Improving the safety and mobility of vulnerable road users through ITS applications [VRUITS] D2.2 assessment methodology

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**D2.2**

**Assessment methodology**

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### Partners

[Images of logos representing different partners]

http://www.vruits.eu

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<th>Description</th>
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<tbody>
<tr>
<td>AW</td>
<td>Average Wage</td>
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<tr>
<td>BCR</td>
<td>Benefit/Cost Ratio</td>
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<td>CBA</td>
<td>Cost-Benefit Analysis</td>
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<td>CSV</td>
<td>Collision Scenario Variable</td>
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<tr>
<td>ESC</td>
<td>Electronic Stability Control</td>
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<tr>
<td>FOT</td>
<td>Field Operational Test</td>
</tr>
<tr>
<td>HMI</td>
<td>Human Machine Interface</td>
</tr>
<tr>
<td>IRR</td>
<td>Internal Rate of Return</td>
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<tr>
<td>ITS</td>
<td>Intelligent Transport System(s)</td>
</tr>
<tr>
<td>NPV</td>
<td>Net Present Value</td>
</tr>
<tr>
<td>PTW</td>
<td>Powered Two-Wheeler</td>
</tr>
<tr>
<td>SV</td>
<td>Situational Variable</td>
</tr>
<tr>
<td>V2I</td>
<td>Vehicle to Infrastructure</td>
</tr>
<tr>
<td>V2V</td>
<td>Vehicle to Vehicle</td>
</tr>
<tr>
<td>VAT</td>
<td>Value Added Tax</td>
</tr>
<tr>
<td>VOT</td>
<td>Value of Time</td>
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<tr>
<td>VRU</td>
<td>Vulnerable Road Users. The categories considered in this deliverable are pedestrians, bicyclists, moped users, and motor cyclists. Excluded are drivers of motorized vehicles.</td>
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<tr>
<td>VTTS</td>
<td>Value of Travel Time Savings</td>
</tr>
<tr>
<td>WLAN</td>
<td>Wireless Local Area Network</td>
</tr>
<tr>
<td>WTP</td>
<td>Willingness to Pay</td>
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EXECUTIVE SUMMARY

ITS Applications have in recent years assisted in reducing the number of fatalities in Europe. However, Vulnerable Road Users (VRUs) have not benefited as much as vehicle users. The EU-sponsored VRUITS project assesses the safety and mobility impacts of ITS applications for VRUs, assesses the impacts of current and upcoming ITS applications on the safety and mobility of VRUs, identifies how the usability and efficiency of ITS applications can be improved, and recommends which actions have to be taken at a policy level to accelerate deployment of such ITS.

This deliverable reports on the needed modification and development of methodologies to assess the impacts of ITS applications for VRUs in the domains of safety, mobility and comfort and cost-benefit analysis (CBA). Safety assessment estimates the potential reduction in fatalities and injuries to VRU as a result of ITS applications for VRUs. Mobility and comfort are relatively new impact areas for study. The definition of mobility used in VRUITS is: Mobility is considered any form of outside (out of house) movement based on the identified soft transport modes: walking, cycling or motorcycling. These forms of movement are defined by trips from a starting point to a destination in order to conduct an out of house activity. Thus, the mobility impact assessment investigates the changes in the movement out of house (trips, length of trips, etc.) that are the result of the use of an ITS applications for VRUs. VRUITS uses the definition of comfort from Slater: “(...) a pleasant state of physiological, psychological, and physical harmony between a human being and the environment” (Slater, 1985: p. 4). Thus, the challenge in VRUITS is to assess comfort impacts as a result of the use of ITS applications by VRUs. Finally, the CBA monetises the quantified impacts (safety, mobility and comfort) to calculate the Benefit-Cost ratios.

An analysis of the sub-groups of VRUs, presented in this report, forms the basis for determining which criteria the impact assessment methodologies must meet. This analysis also illuminates the data necessary as inputs to the impact assessment methodologies.

For each impact assessment area, the state-of-the-art is presented. Each impact assessment area describes the required modifications to the methodology selected for use in the VRUITS project, to meet the demands of the VRU sub-groups as well as the ITS applications selected for analysis in the VRUITS project.

VRU categorisation regarding safety, mobility and comfort

Although all road users are at risk of being injured or killed in a road traffic accident, certain group of road users are at more risks and the fatality of accidents varies between the different road user groups. In particular, the “vulnerable” road users such as pedestrians and cyclists are at greater risk than vehicle occupants and usually the fatality rate is high within those users.

Various definitions of VRUs consider road users vulnerable if they lack external protection. Many also consider people with limited task capability as vulnerable. A point of contention is whether certain groups of car drivers can be considered vulnerable, or whether they should be excluded because they are sufficiently protected by the vehicle or because they are a threat to others. In the VRUITS project, they will not be considered as vulnerable road users.

The absence of a protective cage leads to a mode-related identification of VRUs: pedestrians, cyclists, moped riders and motorcyclists. Fragility leads to the further identification of children and elderly as sub-groups within some of the mode-related classification. Finally, task competency affects the way and (in)ability of some subgroups to function in traffic, which is a risky situation. Fragility and task competency require that age-related sub-groups be taken into consideration. As an example, if an accident between a vehicle and an elderly pedestrian cannot be prevented, the consequences of the accident can be different for this elderly pedestrian compared to a young adult.
Combining the presence of a protective cage and the age categorisation of VRUs in VRUITS results in Table 1.

Table 1. VRU categorisation to be used in VRUITS Impact Assessment Analyses.

<table>
<thead>
<tr>
<th>Mode</th>
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<tr>
<td></td>
<td>7–12 years</td>
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<tr>
<td>Pedestrian</td>
<td>X</td>
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<tr>
<td>Bicyclist</td>
<td>X</td>
</tr>
<tr>
<td>Moped</td>
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<td>Motorcycle</td>
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Methodology for Safety Impact Assessment

The method to assess the safety impacts of ITS on vulnerable road users is based on the method introduced by Kulmala (2010), which was developed for the assessment of safety impacts of ITS for cars. Therefore, some parts of the method were enhanced and adjusted to take also into consideration the vulnerable road users.

The framework of Kulmala (2010) emphasises the system nature of transport: when one element of the system is affected, the consequences may appear in several elements and levels of the system. Therefore, the implemented safety measures influence safety by affecting one or several of the factors contributing to any of these three dimensions of safety: exposure, risk of a collision during a trip, and consequences of a collision. The use of this approach ascertains that the safety impact assessment method will cover all dimensions of road safety, also exposure or the amount of travelling, which is frequently overlooked in the safety assessment studies (Kulmala, 2010).

In addition to the three dimensions of road safety, this framework for the safety impact assessment of ITS also covers behavioural adaptation in addition to engineering effects, and is compatible with other aspects of state of the art road safety theories (Kulmala, 2010). In order to be sure about that all possible impacts (both positive and negative impacts on road safety; direct, indirect and unintended effects of systems) will be covered, the analyses proposed by Kulmala (2010) utilises a set of nine mechanisms via which ITS can affect road user behaviour and thereby road safety. These nine mechanisms have been updated to cover also vulnerable road users, i.e. pedestrians, cyclists, moped users and motorcyclists. Examples are now more focused on changes in behaviour of vulnerable road users and the situations they face in traffic.

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

The main modifications of the method for the purposes of VRUITS project are: i) nine mechanisms have been updated to cover VRUs i.e. pedestrians, cyclists, moped riders and motorcyclists, ii) the
safety impact assessment tool will be updated to include more detailed information on accidents involving VRUs, iii) accident types and circumstances like age, road layout and lighting are considered in more detail when relevant for VRU and when feasible and iv) the expert judgement process will be used to enhance the value of estimates for the nine mechanisms.

**Methodology for Mobility and Comfort Impact Assessment**

The mobility and comfort impact assessment faces a major challenge because there are few methods at this moment to assess mobility and comfort at all, and especially specifically of VRUs, and there is little to no data available on the mobility and comfort of VRUs. The latter point is the responsibility of another task in the VRUITS project (T2.5, Scenarios development), but has bearing on the methodology. A methodology will be developed that integrates the nine-mechanism approach (as in safety), focusing on five of the mechanisms, and similar steps in application with a focus on VRUs.

To achieve an operational method to evaluate the effect of different ITS on VRU mobility and comfort, it is needed to use the guidelines that already exist for the evaluation of ITS projects and applications in general (i.e. most often vehicle motor traffic), and to specify them to the assessment of mobility and comfort of VRUs. From the general model describing comfort and mobility the assessment model has been developed. Previous projects in the field of assessing effects of ITS’s has been the basis to formulating the comfort and mobility assessing model used in VRUITS, but in this study clearly taking into account external aspects in the environment, i.e. how it affects the individuals travel, and internal aspects regarding the individual perception and abilities. Based on the theory found in the literature and the principles described above, the following general mobility model and comfort model was created described in Figure 1. The figure summarises and enhances the differences between mobility and comfort, which forms the basis for the general mobility and comfort assessment in VRUITS:

![Mobility and comfort model](image)

**Figure 1.** Mobility and comfort model, developed from the model found in the TeleFOT project, Impacts on Mobility – Results and Implications. WP 4.4. (2011).

The main modifications of the method for the purposes of VRUITS project are: i) five mechanisms have been updated to cover VRUs i.e. pedestrians, cyclists, moped riders and motorcyclists, ii) the impact assessment tool will be altered to assess mobility and comfort of VRUs, iii) circumstances like age, road layout and lighting are considered in more detail when relevant for VRU and when feasible, iv) a special focus is put on the data available regarding mobility and comfort of VRUs and v) the expert judgement process will be used to enhance the value of estimates for the five mechanisms.
Methodology for Cost-Benefit Analysis

The CBA methodology concerns the monetisation of effects. In order to reach a conclusion regarding the desirability of a project, all welfare aspects of the project, positive and negative, must be expressed in terms of a common unit. The most convenient common unit is money. This means that in a CBA all welfare effects of a project should be measured in terms of their equivalent money value.

In VRUITS the effects of ITS services aimed at VRUs comprise effects in the field of:
- safety,
- mobility (travel time and travel costs),
- comfort,
- environment.

The VRUITS methodology is initially relying on the foundation for ITS impact assessment laid by the eIMPACT methodology while it aims at going beyond the state of the art to achieve a full VRU-centric impact assessment. The main points where the VRUITS CBA methodology innovates are the following:

1. VRU-centric approach to assessing VRU-relevant ITS applications is defined as all relevant monetisation parameters (i.e.: value of life, value of tie etc.) distinguish for different VRU users wherever possible.
2. Monetisation of comfort impacts for VRU users. This point goes beyond merely establishing a VRU-centric approach to the CBA, but also innovates in introducing comfort assessment in a CBA exercise for transport related effects.
3. The breakdown of the impact of ITS applications is quite sophisticated, including the cost of congestion saved by accident aversion, but furthermore, monetisation of the safety impacts accounts also for the element of property damage. This element, despite being marginal when fatal or accidents involving severe injuries are the case, can prove to be a significant cost factor for accidents where slight injuries or property damage alone are the case.
4. This exercise is based on the HEATCO FP6 research on drawing monetary units for the monetisation of the expected impacts. However, except from updating these factors, they will be expanded from an EU-25 to an EU-28 coverage.
1. INTRODUCTION

This report describes the impact assessment methodology for assessing qualitative and quantitative impacts of Intelligent Transport Systems (ITS) on the aspects of safety, mobility and comfort of vulnerable road users (VRUs), and the translation of these impacts into socioeconomic indicators via a cost benefit analysis.

The following subsections introduce the project and the relationship of this deliverable to other tasks and deliverables in the project. The final subsection provides a reading guide to the rest of the document.

1.1 The VRUITS project

In recent years both technological developments and research activities in the fields of Intelligent Transport Systems (ITS) have primarily focussed on motorised transport to improve safety and ecological (environmental) impacts by advancing equipment of vehicles and infrastructure. The uptake of ITS applications has assisted in the decrease of road traffic fatalities, particularly amongst passenger car occupants. However, Vulnerable Road Users (VRUs), such as pedestrians, cyclists, motorcyclists and moped riders have not enjoyed the same decrease in fatalities. Together, they account for 68% of the fatalities in urban areas (CARE, 2009). Motorcyclists account for 16% of fatalities, which is much higher than their contribution to traffic (CARE, 2009). While some projects have considered VRUs from a safety viewpoint, they often aimed at avoiding or mitigating accidents with VRUs by equipping the vehicle and infrastructure. In the vehicle – infrastructure – human approach of ITS research, VRUs and their needs are not an active part of the “human” element in the ITS approach.

What is needed? The VRU must become an active, integrated element in the ITS, addressing safety, mobility and travel comfort needs of VRUs. The EU-funded VRUITS project, which started on 1.4.2013, aims at actively integrating the “human” element in the ITS approach by focussing on needs of all relevant stakeholder groups into the development and adaptation process of innovative ITS solutions aimed at improving traffic safety as well as the general mobility of vulnerable road users. The VRUITS project, which is sponsored by the European Commission DG MOVE, places the VRU road user in the centre, assesses the impact of current and upcoming ITS applications on the safety and mobility of VRUs, identifies how the usability and efficiency of ITS applications can be improved, and recommends which actions have to be taken at a policy level to improve ITS safety and mobility. By applying a multi-disciplinary approach the VRUITS project aims at developing tools to evaluate, field-test and subsequently improve ITS for vulnerable road users.

The first objective of the VRUITS project is to assess societal impacts of selected ITS applications, and to provide recommendations for policy and industry regarding ITS in order to improve the safety and mobility of VRUs. Both ex-ante and ex-post assessment of the applications will be performed in order to come to a consolidated set of recommendations.

The second objective is to provide evidence-based recommended practices on how VRUs can be integrated in Intelligent Transport Systems and on how HMI designs can be adapted to meet the needs of VRUs, and test these recommendations in field trials. Starting from usability study of current ITS applications, guidelines will be provided on the improvement of the HMI for specific user groups, such as elderly drivers. A key concept is also the integration of VRUs in cooperative traffic systems, either through one-way (tags) or two-way communication. The performance and usability of different concepts for the communication between road users in safety critical situations will be assessed. Field trials for a select number of applications will take place in the Netherlands (Helmond), with an emphasis on cyclists and PTW riders, and Spain (Valladolid), with an emphasis on pedestrians.
1.2 Scope and objective of the deliverable

This deliverable reports on the Task 2.4 (T2.4) Impact Assessment Methodology, which is part of Work Package 2 (WP2), VRU needs, ITS prioritization and methodology. The main purpose of this task is to adapt the impact assessment methodology in order to carry out qualitative and quantitative assessment of ITS for sub-groups of VRUs for the aspects of safety, mobility and comfort, and to translate these into socioeconomic indicators.

Safety assessment estimates the potential reduction in fatalities and injuries to VRU as a result of ITS applications for VRUs. Mobility and comfort are relatively new impact areas. The definition of mobility used in VRUITS is: Mobility is considered any form of outside (out of house) movement based on the identified soft transport modes: walking, cycling or motorcycling. These forms of movement are defined by trips from a starting point to a destination (that could also be a public transport stop or station) in order to conduct an out of house activity. Thus, the mobility impact assessment investigates the changes in the movement out of house (trips, length of trips, etc.) that are the result of the use of an ITS applications for VRUs. VRUITS uses the definition of comfort from Slater: “(...) a pleasant state of physiological, psychological, and physical harmony between a human being and the environment” (Slater 1985: p. 4). Thus, the challenge in VRUITS is to assess comfort impacts as a result of the use of ITS applications by VRUs. Finally, the CBA monetises the quantified impacts (safety, mobility and comfort) to calculate the Benefit-Cost ratios.

VRUITS uses a VRU categorisation that is consistent with the literature and with experts’ findings on level of protection, fragility of VRUs and task competency. These facets are relevant for whether VRUs can use the ITS applications and the consequences of doing so. The categorisation differentiates the VRUs by mode of travel (pedestrian, cyclist, moped, and motorcycle) and age (7–12, 13–17, 18–64 and 65+). Vehicle drivers are excluded.

1.3 Relationship with other parts of VRUITS

The objective of WP3 is to perform and report impact assessments of selected ITS on VRU safety, mobility and comfort, both qualitatively and quantitatively. The Impact Assessment methodology defined in T2.4 and will be a basis for a successful execution of this assessment. The Figure 2 shows the relationship and the interactions between WP2 and WP3.
The need for modification of the safety and mobility and comfort assessment methodologies used input from the following tasks:

- T2.1: critical scenarios identified per VRU sub-group. The critical scenarios formed the basis for choosing ITS to improve safety, mobility and comfort of VRUs.
- T2.2: VRU user needs regarding ITS. The user needs identified critical situations for VRUs, assessed the needs of different VRU sub-groups for ITS and applications, and prioritized the ITS potential in view of VRU safety, mobility and comfort.
- T2.3: the selected ITS for VRUs. A subset of the selected ITS were used to determine which modifications of the methodologies were necessary.

1.2 Reading guide

Chapters 2 and 3 describe the approach and background information for the development of the assessment methodology. The resulting methodology can be found in Chapters 4, 5, 6 for the three aspects of the methodology. Chapter 7 contains the summary and conclusions, respectively, while references are listed in Section 8.
2. APPROACH

This chapter describes the approach that was taken in task 2.4 to create the assessment methodology. The methodology needs to assess the effects of VRU-oriented ITS on safety, mobility and comfort, and also needs to encompass a cost-benefit analysis.

In a first step, the assessment will be performed qualitatively for a large group of ITS. Then a selection of ITS will be made, and for this smaller set a quantitative assessment will be performed (see Figure 3).

Qualitative and quantitative assessment

The starting point for the assessment steps is the framework displayed in Figure 4. This framework is similar to frameworks used in other projects (e.g., Wilmink et al., 2008). The same framework can be used for qualitative and quantitative assessment. It shows on the middle row the various types of traffic-related societal impacts: safety, comfort, mobility and environment. These impacts can be monetized and then feed into the cost-benefit analysis on the bottom row. It is noted that even though the environmental impact is not the focus of this project, it does need to be taken into account as an element in the cost-benefit analysis, so that all benefits are considered. For this reason, an impact on emissions will be considered, but only as a derivative of the mobility impact. That is, a change in the distance travelled (in a certain mode) will lead to a corresponding change in emissions.

The project investigated the possibility of including health benefits in the analysis. In contrast to what exists for the monetisation of safety, mobility and environmental impacts, there is no generally accepted methodology to monetise health impacts from increased mobility (let alone addressing the EU-scope). To do so for VRUITS would require modification to the impact assessment framework similar to safety, mobility and comfort that would focus on identifying the impact mechanisms of changes of mobility on the health of VRUs. However, the timeline of VRUITS did not allow the development and application of this framework.

Various categories of data are needed to assess the impacts. They are listed on the top row. All impact types need information on the deployment scenario, such as the functionality of the ITS, the penetration rate of the ITS, any technical performance limits on the ITS and the traveller behaviour, which includes aspects like user acceptance, trust, usability, interaction with the ITS, and changes in travel choices and performance. Additional data may be needed by specific impact types, such as accident
data and predictions on future accidents, data on congestion, demand and modal split, and fleet composition.

The types of impact may influence each other, as indicated by the arrows. Many of the relations can be complex to quantify. That is, changes in subjective and objective safety may be in the same direction, or they may be in opposite directions. Also, influences on safety, for example, Mobility $\rightarrow$ safety, may not necessarily be linear, e.g., safety in numbers. Specifically the following influences have been identified:

- **Safety $\rightarrow$ Comfort**: a change in (objective) safety may lead to a change in perceived (or subjective) safety.
  - Objective safety influences perception of safety, which is an aspect of comfort
    - **This influence can be positive**: higher objective safety increases the feeling of safety (people experience fewer risky situations, less media attention). This applies for example to cyclists who (from T2.2 results) seem very well informed.
    - **This influence can also be negative**: higher objective safety is reached by more safety measures and hence higher awareness of risk and/or a higher workload because of risk-averting manoeuvres; as a consequence the perceived safety goes down
  - A change in safety for one road user may lead to a change in comfort for another.
    - For example, adaptations that make the road safer to pedestrians may cause more stress to car drivers
    - For example, safety systems in cars that protect pedestrians or cyclists may make the car driver more comfortable, because he knows that there is less risk that he will hurt another

- **Safety $\rightarrow$ Mobility**: accidents may cause congestion. Thus, a change in the number of accidents may change the amount of congestion. Congestion is an issue only for motorized vehicles, but the accidents may of course also involve VRUs. Depending on the ITS, the system may lower overall speeds, increasing travel time. A reduction in congestion decreases travel time, but latent demand may arise, increasing travel time. A shift of mode from driving to walking, cycling and moped or motorcycle riding will further decrease congestion and increase safety on VRU modes.

- **Comfort $\rightarrow$ Safety**: the comfort level may influence safety, for example via a false sense of security, or via modification of workload.

