tr>
<tr>
<td>Impact 2010 high</td>
<td>0 / 0</td>
<td>0</td>
</tr>
<tr>
<td>Impact 2020 low</td>
<td>0.3 / 0.4</td>
<td>-0.02</td>
</tr>
<tr>
<td>Impact 2020 high</td>
<td>0.5 / 0.7</td>
<td>-0.03</td>
</tr>
</tbody>
</table>

¹ These figures represent the expected impact if all vehicles were equipped, regardless of the year.
² Fleet vehicle km equipped. Note that the assumed penetration does not take into account the implementation of the infrastructure.

5.12 Safety impacts of Wireless Local Danger Warning (WLD)

The Wireless Local Danger Warning (WLD) system includes two safety functions: warning about stopped vehicle (WLD1) and warning about reduced friction and visibility (WLD2). The relevant safety mechanisms are described below.

**Mechanism 1: Direct in-car modification of the driving task by giving warning**

+ Wireless Local Danger Warning helps focus the driver’s attention on the road ahead (situation awareness) and the risk for an accident will reduce. Some or all drivers will reduce speed. Driver will have longer headways and will avoid overtaking. The consequences of the accidents are less severe due to lower speed.

The numerical estimate of the direct effects of stopped vehicle warning was based on accident figures, indicating that 4% of fatal accidents were related to technical defects (other than tyres, the data of the Finnish accident investigation teams). Half of these were assumed to be related to the stopped vehicle, and a large part of these (90%) could be affected by the system, either prevented (65%) or mitigated (35%). The main classifying factor for this system was the road type (Table 35).

Table 35. Effects of mechanism 1 of ‘stopped vehicle warning’ system on accidents on motorways, rural and urban roads.

<table>
<thead>
<tr>
<th>WLD1</th>
<th>Mechanism 1</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fatalities</td>
</tr>
<tr>
<td>urban</td>
<td>-2,0 %</td>
</tr>
<tr>
<td>rural</td>
<td>-1,8 %</td>
</tr>
<tr>
<td>motorway</td>
<td>-1,8 %</td>
</tr>
</tbody>
</table>

Applied to the shares of relevant road types, for mechanism 1 this means a reduction of approximately 1.8% in fatalities (1.2% for injuries).

The numerical estimate of the reduced friction and visibility warning system was based on studies of weather related road side warning...
systems [Hogema & van der Horst, 1997] [Rämä 2001][Rämä et al., 2001]. The average mean speed decrease corresponds to a 6.8% (with an optimistic estimate of 11.4%) decrease in the injury risk in adverse conditions [Nilsson 2004). The corresponding decrease in the risk of a fatality is 13% (with an optimistic estimate of 21.5%). See Table 36.

Table 36. Effects of mechanism 1 of ‘friction and fog warning’ system on accidents in motorways, rural and urban roads.

<table>
<thead>
<tr>
<th>WLD2</th>
<th>Mechanism 1</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fatalities</td>
</tr>
<tr>
<td>Adverse</td>
<td>-13.0 %</td>
</tr>
<tr>
<td>Normal</td>
<td>0.0 %</td>
</tr>
</tbody>
</table>

Applied to the shares of target conditions, for mechanism 1 this means a reduction of approximately 1.5% in fatalities (1% for injuries).

Mechanism 3: Indirect modification of user behaviour

- A well-working system provides warnings in a reliable manner and the driver learns to trust and rely on the system. The driver delegates the responsibility to the system. This is a negative effect because the system may not always detect and warn in all situations.

- The higher the penetration rate, the more the driver relies on the system to detect the road surface condition (the higher the penetration rates, the more messages from other vehicles the driver receives, and the more the driver is likely to rely on the messages). In addition, the driver might drive with higher speeds than he would without the system.

A small effect of +0.2% is assumed in good conditions and +0.1% in adverse conditions

Mechanism 5: Modification of interaction between users and non-users

+ The non-users (drivers) approaching a hazardous location are forced to slow down when the equipped vehicle in front of them slows down. This decreases their accident risk.

- Some drivers behind the equipped vehicle might overtake because they do not understand the reason for slowing down. On two-lane roads this increases the risk of frontal collisions. Compared to the stopped vehicle situation the adverse weather condition is not as unexpected.

- The driver behind the equipped vehicle might drive too close because he does not understand reason for slowing down. This increases the risk of rear-end accidents.

For the stopped vehicle function the estimated numerical effects were small because of the small number of relevant cases. The effect estimate on injuries was ca -0.4% on motorways and -0.8% on rural and urban roads, for fatalities -0.5% on motorways and -1% on rural and urban roads.

The effect estimate of the friction and fog warning function strongly depends on the penetration level. It was assumed that the effect due
to speed decrease is 50% of the effect of the mechanism 1, i.e. -6.5% (±2%) for fatal accidents, and -3.4% (±1%) for injury accidents.

**Mechanism 6: Modification of the exposure**

- The system might increase driving during adverse road conditions, since driver relies on the system to give warning of any problematic conditions on the route. However, the effect is very small as the increase is probably among drivers with low annual mileage, non-compulsory trips.

The expected percentage changes shown above were multiplied with the relevant accident data proportions in EU-25 data. The estimates for this system were based on road type (see Table 8). The result for 100% fleet penetration is shown in Figure 38.

![Figure 38: WLD’s effect on fatalities with 100% fleet penetration (veh km). The total effect of all relevant mechanisms is indicated in green.](image)

Finally, the full penetration estimates were applied to the fleet penetrations estimated for the target years 2010 and 2020. The first row of the table shows the total impact estimate on fatalities found in Figure 38; also, the effect on injuries and the range for the estimates is given. In addition, the table shows that the estimated penetration rates even for 2020 are small, and consequently also the effects of Wireless Local Danger Warning are still small. The high estimate for the year 2020 would mean 66 avoided fatalities and 1,906 avoided injuries.
Table 37: The effect of WLD on fatalities and injuries for full penetration and four scenarios. For full penetration, the range (low/high) is given.

<table>
<thead>
<tr>
<th>WLD total</th>
<th>Penetration rate for light/heavy vehicles (%)</th>
<th>Reduction in</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Fatalities (%)</td>
</tr>
<tr>
<td>Impact most probable</td>
<td>100 / 100</td>
<td>-4.5</td>
</tr>
<tr>
<td>Impact low</td>
<td>100 / 100</td>
<td>-4.2</td>
</tr>
<tr>
<td>Impact high</td>
<td>100 / 100</td>
<td>-5.7</td>
</tr>
<tr>
<td>Impact 2010 low</td>
<td>0 / 0</td>
<td>0.0</td>
</tr>
<tr>
<td>Impact 2010 high</td>
<td>0 / 0</td>
<td>0.0</td>
</tr>
<tr>
<td>Impact 2020 low</td>
<td>2 / 3</td>
<td>-0.1</td>
</tr>
<tr>
<td>Impact 2020 high</td>
<td>4 / 10</td>
<td>-0.3</td>
</tr>
</tbody>
</table>

1 These figures represent the expected impact if all vehicles were equipped, regardless of the year.

2 Fleet vehicle km equipped

5.13 Safety impacts of Speed Alert (SPE)

The relevant safety mechanisms of SpeedAlert (SPE) are described below.

Mechanism 1: Direct in-car modification of the driving task

+ SpeedAlert is not intervening, it only informs the driver of speed limits and speeding (with a haptic gas pedal and a warning module). Safety will mainly be influenced by improved awareness of the actual speed limit on the current road and of speeding offences. Unintended speeding caused by lack of awareness of the speed limit will be reduced. This is a problem where the speed limit changes several times over short distances, where speed limit sign posting is sparse and where speed limits are not logical to the driver. Speeds will also in the long run be harmonised as also slower drivers tend to increase their speed when using the system (because they rely on the system to tell them when they exceed the speed limit).

+ Lower impact speeds will result in less severe injuries. As average vehicle speeds are reduced with SPE it can be assumed that the Nilsson power model (Nilsson 2004) can be used.

European ISA trials [SRA, 2002][eSafety Forum, 2005][ PROSPER, 2006]) have been used to estimate driver behaviour with SpeedAlert, taking into account that SpeedAlert is defined as a more flexible and voluntary system. Settings can be defined by the driver. The following behavioural adaptation (in line with the traffic simulation findings) is assumed on different roads:

- Motorways: 12% speeding > 5 km/h over the speed limit is reduced to 10%. Average speed is reduced 0.5 km/h. Average speed of speeders is reduced 1 km/h.
- Other rural and inter-urban roads: 20% speeding is reduced to 15%. Average speed is reduced 1 km/h. Average speed of speeders is reduced 2 km/h
- Urban streets: 25% speeding is reduced to 20% in towns. 15% speeding is reduced to 10% in cities. Average speed is reduced 0.5 km/h. Average speed of speeders is reduced 1 km/h
The basic estimate for SpeedAlert was results for different road conditions. The distributions of fatality reduction among road types are displayed in Table 38 and Table 39. The SPE1 estimate reflects the situation in 2010, SPE2 in 2020 (SPE2 has additional, co-operative elements, see Annex 3). The system is expected to be more advanced in 2020. In addition to that, there will be more variable speed limits and enforcement in 2020.

Table 38: Effect estimates of mechanism 1 on different road types (SPE1 – 2010 system).

<table>
<thead>
<tr>
<th>Road Type</th>
<th>Fatalities</th>
<th>Injuries</th>
</tr>
</thead>
<tbody>
<tr>
<td>motorway</td>
<td>-3.0 %</td>
<td>-1.5 %</td>
</tr>
<tr>
<td>rural</td>
<td>-5.5 %</td>
<td>-2.8 %</td>
</tr>
<tr>
<td>urban</td>
<td>-6.0 %</td>
<td>-3.0 %</td>
</tr>
</tbody>
</table>

Applied to the share of relevant road types, for mechanism 1 this means a reduction of approximately 5% in fatalities (2.5% for injuries) for SPE1.

Table 39: Effect estimates of mechanism 1 on different road types (SPE2 – 2020 system)

<table>
<thead>
<tr>
<th>Road Type</th>
<th>Fatalities</th>
<th>Injuries</th>
</tr>
</thead>
<tbody>
<tr>
<td>motorway</td>
<td>-3.5 %</td>
<td>-1.8 %</td>
</tr>
<tr>
<td>rural</td>
<td>-6.0 %</td>
<td>-3.0 %</td>
</tr>
<tr>
<td>urban</td>
<td>-7.5 %</td>
<td>-3.8 %</td>
</tr>
</tbody>
</table>

Applied to the share of relevant road types, for mechanism 1 this means a reduction of approximately 5.5% in fatalities (3% for injuries) for SPE2.

Mechanism 2: Direct influence by roadside systems

Intentional speeding is influenced by lack of awareness of risks, stress, culture and the driver’s self-control. Furthermore, it depends on the risk to be fined and the level of fines, which vary across Europe. A current trend is that camera and police enforcement is rising. This is also the assumption in the assessment of SpeedAlert in eIMPACT.

In France, a large program of fully automated enforcement has been launched in 2002. By the end of 2007, 2,000 speed cameras were expected to be in operation, either fixed cameras or mobile ones, on several types of streets, roads and motorways. The results are very impressive: the introduction of the automatic enforcement system in 2002/3 contributed to a reduction by 22% of national road fatalities in 2004 [Nouvier, 2007]. And this trend continues. The proportion of vehicles travelling at 10 km/h and more above the legal limit decreased from 35% to 20%. The number of vehicles exceeding the limit by more than 30 km/h went down by 80%. Average speeds decreased by 5 km/h between 2003 and 2005. Such reductions in speed will be enhanced by SpeedAlert.

We assume that Speed Alert drivers will set their equipment at a 2 km/h lower speed in 2020 because there is more enforcement, with more efficient enforcement methods (average speed or section control), which produces higher risk of fines in 2020.
It is also assumed that the speed will be further reduced with 5 km/h by the application of Variable Speed Limits (VSL) on traffic or weather controlled sections of the road network, the share of which is assumed to be 20% (of kilometres driven) in 2020.

**Mechanism 3: Indirect modification of user behaviour**

+ With increasing enforcement of speed limits and fines, SpeedAlert has a growing interest to the public. Together with a conventional cruise control it can produce a voluntary speed limiting system. It is probable that some drivers use it in that way if the risk of getting fines is imminent.

+ A current trend is also to use SpeedAlert for Quality assurance. School buses, disabled transports and taxi services will probably more often be obliged to equip vehicles with SpeedAlert to get public contracts. For companies, using SpeedAlert may be a part of their quality and security image.

Drivers and contractors will be influenced by trends towards more enforcement and quality assurance. These two forces together are estimated to stimulate a reduction of the average speed by about 2 km/h by 2020 with SpeedAlert.

**Mechanism 5: Modification of interaction between users and non-users**

+ Reduced speed by SpeedAlert users will influence drivers behind the equipped vehicle, especially on two-lane urban roads. In the ISA trial in Sweden it was found that every ISA car on average influenced the speed of one other car (SNRA, 2002), but this effect depends on the penetration rate. Vehicles with SpeedAlert will influence other non-equipped vehicles in urban areas and on single carriageway roads. This effect is estimated to increase the safety benefit by 40%.

The expected percentage changes shown above were multiplied with the relevant accident data proportions in EU-25 data. The estimates for this system were based on road type (see Table 8). The result for SPE2 for 100% fleet penetration is shown in Figure 39.
Finally, the full penetration estimates were applied to the fleet penetrations estimated for the target years 2010 and 2020 (Table 40). The table also shows the range of estimates for full penetration.

Table 40: The effect of SPE on fatalities and injuries for full penetration and four scenarios. For full penetration, the range (low/high) is given.

<table>
<thead>
<tr>
<th>SPE</th>
<th>Penetration rate for light/heavy vehicles (%)</th>
<th>Reduction in</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Fatalities (%)</td>
</tr>
<tr>
<td>Impact most probable</td>
<td>100 / 100</td>
<td>-8.7</td>
</tr>
<tr>
<td>Impact low</td>
<td>100 / 100</td>
<td>-4.5</td>
</tr>
<tr>
<td>Impact high</td>
<td>100 / 100</td>
<td>-12.6</td>
</tr>
<tr>
<td>Impact 2010 low</td>
<td>2 / 4</td>
<td>-0.2</td>
</tr>
<tr>
<td>Impact 2010 high</td>
<td>3 / 7</td>
<td>-0.4</td>
</tr>
<tr>
<td>Impact 2020 low</td>
<td>30 / 42</td>
<td>-3.6</td>
</tr>
<tr>
<td>Impact 2020 high</td>
<td>46 / 61</td>
<td>-5.2</td>
</tr>
</tbody>
</table>

1 These figures represent the expected impact if all vehicles were equipped, regardless of the year. All impacts are given for system including speed advice for fixed, variable and dynamic speed limits (SPE2), except 2010 low and high that are for speed advice for fixed limits (SPE1).

2 Fleet vehicle km equipped

The high estimate for the year 2020 would mean 1,076 avoided fatalities and 34,887 avoided injuries.
6 Conclusions and recommendations

6.1 Conclusions regarding the estimated penetration rates

The estimates for penetration rates in 2020 ranged from less than 0.5% (Intersection Safety) to 75% for passenger cars and 56% for goods vehicles (ESC). Most estimates were quite low, in particular for the co-operative systems, for which 2020 seems to be too early to expect substantial penetration rates (and thus impacts).