- **Comfort $\rightarrow$ Mobility**: the comfort level may influence the amount of travel overall, or the attractiveness of certain modes, routes, times of day, etc.

- **Mobility $\rightarrow$ Safety**: changes in the amount of travel (number and length of trips) will lead to additional exposure and hence changes in safety.

- **Mobility $\rightarrow$ Environment**: changes in the amount of motorized travel will lead to changes in emissions.
This framework leads to the following questions:

1. How should VRU be defined and categorized?
2. What are the existing methodologies for qualitatively or quantitatively assessing safety, comfort and mobility impacts of ITS and their costs and benefits?
3. What are the critical safety scenarios for VRU?
4. What are the user needs of VRU?
5. What are promising ITS for VRU, and how do they function?
6. How should the existing methodologies be modified to address ITS for VRU?
7. How do the impact types influence each other?

The first four questions ask for background information from the literature or other parts of the project, in particular tasks 2.1, 2.2 and 2.3, that were reported in D2.1 [Bell et al., 2013]. The first two questions are addressed by a literature review in Chapter 3. The third and fourth question were answered in Task 2.1 and Task 2.2, the results of which are summarized in Sections 3.2.1 and 3.2.2.

For the fifth question, functional descriptions have been created for the list of selected ITS from Task 2.3. This list of ITS is analysed for coverage of all VRU types, ITS categories and impact types in Section 3.2.3. Appendix D contains an example of a function description for the Intersection Safety System.

The sixth and seventh question are the main topics of this deliverable. For question 6, Chapter 3 draws conclusions based on the literature regarding the most suitable method and the required adaptations. Based on these conclusions, adapted methodologies have been developed by the project team for each impact type and for the CBA. As these components depend on each other, requirements have been set up on the interfaces between them. Furthermore, an overview of available data sources has been made. This is described in Chapters 4, 5, 6 for safety, mobility and comfort, and CBA, respectively. For question 7, an inventory of potential mechanisms has been made in an internal workshop.
Selection

The eIMPACT project carried out an ITS selection process in order to select a smaller number of systems for in-depth quantitative analysis on the basis of a qualitative assessment carried out on a larger number of systems (Vollmer et al., 2006). The ITS selection used multi-criteria analysis and a portfolio check (ex-post check on the overall result). The multi-criteria analysis ranks the ITS. The portfolio check determines whether all important aspects are covered, for example, that systems address important VRU groups.

In VRUITS, after the qualitative assessment, a selection is made of ITS that will be assessed quantitatively. This selection will be performed by internal and external experts. Criteria for this analysis have been developed by the project team in an internal workshop. Weights for the criteria will be chosen in Work Package 3.

Task 2.4 in VRUITS developed criteria for use in the selection process. These are:

Multi-criteria selection, for initial ranking of systems:

- **Benefits**
  - Impact on safety
  - Impact on mobility & comfort, including travel time and speed and travel costs
  - Modal shift from the car to a different alternative

- **Costs**
  - Monetary cost of system
  - (Absence of negative impacts, possibility to mitigate negative impacts)

- **Deployment**
  - Time to market (near or not)
  - Ease of deployment, low barriers to implementation
  - User uptake
  - Pan-European solution

- **User**
  - Acceptance, by general public, politicians, a range of stakeholders
  - Novelty
  - System addresses multiple age groups, multiple road user groups
  - Usability of the HMI

Portfolio check, for final selection:

- Cover all VRU groups
- Cover all impact categories
- Cover Infra-based, car-based, VRU-based and cooperative ITS
- Be a pan-European Solution
- Address different aspects of driving behaviour: speed, route choice, etc.
- Address negative impacts
- Cover the applications that are piloted in the VRUITS project
- Address critical scenarios identified in T2.1
3. BACKGROUND

This chapter provides the context for the required modification of the safety, mobility and comfort impact assessment methodologies. The chapter provides begins with a discussion of VRU groups and a VRU categorization in Section 3.1. Relevant conclusions on critical scenarios for VRUs, VRU needs and ITS selected to address these are presented in Section 3.2. Sections 3.3, 3.4, 3.5 and 3.6 provide overviews of the state of the art in safety, mobility and comfort and CBA assessment methodologies, respectively. More about the state of the art in safety can be found in Appendices B and C.

3.1 VRU categorization regarding safety, mobility and comfort

Although all road users are at risk of being injured or killed in a road traffic accident, certain group of road users are at more risks and the fatality of accidents varies between the different road user groups. In particular, the “vulnerable” road users such as pedestrians and cyclists are at greater risk than vehicle occupants and usually the fatality rate is high within those users.

The first question is: which road users are vulnerable? There are different definitions in use. The ITS Directive (ITS directive, 2010) defines vulnerable road Users (VRU) as "non-motorised road users, such as pedestrians and cyclists as well as motor-cyclists and persons with disabilities or reduced mobility and orientation". A sub-report of the ITS Action Plan (Eisses, 2011) defines VRUs as pedestrians, cyclists, moped riders, motorcyclists, young and inexperienced car drivers and elderly car drivers. It notes that car drivers are often not considered as VRU, but subgroups can be considered vulnerable because of their increased risk and specific safety issues. On the other hand one might argue that these groups of car drivers present an additional risk to other road users, and that they are not VRUs. According to the World Health Organization (WHO, 2004), in road traffic, risk is a function of four elements: exposure, the probability of a crash, the probability of injury and the outcome of the injury. Various studies have used exposure and other variables to categorize vulnerable road users (Wegman & Aarts, 2006) define VRUs as road users who are vulnerable because of lack of external protection or lack of task capability, leading to a subdivision by mode of transport and age. The research by (Methorst, 2002) and the Dutch Transport Research Centre (AVV, 2003) added another criterion, namely fragility. The AVV report explicitly categorizes novice and elderly drivers as not vulnerable, stating that because a “strict application of these criteria would also label novice drivers (limited task capability) or elderly car drivers (low resilience) as vulnerable, there is a supplementary criterion: the vulnerable should not themselves be a threat to others” (quoted from (SWOV, 2012)).

In summary: all these definitions consider road users vulnerable if they lack external protection. Many also consider people with limited task capability as vulnerable. A point of contention is whether certain groups of car drivers can be considered vulnerable, or whether they should be excluded because they are sufficiently protected by the vehicle or because they are a threat to others. In the VRUITS project, they will not be considered as vulnerable road users.

VRUITS uses roughly the same three criteria to distinguish vulnerable road users as (Methorst, 2002) and (AVV, 2003) as a basis for classifying the road user groups. They are:

- The amount of external protection
- Task competency, i.e., the extent to which people are able to function in risky situations
- Resilience (fragility), i.e., the extent to which people can absorb outside forces

Appendix A provides a detailed description of the three criteria above.

The absence of a protective cage leads to a mode-related identification of VRUs: pedestrians, cyclists, moped riders and motorcyclists. Fragility leads to the further identification of children and elderly as sub-groups within some of the mode-related classification. Finally, task competency affects the way
and (in)ability of some subgroups to function in traffic, which is a risky situation. These last two categories are discussed below.

Below follows review of children’s characteristics as road users aiming at defining appropriate age groups with specific needs concerning their right to survive (safety), to move (mobility and comfort) and to take part in the society. Safety, mobility and comfort are all important concepts which often goes or at least should go “hand in hand”.

Toddlers are at risk on driveways and in other relatively protected areas, since they are drawn to moving vehicles rather than avoiding them (Schieber and Thompson, 1996). Children from the age of 18 months have the ability to fantasise and the physical ability to escape from their surroundings. It is widely accepted that pre-school children cannot experience a viewpoint or attitude other than their own. If children can see someone else, such as a car or driver, they tend to think that the other person can see them even though they may be standing between parked cars. Midland (1995) and Schieber and Thompson (1996) argue for a break point at 6 or 7 years. The difference between that age group or younger compared with older children is considerable in terms of [safe] road-user behaviour. The difference is assumed to depend largely on deficiencies in attention and cognitive abilities, rather than on inadequate perception. It is suggested that pre-school children should not encounter cars in their playing and walking areas. In exceptional cases, they can interact with vehicles travelling at a maximum speed of walking pace. There can be significant differences between the behaviour of children when they cross a street at a pedestrian crossing (MacGregor, et al., 1999).

The next stage, younger children, lies between age 7 and the teens (Schieber and Thompson, 1996, Connely et al., 1998 and Arnold et al., 1990). At this age, children examine the environment logically and grow accustomed to forming hypotheses about it. Such skills can be used to recognise dangerous situations, but children’s behaviour becomes inconsistent because they are still learning how the traffic environment works. Cognitively, crossing the street is a difficult task, and children have not developed the necessary capabilities before the age of 11 or 12. Children under 12 have difficulty estimating the direction, speed, and distance of vehicles in motion (Piaget, 1969; von Hofsten, 1980 and 1983 presented in Arnold et al., 1990; Leden, 1989; Foot et al., 1999 and MacGregor et al., 1999). As early as 1969 Piaget suggested theories that children make decisions that lead to dangerous road-user behaviour because of their inability to understand the connection between time, speed and distance. Therefore, the tendency of children to run out in front of cars can make sense in the child’s conceptual world (Cross, 1988). Younger children accept the same distance gaps when crossing a street in front of cars travelling towards them irrespective of the speed of the cars (Connelly, et al., 1998), i.e. children assume shorter time intervals when the vehicle speeds are higher, and longer time intervals when the speed is lower. Most children make ‘safe’ assessments when vehicle speed is low, but not when the speed is high. One conclusion is that children younger than nine cannot make safe assessments of time intervals to vehicles in traffic. Similar results were produced by Demetre and Lee (1992), with children choosing shorter time intervals than adults; however, children also missed more safe time intervals, so that in some cases children were more careful than adults. Children’s ability to choose safe ways to cross a street, i.e. their assessment of safe routes or places to cross a street, also increases with age (Ampofo-Boatang et al., 1993, Lee et al., 1984). Younger children do not understand, either, that an obscured view of cars is less safe for crossing the street (Demetre and Gaffin, 1994).

In their teens, children become able to think in abstract terms and understand events even though they themselves have not experienced them. It then becomes possible to consider a vehicle’s speed and distance simultaneously. In the early eighties Von Hofsten (1980 and 1983) results (presented by Demetre and Lee, 1992) suggested that children’s development as road users depends on their absorbing more information about their environment over time, so that the information flow gives guidance about what is required as a road user.
For older children, teens, the same principles apply as for adult unprotected road users: they should not cross at locations where vehicle speeds exceed 30 km/h. This applies to routes to school, to the homes of friends and to other leisure activities. The speed of 30 km/h was chosen to give pedestrians a “fair” chance to survive if hit by a motor vehicle. The explanation is that when a pedestrian is hit by a motor vehicle at a speed above 30 km/h the risk for a fatal accident is high about 10% at 30 km/h and 50% at 50 km/h (Teichgräber, 1983; Ashton, 1982 and Waltz et al., 1983).

Children and elderly persons behave more cautiously than other adults (Arnold et al., 1990). It has been suggested that it is developmental and ageing changes make them vulnerable road users. Road crossing is a cognitively difficult task and it is not until the age of 11 or 12 years that children will have developed all the required abilities fully. For the elderly (older than 64 years), these physical and cognitive resources decline with age, but there can be significant individual differences in abilities and in the behaviour of elderly. Older adults can place themselves at greater risk as a result of wrongly estimating the arrival time of moving vehicles, and/or under-compensating of slower walking speeds. The elderly have lower walking speed than younger adults. (Oxley et al., 1997). The variation in individual health and physical abilities can be great for the same age between different elderly persons. In many countries the retirement age has been set at 65 years to mark the beginning of old age in general, based on the general abilities of that age. With respect to bicycling, this is the time when people get their daily routes and bicycle use regularly greatly changed. However, there is some variation, depending on the study. The age varies from 55 (Schoots & Main District (2011), Ormel et al., (2008)) to 75 (SWOV, 2012). The need for a harmonized approach over all modes with respect to data requires a specified age to define elderly for the purposes of analyses in VRUITS. Therefore the limit of older age in this project is set to 65 years and older.

Based on the information above the categorization presented in Table 2 and will be used regarding age structures of vulnerable road users in the VRUITS project:

<table>
<thead>
<tr>
<th>Description</th>
<th>Age in years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Younger children</td>
<td>7–12 years</td>
</tr>
<tr>
<td>Older children; teens</td>
<td>13–17 years</td>
</tr>
<tr>
<td>Adult</td>
<td>18–64 years</td>
</tr>
<tr>
<td>Elderly</td>
<td>65+ years old</td>
</tr>
</tbody>
</table>

Combining the presence of a protective cage and the age categorisation of VRUs in VRUITS results in Table 3. This will be the categories that will be investigated in the VRUITS Impact Assessment Analyses.

<table>
<thead>
<tr>
<th>Mode</th>
<th>7–12 years</th>
<th>13–17 years</th>
<th>18–64 years</th>
<th>65+ years and older</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pedestrian</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Bicyclist</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Moped</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Motorcycle</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
</tr>
</tbody>
</table>
3.2 Relevant information from within VRUITS

The first deliverable of the VRUITS project (Deliverable D2.1 - Technology potential of ITS addressing the needs of Vulnerable Road Users) reported on the results of the first three tasks. The basic research phase was comprised of an initial assessment of critical traffic scenarios for VRUs. Based on accident data analysis, a qualitative assessment of actual user needs in course of focus group discussions and expert interviews and by integrating stakeholder feedback a set of the most promising ITS applications was selected.

3.2.1 Critical scenarios

Task 2.1 was concerned with the identification of critical traffic scenarios (in other words road event situations) in which VRUs are most commonly injured or killed.

Based on available accident data, the main aim of the task was to determine the most critical scenarios for the different types of VRUs – cyclists, pedestrians and motorcyclists. A preliminary task first identified the databases available (accident data, hospital data, in-depth studies and conflict studies) which contain relevant data relating to VRU accidents.

The expected outcome of the task was a precise identification of the circumstances of traffic accidents involving VRUs including common causal factors, pre-crash manoeuvres and collision circumstances (road-type, speed, environmental conditions etc.) to determine the road event situations which should be a priority for ITS interventions.

The task involved a number of phases. The first phase of the task was to identify, as clearly as possible, from existing research and data analyses a number of scenarios that are commonly considered to be implicated in crashes involving VRUs. This was achieved via a review of existing reports on VRU accidents including a report from the WATCHOVER project, review of the SafetyNet and PENDANT databases and a review of published data from the European Road Safety Observatory (ERSO) data repository and the Data Collection, Transfer and Analysis (DaCoTA) project. From this review, a total of up to 14 key scenarios were identified for each VRU group and the subsequent accident analysis was then conducted according to these key scenarios in order to determine which of these was the most commonly occurring.

Different types of databases were used in the analysis. Available data in each database varied and differentiation could be made between in-depth data and macroscopic data.

In-depth data provide very detailed information about specific accidents and can generally be used to provide information on accident and injury, engineering feedback and standards development given the very detailed nature and level of the data that is collected through in-depth crash investigations. However, this type of data is usually dis-advantaged by the fact that the numbers of cases in in-depth databases are usually small and statistical representativeness is sometimes open to question.

Macroscopic data provide cursory information about accidents and are usually based on police investigations of crashes on the roads in which an injury has occurred. The main advantage of this type of data is that it is usually representative for the country in which it was collected but the main disadvantage is that the level of detail is significantly lower than that provided in in-depth databases.

The most important results in terms of the VRUITS accident scenarios are described in turn according to road-user group.
Pedestrians

- In all databases including the CARE database, it was found that accidents were most likely to occur when the pedestrian was crossing the road **remote from a junction (scenario P1)**.

![Critical pedestrian scenario P1.](image)

Figure 5. Critical pedestrian scenario P1.

Table 4 provides insight into the actual severity of the identified scenarios presenting total, fatal and serious accidents in different accident scenarios.

**Table 4: Pedestrian accidents not at a crossing facility.**

<table>
<thead>
<tr>
<th>Pedestrian Action</th>
<th>Number of accidents</th>
<th>% of total accidents</th>
<th>% of accidents not at “crossing facility”</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crossed from Driver’s nearside</td>
<td>5690</td>
<td>22.2</td>
<td>45.9</td>
</tr>
<tr>
<td>Crossed from Driver’s nearside – but masked by parked car</td>
<td>1789</td>
<td>7.0</td>
<td>14.4</td>
</tr>
<tr>
<td>Crossed from Driver’s off-side</td>
<td>2952</td>
<td>11.5</td>
<td>23.8</td>
</tr>
<tr>
<td>Crossed from Driver’s off-side – but masked by parked car</td>
<td>1041</td>
<td>4.1</td>
<td>8.4</td>
</tr>
<tr>
<td>Not known</td>
<td>911</td>
<td>3.6</td>
<td>7.4</td>
</tr>
<tr>
<td>Total</td>
<td>12383</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- The accident analyses suggest that in most, if not all cases, the environmental conditions are not intuitively detrimental to road-crossing. That is, in the majority of the databases, the accidents tended to occur in **fine weather** and the road conditions were found to be **dry**. Also, there was some consistency suggesting that pedestrian accidents tend to occur between 12pm and 6pm.
- It was found that in the majority of cases, the accidents tended to occur in **urban areas** on roads with **lower speed limits (50km/h)**.
- There was variation in some of the parameters – males are slightly over-represented in the CARE database whereas females are over-represented in some of the individual Member State databases – also there was no consistency regarding the **accident month**.
- In the majority of databases including CARE, a **passenger car** was the most frequent collision partner.
- Some important parameters could not be determined. These include **vehicle characteristics**, **vehicle speed pre-collision** and **pedestrian actions prior to collision**.
Cyclists

- The majority of cycling accidents in the accident analysis were found to occur at junctions/intersections (see Table 5).

Table 5. Bicycle accidents at junctions.

<table>
<thead>
<tr>
<th></th>
<th>All cyclists junction accidents</th>
<th>% all cyclist accidents</th>
<th>Fatal and Serious</th>
<th>% all Serious and fatal</th>
</tr>
</thead>
<tbody>
<tr>
<td>T-junction/staggered</td>
<td>7191</td>
<td>41.8</td>
<td>1079</td>
<td>38.9</td>
</tr>
<tr>
<td>Crossroads</td>
<td>2039</td>
<td>11.9</td>
<td>322</td>
<td>11.6</td>
</tr>
<tr>
<td>Private drive</td>
<td>909</td>
<td>5.3</td>
<td>111</td>
<td>4.0</td>
</tr>
<tr>
<td>Roundabout</td>
<td>2284</td>
<td>13.3</td>
<td>299</td>
<td>1.1</td>
</tr>
<tr>
<td>Other</td>
<td>493</td>
<td>2.9</td>
<td>79</td>
<td>2.9</td>
</tr>
<tr>
<td>Total</td>
<td>12916</td>
<td></td>
<td>1890</td>
<td></td>
</tr>
</tbody>
</table>

- One of the most common scenarios involved vehicles pulling out into the path of the oncoming cyclist at an intersection (scenario C1)

![Figure 6. Critical cyclist scenario C1.](image)

- CARE data suggests that the most common scenario involves both cyclist and vehicle heading in the same direction but the vehicle then turns into the cyclist’s path (scenario C2).

![Figure 7. Critical cyclist scenario C2.](image)

- Overall, males are over-represented in the data.
- The majority of the accidents occur in fine dry weather during daylight hours.
- The majority occur in urban areas on roads with relatively low speed limits.
**Powered Two Wheelers**

- The most common scenario in the CARE accident analysis was found to be the PTW being hit by a vehicle (mainly passenger car) initially heading in the same direction and then turning across the path of the PTW (scenario P2).

![Image of critical PTW scenario P2](image)

*Figure 8. Critical PTW scenario P2.*

- This was not consistent with the national database analyses which suggest that the most common scenario involves vehicles pulling out from intersections into the path of the PTW (scenario P1).

![Image of critical PTW scenario P1](image)

*Figure 9. Critical PTW scenario P1.*

- Males were far more likely to be involved in PTW accidents compared to females.
- Most accidents occurred within urban environments.
- It is thought that the majority of accidents occurred on roads with low speed limits (50km/h).
- The majority of accidents occurred in fine and dry weather conditions during daylight hours.
- Most accidents occurred during the ‘summer months’ (May to September).