In 2010, penetration rates are expected to be low for all systems, with the exception of ESC (in passenger cars), which already reaches 30% in the high scenario. One of the reasons behind the low penetration rates is that the fleet renewal rate is quite low, because vehicles have a long lifetime. This is especially relevant for factory installed systems.

On the other hand, assumptions that active policy measures will be taken to accelerate deployment of ESC and eCall boosted the estimates of the penetration rates to levels far above those of the other systems. This emphasises the importance to identify the reasons why penetration rates become substantial or stay low, and to come up with effective promotion activities and incentives in order to use the potential of Intelligent Vehicle Safety Systems to improve road safety as efficiently as possible.

6.2 Main conclusions from the impact analysis

The safety impact analysis presented in this report shows that the selected systems have a significant potential to help improve traffic safety. The systems with the highest impacts are ESC and SpeedAlert, which are expected to help reduce approximately 3,250 and 1,100 fatalities, respectively, as well as approximately 52,000 and 35,000 injuries, in the 2020 high scenario\(^8\). These systems combine high penetration rates with a large target group of accidents and a high effectiveness of the system to prevent the targeted accidents.

Independent of the penetration rate, the systems with the highest potential to help avoid accidents with fatalities and injuries are ESC, Lane Keeping Support and SpeedAlert. While ESC and SpeedAlert are, in the 2020 high scenario, quite close to realising their potential, this is not yet the case for Lane Keeping Support, which has a low penetration rate.

Several other systems have a quite high potential, but limited to moderate impacts because of (very) low penetration rates. Among these are Emergency Braking, Driver Drowsiness Monitoring and Warning, Wireless Local Danger Warning and Intersection Safety (mainly for injuries). eCall, on the other hand, has a high penetration rate in 2020, and is quite effective in preventing fatalities, but it does

\(^8\) Note that the reference case in both future years was the situation without IVSS, but taking into account the autonomous, decreasing trend of accident numbers. This means that, if the systems were available today with the same penetration rates as in those future years, the expected impacts in terms of avoided fatalities and injuries would be considerably higher.
not reduce the number of injuries (in fact, a small increase is expected).

Finally, there are some systems that are quite effective to very effective in what they are designed to do, but target only a small share of accidents with fatalities and injuries. These systems (notably Full Speed Range ACC and Lange Change Assistant) therefore have low impacts in terms of the total number of avoided fatalities and injuries.

The potential of some systems (e.g. Lane Change Assistant (Warning) and Lane Keeping Support) can be increased by designing them in such a way that the system is switched on by default (but can still be switched off should the driver want this).

The traffic impact analysis distinguishes between direct and indirect traffic effects. Simulations with microscopic traffic models showed that the selected systems generally have neutral direct traffic impacts, at the penetration rates examined in eIMPACT. The only exception is SpeedAlert, where some negative travel time effects are expected on rural roads. Because lower speeds are associated with a positive environmental effect, the total direct effects for SpeedAlert are still positive.

Additional calculations based on the number of avoided fatalities and injuries and costs associated with congestion showed that benefits from reduced accident-related congestion can be expected for all systems. The benefits are highest for systems that are effective on congestion-prone roads with high traffic volumes (predominantly motorways). However, the number of avoided accidents is the most important factor. ESC, as the system with the highest number of avoided accidents, has the highest indirect effects.

The neutral effects are not surprising since the systems' main effects are supposed to be on safety – they were not designed to improve throughput. Even when systems showed clear effects (e.g. hard braking or reduced speeds after a warning), the effects were mostly very small, or very local, or only apparent in very rare events. On the level of complete trips as made by vehicles in the EU-25, this generally means that the direct traffic effects are negligible, especially at low penetration rates.

Expressed in monetary terms, the traffic effects (direct plus indirect) of these IVSS are small (but all positive) compared to the safety effects. The safety effects will therefore dominate the cost-benefit analysis.

The effects of individual IVSS (with the exception of ESC) may appear to be quite small, especially when looking at the low scenarios and estimates for the earlier target year 2010. It is, however, typical for traffic safety measures that the magnitude of effects of individual measures is usually not very high – there is no single measure that can solve all problems. In practice, vehicles will usually be equipped with several systems that together may have a considerable potential to increase traffic safety. Another factor to consider is that the expectations for a new measure have been overestimated in the past. The objective of eIMPACT was to make an effort to try to provide reliable, well motivated effect estimates.
6.3 Conclusions about the impact assessment methodology

eIMPACT made a step forward by applying an integrated approach for the impact assessment of IVSS. Prior to the eIMPACT project, many systems were analysed for a narrowly-defined situation, e.g. only motorways, for a limited set of situation tested in a driving simulator, etc. In eIMPACT, all available information about a system was processed in a structured way, so that traffic and safety impacts could be determined for a wide range of situations, resulting in impacts for the whole of the EU. The methodology provides an exhaustive, complete approach to thinking about the possible effects of the use of future systems.

Micro-simulation of traffic flows with equipped and unequipped vehicles formed the basis for the traffic impact analysis. As it turned out, the selected IVSS generally did not change traffic flow patterns much (nor were they designed to, as safety systems), but the translation of system specifications into rules for vehicle and driver behaviour (for unequipped and equipped vehicles) that could be implemented into the simulation models contributed significantly to a better understanding of the systems' working.

Simulation results inevitably refer to narrowly-defined situations, but care was taken to model each system in the relevant situations and additional traffic data (of a more macroscopic nature) was often used to draw conclusions for the EU level. It was found, however, that it is difficult to find data for a large number of EU member states on, for instance, driver behaviour, congestion levels, kilometres driven in certain conditions, etc. Even more difficult to find is information about traffic behaviour on a microscopic scale (e.g. speeds and headways in specific situations).

The strength of the safety impact assessment lies in the application of a tool designed to take into account the nine safety impact mechanisms, the relevant variables in accident data and the frequency of different accident types or conditions in the data.

eIMPACT deals mainly with systems for which there is not yet much experience; little to no empirical evidence about the effectiveness is therefore available. All potential effects, whether intended or unintended, are important to discuss (the implementation and use of a measure on a wider scale or over a longer period typically reveals effects and behavioural adaptation not anticipated in the first estimates). Indirect evidence (such as information on user acceptance and driver reactions in the real context, e.g. from similar systems) and results from simulation studies can be used, but have to be interpreted by professionals when applied for analyses in a certain context (such as in eIMPACT, for the EU level).

The methodology also required general accident data for the EU. The availability of reliable and comprehensive accident databases is essential for the analyses. However, the availability of accident data and the effort involved in obtaining and processing the data are an issue. For instance, the availability of such data for EU-25 is currently a problem. The general trend is that easily available databases include aggregated data (the data that cannot be cross-tabulated according to variables describing accident type and location, vehicles and persons involved etc.), but disaggregated data with more specific information is rare. Fortunately, the CARE database provided...
sufficiently disaggregated data at the European level that could be used in the analyses. However, much work is needed to get harmonised, reliable and comprehensive data for each European country. A critical variable (collision type) was removed from the database during the project. Individual member states had to be contacted to obtain the desired data, and different definitions used for the required classifications needed to be harmonised before the calculations could be carried out. The research into the effects of IVSS would greatly benefit from expanded availability of comprehensive, detailed and harmonised, disaggregated accident data (the data that include specific information for each accident, vehicle and person involved) for each European country.

Finally, the starting point for the impact assessment, the specification of the systems, is not straightforward. Firstly, many definitions of the ‘same’ system exist. It is very important to be transparent about the choices made in the functional and technical specifications and about the assumptions regarding the working of the system based on these specifications. In some cases, it is difficult to establish the reference case (in terms of current traffic flow characteristics and vehicle and driver behaviour, which the system could affect), as vehicle and driver behaviour with and without IVSS need to be described in much detail (in time and space) to enable accurate assessment of the effects. Secondly, most of the systems analysed in eIMPACT do not yet exist, even in prototype form. To develop system specifications in these cases requires significant effort and co-operation among system developers and technicians, human behaviour specialists, and traffic specialists.

eIMPACT put considerable effort into assessing all available information and extracting the input needed for the safety impact assessment methodology, in order to provide reliable and transparent safety impact estimates. The analyses require qualified and experienced experts from engineering, psychology and sociology disciplines. Because the methodology covers many aspects, the performance of analyses can be time-consuming. However, the basis of the assessment is valid and the approach was proven to be feasible in its current set-up and effective in delivering the desired results.