Table 6 presents actual accident numbers in view of the different accident scenarios including a representation of the share of actual fatal and serious injuries in these instances.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>All M/C accidents</th>
<th>%</th>
<th>Fatal and Serious</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not at a junction</td>
<td>6142</td>
<td>32.9</td>
<td>2136</td>
<td>41.2</td>
</tr>
<tr>
<td>Approaching junction</td>
<td>4499</td>
<td>24.1</td>
<td>1143</td>
<td>22.1</td>
</tr>
<tr>
<td>Mid-junction</td>
<td>5850</td>
<td>31.3</td>
<td>1392</td>
<td>26.9</td>
</tr>
<tr>
<td>Leaving junction</td>
<td>1256</td>
<td>6.9</td>
<td>299</td>
<td>5.7</td>
</tr>
<tr>
<td>Other</td>
<td>939</td>
<td>4.8</td>
<td>213</td>
<td>4.1</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>18686</strong></td>
<td></td>
<td><strong>5183</strong></td>
<td></td>
</tr>
</tbody>
</table>
**3.2.2 User needs**

In course of task 2.2, user needs in view of ITS technologies were assessed by applying a variety of different qualitative methods. To evaluate vulnerable road user behaviour, issues and needs in traffic with specific focus on potential solutions through ITS a literature review, focus group discussions and expert interviews were conducted.

**Focus group discussions**

In the course of 20 focus group discussions with 143 participants of the identified VRU groups (pedestrians, cyclists, PTWs, were identified in course of a based on their main/preferred mode of transport, the mode of transport most trips in everyday life are covered)) in Spain, Finland, Austria and the Netherlands user needs were identified focussing on problem areas and critical situations in traffic. Results of the focus groups also provided a preliminary identification of systems and functions that are relevant for both, improving traffic safety and general mobility from a vulnerable road user point of view.

Results of the focus group discussions on critical scenarios in traffic showed that these situations are very strongly dependent on the given mode of transport, with differences between pedestrians and cyclists and motorcyclists. Generally the following four aspects, which are especially important for cyclists and pedestrians of all age groups, were discussed in all focus groups:

- **High speeds of motorised traffic**
- **High speeds and low noise of electric vehicles** (including e-bikes, pedelecs, e-cars, etc.)
- **High complexity and density of traffic situations**, especially at intersections, roundabouts and crossings. In these situations traffic rules are not clear and high traffic speeds in conjunction with road lanes shared by different road user groups can lead to confusion.
- **Weather conditions and maintenance of infrastructure** (i.e. bicycle lanes that need to be kept clear of snow in winter).

Overall most critical situations are associated with motorised traffic and situations that arise due to high traffic complexity, which is frequently related to different road user groups having to share traffic lanes and crossing facilities. The behaviour of car drivers proved to be a major issue especially for PTWs and is seen as causing factor for critical situations. In addition a lack of respect in conjunction with reckless driving behaviour, which often is perceived as aggressive, can lead to situations where motorcyclists need to act to avoid a dangerous situation. This in combination with a perceived lack of visibility, especially in context with situations involving trucks and SUVs, is discussed as significant causing factor for critical situations.

In order to assess ITS knowledge the focus group participants were asked to discuss known safety relevant systems. While the overall number of systems mentioned in the discussion rounds covers a high variety of different systems and provides a good overview over technologies that are currently available on the market, a high share is mainly addressing the needs of motorised traffic.

- Generally a high share of “standard” in-vehicle (car) systems that are solely aimed at increasing the safety and comfort of the car driver, with only few mentions of systems that actively try to increase the safety of vulnerable road users in critical situations were discussed.
- Infrastructure based ITS were mainly discussed in the context of traffic lights and traffic signs.
- Only a small number of Smartphone-based applications were discussed, that can actively be used by pedestrians, cyclists and PTWs for routing and navigation, provide information and warnings in critical situations.

Assessing actual experiences in using ITS there is again a high variety of systems discussed with generally positive attitudes towards usability and reliability of these solutions. Generally it has to be said, that systems participants have experiences with were assessed more positively than those participants have no actual experiences with. There still seems to be a lack of trust towards unknown
technologies, especially in view of traffic safety. Generally experiences stated by the participants of all discussion rounds show:

- experiences on all levels of ITS (mobile applications, in-vehicle, infrastructure based) and technologies (informing, intervening, warning).
- a high level of experiences among car drivers with in-car systems (navigation, Cruise Control etc.).
- actual experiences with various systems are very positive (hardly any statements regarding failing ITS that have actually been experienced)

In view of the willingness to actually use ITS aimed at VRUs it can be said that systems focusing on the following four aspects are considered having the highest potential of improving traffic safety and general mobility:

- Increased visibility of VRUs (communication, warning and intervention): systems aiming at actively providing information and warnings to both car drivers and VRUs to avoid critical situations caused by a lack of visibility are very much appreciated. In critical situations VRUs would generally be willing to use informing, warning and intervening systems.
- Increased overall traffic flow (automation): decreasing the complexity and density of urban traffic situations is seen as a major aspect of increasing subjective road safety among VRUs (especially among pedestrians and cyclists). Intelligent traffic lights and road signs that inform about speed limits, maintenance works and traffic jams are considered beneficial to the general tranquillity and clarity of often complex traffic situations.
- Economic (less fuel consumption) and ecological (less CO₂ emissions) aspects are discussed especially among car drivers and PTWs. Infrastructure-based technologies that support a constant traffic flow and speed limiting systems were perceived as having high potential in these regards.
- Increased comfort in traffic (information and automation): systems increasing comfort of VRUs were not discussed specifically in the various discussion rounds, but usually comfort is related to pre- and on-trip information available via Smartphone- or web-based routing tools.

Discussions on potential hazards associated with ITS vary between the different road user groups, with some groups emphasizing one aspect more than others. Generally the perceived negative effects that were not always based on actual experiences are: loss of autonomy in the riding/driving task, overreliance on a technical solution and overconfidence, the question of responsibility, and the technical reliability of already available solutions.

Overall the discussion rounds provided comprehensive insight into mobility behaviour, needs and issues as well as experiences and attitudes towards intelligent transport systems that are not only aimed at increasing traffic safety, but also at raising general mobility and comfort.

**Expert interviews**

Interviews with experts from research, technology development, transport and traffic policies and representatives of vulnerable road user groups provided insight on the respective dimensions on a more abstract and objective level than the focus group discussions. The aspects discussed with the experts complement and resemble those of the focus group discussions and provided additional insight on the current state of the art including traffic safety issues and future prospects. Infrastructural aspects were mentioned as playing an important role in view of the traffic safety of VRUs. Separating the different road user groups by providing them with the space and the infrastructure needed to be safely and efficiently mobile, especially in urban environments, was identified as one of the major aspects brought up in a number of expert interviews. In addition technologies based on road infrastructure that help to improve traffic flow and inform/warn VRUs in certain situations (i.e.: at traffic lights) are considered to have benefits for all road user groups regardless of their transport mode. Systems aiming at a higher
level of automation and technological support in critical situations in highly complex and dense traffic (i.e.: at intersections, bad weather, at high speeds, etc.), especially for car drivers, can help to improve traffic safety of vulnerable road users. The issue of visibility and conspicuity was already discussed among the VRU discussion rounds where participants stated to often feel unsafe in traffic due to this fact. The experts emphasize this issue and point out the potential of technologies that on the one hand aid car drivers in the detection process of other road users in different situations and on the other technologies that inform/warn the vulnerable road users to be able to actively avoid dangerous situations.

In view of future prospects of ITS and expected developments a broader scale deployment of already existing in-car technologies (i.e.: dynamic speed adaptation, emergency brake assistant, lane departure warning, automatic cruise control, crossing assistance, etc.) are expected on an international level. In addition to technological advancements general developments will have a significant effect on general mobility and transport systems alike. Demographic changes (with population ageing leading to increasing numbers of older road users and the consequent need to adapt traffic systems to changing needs and forms of outdoor mobility) and changing modes of transport (e-vehicles, such as e-cars and e-bikes, becoming more and more popular) need to be taken into account in view of increasing traffic safety by providing technologies and solutions specifically adapted to the needs of different road user groups. These issues again underline the need for sound data bases of traffic safety related data including traffic conflicts, task demands and accident data to adapt existing and future ITS to actual situations in traffic. The complementing results of both focus group discussions and expert interviews lead to a number of scenarios and general mobility issues which could be solved or at least improved by deploying a variety of systems working on vehicle- and infrastructure levels as well as solutions that can actively be used by VRUs.

Based on expert opinion and discussions with actual road users it can be concluded that critical situations for VRUs are usually related to high (car) speeds, high complexity and density of traffic, local weather conditions and infrastructure maintenance. General knowledge among focus group participants in view of ITS solutions was on a high level regarding standard in-vehicle systems, with ITS infrastructure mainly regarding traffic lights and traffic signs. Smartphone-based applications for routing and navigation are already known and regularly used by all involved road user groups for pre-trip and on-trip information. Participants in all countries showed to have experiences on all levels of ITS (mobile applications, in-vehicle, infrastructure) and technologies (informing, intervening, warning) with a high level of experiences, especially among car drivers.

Main identified benefits and advantages of ITS for VRUs are increased visibility of VRUs (communication, warning, intervention); increased overall traffic flow (automation of processes such as traffic lights, etc.); economic (less fuel consumption) and ecological aspects (less CO2 emissions); increased comfort in traffic (information). On the other hand potential adverse effects are a perceived loss of autonomy, distraction (sounds, visuals, interaction with HMI), and potential for overreliance/overconfidence, technical limitations and reliability. Generally the willingness to use ITS and the assessment of benefits for traffic safety as well as general mobility was on a very high level. Experts are seeing future technological advances mainly in the fields of connecting road user groups and supporting communication (V2V, V2I, etc.), increasing visibility (of VRUs) and vision (of motorised traffic), standardisation of technologies, infrastructural developments and adaptation of legal requirements for a broad scale deployment of technologies.

### 3.2.3 Selected ITS

As a main result of the first tasks an inventory of ITS applications aimed at VRUs was established (comprised of a total of 86 systems). A total of 14 systems address pedestrians, 34 address cyclists, 28 for PTWs, and a number of 10 in-vehicle systems which benefit all VRUs groups.
In course of the first project interest group workshop with 40 stakeholders, representatives of VRU groups, national and European authorities, infrastructure service providers and ITS-related representatives of organizations and companies contributed their input to the prioritization of most relevant solutions for the mobility and safety of the three VRU groups. The participants were asked to select the three applications which have the most potential for VRU safety and general mobility and rate these ITS solutions based on the questionnaires, according to the following criteria: safety, mobility, technical maturity, deployment potential, acceptance (by VRU, drivers and government authorities), relevance for older people, relevance for people with disabilities, feasibility for children, usability of system interface. A five-point Likert scale was used for each of them. In addition, they were asked about potential negative side effects of the systems selected. Each of the functions covers a wide range of actual implementations. For assessing the potential impact of the functions, an existing or possible implementation of the function was selected, and the details of the implementation, such as HMI, technology used, reaction of the driver or the system were described in more detail by the participating experts.

Based on the results of the interest group workshop the final inventory of 20 applications, considered most relevant for the impact assessment, was established in course of an iterative discussion process among the project partners and additional external experts. Main focus for the final selection of applications was on taking all road user groups into account. Systems needed to aim at improving comfort and/or general mobility by also considering at least an ITS applications with potential adverse effects, for analysis in course of the assessment process. Additionally a mix of services close to market and future applications was included in the final set of ITS solutions. In the following the 20 selected systems are briefly described in view of their functions.

1. **Blind Spot Detection for Cars and Trucks (BSD)**
   Detection of pedestrians, bicyclists and PTWs in blind spots round the vehicle based on vehicle sensors (mainly addressing the side areas, optionally front and rear). It detects and warns for VRUs and objects in the Blind Spot of the car/truck.

2. **Intelligent pedestrian traffic signal Extended (IPT)**
   IPT is a traffic signal control system that uses sensors such as an infra-red camera to determine the presence of pedestrians and adjusts the traffic signals accordingly. State-of-the-art traffic light management systems use advanced sensors to monitor crossing behaviour of pedestrians.

3. **Intelligent Speed Adaptation (ISA)**
   Compares the current speed of the vehicle with the local posted speed limit and respond if the vehicle exceeds this posted limit. There are two versions of the system, namely a warning and an intervening one.

4. **Red Light Camera / Average Speed Camera (RCL)**
   The red light camera films a vehicle that crosses the red light. The information about the car (colour, brand etc.) and the license plate info is sent to the police. In respect to improving traffic safety for VRUs, the intended reaction is to prevent drivers to cross the red light, and thereby reducing the chance of an accident.
   The average speed camera measures the average speed of vehicles over a specific stretch of road. Unlike speed cameras that capture drivers’ speed at a certain point along the road, average speed cameras track the speed over a set distance, which may be several kilometres.

5. **Intersection Safety Extended (ISA)**
   Intersection Safety assists the driver and VRU in avoiding common mistakes which may lead to typical intersection accidents. It covers these functions: left and right turn assistance and vehicles arriving perpendicular to VRUs at intersections.
6. Pedestrian Detection System + Emergency Braking (PDS+EBR)

The vehicle has a built-in system that continuously scans for VRUs that the vehicle might be in collision course with. If a crash is likely, the system will warn the driver, for instance through sound, visual signals or vibration of the steering wheel (Lexus implements a variation of the system that tightens the drivers’ seat belt, both as a warning and as a safety feature).

7. Trip planning and navigations for VRUs (NAV)

The system provides navigational support to cyclists, along with other information is also provided relating to cycling performance. In many cases, cyclist don’t use the system as a navigation tool (although it is provided) - rather more they use it to review their routes to see how far they have travelled (trip-counter). The devices have a ‘thin-veil’ of navigation overall providing off-route alerts and major turn instructions at intersections – in other words, the level of navigation is much simpler than motorised vehicles.

8. PTW oncoming vehicle information system (PTW2V)

Provides the driver with information on hazards; VRUs (can also be animals). The system works based on radar/infared sensors/camera. Gives a warning for a hazard or provides a view on a screen.

9. VRU Beacon System (VBS)

The VRU has a chip or tag that sends out a signal that can be detected by a device installed in vehicles. This system calculates the trajectories of the detected VRU, in relation with the vehicle trajectory and assesses the possibility of a collision. The driver is then warned about the possible collision and in case of no response the system can brake autonomously to slow down the vehicle. Besides the resulting list of systems to consider in course of the ITS assessment process, the findings of the first tasks in the VRUITS project provide a basis for the consequent tasks especially in view of critical situations in traffic for VRUs, that have a high potential of being addressed by ITS solutions. In addition general mobility and comfort are directly related to the findings of the user needs assessment, which provides insight in a variety of different dimensions of VRU mobility including specific demands and needs in view of technological innovations in the transport sector. In this regard the safety assessment methodology, as well as the mobility and comfort assessment can directly rely on the findings presented in the first deliverable. While the accident data analyses using both CARE and national databases allow determination of the frequency of many relevant situations and scenarios in view of VRU safety there are limitations with regard to under-reporting, validity, reliability and coverage. In addition, the user need assessment provides qualitative findings on barriers and facilitators of general mobility and consequently the comfort needs of pedestrians, cyclists and PTWs.

10. Cyclist digital bicycle rear-view mirror and rear obstacle detection (BRM)

The aim of the system is to increase peripheral and rear viewing area of the cyclist without having to turn around to prevent potential accidents due to lack of vision. The information is visible to the cyclists via display (head-unit) which is located in the handlebar. The system will identify and inform the cyclist about rear approaching vehicles or other cyclists and thus supports the cyclists to have enough side distance to passing cars or other cyclists. Bicyclists are warned by an audio signal about approaching vehicles from behind. An additional warning is raised if the encounter is estimated to be unsafe, i.e. the trajectory of the approaching vehicle is violating the safety zone of the bicyclist.

11. Roadside Pedestrian Presence Warning System (RPP)

Roadside Pedestrian Presence Warning System detects that a pedestrian is close to a crossing (or bus stop) and warns upcoming motorised traffic with flashing lights or information on a display.
12. Urban Sensing System Extended (USS)

Urban sensing systems can help to inform public service and infrastructure providers and other road users about issues and problems as well as dangerous situations in public places and traffic. By making use of already existing data sources either based on a crowd-sourcing approach (either actively based on applications on Smartphone, or passively provided based on network, location, or other data) information on traffic situations (i.e.: dangerous places, accidents, route choice, etc.) actual mobility behaviour (i.e.: chosen routes, route lengths, etc.) can be collected and provided to authorities and transport service providers. The collected data can in turn be used to provide the contributors and other road users with up-to-date traffic information and service notifications (by means of web-based or Smartphone-based platforms). While the collected data is not representative for a certain mode, or even a whole transport system, user-centred adaptation and design processes in traffic, taking actual mobility behaviour into account, are possible by making use of already existing data infrastructures.

13. Cyclists and Pedestrians Automatic Counting (ABI)

This system helps to localize bicycle and pedestrian patterns and provides bicycle- and pedestrian-related traffic information. The Cyclists and Pedestrians Automatic Counting will provide transport planners with access to more detailed and extensive bicycle- and pedestrian related information. The quality of the existing information can increase sharply, with the use of the Cyclists and Pedestrians Automatic Counting system.

14. Night vision and Warning (NVW)

Night vision and warning systems use infrared radiation from pedestrians, animals and roadsides features to give drivers an enhanced view of the situation ahead.

15. Information on vacancy on bicycle racks (IVB)

By placing sensors in bicycle racks, active signs and SMS services can provide information on vacancy.

16. Bicycle to car Communication (B2V)

The system informs / warns motorised traffic (especially car drivers) about cyclists on the road, in the vicinity of the vehicle and the cyclist of oncoming vehicle and be warned about the risk of collisions.

17. Rider monitoring system (RMS)

The system aims to prevent accidents due to PTW rider distraction. The system monitors the condition and gaze of the driver and tries to keep him/her attended to the driving tasks. The system provides information to the rider via mobile device (display) e.g. concerning his/her riding pattern, optimal route and needs for a break in case drowsiness is detected.

18. Crossing Adaptive Lighting (CAL)

Crossing Adaptive Lighting mounted at (zebra) crossing lights the (zebra) crossing when pedestrians and cyclists use it. When the pedestrian/cyclist activates the system, by through detection from an automated device, the lights are activated/brightened to light the crossing. The system increases the safety of (zebra) crossing users by increasing their visibility to drivers (reducing the chance that the pedestrian/cyclist is not or late observed by the driver) and by making the crossing action more safe for the pedestrians/cyclists due to the improved lighting.

19. Infotainment (INFOT)

Information about traffic jam, accidents, weather, Points of Interest (POI) or music entertainment is received through a mobile phone or in built-in systems in the vehicle (Can also be a stand-alone unit for example a pedestrian or bicyclist). This system is not primary developed for reducing accidents; however information given by the system can be useful or may help to prevent incidents.
20. Real time passenger information (RTPI)

The system gives bus and train users information regarding the timing of the next available bus or train or tram. It warns the public transport users if the service is running late. Also advises on things such as next number of bus/train/tram due at stop and origin/destination etc.

21. Green Wave for Cyclists (GWC)

A green wave is an intentionally induced phenomenon in which a series of traffic lights are coordinated to allow continuous traffic flow over several intersections in one main direction. Bicycles travelling along with the green wave (at an approximate speed decided upon by the traffic engineers) will see a progressive cascade of green lights, and not have to stop at intersections.

22. Road weather warning for pedestrians (VRU-RWW)

The system provides warnings of very slippery walking conditions to pedestrians during winter time. The warnings are (a) available on the internet (b) read on the weather reports in local radio channels of the national radio/TV, and (c) the information is also sent through text message to subscribed persons in several cities.

23. Bicycle forward obstacle warning (FOD)

The system warns cyclists for obstacles (poles, other bicycles) in front of their bicycle. The bicycle will be equipped with a sensor (camera) facing in forward direction. A user interface will warn the bicycle driver for obstacles or potholes in the pavement in front of the bicycle. The cyclist will be warned in time to avoid an incident, and with minimal distraction from their driving task.

3.3 State of the Art of VRU Safety Assessment methodologies

The objective of this literature review is to identify and investigate available safety impact assessment methods for ITS, discuss the VRU groups that will be considered, and based on this investigation to select a suitable safety impact assessment method and identify which modifications are needed to adapt it to the specific needs of assessment of ITS aimed at VRUs. Assessments of safety of ITS have been performed in many EU projects, such as eIMPACT, PReVAL, ITS Testbeds, euroFOT and SAFESPOT. These projects mostly considered systems that impact the safety of non-VRUs or at least do not specifically target VRUs. For example, for eIMPACT only 1 out of the 12 analyzed systems specifically addressed VRUs; for PReVAL this number was 0. Moreover, even when VRUs were considered, this was done from the vehicle perspective, where the VRU is considered merely as a collision object, not as a subject with own behavior. Finally, the results of the assessments were reported as overall effects, and not specific for different user groups – that is, these methods lump all VRU accidents into one big group, without any distinction of accident type, circumstance or VRU type. It seems therefore that modifications may be needed to these existing assessment methods for application to the case of VRU’s. Appendix B provides more detailed information on some of the methods below.

The interactIVe project (Larsson et al., 2012) included a literature review that investigated safety impact assessment methods. A large part of the following literature review is deducted from this report and where possible new insights and resources have been included. Other sources have also identified and classified types of assessment methods, for instance the TRACE project (Pappas et al., 2008; Karabatsou et al., 2007; Page et al., 2007) has identified methods for ex-ante (a priori) and ex-post (a posteriori) evaluation. Similar overviews are made by Joksch & Wuerdemann (1972) and Busch (2005).

Putting different sources together, the following methods can be distinguished for an ex-ante and ex-post evaluation of active safety systems:
**Safety mechanisms:** The safety mechanism approach is summarized in Kulmala (2010) as follows. Kulmala (2010) states the framework of a safety assessment of ITS should (1) cover all three dimensions of road safety—exposure, crash risk and consequence, (2) cover the effects due to behavioural adaptation in addition to the engineering effect (effect on target accident contributory factors) and (3) be compatible with the other aspects of state of the art road safety theories. This entails an estimation of the target population of the ITS and an expert evaluation of its effectiveness in preventing or mitigating accidents. A framework for assessing the road safety impacts that fulfils these requirements is the nine-point list of ITS safety mechanisms. These are explained later in Section 4.1. The safety mechanism approach can be seen as an example of the step-by-step approach discussed next.

Gårder et al. (2013) presents a case study of the effect of backup warning systems and compare estimates from three groups (experts, taxi drivers and students). The groups were asked to give direct estimates of the full effect, and step-by-step estimates of subcomponents of the system. However, step-by-step estimates and direct estimates may lead to different results is that adaptation and new behaviour may lead to new types of crashes occurring (possibly still with young children playing behind cars) and that the step-by-step methodology as used here did not include such effects. However the safety mechanism approach takes account of these mechanisms. Therefore because of less variance and more transparency Gårder et al. recommend the step-by-step process based on individual (personal) estimates.

**Expert Questionnaires:**

- Winkelbauer et al. (2013) present the results of two expert questionnaires focusing on the potential safety and mobility benefits to child pedestrians of targeted types of Intelligent Transportation Systems (ITS). Based on the first questionnaire, fifteen problem areas were defined. In the second questionnaire, the experts ranked the fifteen areas, and prioritized related ITS services, according to their potential for developing ITS services beneficial to children. The approach to rank the measures to get a type of evaluation worked out well.

- This approach was also used by Winkelbauer et al. (2012) in a comprehensive study of PTW safety measures. Winkelbauer et al. prepared a comprehensive list of currently applied and potential PTW safety measures, also providing relevant information on each of the measures. The "list of measures" was collected by two sources. On the one hand, 2BESAFE partners were asked for input and have delivered a total of 130 answered questionnaires describing measures, standards, guidelines and programs. On the other, numerous road safety programs were analysed and all measures proposed within these programs were added to the "List of Measures". At a later stage, more detailed descriptions for all measures were collected and all measures were rated by expert judgment so that a type of evaluation of the measures was performed that could indicate each measure’s effectiveness taking into account several factors that contribute to a measure being successful.

**Accident reconstruction:** this is based on case study-approach, where accident scenarios are simulated with and without the ITS present, and the outcomes are compared. The scenarios are retrieved from an in-depth accident database. The analysis is either automated, and then it can cover all relevant accidents, or it is done manually, and then it is restricted to selected cases only. Then the analysis, however, is carried out in more detail.

**Black box statistical analysis:** TRACE considers a method based on artificial neural networks that assesses safety-based on information about the relevance and influence of the ITS on accident characteristics.
• **Ex-post evaluation:** this is based on accident data with and without the ITS. Two problems recognized by Busch (2005) are that sufficient data becomes available only a long time after the introduction of the ITS, and that it is difficult to properly take into account the applications that prevent accidents (since they no longer appear in the data). Furthermore, the author distinguishes assessment methods for passive and active safety systems, and for each case a subdivision is made into methods based on controlled tests, simulations and accident data. For active safety systems, controlled tests typically evaluate minimum requirements e.g. on brake operation or lighting. Simulations require a driver model; one approach is to use driving simulators but this usually leads to small sample sizes.

• **FOT data analysis:** It is a frequently used approach; this approach uses FOT data to assess safety. The analysis uses data on near accidents or risky events and translates that data into an estimate on safety.

• **Effectiveness methodology using a tree approach:** This approach is based on mapping an accident database to a tree to classify the conditions of the injuries. The mapped accidents are multiplied by percentage of road users that didn’t not die/injured to estimate the effect of an ITS measure.

**Conclusion about for choice of safety impact assessment method**

Based on the impact assessment methodologies discussed, a question that still remains is how to integrate the specific characteristics of the VRU within the safety impact assessment, when the development of a generic impact assessment method in relation to the VRU’s is quite limited. The methodologies reviewed above have hardly been applied to VRUs. Methods based on ex-post analysis of accident statistics are not relevant for the case of ITS for VRU, because little or no statistical data on such applications are available. Thus, ex-ante assessment methods see more appropriate. A comprehensive approach that covers all possible safety effects is the safety mechanisms method, and therefore this will be used in the VRUITS project. Techniques like accident reconstruction can optionally be used to derive estimates for one or more safety mechanisms.

The essence of the safety mechanism approach is that for each mechanism one determines the effectiveness of the ITS in addressing this mechanisms. These effectiveness rates are then combined into one overall rate, which is applied to a collection of accidents (for example the accidents in the European CARE database) to find the effectiveness for each accident. In the end, this determines an effect of the ITS on fatalities, injuries and/or accidents.

In most cases, the effectiveness of the ITS depends on the circumstances. Then the collection of accident scenarios is subdivided into subgroups by these circumstances, the effectiveness rates are determined for each subgroup separately, and the analysis is done per subgroup. Finally the results per subgroup are combined to find the overall effectiveness.

Circumstances can for example be the following:

- accident type.
- environmental circumstances like weather and lighting.
- road type and configuration.
- transport modes of the collision partners.
- age of the collision partners.

This approach faces several challenges:

- Availability of accident indicators: accident databases may not contain all the indicators that are needed to properly assess the impact of an ITS.
  - One issue is that there may be insufficient data to identify the circumstances. Accident types need to be defined in greater detail than what is typically done in car-oriented
safety studies like eIMPACT (Wilmink et al., 2008), and also the road configuration (bike lanes or paths, traffic lights, crossings, etc.) need to be provided in greater detail.

- Another issue is that the estimation of the effectiveness may need detailed data. For example, if this estimation is done by accident reconstruction techniques, then a considerable amount of data is needed to be able to reconstruct the accident in sufficient data. Initial speeds, positions and acceleration evolutions of all participant will be needed as a minimum. Also the road geometry needs to be described in some detail.

- Underreporting: this is a severe problem for VRUs that may skew results completely. Not only are absolute problem sizes unknown, but also the relative size of various safety problems compared to each other.

- Effectiveness per subgroup: for each subgroup of accidents, effectiveness rates need to be determined for all mechanisms. Some issues are:
  - Since the ITS under consideration are innovative, there are likely not many effectiveness rates available in the literature.
  - Methods for determining such rates all have limitations. For example, accident reconstruction can be used to estimate the intended effect of an ITS, but not the unintended effects or long term effects. Expert judgment is of limited scientific quality. Field trials or simulator studies are costly and are typically not able to capture long term effects. Technical tests typically do not take driver reactions into account.
  - If the number of subgroups is large, it can be a daunting task to obtain effectiveness rates for all subgroups. Often one makes some assumptions to reduce the number of independent estimates.

### 3.4 State of the Art of Mobility Methodologies

When assessing available literature in the fields of mobility and comfort of vulnerable road users there is a strong distinction regarding the approach applied on how to assess these aspects. While there are a number of papers that do not clearly define either, there are a number of research projects that provide a good picture of the general mobility level of VRUs, applying methodologies with a number of indicators for assessment, and studies considering comfort of VRUs as a multi-dimensional research topic that needs to be assessed on both a qualitative and a quantitative level.

While mobility levels, levels of service and general mobility behaviour have been a very active research field, with a rising number of data sets available on both national and international levels, the concept of comfort for pedestrians, cyclists and PTWs is often not dealt with explicitly and in detail. Nevertheless there are a number of studies, especially from the fields of spatial planning, architecture and civil engineering, specifically addressing this topic and involved variables.

While safety effects of ITS technologies have already been in the focus of previous studies, no definite mobility and comfort assessment methodology for vulnerable road users is available.

Based on the following results of the literature search the general concepts of mobility and comfort of VRUs are separately discussed, and models for assessment as well as potential data sources are presented in order to serve as a basis for the suggested methodology for the mobility and comfort assessment of ITS technologies.

Starting out with a short discussion of general mobility based on available literature and defining the terms in view of vulnerable road users, tools and indicators for empirical assessment and methodologies for data collection are presented. In addition, again based on a literature search, findings on comfort, available definitions of the term in view of vulnerable road users, dimensions to take into account as well as empirical assessment and data collection methods are presented. Aspects to be taken into account in the course of adapting existing assessment methodologies are summarised.
This section will describe the state of the art of the mobility methodologies, section 3.5 will deal with the state of the art of the safety methodologies.

### 3.4.1 What is mobility

Mobility in general is referred to as “… physical movement. Mobility can be provided by means of walking, cycling, public transport, ridesharing, taxi, cars, lorries and other modes. A range of factors such as increased speed, service quality or affordability of a mode improve access of use of a particular mode by people.” (see Chakwizira, 2009).

Another definition can be found in a report by the Victoria Transport Policy Institute according to which "mobility refers to the movement of people or goods. It assumes that “travel” means person- or ton-miles, “trip” means person- or freight-vehicle trip. It assumes that any increase in travel mileage or speed benefits society.” (see Litman, 2011).

Oxley and Whelan (2008) define mobility as follows: “Mobility is essential for general independence as well as ensuring good health and quality of life (generally considered to include dimensions such as physical health, psychological well-being, social networks and support, and life satisfaction and morale) by virtue of enabling continued access to essential services, activities, and other people.” But the authors also stressed that mobility should encompass more than travel alone. For example, Suen and Sen (2004) argue that being mobile means to be able to travel where and when a person wants, to be informed about travel options, to know how to use them and to be able to use them, and to have the means to pay for them — with the private vehicle coming closest to providing full mobility.

Metz (2000) extended the notion of mobility even further, to encompass the following elements:

1. Travel to achieve access to desired people/places;
2. Psychological benefits of movement, “getting out and about” (closely associated with feelings of independence and self-esteem);
3. Exercise benefits (muscle and bone strength, cardiovascular improvements, and overall health);
4. Social involvement in the local community (associated with reduced mortality); and
5. Potential travel options (i.e. to know that a trip could be made if necessary; e.g., in case of emergency.

Regarding walking and cycling Litman states that “Walking and cycling help provide basic mobility, that is, they provide access to activities that society considers essential or important, such as medical services, education, employment, basic commercial and social activities (see also “Basic Access,” VTPI, 2004). This provides benefits both to users and to society overall, by improving people’s opportunities to participate in economic and social activities.” or further „It (walking and cycling) provides health and fitness, enjoyment, basic mobility, connections between and access to other modes, opportunities for people to interact with their communities and the environment, and a cost effective alternative to motorized travel.“ In addition, Methorst (2014) outlines actual pedestrian quality needs and emphasizes the importance of walking not only as mode of transport, but as prerequisite for sojourning in public space in general.

Mobility is associated with the term accessibility. But Chakwizira (2009) states that “accessibility” should not be confused with mobility. Mobility refers to physical movement, but in general, increased mobility tends to increase accessibility. Cities and other major activity centres tend to have a relatively poor vehicle mobility (due to congestion), but are socio-economically vibrant due to excellent accessibility. This owes to activities that are clustered together and the existence of many travel options. In this regard accessibility is viewed as an over-arching and more comprehensive measure in the pursuit of socio-economic competitiveness” (World Bank, 2008). Furthermore Litman (2010) states that “mobility is just one factor in accessibility; equally important are land use (the distribution of destinations
and therefore the distance that must be travelled to reach activities), network connectivity (the quality of roads and paths), and the quality, affordability and integration of accessibility options (walking, cycling, public transit, taxi, delivery services, electronic communication, etc.). Automobile-oriented improvements often turn out to provide less accessibility benefit, and non-motorized improvements provide greater benefit, than conventional indicators suggest. For example, expanding congested roadways may do little to improve accessibility if it stimulates sprawl or creates barriers to non-motorized travel, forcing people to drive for trips that would otherwise be made by walking and cycling. On the other hand, creating compact, mixed, walkable, “smart growth” communities can improve accessibility without increasing mobility. Mobility-oriented indicators such as roadway level-of-service ignore such impacts.

The issue of accessibility and usability is of increasing relevance for modern transport systems especially in view of demographic change and the increasing share of older road user, with specific mobility needs, who are often times dependent on soft transport modes such as walking, cycling and public transport (Bell et al, 2010).

Mobility has been discussed in a rather wide variety of aspects ranging from different involved levels as well as in view of tangent dimensions, starting from social and psychological factors to health and technology related aspects to consider.

3.4.2 Mobility models

General mobility models usually rely on factors directly or indirectly influencing and, impacting road user behaviour. In this regard models vary in view of the variables taken into consideration with models ranging from very basic to a more complex depiction of the relevant dimensions of mobility. The model presented by Frank and Pivo (1994) for instance only integrates urban and non-urban form factors into the conceptual model of relevant factors influencing travel behaviour (see Figure 10).

![Figure 10. Mobility model (Frank and Pivo 1994)](image)

The model posed by Frank and Pivo is strongly focusing on aspects of infrastructural and land-use density in relation to multi-modal transport, with urbanisation being a major factor. Nevertheless societal aspects, technological or behavioural dimensions are not touched upon due to the focus on specific impacts of land use on mode choice and travel behaviour.
To provide an overview of models identifying all relevant factors influencing mobility on both individual and societal level, Risser et al (2011) provide a more holistic overview with the traffic diamond (see Figure 11) which is taking all tangent fields into account to describe mobility.

The diamond does not only consider traffic as central part of mobility but it takes all different factors influencing it into account. Individual preconditions such as experiences and education are discussed as are technological aspects, focussing on the vehicle and infrastructural level as well as other technical aspects of travel. In addition societal impacts and factors, such as legal and normative aspects, determining the societal framework of mobility is considered relevant.

Actual interactions between road user (groups) constitutes the final element in this holistic mobility model referring to communication, conflicts and relations of different road users in traffic situations.

Another attempt to show what factors influence mobility of pedestrians is made by Methorst (Methorst et al., 2010), based on the three decision levels by Michon (1979) providing a model which not only considers the individual aspects of mobility but rather focuses on general levels influencing mobility:

1. **Strategic level**: pedestrian mobility options are influenced by both objective and subjective factors. Some objective factors are distances longer than walking distance (in itself a subjective measure), serious gaps in routes to (essential) destinations and competition by (apparently) affordable means of transportation (bicycle, moped, public transport, the private car). Examples are: growing distances to essential destinations; contiguous public transport not available. Safety perception and the perception of the strain of walking are important subjective factors. There can also be social and health obstacles to walking. Child protection can take a form that they are not allowed to travel and play independently. Car-dependency and subsequent policy thinking leads to neglecting pedestrian facilities and helps to create a class of people that lack mobility.

2. **Tactical level**: when walking, people are confronted with barriers and obstacles that force them to take detours and to change intentions regarding their operational behaviour. Gaps in the pedestrian network, forcing a pedestrian to cross a (busy) street, to make use of the carriageway or to take a detour are quite common and make the pedestrians' life difficult. Common examples are also obstructed sidewalks near construction sites, obstacles on the pavement and the barrier effects of rail and waterways. Heavy and fast traffic are other menaces that they have to cope with. If one comes across these hindrances often, it will affect one's
perception of the attractiveness of walking and thus ones strategic choices to walk or not to walk.

3. **Operational level:** most pedestrian problems become manifest on the operational level. It may get difficult or even impossible to walk. Examples are: too much traffic that make it difficult or impossible to cross a street, steep slopes, litter, dog dirt, concrete obstacles, frightening people or animals blocking one's way, etc. There may be severe safety risks; traffic safety could be threatened by the objective existence of the risk of traffic accidents or single injury accidents (falls mostly). Objective risks are converted into perceived traffic or security risks, but not necessarily in a linear way.

According to the work of Sammer at al. (2011) the definition of VRU mobility to be used in the context of the development process of the mobility and assessment methodology is that VRU mobility is any form of outside (out of house) movement based on the identified soft transport modes: walking, cycling or motorcycling. These forms of movement are defined by trips from a starting point to a destination (where the destination can also be a public transport stop or station) in order to conduct an out of house activity.

### 3.4.3 Available data on mobility

Databases directly focussing on the mobility of vulnerable road users will be defined in the course of the task 2.5, Scenario Development. Nevertheless a number of different approaches to mobility data collection and correspondingly available mobility data have been identified in course of the literature review on mobility research in EU member states.

There are some examples of detailed information on pedestrians' and bicyclists' mobility that can be used as background data of exposure (Gustafsson and Thulin, 2003). Such information is, e.g., about the number of times the specific type of road user is using a road, crossing a street etc. at a specific type of location per year. When dealing only with crossing the street by pedestrians, types of locations of interest are signalized marked crossings, marked crossings, and places with no special crossing facility. Mobility can be assessed based on the following variables defining out of house mobility (Sammer et al., 2011):

- Region (urban, rural, etc.)
- Number of trips per person
- Mode of transport
  - Main mode of transport (for a specific trip [purpose])
  - Modal-Split (of all used modes on a trip),
- Trip purpose
- Trip duration
- Route choice
- Travel distance
- Travel length
- Travel speed
- Time spent on travelling, duration
- Number of journeys
- Departure time/arrival time

While there a number of mobility studies on all levels, regional, national and European, standardised data for comprehensive mobility behaviour assessment are not available, not least due to significant differences in theoretical and methodological approaches, sampling etc. in the involved countries.
Schafer (2000) provides a comprehensive overview on the existing availability of mobility behaviour studies on an international level by the year 2000. While the data is outdated in a number of countries, the mentioned travel surveys are still the only available representative mobility behaviour data for the respective country. In some cases, as for instance Germany, there are newer, follow-up survey data available. In this case data from 2002 and 2008 collected in course of the “Mobilität in Deutschland” (mobility in Germany) studies conducted by INFAS (Institut für angewandte Sozialwissenschaft [Institute for applied social sciences]) and DLR (Deutsches Zentrum für Luft- und Raumfahrt e.V. - institute for Verkehrsforschung [national aeronautics and space research centre of the Federal Republic of Germany]) provide more up-to-date information. For instance after the last mobility survey in Austria in 1995, a recent survey was initiated in the end of 2013 and will be finalised only by the end of 2014, which is a huge gap.

Table 7. Overview over travel surveys (Schafer, 2000: 3).

<table>
<thead>
<tr>
<th>Countries</th>
<th>Survey year</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>1985/86</td>
<td>Adena and Montesin (1988)</td>
</tr>
<tr>
<td>Austria</td>
<td>1995</td>
<td>Herry et al. (1998)</td>
</tr>
<tr>
<td>Japan (urban areas)</td>
<td>1987, 1992</td>
<td>Ministry of Infrastructure (n.d.)</td>
</tr>
<tr>
<td>Singapore</td>
<td>1991</td>
<td>Olszewski et al. (1994)</td>
</tr>
<tr>
<td>Others</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rural areas in Ghana, Tanzania, Zambia</td>
<td>late 1980s</td>
<td>Riverson and Carapetis (1991)</td>
</tr>
</tbody>
</table>

In addition to the studies mentioned above some projects recently have been dealing with the methodological approach for collecting mobility data (relevant variables, sampling procedures etc.), and also with the question how to conduct cross-country comparisons (for instance see Sammer et al., 2011). These studies can only serve as a general guideline for quality assessment of databases used in course of the mobility assessment process.