### 6.4 Recommendations

The positive experiences with the application of the integrated eIMPACT assessment approach suggest that the safety assessments of any advanced driver assistance systems (stand-alone and co-operative) should be based on this type of approach. In the future, when more accurate data are likely to be available, the safety estimates can be further improved. Some suggestions for improvements, refinements and new areas of application for the approach are:

- Application of parts of the methodology to other systems as a sort of decision support, as a first ‘screening’ activity of the potential of IVSS.
- In the impact assessment, systems were analysed individually rather than as bundles of several systems. This reduced the complexity of the analysis and enabled the provision of
tangible results, clearly showing how a particular system can contribute to traffic safety. A next step is the assessment of logical combinations of systems, based on making full use of the promising technologies available. For this, a vision is needed on the combined use of components and functionalities. N.B. When systems are combined, the effects of the individual systems in the bundle cannot be simply added up, as the systems may target the same groups of accidents. In addition, one function will sometimes reduce the need for another function (e.g. a Full Speed Range ACC may reduce the need for an Emergency Braking system). Hence, possible interactions of the effects of individual systems should be taken into account.

- Further analysis of the needs for IVSS in the EU by cluster. There are differences in the shares of accidents by collision types or conditions, which means that the efficiency of specific systems varies between clusters.

- For future impact assessments of IVSS (or other systems that have very subtle and very local effects on traffic), it is recommended to take more time for the system specification. An iterative approach seems inevitable, in which initial specifications can be refined. It is important to define a moment at which the specifications are considered 'final', in order to be able to do the traffic (and safety) impact assessment efficiently.

- Better availability and comparability of accident data for the EU member states would reduce the effort needed for quantification of the safety impacts in terms of avoided fatalities and injuries.

To solve the problem of lack of reliable evidence of acceptance and behavioural adaptation by users of IVSS, Field Operational Tests (FOTs) can be very helpful. However, FOTs should be carefully set up to generate data for the wide range of relevant situations that any driver might encounter.

FOTs can complement micro-simulation, which can be a powerful tool to analyse IVSS. Currently, microscopic traffic simulation models are especially suited to analyse systems that influence longitudinal behaviour (speeds, following behaviour). Lateral effects such as the choice of (position in) lane could not be modelled accurately with the available models. Research into the modelling of lateral effects is needed to enable traffic simulation of systems such as Lane Keeping support and Lane Change Assistant. Also, there is a need for more microscopic traffic data (speed distributions, accelerations, headways, lateral position etc.), to enable more accurate calibration of microscopic traffic models. Preferably, there should be data for different regions of the EU, as driving behaviour varies between regions (and between urbanised and rural areas). Apart from data from FOTs, other data sources (loop detectors, radar, cameras etc.) can be used.

N.B. The FESTA project (Field operational test support Action) is developing a methodology for running FOTs and will give recommendations for data collection.
Acknowledgements

The work in WP3000 could not have been done without the support of all the partners in the eIMPACT consortium, and many people outside the consortium. We would like to thank the following people/organisations for their contribution:

- The partners in the TRACE-project that provided the accident data. eIMPACT worked in co-operation with the parallel TRACE project, focusing on accident causation analysis. TRACE provided eIMPACT with the accident data needed for the safety impact calculations. The data was based on the CARE database and an internal data enquiry organised among TRACE partners. During the project, information about the methodological approaches was shared in project meetings and in a workshop. In addition, a common workshop was arranged to discuss the results of the work. In TRACE, the main responsible partner for providing eIMPACT with data was Loughborough University. (National Accident Data for Great Britain is collected by police forces and collated by the UK Department for Transport. The data are made available to the Vehicle Safety Research Centre at Loughborough University by the UK Department for Transport. The Department for Transport and those who carried out the original collection of the data bear no responsibility for the further analysis or interpretation of it.) CDV (eIMPACT and TRACE partner) had responsibility to provide the Central Eastern European accident data.

- The OEMs and suppliers that took part in the WP3100 Scenario Workshop.

- The PReVENT partners and other external parties who provided information on the systems.

- The EUCAR working group on safety, for providing feedback on safety results.

- Fabrizio Minarini, eIMPACT project officer at the EC.
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Annex 1 Keywords

intelligent vehicle safety systems, impact assessment, penetration rates, traffic impacts, traffic safety impacts, accident causation, fatalities, injuries, congestion costs, methodology.
# Annex 2  Glossary

## The selected systems:

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ESC</td>
<td>Electronic Stability Control</td>
</tr>
<tr>
<td>FSR</td>
<td>Full Speed Range ACC</td>
</tr>
<tr>
<td>EBR</td>
<td>Emergency Braking</td>
</tr>
<tr>
<td>PCV</td>
<td>Pre-Crash Protection of Vulnerable Road Users</td>
</tr>
<tr>
<td>LCA</td>
<td>Lane Change Assistant (Warning)</td>
</tr>
<tr>
<td>LKS</td>
<td>Lane Keeping Support</td>
</tr>
<tr>
<td>NIW</td>
<td>NightVisionWarn</td>
</tr>
<tr>
<td>DDM</td>
<td>Driver Drowsiness Monitoring and Warning</td>
</tr>
<tr>
<td>ECA</td>
<td>eCall (one-way communication)</td>
</tr>
<tr>
<td>INS</td>
<td>Intersection Safety</td>
</tr>
<tr>
<td>WLD</td>
<td>Wireless Local Danger Warning</td>
</tr>
<tr>
<td>SPE</td>
<td>SpeedAlert</td>
</tr>
</tbody>
</table>

## Terms used in the safety impact analysis:

- **accidents**: all accidents involving personal injury.
- **bus (or coach)**: Motor vehicle with at least four wheels, used for transporting people. Public or private use. Type DK driving licence required (BE, GB, IE, NI). Includes bus, more than 8 and 16 seats, minibus, trolley-bus (except LU), scheduled bus, unscheduled bus, school bus.
- **CARE**: Community Road Accident Database. CARE is a Community database on road accidents resulting in death or injury (no statistics on damage – only accidents). The major difference between CARE and most other existing international databases is the high level of disaggregation, i.e. CARE comprises detailed data on individual accidents as collected by the Member States.
- **E112**: Calls made to the emergency number 112 containing location information.
- **FARS**: The Fatality Analysis Reporting System (FARS) contains data on all vehicle crashes in the United States that occur on a public roadway and involve a fatality.
| **fatality** | death within 30 days of accident, except ES (24 hours), FR (6 days), IT (7 days), PT (24 hours). Suicide not included (except DK, ES, FR). Natural death not included (except LU, SE). |
| **goods vehicle** | Heavy goods vehicle: motor vehicle with at least four wheels, with a permissible gross weight of over 3.5 tons, used only for the transport of goods. With or without a trailer. Type C driving licence required. Includes road tractor, road tractor with semi trailer, lorry >3.5t, tanker. Lorry up to 3.5 tons and van: motor vehicle with a permissible gross weight of up to 3.5 tons, used only for the transport of goods. Type BE driving licence required. Includes vans. |
| **passenger car (or taxi)** | Passenger car or taxi: motor vehicle with three or four wheels, used to transport only or mainly people. Seating for no more than 8 passengers. Type BE driving licence required. Includes minibus (GB, NI). Motor vehicle with four wheels for public use in the transport of people. |
| **PReVENT** | PReVENTive and Active Safety Applications. The Integrated Project PReVENT is a European automotive industry activity co-funded by the European Commission to contribute to road safety by developing and demonstrating preventive safety applications and technologies. |
The PReVAL subproject provided the PReVENT project with a harmonised evaluation framework, define a methodology to be used in the impact assessment of various applications and apply the methodology to a set of given use cases.