3.4.4 Mobility impact assessment tools

Table 8 shows how Litman (2011) summarises parameters that reflect transportation:
Table 8. Comparing Transportation Measurements (Litman, 2011)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Traffic</th>
<th>Mobility</th>
<th>Access</th>
</tr>
</thead>
<tbody>
<tr>
<td>Definition of Transportation</td>
<td>Vehicle travel</td>
<td>Person and goods movement.</td>
<td>Ability to obtain goods, services and activities.</td>
</tr>
<tr>
<td>Unit of measure</td>
<td>Vehicle-miles and vehicle-trips</td>
<td>Person-miles, person-trips and ton-miles.</td>
<td>Trips</td>
</tr>
<tr>
<td>Modes considered</td>
<td>Automobile and truck.</td>
<td>Automobile, truck and public transit.</td>
<td>All modes, including mobility substitutes such as telecommuting.</td>
</tr>
<tr>
<td>Common performance indicators</td>
<td>Vehicle traffic volumes and speeds, roadway Level of Service, costs per vehicle-mile, parking convenience.</td>
<td>Person-trip volumes and speeds, road and transit Level of Service, cost per person-trip, travel convenience.</td>
<td>Multi-modal Level of Service, land use accessibility, generalized cost to reach activities.</td>
</tr>
<tr>
<td>Consideration of land use.</td>
<td>Favors low-density, urban fringe development patterns.</td>
<td>Favors some land use clustering, to accommodate transit.</td>
<td>Favors land use clustering, mix and connectivity.</td>
</tr>
<tr>
<td>Favored transport improvement strategies.</td>
<td>Increased road and parking capacity, speed and safety.</td>
<td>Increased transport system capacity, speeds and safety.</td>
<td>Improved mobility, mobility substitutes and land use accessibility.</td>
</tr>
</tbody>
</table>

The model provided by Litman gives insight into frameworks on how to generally assess mobility, focussing specifically on motorised transport. Variables that are presented reflect the dimensions that should be considered. Units of measure, considered modes, performance indicators, consumer benefits as well as land use, and not least improvement strategies, are also viable for the assessment of vulnerable road user mobility.

Another approach to mobility assessment is available via the EUROSTAT definition of the modal split of passenger transport: The main indicator is defined as the percentage share of each mode of transport in total inland passenger transport performance. The transport modes considered are: a) passenger cars, b) buses & coaches and c) trains (metro & tram, light rail are excluded). The measurement unit is passenger-kilometre, that is, one passenger travelling a distance of one kilometre. “Inland passenger transport” signifies that data refer only to transport on national territory, regardless of the nationality of the vehicle. But this definition does not consider soft transport modes at all. It needs to be modified in order to be able to assess the real mobility behaviour of the population, where road use as a VRU certainly plays a considerable role.

A recent study conducted in Austria focussed on the definition of methodologies to representatively assess mobility behaviour of the Austrian population based on a variety of different data collection methods. Main tools for travel behaviour assessment are focussing on standardized methods, mainly in the field of travel surveys. In addition there are a number of articles focussing on more qualitative approaches to mobility assessment (Clifton, 2001). Clifton points out that the differentiation between qualitative and quantitative tools in the fields of mobility behaviour assessment is often not determined by the actual tool, e.g.: surveys, but rather by the content that is collected, which is frequently strongly focussing on individual and qualitative attitudes (Clifton, 2001: 4). Table 9 provides an overview of potential methods for both qualitative and quantitative assessment. While qualitative tools give more insight into attitudes, quantitative tools provide the opportunity of identifying behaviour trends and changes over time on a representative level. Modern mobility behaviour studies combine qualitative and quantitative assessment tools in order to gather both basic mobility data (number of trips, purpose, etc.) and attitudes in the mobility context.
Table 9. Overview of Methods for Qualitative and Quantitative Assessment

<table>
<thead>
<tr>
<th>Qualitative Tools</th>
<th>Quantitative Tools</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attitudinal Surveys</td>
<td>Mobility Surveys (exposure, trip lengths, trip purposes, mode choice, etc.)</td>
</tr>
<tr>
<td>Focus groups</td>
<td>Spatiotemporal data (from mobile phones, GPS, WLan, etc.)</td>
</tr>
<tr>
<td>Personal Interviews</td>
<td>Travel time budget diaries</td>
</tr>
<tr>
<td>Travel behaviour observation</td>
<td>Travel behaviour observation</td>
</tr>
</tbody>
</table>

3.5 State of the Art of Comfort Methodologies

As described in section 3.4, this section will deal with the state of the art of the safety methodologies, following the same steps as for the state of the art of the mobility methodologies.

3.5.1 What is comfort

Looking at available literature dealing with aspects of comfort of vulnerable road users there are a number of research activities especially in the fields of spatial planning, where pedestrian walkways and bicycle paths are assessed in view of comfort of the respective user groups. While there are studies only taking comfort on a very general level into account, there is literature dealing with this topic on a multi-dimensional level assessing different physical, psychological and physiological aspects of this aspect of mobility.

Comfort is strictly discussed in its relation to travel and mobility in this context as there are very different ways to understand this term in different disciplines. E.g., in medicine or nursing “comfort” is mainly discussed in view of patient’s needs in treatment (see: Tutton & Seers, 2002).

Comfort is often assessed in a broader context, as a part or as a synonym of the concepts “walkability” or “cyclability” which illustrates once again the multi-dimensional aspect of this issue.

Methorst (2003) outlined the aspects that influence general mobility and traffic safety, and he integrated all relevant dimensions into the approach by not only regarding internal and external aspects of mobility, but also by taking societal and technological developments into account.
In this view comfort is related to all of the presented dimensions discussed above. Thereby a number of potential approaches for assessment become visible, varying greatly according to the specific dimension to be addressed. While the societal sector and especially the human factors in the context of ITS need to be approached by social scientific assessment, including qualitative and quantitative approaches, the technological dimensions are more strongly related to the evaluation of both administrative and infrastructural framework conditions. This comprehensive model serves as a holistic approach to provide insight in the actual dimensions that are actually tangent to the comfort topic in general.

In addition Methorst also presents a hierarchical model of general needs of pedestrians with respect to traffic and mobility preconditions, which is also adaptable to other VRU groups.

Starting from the essential preconditions for being mobile, related to health and general traffic safety, the model classifies comfort and attractiveness on top of the pyramid as most important "satisfiers".

![Diagram](image1.png)

**Figure 12.** The 'Pizza Model' for traffic and road safety interventions (Methorst, 2003).

![Diagram](image2.png)

**Figure 13.** Pyramid of needs of pedestrians in public space (Methorst, 2003).
In general, the comfort of vulnerable road users is mainly discussed in the context of LOS (level of service) that reflects how certain infrastructure settings or infrastructure elements fit the mobility needs of different road user groups (see Landis et al., 2007; Muraleetharan et al., 2005), while interaction with other road users that might strongly influence comfort is hardly ever discussed.

A specific definition that could be relevant especially in view of the implications of ITS solutions for vulnerable road users, comes from Slater, according to which comfort is:

"(...) a pleasant state of physiological, psychological, and physical harmony between a human being and the environment" (Slater, 1985: p. 4). This definition already provides insight into three general dimensions – physiological, psychological and physical - relevant for the assessment of comfort regarding to Slater. Each of these three dimensions is of course to be defined and assessed separately, in order to take the complexity of this issue into account.

A definition of the three dimensions, specifically addressing pedestrian comfort, can be found in a study of Sarkar from 2002, where comfort needs of pedestrians in high density and high complexity urban scenarios are discussed. Sarkar pleads for a two level approach for the assessment, on a micro and a macro level (Sarkar, 2002: pp. 6): the macro level encompasses the general circumstances and the infrastructural context including relevant standards and criteria, referred to as "service levels". The micro level focuses on the actual quality of the task and on factors that directly influence the individual perceptions referred to as "Quality levels". This broadens the definition by Slater, as the micro level specifically addresses individual circumstances under which a certain mode is used or has to be used and allows for a more specific assessment of the actual quality of certain situations. This indicates also clearly that comfort assessment is varying with the mode used, as there are specific differences concerning the involved physical, psychological and physiological work load. To assess work load appropriately, infrastructural, societal and individual circumstances need to be taken into account for the respective mode.

This approach to pedestrian comfort, and VRU comfort in general, is thus very strongly relying on infrastructural and environmental factors that affect comfort, as the following list of indicators illustrates (Sarkar, 2002: pp. 6):

I. Provision of stopping places and secondary seating
II. Protection from adverse weather conditions
III. Level of noise
IV. Level of air pollution

While there is also a reference to the accommodation of pedestrian needs and the psychological level of comfort, no specific tools to assess this dimension more than walking speeds and the abilities to engage in social interactions are specifically discussed.

A study focusing stronger on the qualitative aspect of comfort (of pedestrians), while defining comfort similarly, includes the emotional component of this aspect more explicitly:

"(...) comfort for pedestrians is a positive emotional reaction to external surroundings (the walking environment) in different situations, including physiological, physical, social and psychological reactions." (Ovstedal & Ryeng, 2002: p. 2). The emotional component of comfort is considered as: "(...) short-lived emotional reactions rather than cognitive reflections (...)" (Ovstedal & Ryeng, 2002: p. 2). This approach implies a stronger focus on individual assessments of comfort that is influenced by both external and internal factors. The actual questions that Ovstedal and Ryeng included in their study focus on "thermal comfort, visual comfort, acoustic comfort, tactile comfort, smells, air pollution and allergens, the ease to move and the feeling of security" (Ovstedal & Ryeng, 2002: p. 2). They also introduce the concepts of efficiency and perceived safety which opens the discussion not only to infrastructural aspects and indicators such as walking speed, but to characteristics that help to specify certain needs in relation to individual preferences and (in)abilities.
Likewise, the research project PROMOTE focusing on pedestrian comfort needs shows the importance of considering individual characteristics such as age, gender and state of health, especially in the connection with mobility impairments, as essential factors for assessing comfort.

Overall it has to be pointed out, based on the literature search and review of current studies in the mobility research field, that there is a severe lack of both theoretical and empirical discussion of the comfort topic. Work in VRUITS will help to close this gap a bit. Moreover, in view of the assessment of potential impacts of ITS on the comfort of VRUs the existing methodologies will be extended to consider technological solutions form the ITS fields in the assessment process.

### 3.5.2 Comfort models

Models strictly focusing on the comfort aspect of mobility are somewhat scarce, but Sarkar (2002) provides a very comprehensive model integrating most of the dimensions and aspects discussed above. The model starts from a base level where the basic needs of all (vulnerable) road users need to be accounted for, specifying both macro- and micro conditions and identifying measures and potential outcomes. This model already represents a comparatively complete approach at evaluating comfort levels. While directly addressing pedestrians it also provides an equally viable approach for cyclist and PTW comfort assessment, as it does not directly involve specifics that would exclude one group, if one replaces "sidewalks" by a more general term like, e.g., environment.

![Diagram of Evaluation of Comfort Requirements in urban sidewalks](image)

*Figure 14. Evaluation method of pedestrian comfort (Sarkar 2002).*
The tools to apply the above model of course need to be adapted to the target group. Based on the respective VRU group certain aspects need to be adjusted or changed in order to accommodate the particularities of the different modes. These differences could be minor however, as for instance stopping places are basically more relevant for pedestrians and cyclists, but can also increase comfort and general quality of the riding experience of PTWs (i.e.: by providing restrooms, etc.).

Another interesting model is provided by Ovstedal and Ryeng (2002). It is also mainly aiming at pedestrians, but the elements of the model are generally relevant for all vulnerable road user groups. The model integrates both the individual and the environmental level. While the environmental level is mainly focussing on the traffic conditions and the available infrastructure, the individual level is limited to the individual assessment of the weather conditions.

![Main factors influencing comfort feeling](image)

**Figure 15. Main factors influencing the feeling of comfort when walking (Ovstedal & Ryeng, 2002).**

This model does not only emphasize the importance of individual characteristics such as the main intentions when walking (or when using one of the VRU modes), which can range from social activities, looking for a safer environment (away from dense urban traffic) to recreational purposes (Ovstedal & Ryeng, 2002: pp. 9). The model of Ovstedal and Ryeng also proposes a hierarchical approach to comfort assessment.

Study results of the PROMPT project show that certain preconditions need to be satisfied, based on individual trip purposes. One aspect that this model introduces (which has only been marginally considered in the other studies in regard to comfort) is the need for information, specifically the need to find one's way and to get an overview on the surroundings. This aspect of information also takes up the issue of pre- and on-trip information that should be provided to the different VRU groups.

Both models above, providing an evaluation model for pedestrian comfort and explicating essential factors for pedestrian comfort, suggest that comfort assessment should consider internal and external factors that influence the individual feeling of comfort. Not only the level of service but also the quality level provided to the respective road user groups is considered in a micro-macro approach allowing finer gradations of the comfort topic by also accounting for the levels of physical, psychological and physiological needs of VRUs. One essential finding relates to the fact that gender, age and state of health are essential factors in assessing the factors that influence the comfort when walking, cycling and riding a motorcycle in traffic.

The tools to assess comfort are determined by the defined factors and need to cover both qualitative and quantitative variables. A qualitative evaluation of actual user needs in order to identify individual assessments and ratings of walking and cycling conditions as discussed in the models above is essential for capturing a comprehensive view of the comfort level in regard to certain infrastructure, topography or region.
ITS solutions aiming at improving the respective levels of comfort can be assigned by looking at the factors that are proven to affect the assessment of comfort by vulnerable road users. Thereby also factors such as workload related to travel, stress related to travel and/or uncertainty related to travel situations have to be taken into account, as these psychological factors are strongly related with the individual perception of comfort.

### 3.5.3 Available data on comfort

As outlined above most projects dealing with aspects of walkability, cyclability and the preconditions for PTW usually provide data for general comfort assessment. These assessment approaches vary by project goals, applied data collection methods and vulnerable road user group. Due to the nature of the construct "comfort" data on comfort is strongly based on qualitative data, frequently collected with the help of road user questionnaires and observations in the public space, or based on check list rankings.

The EU project PROMPT (2004) provides a well usable database on case studies on pedestrian comfort conducted in 6 EU countries, including France, Switzerland, Norway, Belgium, Finland and Italy. Comfort is assessed on the above discussed micro- and macro levels, and the data are collected in the frame of interviews with pedestrians. The PROMPT study from 2004 is also the only available study that provides data on pedestrian comfort that allows cross-country comparisons regarding the six countries presented in Table 10.

**Table 10. Study description PROMPT (Ovstedal and Ryeng, 2004: 22).**

<table>
<thead>
<tr>
<th>Country data available</th>
<th>Regions</th>
<th>Sample size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Finland</td>
<td>City centre/suburb</td>
<td>199</td>
</tr>
<tr>
<td>France</td>
<td>Residential area</td>
<td>119</td>
</tr>
<tr>
<td>Italy</td>
<td>Residential area/suburb</td>
<td>159</td>
</tr>
<tr>
<td>Norway</td>
<td>City centre</td>
<td>180</td>
</tr>
<tr>
<td>Switzerland</td>
<td>Residential area/suburb</td>
<td>131</td>
</tr>
<tr>
<td>Belgium</td>
<td>City centre/suburb</td>
<td>304</td>
</tr>
</tbody>
</table>

The data collected provides a good overview over urban areas, including residential and suburban areas. The data was collected based on a specifically developed pedestrian comfort questionnaire, incorporating the above discussed dimensions of comfort of vulnerable road users, taking both psychological as well as external, physical factors into account.

The results presented by Ovstedal and Ryeng (2004: 51) are covering a wide range of indicators, including attractiveness, social aspects as well as dressing and serve as the basis for a comprehensive evaluation of the comfort assessments of the respondents in the participating countries. These also allow statements on factors like, e.g., region, urgency of need of action, the specific dimension that requires attention in the pedestrian environment etc.. However, this kind of data is only available for the participating six partner countries and is specifically focussing on pedestrians, not taking cyclists and PTWs into account. A solid data basis for assessing comfort needs to provide information on the other VRU groups as well, and it should allow cross-country comparisons on a European level.

### 3.5.4 Comfort impact assessment tools

According to the notion that comfort is a highly diverse topic in regards to the dimensions to be measured (physical, psychological, and physiological), and considering the goal that the comfort level of
different VRU groups should be measured and the specifics of each VRU group should be taken into account appropriately, a combination of qualitative and quantitative instruments is envisaged.

The proposed approach by Sarkar, see Table 11, is mainly relying on survey methods and check lists to cover all aspects seen in the below table. While this approach includes the three dimensions of physical, psychological and physiological aspects as well as a set of indicators for assessment, there still seems to be a lack of individual characteristics that should be taken into account such as gender, age and state of health.

Table 11. Short version of the "Evaluation criteria for comfort levels for pedestrian circulation in urban networks" (Sarkar, 2002).

<table>
<thead>
<tr>
<th>Comfort Types</th>
<th>Attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical</td>
<td>adequate walkway</td>
</tr>
<tr>
<td></td>
<td>continuous sidewalk</td>
</tr>
<tr>
<td></td>
<td>comfortable for vulnerable users</td>
</tr>
<tr>
<td></td>
<td>walkway free of impediments</td>
</tr>
<tr>
<td></td>
<td>comfortable walking surface</td>
</tr>
<tr>
<td></td>
<td>seating</td>
</tr>
<tr>
<td></td>
<td>protection from extreme weather conditions</td>
</tr>
<tr>
<td>Psychological</td>
<td>ability to maintain desired walking speed</td>
</tr>
<tr>
<td></td>
<td>ability to participate in various pedestrian activities</td>
</tr>
<tr>
<td>Physiological</td>
<td>noise</td>
</tr>
<tr>
<td></td>
<td>pollution</td>
</tr>
</tbody>
</table>

The broader approach by Ovstedal and Ryeng (2004) focuses more strongly on qualitative aspects, especially concerning perceived safety and security as specifically important issue for VRUs, see table 10. This model also integrates efficiency into the assessment, as well as general attractiveness of the used infrastructure. In addition, comfort is specifically addressed by evaluating individual assessments, mainly in connection with weather characteristics.

Table 12. Dimensions describing the pedestrian environment (Ovstedal and Ryeng, 2002).

<table>
<thead>
<tr>
<th>Safety and security</th>
<th>Feeling safe when walking at the site, confident in walking alone at the site both during daytime and when it is dark, not afraid of whom to meet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attractiveness</td>
<td>Hard to get an overview of the traffic situation, appealing surroundings, not unpleasant odours</td>
</tr>
<tr>
<td>Traffic conditions</td>
<td>Pleasant sound level, pleasant and exiting sounds, no bothersome car traffic, fresh air</td>
</tr>
<tr>
<td>Social meeting places and pleasantness</td>
<td>Easy to meet requirements for rest, food and toilet, enough places to sit down, be protected from the weather by buildings, vegetation or topography, smooth and nice pavement surface</td>
</tr>
<tr>
<td>Move efficiently</td>
<td>Minimal differences in altitude, not too windy, feel free to choose your own speed, not too much presence of vegetation, nature and water</td>
</tr>
<tr>
<td>Physiological factors</td>
<td>Not too high temperatures, not too hard/exhausting trip, not too dry air, not being blinded by light</td>
</tr>
<tr>
<td>Dressing</td>
<td>Not too little clothing and too thin shoes</td>
</tr>
<tr>
<td>Space and light</td>
<td>Not too narrow surroundings and not too dark</td>
</tr>
<tr>
<td>Comfort</td>
<td>Comfortable weather for walking, comfort feeling</td>
</tr>
</tbody>
</table>
Both of these approaches for assessing comfort on a qualitative level apply survey methods to cover the individual road user assessments. In addition they apply check list methods to rate available infrastructure (i.e.: pavement conditions, continuity of sidewalks/cycle paths, seatings, etc.) on different scales. By applying a combined approach that integrates both survey methods for individual road user ratings and observations for infrastructure assessments and road user behaviour, both provide insight into the internal and external factors that determine the comfort of different VRU groups. A combination of both qualitative and quantitative factors into one model will help to generate an appropriate tool for comfort assessment.

Table 13. Assessment tools for different dimensions of comfort assessment (based on Ovstedal and Ryeng and Sarkar, 2002).

<table>
<thead>
<tr>
<th>Comfort Types</th>
<th>Attributes</th>
<th>Assessment</th>
<th>Tools</th>
</tr>
</thead>
</table>
| **Physical**  | Available infrastructure:  
  • adequate walking/cycling surface (continuous sidewalk, [no] impediments, segregation of traffic lanes, etc.)  
  • seating  
  • protection from (extreme) weather conditions  
  • presence of vegetation, nature etc. | Quantitative Assessment | Infrastructure evaluation (usability, accessibility studies) |
| **Physiological** | Contextual variables and environmental conditions:  
  • noise  
  • pollution  
  • weather conditions (temperatures, rain, etc.)  
  • clothing | | (Traffic) Observation  
 Survey |
| **Psychological** | Individual attitudes:  
  • ability to maintain desired walking speed  
  • ability to participate in various pedestrian activities  
  • feeling safe  
  • Hard to get an overview over the traffic situation,  
  • Pleasant sound level | Qualitative Assessment | Focus Groups  
 In depth interviews  
 Attitudinal Surveys |

The qualitative part focuses on individual attitudes and assessments. Quantitative dimensions cover environmental and infrastructural conditions, both directly effecting comfort of vulnerable road users. The comfort assessment of VRUs needs to integrate both approaches into the process to allow for a comprehensive insight on both internal and external factors that have an impact on the individual assessment of comfort.

The specifics of each tool vary in the studies applying them in the comfort context, e.g. with respect to sampling methodologies, sample sizes, details of the methodological application, etc.

When trying to connect general concepts of comfort, walkability, cyclability, etc. to ITS solutions and their potential impacts on the travel comfort of vulnerable road users not only systems directly aiming at improving comfort are of relevance but also those that are safety related. The studies above show that objective as well as perceived safety play an integral role in the individual comfort perceptions. Systems that allow VRUs to identify potentially critical scenarios in traffic and to avoid them, by being
warned, routed or re-routed based on current traffic situations and/or general conditions, are directly related to the comfort concept.

3.6 State of the Art of CBA Methodologies

This section discusses the methodology through which the actual model for the cost-benefit analysis will be developed. The section starts with an overview of existing standard CBA methods, followed by a general description of the CBA methodology: what are the principles behind a CBA and what steps need to be taken in a CBA.

3.6.1 Existing standard CBA methods

Over the years, there has been an ever increasing amount of practice regarding the monetisation (through CBA) of impacts of transport projects. The EU issued a Guide to Cost-Benefit Analysis of investment projects in 2008 (European Commission, 2008), to be followed for applications relevant to Structural and Cohesion Funds. This Guide provides a framework for the CBA while describing what kind of impacts should be taken into consideration when performing one. It mentions that both consumers’ and producers’ surplus should be included in the analysis (including the value of time savings and unperceived benefits to the users). However, the Guideline proposes no unit values for evaluation at a European level, but rather indicates what the common practice is. The most recent attempt to produce monetary unit values for use in the CBA was the HEATCO FP6 research project (Bieckel et al., 2006) that dealt with producing values for safety, environment, congestion and travel time savings for all EU countries at that time (EU-25). In this study, we have chosen to adopt the values produced by HEATCO, as far as they are available for the impacts addressed. More recent values are available for individual member states, such as the ones published by the institute for road safety research of the Netherlands (SWOV, 2011). Nevertheless the values produced by HEATCO were preferred so as to secure consistency of the dataset for all countries. Where the values produced by HEATCO do not suffice for the monetisation of benefits, specific sources of monetary values have been used as presented in later sections of this study.

Regarding evaluation of ITS applications there is extensive literature. The eIMPACT project (Alkim et al., 2008; Baum et al., 2008; Benz et al., 2008), deals with the impact assessment of ITS applications, developing a tailor-made ITS CBA methodology that assesses the impacts on traffic and safety of selected applications. Nevertheless only one of the examined applications is targeting VRUs and when doing so, this is not done in a VRU-specific framework. Despite the extensive existing literature, assessing the impacts for VRUs at a way that targets their specific needs and elaborating per VRU group is something that has not drawn much attention until now. For example, no methodology has been developed that would try to capture and monetise the impact ITS systems have on the comfort level of VRUs. In the development of the impact assessment framework of VRUIS, we follow-up on the work carried out by eIMPACT, by addressing the impacts of ITS applications also specifically for VRU groups, and by providing monetary unit values to monetise these impacts. The monetisation is performed by taking into consideration a VRU-centric approach on the evaluation of those impacts.

Overall, the CBA is a useful tool in project appraisal, but it is not without limitations. For instance, if not all project impacts can be known in monetary terms, or if policy-makers place high weight on non-efficiency criteria such as self-reliance and regional and temporal equity, the application of the CBA as tool for decision making is of limited value. Especially important is to highlight that in a CBA equity issues are not addressed: the methodology is indifferent as to who benefits from a project and who faces the costs. Cost and benefit occurring to a VRU or to multinational corporations company have an equal weight. As long as total benefits outweigh total costs, the result of the CBA is positive. This could be overcome to look more in detail who receives the benefits and costs by looking at the impacts on the different stakeholders.
3.6.2 Definition of CBA characteristics

Investment appraisal in general, and cost-benefit analysis (CBA) in particular, is the formal process that provides and formulates a framework within which investment decisions can be made. Measures are assessed according to criteria such as costs, revenues, socio-economic benefits and risks.

Evaluations have to distinguish public versus private, collective versus particular (or individual) interests. In CBA it is important to bear in mind that different sectors/stakeholders will often have different objectives. Since the analysis necessarily should reflect the appraiser’s objectives, the impacts included in the analysis, the importance given to the various impacts, as well as the discount factor used, is determined by the interest of the appraiser. It follows that the outcome of an analysis may differ depending upon the stakeholders’ viewpoint. For instance, the outcome of a CBA may exhibit a potential difference in the benefits enjoyed by a vulnerable road user compared to those enjoyed other road users. Furthermore, benefits of a certain measure could fall very unbalanced compared to cost for a stakeholder: it may be possible that a governmental organisation bears the cost of an alternative, but that other stakeholders largely benefit from the alternative.

A CBA from the perspective of society as a whole is often called a socio-economic cost-benefit analysis. A socio-economic CBA involves the identification of all effects of a project on the welfare of all members of society. In welfare economic theory this is expressed in utility, which is a rather intangible measure. A common unit of measurement is required to establish whether aggregate benefits outweigh aggregate costs, given a certain discount rate during the lifetime of the project. Generally, the common unit is money. Impacts are evaluated if possible on the basis of prices observed in the market, with certain necessary adjustments. Where impacts lack an appropriate market price or cannot be directly measured in monetary units, it is sometimes possible to estimate unit money values indirectly through some form of shadow pricing. Nonetheless, some impacts that cannot be valued in money (intangibles) remain in principle outside the quantitative analysis. From a society point of view a CBA is conducted in terms of resource costs, i.e., the real net costs to society of the impacts it has. Taxes and transfer payments are excluded. Also excluded in many national CBA applications is valuation of impacts outside the country concerned. For appraisal from a Europe-wide perspective the geographical impact area must be agreed upon.

A CBA is conducted on the basis of incremental analysis, focusing on differences between the situations with and without the project. That is, only project-specific effects are considered. It is therefore of great importance that the assumptions are specified regarding what would happen if the project is not implemented (Business As Usual scenario).

Figure 16. Illustration of a project effect as it is used in a CBA.

This means that in a CBA two scenarios will have to be developed. One scenario must be a Business As Usual (BAU) scenario: in VRUITS this will be the situation in which it is assumed that there will be
no implementation of the particular ITS services that are to be evaluated (there may thus be other ITS services which are implemented). The BAU scenario is not the same as a ‘do-nothing’ scenario since developments in the population will continue to take place (for example increasing share of elderly) as well as changes in mobility (for example increasing share of saver cars). The second scenario (also called the ‘with’-scenario) is the situation in which it is assumed that ITS services aimed at VRUs are introduced. The differences between the two scenarios are the project effects. Only these project effects are taken into account in the CBA.

### 3.6.3 Steps in a CBA

The set-up of a thorough framework for project appraisal comprises the following steps:

1. Development of the business as usual situation as a basis for comparison with the situation in which ITS services aimed at VRUs are implemented. An assessment is made of the effects that will take place in a scenario with (new) ITS services compared to the business as usual scenario. This may concern operational improvements, comfort improvements and safety improvements.

2. Calculation of the costs of the project for each stakeholder: implementation costs, operating and maintenance costs, avoided costs, termination costs.

3. Quantification and monetisation of effects for all stakeholders that are affected by implementing the project: this step will translate the effects derived in the step before into monetary terms. E.g., the value of improved monitoring capacity will be assessed, and the resulting effects will be expressed in euros as much as is possible. Those effects which are important for the welfare of society, but that cannot be expressed in monetary terms will be included as pro memoria items.

4. Trade-off: finally the costs and benefits will be balanced, and these will be expressed in indicators such as net present value (NPV), Internal rate of return (IRR) and payback period as explained in section 3.6.6.

5. Sensitivity analysis: The outcomes of the CBA in terms of NPV or related indicators, however, are meaningless if the underlying assumptions are not soundly based. Assumptions regarding the physical size of costs and benefits, as well as prices and timing should be reviewed systematically. This is done by determining the NPVs (the output) for different assumptions regarding costs and benefits (including prices and timing), while the other variables are set to their base values.

### 3.6.4 Decisions to be supported by CBA analysis

The goal of the cost-benefit assessment must be clear: is the goal to determine the profitability of a new ITS service for all VRUs, for one specific VRU group, for other stakeholders or for the society as a whole. In the latter case, it also has to be decided whether the profitability will have to be determined for each EU country separately or only for the EU-28 as a whole. It also has to be determined if the profitability of individual ITS services will be determined or of multiple ITS services that are to be introduced at the same time. These kinds of decisions have to be made before the CBA starts.

### 3.6.5 Identification of stakeholders

In identifying the relevant impacts it is essential to first identify the relevant stakeholders. Stakeholders can be classified according to their role or interest in the proposed project. Table 14 provides a general outline of this categorisation within the context of ITS services aimed at VRUs.
Table 14. Stakeholders of ITS services for VRUs.

<table>
<thead>
<tr>
<th>Stakeholders (not exhaustive)</th>
</tr>
</thead>
<tbody>
<tr>
<td>VRUs (categories of VRUs are defined in WP 2.1-WP 2.3)</td>
</tr>
<tr>
<td>Other road users</td>
</tr>
<tr>
<td>Health care sector (hospitals)</td>
</tr>
<tr>
<td>Manufacturers of ITS systems</td>
</tr>
<tr>
<td>Governmental organisations</td>
</tr>
<tr>
<td>Insurance companies</td>
</tr>
</tbody>
</table>

The stakeholder group comprises first of all the stakeholders that are the (potential) users of the ITS services: the VRUs. The use of these ITS services also have an impact on third parties, or non-users, such as the health care sector (e.g. fewer casualties due to improved safety) or other societal actors such as insurance companies (e.g. lower insurance costs as a result of fewer accidents). Governmental organisations could see both an increase and decrease in costs and benefits. For instance if governments needs to make additional costs in order to make the implementation of the ITS services possible, this involves a cost for them. If, on the other hand, fewer accidents take place resulting in less medical expenditures for the government this results in a benefit.

When focussing on society, transfers between actors are disregarded. This results for example in the fact that the revenues for manufacturers of ITS systems are disregarded in the final CBA result because VRUs or governments will have to pay for these ITS systems.

### 3.6.6 Expressing the CBA outcome: NPV, IRR and BCR

To compare current and future costs and benefits, the annual cash inflows and cash outflows of the project, compared to the base case, have to be discounted. A frequently applied measure in CBA is the Net Present Value (NPV). The NPV is defined as the cash equivalent today of a sum receivable or payable at a future date. In order to calculate the NPV, it is necessary to discount future benefits and costs. This discounting reflects the time value of money. Benefits and costs are worth more if they are experienced sooner. The higher the discount rate, the lower is the present value of future cash flows. Hence the value of the discount factor reflects the preference of society for today’s income versus income later in time. The discount rate represents also the cost associated with diverting investment resources from alternative investments or from consumption. The following equation is used for calculating the NPV:

\[
\text{Net Present Value (NPV)} = B_0 - K_0 + \sum_{t=0}^{n} \frac{B_t - K_t}{(1+r)^t}
\]

Where:

- \( n \) is the project life in years;
- \( B \) is the present value of cash inflows in year \( t \);
- \( K \) is the present value of cash outflows in year \( t \);
- \( r \) is the annual discount rate.
If the net present value is positive, this means that over the project life time the discounted cash inflows are higher than the discounted cash outflows of a project. This means that the project has a profitability that is higher than the discount rate and is attractive to society. Hence:

If NPV: $\text{NPV} > 0$, the project or solution is attractive for society (profitability is higher than discount rate used)

If NPV: $\text{NPV} < 0$, the project or solution is not attractive enough for society (profitability is lower than discount rate used)

Another measure often applied in CBA is the Internal Rate of Return (IRR). The IRR is the discount rate that equates the present value of the costs with the present value of benefits associated with a project. The IRR, in other words, is the discount rate at which the NPV of an investment opportunity equals zero.

$$\sum_{i=0}^{n} \frac{B_i - K_i}{(1+i)} = 0$$

where $i$ is the Internal Rate of Return

The internal rate of return has to be higher than the interest costs against which the capital for the investment is borrowed. Hence:

If IRR: $\text{IRR} > \text{cost of capital}$, the project is attractive for society.

If IRR: $\text{IRR} < \text{cost of capital}$, the project is not attractive for society.

A last measure that is sometimes used to express the outcome of a CBA is the Benefit/Cost ratio (BCR). The Benefit/Cost Ratio is a simple measure of profitability The ratio simply divides the discounted benefits by the discounted costs.

Benefit: Cost Ratio = $\frac{\sum B_t}{\sum K_t}$

Where $B_t$ is the present value of the cash inflows

$K_t$ is the present value of the cash outflows

This implies that if the BCR is larger than 1, the discounted benefits are higher than the discounted costs, and the project is attractive to society:

If BCR: $\text{BCR} > 1$, the project is attractive for society

If BCR: $\text{BCR} < 1$, the project is not attractive for society.

In case of more than one alternative, the general consequence of the three measures mentioned above, is that the project with the highest IRR or B/C ratio has highest attractiveness from socio-economic point of view. However, for cases with both single and multiple alternatives, it is useful to assess the cash flows behind the ratios.

### 3.6.7 Discount rate

The discount rate expresses the rate of return that would have been generated in case of an alternative use of the means. In European countries there is a large variation in the prescriptions for the use of the discount rate. For the 2007-2013 period, the European Commission has suggested using two benchmark social discount rates: 5.5% for the Cohesion countries and 3.5% for the others. In the calculations the *discount rate of 5.5%* will be used, in the sensitivity analysis the effect of a higher and lower rate will be calculated.
3.6.8 Base year and time frame

When determining the time horizon for the CBA, questions have to be addressed like: when is the alternative implemented? Until when is the alternative considered? An unbiased comparison of project cases and the base case requires that they be analysed over equivalent time frames.

In T2.5 the time frame will be established. It is suggested to adopt a time frame that takes into account the lifetime of the (new) devices/techniques that will be implemented in the near future.

3.6.9 Geographical scope

The CBA will be carried out from an EU-28 perspective. This means that for the cost definition, the total investments by European countries/agencies/individuals are taken into account, and for the benefits the benefits in all of the EU-28 countries.

3.6.10 Sensitivity analysis specifications

Sensitivity analyses shows to what extent the viability, often expressed by the NPV, of a project is influenced by variations in major quantifiable variables.

The values of these variables for the most probable outcome scenario are influenced by a great number of factors. They are based on assumptions and depend on future developments; the actual values may differ from the forecasted value. Therefore, an analysis will be carried out to assess how sensitive outcomes are for these assumptions. This will be done by:

- Varying key parameters such as investment costs, operational costs, discount rate, etc.
- Carrying out a break even analyses that indicates the bandwidth of the CBA outcomes, e.g.:
  - What are the maximum investment costs in order to still have a positive CBA, given the baseline assumptions on the effectiveness of the systems?
  - What is the minimum required effectiveness of the systems in order to have a positive CBA, given the baseline costs of the systems?

3.7 Conclusions

This chapter draws required conclusions about many aspects that form the basis for the qualitative and quantitative impact assessment of ITS for VRUs. These include the definition of VRUs used in VRUITS, the selection of methodologies for assessment, information gathered from within and outside this VRUITS project.

The definition of the VRUs to be addressed in this study is crucial, as different definitions of VRUs exist and the boundary of the definition has significant implications for the methodology selection and the data required for assessment. Based on the criteria concerning external protection, task competency and resilience, VRUITS will focus on the following VRU groups as shown in Table 15.
Table 15. VRU categorisation to be used in VRUITS Impact Assessment Analyses.

<table>
<thead>
<tr>
<th>Mode</th>
<th>Age in years</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>7–12 years</td>
</tr>
<tr>
<td>Pedestrian</td>
<td>X</td>
</tr>
<tr>
<td>Bicyclist</td>
<td>X</td>
</tr>
<tr>
<td>Moped</td>
<td>X</td>
</tr>
<tr>
<td>Motorcycle</td>
<td>X</td>
</tr>
</tbody>
</table>

The identification of critical scenarios and of VRUS needs provided input to the selection of the ITS to be examined in this project. These activities were carried out in earlier tasks of VRUITS. The selected ITS will undergo qualitative and quantitative assessment later in the project.

Taking into account the ability to assess the impacts of ITS systems that do not yet exist or for which little or no empirical impact evidence exists, the “safety mechanism” methodology as described in Kulmala (2010) was chosen as the safety impact assessment methodology for VRUITS.

General concepts of mobility and comfort of VRUs were discussed along with models for assessment data sources as a basis for use in the models. There are few methods currently available to assess mobility and comfort, and of VRUs specifically, especially compared to the number of safety assessment methodologies. Furthermore, little or no data is available on the mobility of VRUs, and even less so on the comfort of VRUs. The proposal to use a variant of the mechanisms methodology developed for safety and applied to mobility and comfort will be proposed in Chapter 5.2.

The CBA methodology for assessing the impacts of ITS on VRU exists and can be extended to address the specific VRU aspects at the European level.
4. METHODOLOGY FOR SAFETY IMPACT ASSESSMENT

This chapter provides an overview of the safety impact assessment method prior to VRU|ITS, then describes what modifications are necessary for application to VRUs in VRUITS.

4.1 Overview of Model development prior to VRUITS

The safety impact assessment method applied in VRUITS was reported by Kulmala (2010). The method has been developed and applied at VTT in several previous projects starting from eIMPACT (Wilmink et al., 2008) to PreVAL (Scholliers et al., 2007), CODIA (Kulmala et al., 2008a), INTERSAFE2 (Wimmershoff et al., 2011), Minifaros (Fuerstenberg & Boehning, 2012) and two Finnish projects. The starting point to the safety impact assessment in VRUITS is in the model applied in INTERSAFE2 as it includes the latest amendments. The following text is describing the model and modifications which have been included in it during the other projects in which the model has been exploited.

General

The starting point for the development of safety impact assessment method to be used in VRUITS project was safety impact assessment framework presented by Kulmala (2010). The framework of Kulmala (2010) is based on the theoretical background presented by Nilsson (2004) according to which the traffic safety consists of three dimensions, which are (1) exposure, (2) risk of a collision to take place during a trip and (3) consequences (= risk of a collision to result in injuries or death) (Nilsson 2004, Figure 17). The volume of the rectangular box is the expected number of injured or fatalities and thus the number of injuries or fatalities in road accidents depends on the three dimensions – exposure, accident rate and injury severity.

![crash risk diagram](image)

**Figure 17. The dimensions of road safety (Nilsson 2004).**

The framework of Kulmala (2010) emphasises the system nature of transport: when one element of the system is affected, the consequences may appear in several elements and levels of the system. Therefore, the implemented safety measures influence safety by affecting one or several of the factors contributing to any of these three dimensions of safety. The use of this approach ascertains that the safety impact assessment method will cover all dimensions of road safety, also exposure or the amount of travelling, which is frequently overlooked in the safety assessment studies (Kulmala 2010).

In addition to the three dimensions of road safety (as indicated in Figure 17) the framework for the safety impact assessment of ITS should also cover the effects due to behavioural adaptation in addition to engineering effects, and be compatible with other aspects of state of the art road safety theo-
ries (Kulmala 2010). In order to be sure about that all possible impacts (both positive and negative impacts on road safety; direct, indirect and unintended effects of systems) will be covered, the analyses proposed by Kulmala (2010) utilises a set of nine mechanisms via which ITS can effect road user behaviour and thereby road safety. These nine mechanisms cover the three aspects of road safety in a systematic manner and are based on a ten-point list compiled by Draskóczy et al. (1998). In the following the nine mechanisms are adopted from Kulmala 2010:

1. **Direct in-car modification of the driving task** by giving information, advice and assistance or taking over part of the task. 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 and unintended impacts.

2. **Direct influence by roadside systems** mainly by giving information 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.

3. **Indirect modification of user behaviour** in many, largely unknown ways. Indirect modification of user behaviour is often called behavioural adaptation, and will often not appear immediately after a changer but may show up later and it is very hard to predict.

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 for example change their behaviour by imitating the behaviour of equipped drivers.

5. **Modification of interaction between users and non-users.** ITS will change the communication between equipped road users. This change of communication may also 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.

6. **Modification of road user exposure** by for example information, recommendation, restrictions, and debiting. 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.

7. **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. Different travel modes have different accident risks, therefore any measure which influences modal choice, has also impact on traffic safety.

8. **Modification of route choice** by route diversions, route guidance systems, dynamic route information systems and hazard warning systems monitoring incidents. Different parts of the road network 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 traffic safety.

9. **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.

As indicated by Kulmala (2010) many of these mechanisms are closely linked to one another, and could be combined. Examples of these are mechanisms of direct driving behaviour modification (1–2), indirect driving behaviour modification (3–5), and travel pattern modification (6–8). The mechanisms have not, however, been combined since the purpose of the framework is to illustrate the types of different possible effects (both positive and negative) of IT systems on safety.