TRaffic Accident Causation In Europe. The TRACE project looks into accident causation and the evaluation of the safety benefits of technologies.

Terms used in the traffic impact analysis:

- **headway**: The headway between vehicles is the amount of time that elapses between two vehicles passing the same point travelling in the same direction on a given route.

- **intended speed**: The intended, or desired speed, is the speed that drivers choose when they are not influenced by any vehicle ahead of them.

- **micro-simulation**: Micro-simulation models are computer models where the movements of individual vehicles travelling around road networks are determined by using car following, lane changing and gap acceptance rules.

- **time-to-collision**: The time-to-collision is the time that remains until a collision between two vehicles would have occurred if the collision course and speed difference are maintained.
# Annex 3  System specifications

## Electronic Stability Control | Acronym: ESC

### Functional description of system

The aim of ESC is to stabilize the vehicle within the physical limits and prevent skidding through active brake intervention and engine torque control.

ESC compares the driver's intention with the vehicle's response, determined by measuring lateral acceleration, rotational speed (yaw velocity) and individual wheel speeds. ESC then breaks individual front or rear wheels and/or reduces excess engine power as needed to help correct under-steering or over-steering.

ESC also includes anti-lock brakes and all-speed traction control, which senses drive-wheel slip under acceleration and individually breaks the slipping wheel or wheels, and/or reduces excess engine power, until control is regained.

ESC cannot override a car's physical limits. If a driver pushes the possibilities of the car's chassis and ESC too far, ESC cannot prevent a crash. It is a tool to avoid spinning and to help the driver to maintain control.

### Avoiding an obstacle

The system is active at all times. It works as follows:

- ESC checks in which direction the driver wants to steer;
- ESC checks where is the vehicle is headed to;
- If the desired direction does not match the heading, ESC stabilizes the vehicle by intervening in the braking system without any further driver action. The car is held on track more safely.

### System components and costs

An ESC system, according to the functional description above (evaluated in eIMPACT), requires the following components:

- Hydraulic modulator unit with attached ECU
- Sensors Wheel-speed / Steering-angle / Yaw-rate and lateral acceleration

**Costs: (total sum of components incl. implementation costs)**

2010: 158 EUR  
2020: 145 EUR

*Source cost data: eIMPACT consortium with the exception of Centro Ricerche Fiat.*
ESC is now a widely deployed system, ready to perform in every vehicle platform.

<table>
<thead>
<tr>
<th>Full Speed Range ACC</th>
<th>Acronym: FSR</th>
</tr>
</thead>
</table>

**Functional description of system**

The Adaptive Cruise Control Full Speed Range (FSR-ACC) system keeps a driver-set speed or, in case the vehicle in front is slower, a driver-set distance to this vehicle. The system is activated by the driver. When the vehicle comes to a standstill, it only starts again after a command by the driver. The system is deactivated either by a driver input (“deactivate”) or by a driver intervention (braking). From deactivation a “resume” is possible activating the previous values for desired speed and distance.

The goal of the system is to keep a safe headway and extend the operating range of the conventional cruise control by making it usable in more traffic situations than in free flow driving and by providing this functionality at all speeds, from standstill to stop&go traffic to high speed driving. When a deceleration is required that is stronger than the system limit (around 4 m/s²) the driver is warned, e.g. by an audible signal. Within the deceleration limit rear-end crashes are avoided in following traffic. An avoidance of other standing obstacles is not tackled by the system.

**System components and costs**

An FSR system, according to the functional description above (evaluated in eIMPACT) requires the following components:

- Long-range (150m) radar with beam-shaping (wide angle in front of the vehicle and narrow in the far field)
- Warning module
- Display extension
- Braking actuation
- Vehicle trajectory estimation
- Driver intention estimation

**Costs: (total sum of components incl. implementation costs)**

- **2010**: 158 EUR
- **2020**: 143 EUR

_Source cost data: eIMPACT consortium with the exception of Centro Ricerche Fiat._

**Remarks**

(none)
**Emergency Braking**

**Acronym:** EBR

---

**Functional description of system**

The aim of EBR, a fully automatic system, is to avoid or mitigate longitudinal crashes (braking only). The system reacts if a vehicle approaches another leading vehicle. The system reacts in three steps:

1) Optical and acoustical warning, if the approach could lead to an accident.
2) Autonomous partial braking, if the distance is reduced further.
3) Autonomous full braking, if an accident appears inevitable. Input is the distance and the relative speed to a leading vehicle.

The system reduces the impact speed in case of immediate danger, which increases passive safety and reduces accident consequences. It results in:

- Reduced risk of injuries / collision mitigation through decreased impact velocity.
- Reduced braking distance through immediate braking action and adapted, improved brake assist function.
- Support for collision avoidance and collision mitigation.

The system works as follows:

- It continuously senses the distance to vehicles ahead (radar).
- This is followed by object identification (listing).
- The differential velocity to objects is calculated.
- The driving corridor is calculated.

The system then provides as output the time to collision to relevant objects in driving corridor, and action (warning and/or braking) is taken when needed.

---

**System components and costs:**

An EBR system according to the functional description above (evaluated in eIMPACT) requires the following components:

- Mid-Range-Radar MRR
- Braking actuation
- Vehicle trajectory estimation
- Driver intention estimation
- Warning Module

**Costs:** (total sum of components incl. implementation costs)

**2010:** n.a.

**2020:** 107 EUR

Assumption: An additional camera could be necessary in order to assure liability obligations.
and enable the full potential of EBR.

*Source cost data: eIMPACT consortium with the exception of Centro Ricerche Fiat.*

**Remarks:**
The system is technically based on the Full Speed Range ACC. It also is one of the first steps of the introduction of collision avoidance systems.

---

### Pre-Crash Protection of Vulnerable Road Users

**Functional description of system**
The aim of PCV is to detect vulnerable road users and employ fully automatic emergency braking (no passive safety) when a collision is unavoidable.

The system is meant for both passenger cars and goods vehicles. It improves safety via the protection of road users outside the vehicle, such as pedestrians, cyclists and other vehicles. The focus is on front crash scenarios, on the period between 1-3 seconds (this varies with OEM) and 100 milliseconds before impact. The system mitigates the consequences of crashes through autonomous braking.

The system takes the driver's place in case the driver doesn't brake at all or not sufficiently. Pedestrians are detected within a distance of 40 meters. Due to autonomous and/or more effective braking the consequence is a reduced collision speed. Some fatalities will hence be transformed to severe and light injuries.

The figure below simply shows the regions in front of the vehicle corresponding to detection, classification, decision and activation.

![Detection Areas](image)

### System components and costs
A PCV system, according to the functional description above (evaluated in eIMPACT), requires the following components:

- Stereo video system
- Braking actuation
- Vehicle trajectory estimation
- Driver intention estimation

**Costs: (total sum of components incl. implementation costs)**
PCV differs from EBR in the following ways:

- the special focus on vulnerable road user which have different detection characteristics and thus the need of a different sensor technology;
- a wider detection angle and typically shorter detection time.

**Lane Change Assistant (Warning)**

**Acronym**: LCA

**Functional description of system**

The system enhances the perception of drivers in lateral and rear areas and assists them in lane change and merging lane manoeuvres through three functions:

- **rear monitoring and warning**: to improve driver attention and decrease the risk of collision in the rear area of the vehicle, particularly in case of limited visibility or critical workload of driver attention;
- **lateral collision warning**: to detect and track (in general moving) obstacles in the lateral area and to warn the driver about an imminent risk of accident (e.g. collision);
- **lane change assistance with integrated blind spot detection**: to assist the driver in lane change manoeuvres while driving on roads with more than one lane per direction.

Vehicle-to-vehicle accidents is the main category of accidents that benefit from the system. In particular, when sensor data detect an obstacle in the lateral and rear area of a vehicle, including the blind spot area, the system gives to the driver visual (i.e. lamps) or acoustic (i.e. alarm) information using a warning module, in order to stimulate the driver reaction. The illustration below outlines the scope of a LCA system.
Two MRR components looking sidewise and backwards in conjunction and a warning module
to display information are regarded as sufficient for an LCA system. A third radar looking
directly backwards to monitor the rear would improve the system, but this would increase
the costs of the system.

System components and costs:
An LCA system according to the functional description above (evaluated in eIMPACT)
requires the following components:

- Warning Module
- 2 Mid Range Radar (MRR – in the rear)

Costs: (total sum of components)
2010: 130 EUR
2020: 103 EUR

Source cost data: eIMPACT consortium with the exception of Centro Ricerche Fiat.

Remarks
- The LCA system evaluated in eIMPACT is assumed to be active all the time and if a
  minimum velocity is exceeded. In addition, an LCA System could basically be
designed such, that a driver could switch it off, but such a feature is not
recommended.
- **Including a haptic steering wheel** could improve a driver’s reaction, but such a
  feature increases price and complexity. Hence, the eIMPACT LCA system description
does not include this functionality.
Lane Keeping Support  Acronym : LKS

Functional description of system:
A lane keeping system for passenger cars and commercial vehicles supports the driver to stay safely within the “borders” of the lane. It determines the vehicle position relative to lane markings and combines this with recognition of driver intention or behaviour (e.g. taking turning lights into account or via analysing the motion of the vehicle via ESC) to check for unintentional lane departure. The system is for use on motorways and rural roads, and works under various road- and driving conditions. There are two phases of development which reflect different objectives and situations.

Phase 1: the driver is warned by sound or by a steering wheel with haptic feedback, but the vehicle would continue to leave the lane without any intervention of the driver.

Phase 2: the driver is assisted by an active steering wheel trying to intervene in order to keep the vehicle on a correct path within the lane. **Phase 2 is investigated and evaluated in eIMPACT.**

The system can be switched off by the driver, and temporarily switches itself off when lane markings cannot be detected well enough or the velocity is below a predefined threshold.

The driver is always informed of the availability of the system (e.g. integrated display in the warning module).

The system is an intervening system, but does not keep the vehicle autonomously in the middle of the lane. The driver is always responsible for the driving direction of the vehicle.

Note that some implementations of LKS systems are already on the market. Depending on their specific functions they may require additional components.
System components and costs:
An LKS system, according to the functional description in phase 2 above (evaluated in eIMPACT), requires the following components:

- Active steering system
- Warning Module
- Mono camera (front)
- Stabilize vehicle

Costs: (total sum of components)

**2010:** 273 EUR

**2020:** 223 EUR

*Source cost data: eIMPACT consortium with the exception of Centro Ricerche Fiat.*

Remarks:
For eIMPACT we chose *not* to consider digital map databases. Digital maps can be used to keep the system operational even if the lane markings are missing or ambiguous for a short road section, but add cost and complexity to the system.

We also chose not to consider forward looking active sensors (radar/lidar/laser) for eIMPACT. Such sensors can provide data on travel paths of vehicles ahead. These systems could enhance the functionality but would also increase cost and complexity.

NightVisionWarn

<table>
<thead>
<tr>
<th>Acronym</th>
<th>NIW</th>
</tr>
</thead>
</table>

**Functional description of system**

The aim of NIW is to extend the visible range for a driver in darkness, including obstacle detection and warning, as well as warning for vulnerable road users.

The visible range for the driver in darkness is extended without disturbing on-coming drivers by using an “invisible high beam”. This is achieved by using an infra-red camera looking forward and displaying its view on a screen in the vehicle. The display shows the area in front of the vehicle with a longer range of visibility than with the normal low-beam headlights (see figure).

It detects and warns for obstacles and vulnerable road users if a critical driving situation is detected. It reduces fatalities and injuries for all kinds of accidents occurring in darkness.
System components and costs:
A NIW system according to the functional description above (evaluated in eIMPACT) requires the following components:
- Display extension
- Warning Module
- Active illumination for NIR
- Mono Camera image guided

Costs: (total sum of components incl. implementation costs)
2010: 202 EUR
2020: 163 EUR

Source cost data: eIMPACT consortium with the exception of Centro Ricerche Fiat.

Remarks:
Application of FIR technology if obstacle warning (non infrared emission objects) is excluded.

Driver Drowsiness Monitoring and Warning

Functional description of system
The Driver Drowsiness Monitoring and Warning system monitors the condition of the driver with respect to symptoms of drowsiness. When it diagnoses the driver as ‘hypovigilant’ (i.e., ‘drowsy’, or even ‘sleepy’), the type of warning issued depends on the criticality of the traffic situation, i.e., the estimated momentary risk. Warnings can range from alert sounds to seat belt vibration. The expected reaction of the driver is to pull over and take a rest or another measure (e.g., going home by train).

The system’s architecture is shown below.

The system gives the warning based on onboard driver physiology monitoring sensors and vehicle and driver sensors. The following parameters are measured:
- The eyelid activity (PERCLOS, i.e., percentage of time that eyelids are closed), which is measured by the Eyelid Sensor (ELS).
- The steering grip sensor provides information about the pressure the driver applies on the steering wheel on the left and right side respectively, where the
variation of the steering grip pressure as a function of time is related to state of vigilance. This is combined with the PERCLOS measure to obtain a final physiological classification of drowsiness level.

- Lateral position measurement relative to the edge line of lane (using a camera); steering wheel parameters; speed and speed variability.
- Environmental parameters: road geometry, presence and location of surrounding vehicles (video-based), GPS-derived measures.

The Driver Drowsiness Monitoring and Warning system works in all lighting conditions and basically at all allowed speed ranges. The system works at all road types, although it works best on motorways because of the quality of lane markings for lateral position measurement. The limitation of the system is that lane markings should be of reasonable quality.

### System components and costs

A DDM system, according to the functional description above (evaluated in eIMPACT) requires the following components:

- Warning module
- Steering grip sensor
- Driver monitoring camera
- Mono camera for line monitoring

### Costs: (total sum of components incl. implementation costs)

**2010:** 118 EUR  
**2020:** 98 EUR

*Source cost data: eIMPACT consortium with the exception of Centro Ricerche Fiat.*

### Remarks

(none)

### eCall (one-way communication)

**Acronym:** ECA

**Functional description of system**

The Pan-European in-vehicle emergency call system is known as eCall. The eCall system is based on either the automatic detection of an accident with a sensor or a manual emergency call made by pushing a button. The eCall system includes both functions. In both cases a normal voice communication is opened to the emergency centre after a small delay, and accident vehicle location and identification as well as possible accident severity information is transmitted automatically. The automatic detection of an accident is based on the vehicle's sensors or the sensors built into the eCall device. The in-vehicle sensors can detect e.g. the triggering of an airbag, intense deceleration, vehicle roll-over or a sudden temperature increase. The data of the vehicle location and direction at the time of the accident is obtained from satellite positioning.
The benefits of the eCall system are primarily based on the faster relaying of essential initial accident information, such as the type of accident and the precise accident location. The acceleration of the road-accident response time is expected to reduce the severity of road accidents. The eCall system itself will not reduce the number of original accidents, but it may decrease the number of secondary accidents.

**The automatic eCall triggering strategy**

The automatic eCall trigger will be designed to be safe and robust, i.e. designed so that a minimum of false alarms is generated.

The automatic eCall is triggered by an in-vehicle sensor or sensors. Currently, the use of the airbag signal as the trigger is preferred by the vehicle industry.