The starting point for the impact analysis is the system descriptions, which e.g. describe the purpose of the system, the anticipated driver reactions and the expected safety benefits. Afterwards, the rele-
D2.2
Assessment methodology

Vant safety mechanism are selected for each studied ITS. The safety mechanisms refer to the earlier presented nine mechanisms which aim to cover the three aspects of road safety in systematic manner. In this phase the description of expected changes in driver behaviour together with the estimation of numerical percentage value for the change in fatalities and injuries will be done for each safety mechanism. The numerical estimates are motivated by (1) already available empirical evidence on safety impacts of systems with partly similar functionalities, (2) expert evaluations of safety impacts and (3) indirect evidence on safety impacts, which refers to more general assessment of the effects based on knowledge on driver behaviour, traffic flow and effects of comparable systems. (Kulmala 2010).

It is expected that the effects of IT systems on VRUs will vary according to background variables (collision type, link or intersection, road type, weather conditions, vehicle type and lighting). In the next step a main classifying variable is chosen from the background variables for each system, called as basic variable. The basic variable is the variable for which most reliable evidence of behavioural based safety effects are available. In previous projects, for example, the collision type has in many cases been chosen as the basic variable since it has been known (based in the previous field tests and literature) how effective the system has been estimated to be for different collision types in a certain area or country in Europe. (Kulmala, 2010).

The effect estimates were applied to the EU-25 road accident data, so that the distribution of the background variables (accident type, link or intersection, road type, weather or lightness) weighted the estimate i.e. it was assumed that the IT system under assessment was more effective e.g. on rural and urban roads than on motorways. The focus was on how powerful the system is to affect different accidents in defined circumstances, not on the frequency of the accident type in question. Moreover, the weights of the effect for a background variable could vary by mechanism, e.g. there might be some reason to weight the effect according to road type in direct effects (mechanism 1) but not in exposure effects (mechanism 6). In weighting, the effect estimate indicated in percentage changes were multiplied with the share (%) of relevant accidents. (Kulmala, 2010).

Firstly, the safety impact estimates in terms of percentage changes were provided for a 100% fleet mileage penetration. In addition, the effect estimates were provided for selected target years by using the estimated fleet mileage penetration rates. In general, a linear development of the effects for different penetrations was assumed. In this phase also the accident trends for the target year were taken into account. In first projects the target years were 2010 and 2020; later the target years and data have been updated for 2020 and 2030 (Kulmala et al., 2008a; Wimmershoff et al., 2011). Finally, the impacts were provided in numbers of avoided accidents, injuries and fatalities. (Kulmala, 2010).

In addition, the effect was weighted according to all other situational variable categories. These additional analyses were conducted to provide safety estimates that show in which circumstances the most substantial safety benefits could be gained. (Kulmala et al., 2008b).

Data

For accidents, INTERSAFE2 (Wimmershoff et al., 2011) used the accident data of eIMPACT project which was collected by the parallel TRACE project. The data included accident data for the EU-25 countries from 2005 (Wilmink et al., 2008). INTERSAFE2 updated the accident data to include new member countries Romania and Bulgaria and extended the database to EU-27. The aim is to further extend the accident data in VRUITS project to cover EU-28. The accident data for EU-25 in eIMPACT project was divided into three clusters shown in Figure 18. The new countries included in INTERSAFE2 project were added to cluster 3 (red). The clusters were formed based on the prevalent safety situation in each country and therefore the countries with similar road safety situation were included in the same cluster. The clusters will be updated in VRUITS project by using the latest road safety and vulnerable road user safety related statistics.
Assessment methodology

Figure 18. The three clusters in EU-25 accident data (cluster 1 = yellow, cluster 2 = orange, cluster 3 = red) (Wilmink et al. 2008).

The categories for situational variables used in accident classification were:

- Vehicle type (passenger car/goods vehicle)
- Collision type (collision on the road with pedestrian, collision on the road with all other obstacles, collision besides the road with pedestrian or obstacle or other single vehicle accidents, frontal collision, side-by-side collision, angle collision, rear collision, other accidents with two vehicles)
- Road type (motorway/rural/urban)
- Weather conditions (normal/adverse)
- Lighting conditions (daylight/night)
- Location (intersection/not intersection)

In the VRUIITS project we will explore the possibility to include age as an additional situational variable since the safety effect of ITS might vary among the age groups of vulnerable road users. The planned age groups are: child 7–12 years old, child 13–17 years old, adult 19–64 years old and elderly 65+ years old. The motivation for these age groups is described in Section 3.1 of this deliverable.

The eIMPACT project (Wilmink et al., 2008) made forecasts for road safety development until 2020 with the help of a predictive model for fatality rates (against vehicle kilometres and vehicle stock) for each of the three country clusters within EU-25. However, the actual forecasts for fatalities, injuries and accidents for years up to 2030 were calculated as the products of the fatality rate and vehicle kilometre forecasts in CODIA project for each cluster (Kulmala et al., 2008a). With regard to injuries (and
injury accidents), specific models were calculated as the development of injuries had not been as positive as for fatalities during the period 1991–2006. A comparison of realised fatalities in 2009 (European Commission, 2009) and the CODIA forecast for 2010 showed only minor differences. Therefore INTERSAFE2 (Wimmershoff et al., 2011) decided to still use these forecasts for fatality and injury rates developed in CODIA. However, the aim is to update the accident database for the safety assessment of VRUITS project (together with an on-going Drive C2X project).

In INTERSAFE2 (Wimmershoff et al., 2011) the vehicle stock data was obtained mainly from different national statistics from 2009 found on the Internet. It was combined with the data from the Statistical pocketbook 2010 (European Commission 2010) on vehicle stock (passenger cars, goods vehicles and buses) in 2008 and new vehicle registrations of 2009. The aim is to update the vehicle stock information during VRUITS project (together with Drive C2X).

In the eIMPACT study (Assing et al., 2006) the vehicle stock data of 2005 was processed to give estimates for vehicle fleets in 2010 and 2020. The same methodology as in eIMPACT was employed in CODIA (Kulmala et al., 2008a) to predict vehicle stock for 2015 and 2030. In INTERSAFE2 (Wimmershoff et al., 2011), the CODIA predictions were updated based on the 2009 vehicle stock data. The prediction will be conducted again in VRUITS project.

In INTERSAFE2, the shares of new vehicles coming to the market having the system were estimated based on the figures used in CODIA (Kulmala et al., 2008a) and expert opinions of the INTERSAFE2 project members (Wimmershoff et al., 2011). The target years were 2020, 2025 and 2030. In VRUITS, penetration rate assumptions must be harmonised over impact areas (Task 2.5).

The penetration rates are converted into the share of driven mileage by weighing the vehicle age related fleet distribution by the vehicle age distribution of annual vehicle kilometres. The reasoning for this conversion is that the share of vehicles (or roads) equipped is not the same as the share of kilometres travelled by equipped vehicles (or the share of vehicle kilometres travelled on roads that are equipped) (Wilmink et al., 2008). Cooperative systems are likely to be introduced first on new vehicles which usually travel more kilometres than older vehicles and possibly on busier roads as well.

In INTERSAFE2 (Wimmershoff et al., 2011), annual vehicle kilometres of vehicles of different age, compared to those driven by the 1-year old vehicles, were available only from Swedish (SIKA 2010), German and Finnish statistics. These statistics were used to estimate the annual vehicle kilometres in the EU-27 countries. The annual vehicle kilometres were calculated as \( (F1 + SE + 2*DE) / 4 \). Germany is a little more typical European country in terms of traffic than Finland or Sweden so its statistics were weighted by a factor of 2. In this way, a rough estimate of the annual vehicle kilometres of vehicles of different age in the EU-27 was achieved. The same assumptions and mileages will be used in VRUITS unless we get this information from more countries.

In INTERSAFE2 (Wimmershoff et al., 2011), the share of the driven mileage with the system was estimated separately for each of three European regions (Northern and Central Europe, Southern Europe and Eastern Europe). Typically the share of the driven mileage with the system was higher for Northern and Central Europe than EU-27 and lower for Eastern Europe than EU-27. These estimations were carried out as in eIMPACT (Wilmink et al., 2008). Most likely the same method will also be applied in VRUITS.

4.2 Modifications of safety methodology to take into account VRUs

4.2.1 Step-by-step application of the overall safety impact assessment method

The safety impact assessment method used in VRUITS project follows the steps and applies the tool reported by Kulmala (2010). In the following, the method as adopted for the VRUITS project is presented (Figure 19).
Assessment methodology

1. System descriptions

The process starts by writing of comprehensive system descriptions so that everyone has a clear and convergent understanding on the systems under assessment, their functioning, technical limitations and anticipated user reactions\(^1\). The examples of issues to be covered in the system descriptions are listed in the following:

- Description of the purpose and technical performance of the system
  - informative/warning/intervening/controlling
  - stand-alone / cooperative x2x (v1i, v2v, i2vru, v2vru)
  - What kind of information is given to the user? How and when?
- Description of the safety problem addressed with the system
- Description of type of accidents the system aims to prevent or description of type of accidents consequences the system aims to mitigate
- Description of circumstances in which the system works or is assumed to work / does not work
- Expectation of effects on the behaviour of the driver / other road users; effects on safety

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\(^1\) This is due to the fact that assessment is prescriptive, that is, the systems do not exist yet or for which no empirical data is available.
D2.2
Assessment methodology

- anticipated driver reactions; change in driver behaviour (direct and indirect effects; behavioural adaptation)
- anticipated VRU reactions; change in VRU behaviour (direct and indirect effects; behavioural adaptation)
- interactions between the system and the user, interactions between the system and other applications
- interactions between the users of the system
- interactions between users and non-users of the system; change in non-user behaviour

2. Qualitative safety impact assessment
   During the next step the relevant safety mechanisms are selected for each investigated IT system. This includes description of expected changes in driver and VRU behaviour and documentation of the expected effects based on existing literature and other evidence available. This other evidence includes already available empirical evidence on safety impacts of systems with partly similar functionalities and indirect evidence on safety impacts such as more general assessment of the effects based on knowledge on driver/VRU behaviour, traffic flow, and effects of comparable systems. The reference case for the estimates is the situation without any IT system, and in most cases a linear development of effects is assumed.

3. Selection of systems for more detailed assessment
   Based on the qualitative assessment the systems will be prioritised. The selection of systems for the final assessment will be done in VRUITS workshops. Multi-criteria assessment will be used as part of the process.

4. 5 step expert judgement process
   The process for the collection of expert evaluations is described in more detail in chapter 4.3.4 of this deliverable. The earlier estimates of the effects (literature review and other evidence) will be combined with the collected expert estimates based on which a numerical percentage value for the change in fatalities and injuries will be estimated for each safety mechanism.

5. Selection of main accident category
   One background variable will be chosen as the main classifying variable for each investigated system, called as basic variable. This is done since it is expected that the effect of the IT systems will vary according to the background variables (collision type, link or intersection, road type, weather conditions, vehicle type and lighting) presented in chapter 4.1 of this deliverable. The basic variable is the variable for which most reliable evidence of behavioural based safety effects are available. Based on the experiences from previous assessment works (e.g. Wilmink et al., 2008; Wimmerhoff et al., 2011), it is more likely to gain evidence of the effects of systems only concerning some specific situation(s), and the total effect estimate could be then linked to this specific situation or basic variable.

6. Calculation of effects for 100% fleet penetration
   The effect estimates are applied to the EU-28 road accident data, so that the distribution of the main classifying variable (accident type, link or intersection, road type, weather, vehicle type or lightness) weights the estimate. In weighting, the effect estimate indicated in percent changes is multiplied with the share (%) of relevant accidents. (Kulmala, 2010). The calculations to obtain the changes in number of accidents will be carried out by an Excel tool which has been reported by Kulmala (2010) for structuring the accident data and effect estimates.

7. Calculation of effects for estimated penetration rates in 2020 and 2030.
   The target year estimates will be calculated by using the estimated penetration rates of the selected IT systems for the years 2020 and 2030, and taking into account accident trends. In general, a
linear development of the effects for the different penetrations is assumed (unless stated otherwise). The penetration rates and accident trends will be estimated by task 2.5 of VRUITS project.

8. Calculation of effects in numbers of injury accidents, injuries and fatalities

At the end, the impacts are provided in numbers of avoided injury accidents, injuries and fatalities if sufficient statistical data is available concerning the accident types that the ITS aims to prevent. Otherwise the results are based on a more qualitative assessment of the safety effects made by experts.

Even though the data allows us to present the results in numbers of avoided injury accidents, injuries and fatalities it must be noted that a certain degree of uncertainty exists related to the results. In general, we can have uncertainty related to a) estimates of safety effects (depends on the results of expert questionnaire and findings from literature), b) accident data (for some systems we might have better data related to accident types the system aims to prevent than to some other ones), and c) estimated accident trends and penetration rates. The range of uncertainty related to each earlier mentioned item varies according to the system under investigation and thus it not possible to provide any estimate on the general uncertainty of our assessments before the exact systems to be assessed are known. Therefore, this issue will be taken into consideration in WP3 when the assessment method will be applied and the level of uncertainty will be discussed when reporting the results.

4.2.2 Adaptation of nine mechanisms to take into consideration VRUs

The nine ITS safety mechanisms below form the framework for the safety impact assessment method. Kulmala (2010) presented a nine-point list of ITS safety mechanisms focusing on drivers. These nine mechanisms have been updated to cover also vulnerable road users, i.e. pedestrians, cyclists, mopeds and motorcyclists. Examples are now more focused on changes in behaviour of vulnerable road users and the situations they face in traffic.

- **Mechanism 1: Direct modification of the task of road users** by giving information, advice, and assistance or taking over part of the task. This may influence their attention, mental load, and decision about action (for example, driver/rider/cyclist/pedestrian choice of speed). 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/rider/cyclist/pedestrian distraction) impacts. Example of such mechanism is when the motorcyclists will receive a warning (and a request to reduce their speed if needed) when a steep curve is ahead.

- **Mechanism 2: Direct influence by roadside systems** mainly by giving information and advice. Without the possibility to control the road users’ 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. Example of such a system is intelligent traffic lights which are prioritising pedestrians and therefore assumed to reduce walking against the red light. When the waiting time is shorter the road users are expected to better respect the red light.

- **Mechanism 3: Indirect modification of user behaviour** in many, largely unknown ways. The driver/rider/cyclist or the pedestrian will always adapt to the changing situation. This is often called behavioural adaptation, and will often not appear immediately after a change but may show up later and it is very hard to predict. The indirect modification is more long-term than the very direct, short-term reactions to the system in mechanisms 1 and 2. Long-term behavioural adaptation may appear in many different ways (for example, by reallocation of attention resources, by accepting smaller gaps if the road user feels safer, by change of expectation of the behaviour of other road users). This adaptation may frequently be due to delegation of re-
sponsibility of the current task partly or totally to the system, which the road users have learnt to rely on. Such evidence exists when e.g. pedestrians/cyclists receive warnings of approaching dangerous situations via their mobile phone or other applications. The road users learn to rely on this information and thus might observe their surroundings less carefully.

- **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 road users may for example change their behaviour by imitating the behaviour of equipped road users (for example riding closer or faster than they should, not having the equipment).

- **Mechanism 5: Modification of interaction between users and nonusers.** ITS will change the communication between equipped road users. This change of communication may also 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.

- **Mechanism 6: Modification of road user exposure** by for example information, recommendation, restrictions, debiting or increased comfort in car driving, PTW riding, cycling or walking. This mechanism covers only changes in the amount of travelling, i.e. whether the road user decides to make more or fewer, or longer or shorter, trips due to the system. Traffic information about slippery roads might encourage especially elderly to cancel the trip.

- **Mechanism 7: 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. Different travel modes have different accident risks, therefore any measure which influences modal choice, has also impact on road safety. Traffic information can lead to travellers choosing a safer mode, i.e. modify the modal choice.

- **Mechanism 8: Modification of route choice** by 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. Note that route changes also affect exposure, and the exposure changes due to the route changes can be taken into account either under this mechanism or mechanism 6.

- **Mechanism 9: Modification of accident consequences** by intelligent injury severity reducing systems activated when the vehicle crashes in to another vehicle or in to a pedestrian, by quick and accurate crash reporting and call for rescue, and by reduced rescue time. Intelligent transport systems providing warning on slippery road conditions can affect safety via this mechanism if they make the cyclists/mopedists to wear helmet or to fasten it more carefully than normally.

If feasible, the estimates of the effect of the mechanisms should be done by using a step-by-step process instead of direct estimates as e.g. done in Gårder et al. (2013) concerning mechanisms 1 and 2. When using the step-by-step methodology, estimates consider the reliability of the system, and the probabilities that road users will perceive an alarm/information from the system, comprehend the received information about the potentially dangerous situation ahead, react in time and take the correct action. The step-by-step process based on individual (personal) estimates is recommended because of less variance between assessors and more transparency compared to the direct estimates.
4.2.3 Identification of accident types to be prevented with the selected systems

Many databases such as those described in section 3.2 above are useful for describing the nature and circumstances of accidents at a macroscopic level but many of them cannot offer insight into the overall effectiveness of new ITS solutions in terms of safety. One reason why this is so is because the ITS solutions that are implemented are so new that not enough time has elapsed since their installation to show an effect – accidents are comparatively rare events and data collection may have to be conducted over a period of many months or years in order to capture relevant data relating to general system effectiveness.

In other cases, whilst limited data may be available, the data collection protocols are simply not sufficient to provide data at a level that is sufficient to provide an informed analysis of overall system effectiveness. Therefore, it is essential that other data are gathered to address research questions regarding system effectiveness using well-developed methodologies (such as Field Operational Tests - FOTs) and from such types of studies, estimations of system effectiveness in terms of accident reduction and avoidance may eventually be possible. Such new data collection systems are inevitable if effectiveness data are truly required. An assessment of the available data for assessment of the effectiveness of current ITS solutions are provided below. As can be seen, in most cases there is as yet insufficient data to make rigorous assessments of the systems that are reviewed within the VRUITS project.

Blind-Spot Detection (BSD)

This system is intended to prevent all VRU accidents at intersections and accidents involving vehicles leaving a stopped or parked position. The situational variables that are relevant to this system include junction type, signals, speed, vehicle type, road type, weather conditions and presence of pedestrian crossing facility, cycle lane provision and visibility of the VRU. Some data on Blind Spot Detection systems may exist although the numbers of relevant accident cases is likely to be small in numbers. In time, data should be available from in-depth studies and injury surveillance databases but in the short-term, the CARE database could be relevant for estimating the numbers of cases in which the system is likely to be effective. If data do not become available, there are alternatives such as new data collection activities using in-depth accident investigations. Alternatively, statistical modelling and forecasting may be of benefit. Field Operational Tests (FOTs) of such systems represent another possibility.

Intelligent Pedestrian Traffic Signals (IPTS)

Such systems are designed to be effective for preventing pedestrian and cyclist accidents at signalised intersections. The systems do not really have an effect on PTW accidents. Therefore the situational variables that are relevant to this system include junction type, signals, speed, vehicle type, road type, weather conditions and presence of pedestrian crossing facility, cycle lane provision and visibility of the VRU. As these are relatively new systems which have not yet penetrated the market in large numbers, there is likely to be little data that would be useful in determining their overall effectiveness. Therefore, analysis of the CARE database could be relevant in the short-term for estimating the likely numbers of cases in which the system is likely to be effective. In the longer term, new data collection activities will be necessary including in-depth accident investigations. Alternatively, as with BSD systems, statistical modelling and forecasting may be of benefit. Field Operational Tests of such systems represent another possibility.

Intelligent Speed Adaptation (ISA)

These systems are designed to reduce the severity of all VRU accidents by forcing the vehicle to comply with relevant speed limits. The situational variables that are relevant to the system include vehicle speed, road type, road environment, vehicle type, pedestrian crossing facility, cyclist facility, VRU
visibility, and weather and road details. Some data on ISA systems already exists and data from the UK ISA trails and the PROSPER study should be referenced for overall system effectiveness. As ISA is not yet commercially available, no other sources if data are available although future FOTs of ISA systems will be of great benefit in assessing their effectiveness in VRU accidents.

**Red-Light Camera (RLC)**

Red-Light Cameras are essentially enforcement devices that are used to dissuade drivers from taking unnecessary risks at signalised intersections. However, it is easy to see how the devices could be effective in preventing VRU accidents. The situational variables that are relevant to this system include junction type, signals, speed, vehicle type, road type, weather conditions and presence of pedestrian crossing facility, cycle lane provision and visibility of the VRU. Because of the nature and purpose of the systems, there could be police data available in certain EU Member States that give an indication of infringements. However examining their effectiveness in preventing VRU accidents may be more difficult to determine and may require data analysis looking at accident rates at relevant intersections – perhaps using a case-control study. Simple roadside observations might also be considered. CARE data may be utilised for looking at the numbers of scenarios in which the systems could be effective for all VRUs but the data within CARE is not able to discriminate on signal state so assumptions would be necessary.