The system will be designed to reflect as many different crash types as possible (e.g. front, rear, side and roll crashes).

**The manual eCall triggering strategy**

The manual eCall trigger will be designed so that accidental triggers are rare. There are different scenarios for how accidental triggers can be avoided. One solution could be that the system will alarm only when the button has been pushed twice within 5 seconds. Appropriate education is needed in order to minimise the number of manual eCalls without emergency content.

**System components and costs**

An ECA system, according to the functional description above (evaluated in eIMPACT) requires the following components:

- Public Service answering Point (PSAP)
- GPS
- mobile phone (and corresponding infrastructure of a mobile network operator (MNO))

**Required Technologies:** The eCall-message generated in the vehicle – providing the so-called Minimum Set of Data (MSD) via mobile phone – is enriched and transmitted via a mobile network operator (MNO) to a PSAP system (Public Service Answering Point is an infrastructure system). The PSAP activates all required activities to send out emergency vehicles to the location of the accident.

The GPS system is used to determine the position of the accident vehicle and is part of the...
transmitted MSD.

**Costs: (total sum of components incl. implementation costs)**

**2010:** 61 EUR; PSAP infrastructure: 29.4 M EUR per year  
**2020:** 60 EUR; PSAP infrastructure: 29.4 M EUR per year  

*Source cost data: eIMPACT consortium with the exception of Centro Ricerche Fiat.*

**Remarks:**

The ECA system evaluated in eIMPACT is based on investigations of EU-funded projects to prove the technical feasibility (e.g. GST project (Global System for Telematics)). Many European countries signed a Memorandum of Understanding (MoU) for the introduction and are currently preparing the deployment of an eCALL system. First installations of eCALL will provide more accurate figures for the costs of PSAPs.

**Intersection Safety**  
**Acronym:** INS

**Functional description of system**

Intersection Safety assists the driver in avoiding common mistakes which may lead to typical intersection accidents. The safety impact assessment of eIMPACT covers two functions:

1) **Traffic light assistance:** The driver shall be prevented from ignoring the red light. This ends in an urgent acoustic warning if the situation becomes critical. In order to assist the driver in avoiding such a hazard a speed recommendation will be given when approaching an intersection with traffic lights, depending on the current and intended status of the traffic light. With this additional information, the driver is able to drive with appropriate speed, knowing in advance which situation he will be faced with when reaching the intersection.

2) **Right-of-way assistance:** The right-of-way assistance pays special attention to lateral traffic. The system warns the driver if he seems to violate a right-of-way but also if somebody else is expected not to give the right-of-way to the case vehicle. It supports the driver in finding an acceptable gap between vehicles in order to cross the intersection safely. Visual information on the screen and, if necessary, an acoustic warning shall support the driver in his decision making (e.g. a warning that gives an assessment of the gap to the on-coming vehicles) but also directly prevents accidents that occur because of inattention or occluded field of view of the driver. This warning is based on the predicted trajectories of the case vehicle and other road users (see figure below).
3) Left-turn assistance: The left-turn assistance warns the drivers about potential collision with other vehicles with crossing path. The left-turn assistance pays special attention to oncoming traffic during the left turn. According to speed and distance to conflict area of both vehicles, the controller checks the risk of the situation and presents visually a risk level (green, yellow, red) to driver. The risk level is presented with a continuous manner for the time of an identified risky situation. It supports the driver in finding an acceptable gap between vehicles in order to cross the intersection safely. Also an acoustic warning is given if the situation is dangerous (no safe left turn). Visual information on the screen and in the end acoustic warning shall support the driver in his decision making (e.g. warning that gives an assessment of the gap to the on-coming vehicles) and the system might also be able to prevent accidents that occur because of inattention or occluded field of view of the driver.

System components and costs
An INS system, according to the functional description above (evaluated in eIMPACT) requires the following components:

- V2X communication unit
- Locally high resolution positioning
- Digital intersection maps on lane level
- Warning module

Hazardous intersections need to be equipped with a traffic status and forecast unit for all the traffic lights of the intersection.

Costs: (total sum of components incl. implementation costs)
2010: n.a.
2020: 960 EUR; infrastructure equipment: 35.2 M EUR per year

Source cost data: eIMPACT consortium with the exception of Centro Ricerche Fiat.

Remarks
INS is supposed to be a fully cooperative approach. Nevertheless, the collision avoidance function can profit from additional autonomous sensor based functions.
**Functional description of system**

The PReVENT system WILLWARN (Wireless Local Danger Warning - WLD) supports the driver in safe driving by inter-vehicle communication.

The system detects hazards via its own sensors and communicates the hazard information to other vehicles via vehicle-to-vehicle communication. Messages are exchanged with oncoming traffic and by networking (hopping). The messages are kept alive in a road-network for some time and distance depending on the equipment rate of the system. Also, information from the roadside (road works, roadside units, etc.) can be integrated via infrastructure-to-vehicle communication. Only drivers approaching the hazardous spot will get the warning. It is expected that the warnings are given approximately 10 seconds before the driver reaches the hazardous spot. The system provides only warnings. Thus, the system provides drivers with the opportunity to adapt the vehicle speed and inter-vehicle distance early-on, leading to a higher situational awareness of potential unforeseen danger. The system is designed primarily for non-urban roads.

The WLD safety impact analysis covers the following applications:

1. (Detection) and warning of obstacles (other vehicle) on the road. Warning about an obstacle is given if one's own car is an obstacle for others. This means that the vehicle has an accident and might be an obstacle for other vehicles. The warning can be submitted based on airbags, emergency flasher etc.

2. Detection and warning of reduced friction or reduced visibility due to bad weather. The warnings are given to the drivers only if they are confirmed by a substantial number of cars. Sensors used for detecting the low friction/visibility might be lights, wipers, temperature, wheel speeds, gyro - or in the future friction and visibility sensors.

The figures below illustrate the scenarios investigated in eIMPACT.

---

**System components and costs**

A WLD system according to the functional description above (evaluated in eIMPACT) requires the following components:

- V2V communication unit
- GPS-module
- Digital map
- Warning module

**Costs: (total sum of components incl. implementation costs)**

**2010:** n.a.

**2020:** 132 EUR

*Source cost data: eIMPACT consortium with the exception of Centro Ricerche Fiat.*

---

**Remarks**

As the detected hazardous situation is transferred to another vehicle by vehicle-to-vehicle communication.
communication, not only the traffic density, but also the penetration level of WLD vehicles needs to be high enough to be able to achieve the maximum safety effects of the system. The concept of warning dissemination and transport in the car used in WLD enables a high benefit even at low equipment rates.

**SpeedAlert**  
*Acronym: SPE*

**Functional description of system**

Speed Alert is a map and camera based system warning for speed limits by use of a haptic gas pedal and a warning module for when the speed limit is exceeded. The goal is to reduce the number of accidents due to speeding. The system informs about static, temporary and variable speed limits. The driver remains responsible for maintaining a safe and proper speed. The system does not monitor the conditions of the road, tires, etc.

The system is introduced in 2 phases:

- **Phase 1:** Stand-alone system that gives speed limit advice based only on static and fixed time dependent speed limits. This system will be operational in 2010.
- **Phase 2:** Cooperative system that also takes into account information broadcast by traffic centres, VMS-es and beacons, and gives speed advice not only based on speed limits but also based on recommended speeds. In particular, the system dynamically recommends speeds in curves, near work zones and schools, on slopes and bridges, and for events, weather and traffic. This system will be operational in 2020.

A display informs the driver of the present speed and numeric speed limit, with additional colour coding (green = below speed limit, yellow = slightly above, red = far above). A special symbol is used if there is insufficient data. We propose to use separate symbols to distinguish between speed limits and advisory speeds (e.g., a red circle for speed limits and a blue background for advisory speeds). If the speed limit is exceeded by a certain margin for a prolonged time (in the order of seconds), the driver is warned by an additional audio signal, optionally combined with a haptic signal through the accelerator. The margin is in the 0 – 20 km/h range, for example 10 km/h if speed enforcement is unlikely, and 5 km/h if likely. This can be set by the driver.

The system can be switched off by the driver.

It is assumed that it will take some time to deploy full coverage of speed limits on digital maps by map providers. Improvement of the speed limit data update process will improve the data quality by 2010. Provision of variable and temporary speed limits is included in the 2020 system.

**System components and costs**

A SPE system according to the functional description above (evaluated in eIMPACT) requires the following components:

- Positioning system (GPS/GNSS)
- Digital maps with static speed limit
- mono camera (front)
- Display extension
- Haptic gas pedal
- DAB (digital audio broadcast) (2020)
- SRC (sample rate conversion) (2020)
- GPRS (general packet radio service) (2020)

**Costs: (total sum of components incl. implementation costs)**

**2010:** 233 EUR  
**2020:** 200 EUR  

*Source cost data: eIMPACT consortium with the exception of Centro Ricerche Fiat.*

**Remarks**

The Speed Alert system evaluated in eIMPACT is based on the technological concept developed by the SpeedAlert consortium.

The maps are updated once per year (through CD/DVD) from 2010 onwards, and on-the-fly from 2020 onwards.

In 2010 the maps will have 90% coverage of main roads (motorways, national highways) and 20% coverage of urban and rural roads. In 2020 these figures are 100% and 80%, respectively.
## Annex 4 Penetration rates

### Table 41: Penetration rates (fleet)

<table>
<thead>
<tr>
<th></th>
<th>2010</th>
<th></th>
<th>2020</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>passenger cars</td>
<td>goods vehicles</td>
<td>passenger cars</td>
<td>goods vehicles</td>
</tr>
<tr>
<td></td>
<td>low</td>
<td>high</td>
<td>low</td>
<td>high</td>
</tr>
<tr>
<td>ESC</td>
<td>25%</td>
<td>30%</td>
<td>6%</td>
<td>10%</td>
</tr>
<tr>
<td>FSR</td>
<td>0.01%</td>
<td>0.01%</td>
<td>0.01%</td>
<td>0.01%</td>
</tr>
<tr>
<td>EBR</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>PCV</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>LCA</td>
<td>0.2%</td>
<td>0.7%</td>
<td>0.02%</td>
<td>0.4%</td>
</tr>
<tr>
<td>LKS</td>
<td>0.9%</td>
<td>2.2%</td>
<td>0.2%</td>
<td>0.9%</td>
</tr>
<tr>
<td>NIW</td>
<td>0.2%</td>
<td>0.7%</td>
<td>0.02%</td>
<td>0.4%</td>
</tr>
<tr>
<td>DDM</td>
<td>0.2%</td>
<td>0.3%</td>
<td>0.2%</td>
<td>0.8%</td>
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<tr>
<td>ECA</td>
<td>0.1%</td>
<td>0.3%</td>
<td>0.1%</td>
<td>0.4%</td>
</tr>
<tr>
<td>INS</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>WLD</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>SPE</td>
<td>2%</td>
<td>3%</td>
<td>2%</td>
<td>4%</td>
</tr>
</tbody>
</table>

### Table 42: Penetration rates (fleet km's)

<table>
<thead>
<tr>
<th></th>
<th>2010</th>
<th></th>
<th>2020</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>passenger cars</td>
<td>goods vehicles</td>
<td>passenger cars</td>
<td>goods vehicles</td>
</tr>
<tr>
<td></td>
<td>low</td>
<td>high</td>
<td>low</td>
<td>high</td>
</tr>
<tr>
<td>ESC</td>
<td>29%</td>
<td>34%</td>
<td>10%</td>
<td>15%</td>
</tr>
<tr>
<td>FSR</td>
<td>0.01%</td>
<td>0.01%</td>
<td>0.01%</td>
<td>0.01%</td>
</tr>
<tr>
<td>EBR</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>PCV</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>LCA</td>
<td>0.2%</td>
<td>0.9%</td>
<td>0.03%</td>
<td>0.6%</td>
</tr>
<tr>
<td>LKS</td>
<td>1.1%</td>
<td>2.9%</td>
<td>0.3%</td>
<td>1.4%</td>
</tr>
<tr>
<td>NIW</td>
<td>0.2%</td>
<td>0.9%</td>
<td>0.03%</td>
<td>0.6%</td>
</tr>
<tr>
<td>DDM</td>
<td>0.2%</td>
<td>0.4%</td>
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<td>1.1%</td>
</tr>
<tr>
<td>ECA</td>
<td>0.2%</td>
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<td>0.2%</td>
<td>0.6%</td>
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<tr>
<td>INS</td>
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<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>WLD</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>SPE</td>
<td>2.0%</td>
<td>3.3%</td>
<td>3.7%</td>
<td>7%</td>
</tr>
</tbody>
</table>
Annex 5  Market status of systems

To develop the scenarios in 2010 and 2020 for the systems investigated in eIMPACT, the current status of the systems was considered. Table 43 provides an overview of the systems and the extent to which OEMs have equipped the vehicles with these systems.

Table 43: Inventory of market status IVSS Equipment anno 2008 (source: eIMPACT consortium)

<table>
<thead>
<tr>
<th>System</th>
<th>Market status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electronic Stability Control (ESC)</td>
<td>On market – all OEMs, but not in all lines</td>
</tr>
<tr>
<td>Full Speed Range ACC (FSR)</td>
<td>On market – MB, BMW, Audi, Lexus</td>
</tr>
<tr>
<td>Emergency Braking (EBR)</td>
<td>Partially on market – MB truck</td>
</tr>
<tr>
<td>Pre-Crash Protection of Vulnerable Road Users (PCV): (Collision Mitigation and Pre-Crash Protection of Road Users - Pre-Crash Safety)</td>
<td>Partially on market – MB, BMW, Volvo, Lexus – assisted braking</td>
</tr>
<tr>
<td>Lane Change Assistant (Warning) (LCA) / (Lateral &amp; rear monitoring, lane change aid and lateral collision warning - Lane Change Assistant)</td>
<td>Partially on market – Audi, Volvo – warning and only small steering force</td>
</tr>
<tr>
<td>Lane Keeping Support (LKS)</td>
<td>Partially on market – BMW, Audi, Volvo, MB, Citroen, Lexus – warning and limited steering support</td>
</tr>
<tr>
<td>NightVisionWarn (NiW) / (Night Vision)</td>
<td>On market – MB, BMW, Lexus, warning will come soon</td>
</tr>
<tr>
<td>Driver Drowsiness Monitoring and Warning (DDM)</td>
<td>Is expected within the next 2 years</td>
</tr>
<tr>
<td>eCall (one-way communication) (ECA)</td>
<td>Is partially on the market BMW, Lexus, MB-Tele Aid (USA only)</td>
</tr>
<tr>
<td>Intersection Safety (INS)</td>
<td>-</td>
</tr>
<tr>
<td>Wireless Local Danger Warning (WLD)</td>
<td>-</td>
</tr>
<tr>
<td>SpeedAlert (SPE)</td>
<td>Several systems for speed limit advise are available</td>
</tr>
</tbody>
</table>
Annex 6  Technical reports in WP3000

This deliverable has been based on the three technical reports produced in WP3000. These are:

<table>
<thead>
<tr>
<th>Task</th>
<th>Report</th>
</tr>
</thead>
<tbody>
<tr>
<td>3100</td>
<td>Scenarios for market acceptance and penetration, Technical report of WP3100 of eIMPACT, contact person Niina Sihvola (VTT)</td>
</tr>
<tr>
<td>3300</td>
<td>Safety impacts of stand-alone and cooperative IVSS, Technical report of WP3300 of eIMPACT, contact person Pirkko Rämä (VTT)</td>
</tr>
</tbody>
</table>