**Intersection Safety (IS)/ Right and left Turn Assist**

These systems represent a very new development which is thought to be effective in preventing VRU accidents in which vehicle is turning right and crosses the path of the VRU. The situational variables that are relevant to this system include junction type, signals, speed, vehicle type, road type, weather conditions and presence of pedestrian crossing facility, cycle lane provision and visibility of the VRU. Due to systems being a relatively new development, data relating to system effectiveness is thought to be very limited although some data may be available from Police accident records in some EU Member States. In time, in-depth data from accident investigations should provide some evidence although it may take several years for such data to become available. Traffic/statistical modelling may be of use in determining system effectiveness whilst FOTs may also be a useful tool. In the short-term, CARE data may be utilised for looking at the numbers of scenarios in which the systems could be effective for all VRUs.

**Pedestrian/cyclists detection system and emergency braking (PDS+EBR)**

These systems are designed to be effective mainly in Frontal Accidents in which pedestrian/cyclist is on the street in FRONT of the vehicle. In certain circumstances, the systems could also operate in situations where the VRU is travelling (walking or cycling) along the road edge. The situational variables that are relevant to this system include junction type, signals, speed, vehicle type, road type, weather conditions and presence of pedestrian crossing facility, cycle lane provision and visibility of the VRU. As Intersection Safety systems above, due to systems being a relatively new development, data relating to system effectiveness is thought to be very limited although some anecdotal data may be available from in-depth data from accident investigations. Traffic/statistical modelling may be of use in determining system effectiveness whilst FOTs may also be a useful tool. In the short-term, CARE data may be utilised for looking at the numbers of scenarios in which the systems could be effective for all VRUs although the systems are thought to offer only limited benefit to PTW riders.

**Navigation Systems for VRUs**

These systems are only thought to provide benefit for pedestrians and cyclists and the situational variables in which they might be relevant include junction type, signals, speed, vehicle type, road type, weather conditions and presence of pedestrian crossing facility, cycle lane provision and visibility of the VRU. The safety benefit is thought to be limited and comfort/mobility issues are probably more
relevant although they may offer benefit in an advisory capacity to warn the VRU of problematic road or pavement surfaces. No data are thought to exist on the effectiveness of such systems although FOTs of navigation systems have been conducted mainly relating to passenger vehicles. FOTs relating to navigation use by VRUs would be a positive development.

**On-coming Vehicle Information System**

Such systems are relevant to PTW riders only and will warn the rider that a vehicle is on-coming particularly around bends where the rider cannot see ahead. Therefore the situational variables relating to these systems include junction/road type, road topography, road environment (rural/urban), vehicle type, rider visibility, road/weather conditions and road surface conditions. No data are as yet available on such systems although FOTs might be the best method of assessing their effectiveness. PTW organisations (such as ACEM etc.) should be contacted for future updates relating to these systems.

**VRU Beacon Systems**

These systems will inform a vehicle driver of the presence of a VRU away from an intersection. The situational variables of relevance include speed, road environment (rural/urban), vehicle type, VRU visibility, weather and road details. As with other systems listed above, due to systems being a relatively new development, data relating to system effectiveness is thought to be very limited although some data may be available from Police accident records in some EU Member States. In time, in-depth data from accident investigations should provide some evidence although it may take several years for such data to become available. Traffic/statistical modelling may be of use in determining system effectiveness whilst FOTs may also be a useful tool. In the short-term, CARE data may be utilised for looking at the numbers of scenarios in which the systems could be effective for all VRUs.

**Rear-view Bicycle Digital Display/Mirror**

Such devices are relevant for cyclists only and the situational variables include junction type, signals, speed, road environment (rural/urban), vehicle type, cyclist facility, cyclist visibility, weather and road details. No data are as yet available on such systems although FOTs might be the best method of assessing their effectiveness. Cyclist organisations should be contacted for future updates relating to these systems.

**Roadside Pedestrian Presence (RPP)**

These systems are relevant for pedestrians only and are designed to inform the drivers of vehicle about the presence of pedestrians at the roadside. The situational variables that are relevant to this system include junction type, signals, speed, vehicle type, road type, weather conditions and presence of pedestrian crossing facility, cycle lane provision and visibility of the VRU. As above, due to such systems being a relatively new development, data relating to system effectiveness is thought to be very limited although some data may be available from Police accident records in some EU Member States. In time, in-depth data from accident investigations should provide some evidence although it may take several years for such data to become available. Traffic/statistical modelling may be of use in determining system effectiveness whilst FOTs may also be a useful tool. In the short-term, CARE data may be utilised for looking at the numbers of scenarios in which the systems could be effective.

**Urban Sensing Systems**

Relevant for all VRU accidents in the urban environment and therefore the situational variables of relevance are junction type, signals, speed, vehicle type, road type, weather conditions and presence of pedestrian crossing facility, cycle lane provision and visibility of the VRU. As IS systems above, due to systems being a relatively new development, data relating to system effectiveness is thought to be very limited although some anecdotal data may be available from in-depth data from accident investi-
gations. Traffic/statistical modelling may be of use in determining system effectiveness whilst FOTs may also be a useful tool. In the short-term, CARE data may be utilised for looking at the numbers of scenarios in which the systems could be effective for all VRUs.

Night-Vision and Warning Systems

These systems are relevant at night-time for all VRUs. The situational variables include Junction type, Signals, Speed, Road environment (Rural/Urban), Vehicle type, Pedestrian crossing facility, Pedestrian visibility, Weather, Road details, Lighting conditions. Due to systems being a relatively new development, data relating to system effectiveness is thought to be very limited although some data may be available from Police accident records in some EU Member States. In time, in-depth data from accident investigations should provide some evidence although it may take several years for such data to become available. Traffic/statistical modelling may be of use in determining system effectiveness whilst FOTs may also be a useful tool. In the short-term, CARE data may be utilised for looking at the numbers of scenarios in which the systems could be effective for all VRUs.

Automatic Bicycle Identification / Bicycle to Car Communication

Such devices are relevant for cyclists only and the situational variables include Junction type, Signals, Speed, road environment (rural/urban), vehicle type, cyclist facility, cyclist visibility, weather and road details. No data are as yet available on such systems although FOTs might be the best method of assessing their effectiveness. Cyclist organisations should be contacted for future updates relating to these systems.

Information of Availability of Bicycle Racks

Such devices are relevant for cyclists only, although their safety benefits are unclear. The situational variables include Junction type, Signals, Speed, road environment (rural/urban), Vehicle type, Cyclist facility, Cyclist visibility and Weather and road details. No data are as yet available on such systems although FOTs might be the best method of assessing their effectiveness. Cyclist organisations should be contacted for future updates relating to these systems.

Rider Monitoring Systems

Such systems are relevant to PTW riders only and will warn the rider that a vehicle is on-coming particularly around bends where the rider cannot see ahead. Therefore the situational variables relating to these systems include junction/road type, road topography, road environment (rural/urban), vehicle type, rider visibility, road/weather conditions and road surface conditions. No data are as yet available on such systems although FOTs might be the best method of assessing their effectiveness. PTW organisations (such as ACEM etc.) should be contacted for future updates relating to these systems.

Cross Adaptive Lighting

These systems will inform a vehicle driver of the presence of a VRU away from an intersection. The situational variables of relevance include speed, road environment (rural/urban), vehicle type, VRU visibility, weather and road details. As with other systems listed above, due to system being a relatively recent development, data relating to system effectiveness is thought to be very limited although some data may be available from Police accident records in some EU Member States. In time, in-depth data from accident investigations should provide some evidence although it may take several years for such data to become available. Traffic/statistical modelling may be of use in determining system effectiveness whilst FOTs may also be a useful tool to consider. In the short-term, CARE data may be utilised for looking at the predicted numbers of scenarios in which the systems could be effective for all VRUs.
Infotainment

Infotainment involves many forms of electronic media but overall infotainment systems are not expected to provide a safety benefit. However, accidents may be caused through use of Infotainment systems through distraction of the VRU. Accident data may be available that allows an assessment of the numbers of accidents that have been caused through use of such systems during road travel although the best source would be data from in-depth accident investigations. FOTs of such systems would be hard to conduct.

Real-time Passenger Information System

Whilst the use of these systems offers much in terms of passenger mobility, they are thought to be neither detrimental nor beneficial for safety.

Table 16: Preliminary overview of accident types prevented by selected systems

<table>
<thead>
<tr>
<th>Accident types to be potentially prevented</th>
<th>VRU type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pedestrians</td>
<td></td>
</tr>
<tr>
<td>Cyclists</td>
<td></td>
</tr>
<tr>
<td>PTWs</td>
<td></td>
</tr>
<tr>
<td>Accidents at (signalised) intersections</td>
<td>x</td>
</tr>
<tr>
<td>Accidents at signalised intersections with a vehicle running a red light</td>
<td>x</td>
</tr>
<tr>
<td>Accidents in which vehicle is turning right / left and crosses the path of VRU</td>
<td>x</td>
</tr>
<tr>
<td>Accidents outside intersections in situations when vehicle is passing a cyclist</td>
<td>x</td>
</tr>
<tr>
<td>Accidents with vehicle leaving stopped/parked position</td>
<td>x</td>
</tr>
<tr>
<td>All accident types (with vehicles)(at night)</td>
<td>x</td>
</tr>
<tr>
<td>Single-actor accidents</td>
<td></td>
</tr>
<tr>
<td>(Frontal) Accident in which VRU is on the street (at night)</td>
<td>x</td>
</tr>
<tr>
<td>Accidents in which the VRU is on the road edge (at night)</td>
<td>x</td>
</tr>
<tr>
<td>Accidents with vehicles approaching from the rear</td>
<td>x</td>
</tr>
<tr>
<td>Accidents with vehicles while VRU is turning</td>
<td>x</td>
</tr>
<tr>
<td>Accidents with vehicles at zebra crossings (at night)</td>
<td>x</td>
</tr>
<tr>
<td>All accidents due to distraction/drowsiness</td>
<td>x</td>
</tr>
<tr>
<td>All accidents in which vehicle crosses the path of VRU</td>
<td>x</td>
</tr>
</tbody>
</table>

4.2.4 Description of the method to collect expert estimates

The expert judgement process will be used in VRUITS project to enhance the value of the assessment by supplementing and ascertaining the qualitative estimates of the safety effects of ITS to vulnerable road users. The expert judgement process can be used to improve the validity and reliability of expert opinions. The different phases of an expert judgement process proposed by Leden et al. (2000) are:

1. Selection and training of experts
2. Elicitation of experts judgements
3. Modelling and combination of expert judgement
4. Sensitivity analysis
5. Discussion and feedback from experts
6. Documentation of experts’ reports

The expert estimates in the VRUITS project will be collected via a survey which will cover safety, mobility and comfort aspects of the system. All the phases proposed by Leden et al. (2000) will also be used in VRUITS project except sensitivity analysis which will only be used if it is, for special reasons, required for the impact assessment.

The collection of expert estimates in VRUITS project will consist of five steps:

1. Selection of experts. Each partner will be asked to contribute for finding the suitable experts to answer the questionnaire. Previous VRU related research projects, VRU related workshops and/or conferences are for example considered as good sources to identify suitable experts.

2. Assessments made by individual experts. The expert estimates will be collected via an internet survey which will be sent to a predetermined number of experts. The final number of systems included in the survey will be decided after the second interest group workshop. The experts will have the possibility to skip the systems which are not familiar to them and/or they do not feel comfortable in answering. According to the current plan there will be several variations of the internet survey in which the order of the system varies. Thus we can avoid the problem that the questions concerning the first systems will receive more answers than the ones at the end of the survey.

3. Combination of expert judgements. Each partner involved in WP3 will analyse the collected expert estimates and will present a combined assessment. This “company assessment” will be based on the collected expert estimates and the expertise of the people working in their company.

4. Discussion and feedback from experts. The company assessments will be reviewed by associated members of VRUITS. The estimates provided by the partners together with the comments from the associated members will be discussed (e.g. in a workshop), and based on the discussion the final estimates will be formulated.

5. Documentation of the results.

4.3 Summary of methodology for safety impact assessment

The method to assess the safety impacts of ITS on vulnerable road users is based on the method introduced by Kulmala (2010), which was developed for the assessment of safety impacts of ITS for cars. This method is aimed at ITS – as is VRUITS -- and is comprehensive in its approach, covering all three dimensions of road safety—exposure, crash risk and consequence, the effects due to behavioural adaptation in addition to the engineering effect (effect on target accident contributory factors) and is compatible with the other aspects of state of the art road safety theories. Some parts of the method were enhanced and adjusted to take also into consideration the vulnerable road users. The main modifications of the method for the purposes of VRUITS project are: i) nine mechanisms have been updated to cover VRUs i.e. pedestrians, cyclists, moped riders and motorcyclists, ii) the safety impact assessment tool will be updated to include more detailed information on accidents involving VRUs, iii) accident types and circumstances like age, road layout and lighting are considered in more detail when relevant for VRU and when feasible and iv) the expert judgement process will be used to enhance the value of estimates for the nine mechanisms.

The methodology is embedded in an assessment process adopted for the VRUITS project. The assessment process consists of eight phases which are 1) writing of comprehensive system descriptions, 2) qualitative safety impact assessment in which the relevant safety mechanisms are selected
for each investigated IT system, 3) selection of systems for more detailed assessment, 4) 5 step expert judgment process for the collection of expert evaluation via web survey, 5) selection of main accident category, 6) calculation of effects for 100% fleet penetration, 7) calculation of effects for estimated penetration rates in 2020 and 2030, and 8) calculation of effects in numbers of injury accidents, injuries and fatalities.

In the next phase of VRUITS project, in WP3, the method as described in section 4.2.1 (step-by-step application of the overall safety impact assessment method) will be implemented to assess the safety impacts of selected ITS on vulnerable road users.
5. METHODOLOGY FOR MOBILITY AND COMFORT IMPACT ASSESSMENT

The chapter describes the methodology developed to be used in VRUITS regarding assessment of mobility of comfort of VRU in relation to ITS, and the procedures that will be used in the assessment.

5.1 Beyond the state of the art

The challenges that need to be addressed to develop the safety impact assessment regarding the special focus on VRUs are also central for the mobility and comfort impact assessment methodology, but also in specific (will be elaborated in more detail below):

- There are very few methods available up today to assess mobility and comfort, and of VRUs in specific, much fewer in comparison to the present number of methodologies to assess safety.
- There is a present risk that little or no data is available on the mobility of VRUs, and especially data on comfort of VRUs.
- Integrate the eIMPACT methodology with the expert judgment process for assessing mobility and comfort. This will enhance the value of the assessment for the mobility and comfort mechanisms to be more transparent, reliable and objective. This process will be done for systems for which there is little or no empirical evidence on their effects, and so far little or none empirical effects are known regarding both qualitative and quantitative mobility and comfort factors of VRU.
- Focus the eIMPACT methodology on VRUs, while up to now, the methodology does not consider VRUs in sufficient detail. Based on the analysis of scenarios, appropriate mechanisms and background variable categories it will be identified where the mobility and comfort effects of new ITS systems for VRU can be accounted for. Data needs of the method will be identified. Adaptations can e.g. include detailed descriptions of mobility and comfort or user classification.

The literature review on mobility and comfort has identified different methodologies to understand the mobility and comfort of VRU groups, but the available methodologies tend to overlap the two different aspects mobility and comfort. The methods tend also to focus on to understand mobility and comfort; they are often not so specific in assessing or quantifying the aspects of mobility and comfort of VRU groups.

Methods based on ex-post analysis of mobility and comfort in the case of ITS for VRU, or different VRU groups, does not exist at all. Therefore, ex-ante assessment methods seem more appropriate, and is also basically the only available starting point since no studies have been conducted on the subject mobility and comfort in the case of ITS for VRU up to now. Since the ITS under consideration are innovative, there are likely not many effectiveness rates available in the literature either.

Of both validity reasons and reliability reasons it is suitable to assess mobility and comfort in parallel with some other aspect, in this case safety. It is also suitable to use a method also developed and tested in another area (again safety), to be able to take advantage from previous method development within the eIMPACT method, even though it is obvious that the method needs to be altered. The advantage of translating the safety mechanism approach into a mobility or comfort mechanism approach is that for each mechanism the validity can be compared, at least from a general perspective. With the method assessments of effect on mobility and comfort are calculated. The approach faces several challenges; the most important one is that the availability of mobility and especially comfort data is very scarce, maybe not existing at all. The assessments of effect rates are then combined into one
overall rate, which is applied to a collection of available data or knowledge on mobility and comfort respectively of different VRU groups. In the end, this determines an effect of the ITS on mobility and comfort.

One can expect that the effect of the ITS depends on the circumstances or scenarios, or on the type of location, such as environmental circumstances like weather and lighting, road type or type of urban environment, transport modes and age of the road users. Another issue is that there may be insufficient data to identify the circumstances, meaning that data on mobility or comfort do exist, but the exposure is not presented in detail with respect to the type of road environment, and different studies on comfort may not give that detailed information on studied types of road environment. The road configuration (bike lanes or paths, traffic lights, crossings, etc.) also need to be provided in some detail, and that type of information may not be available.

Underreporting in terms of mobility of bicyclists and pedestrians is also an expected challenge, meaning that the existing and present travel surveys tend to underestimate the travels made, especially travels by foot. The reason for this is that it is often the main travel mode that is asked about in travel surveys, which then often is public transport, which is then reported. The travel by foot to and from the public transport might not be described therefore sufficiently. Travel surveys also often focus on the trips with a clear purpose, starting point and a destination, with the result that travel for exercise or for sojourning by foot or by bike are not reported in the travel surveys.

Methods for determining effects ex-ante all have limitations. For example, long term effects are difficult to predict and generally future effects are difficult to predict. Expert judgment is of limited scientific quality.

The next step is consequently to develop a general methodology to study and assess mobility and comfort, a methodology that is developed to take into account the characteristics of mobility and comfort of VRUs. After that the methodology is applied to the eIMPACT method. The result is a procedure to assess mobility and comfort of VRUs in relation to the effect of ITS.

5.2 Development of mobility and comfort methodology to take into account VRUs

The goal with the general methodology development of assessing mobility and comfort is to take into account the internal (individual) and external (the environment) factors of mobility and comfort of different VRU groups, as it has been shown that these two general aspects affect both the mobility and the comfort of VRUs. Mobility of pedestrians was described by Methorst based on the three decision levels by Michon (1979). Michon's model can also be used as a basis to describe mobility of VRUs in general (section 3.4, State of the Art of Mobility and Comfort Methodologies). On the strategic level VRU mobility is influenced by factors both external/environmental such as distance and gaps in routes; the environment, and internal/individual, such as different groups access to the transport system. On the tactical level VRUs can be confronted with barriers and obstacles (external). If one comes across these hindrances often, it will affect one's perception of the attractiveness of walking and thus ones strategic choices to walk or not to walk (internal). In the operational level examples are frightening people, too much traffic that make it difficult or impossible to cross a street, or steep slopes. These aspects include perceived risk and security risks that both affect the internal and external factors.

The starting point for the development of the methodology to assess comfort of VRU are the two models by Sarkar (2002) and Ovstedal and Ryeng (2002) (section 3.4, State of the Art of Mobility and Comfort Methodologies). It is necessary to take into account the Quality levels; external related to the environment, and the Service levels; internal aspects such as physical efforts and perception of the environment, according to Sarkar (2002). Similar factors are called the individual level (feeling safe and secure) and the environmental level (pavement conditions and traffic conditions) according to Ovstedal and Ryeng (2002). It is thus clear that there is some overlap between mobility and comfort;
the two aspects mobility and comfort can therefore not be totally distinguished in theory, but will be separated in the following development of methodology, to be able to assess the two aspects.

To achieve an operational method to evaluate the effect of different ITS on VRU mobility and comfort, it is needed to use the guidelines that already exist for the evaluation of ITS projects and applications in general (i.e. most often vehicle motor traffic), and to specify them for application in the assessment of mobility and comfort of VRUs. From the general model describing comfort and mobility the assessment model has been developed. Previous projects in the field of assessing effects of ITS’s have been the basis to formulating the comfort and mobility assessing model used in VRUITS, but in this study clearly taking into account external aspects in the environment, i.e. how it affects the individuals travel, and internal aspects regarding the individual perception and abilities. Based on the theory found in the literature and the principles described above, the following general mobility model and comfort model was created described in Figure 20. The figure summarises and enhances the differences between mobility and comfort, which forms the basis for the general mobility and comfort assessment in VRUITS:

![Mobility and comfort model](image)

Figure 20. Mobility and comfort model, developed from the model found in the TeleFOT project, Impacts on Mobility – Results and Implications. WP 4.4. (2011).

The next step is to generate research questions and hypotheses based on the different factors or aspects described in the model above, in relation to specific ITS. The goal is to be able to test the effect of different ITS on the mobility and comfort of different VRU.

In the project TeleFOT (TeleFOT project, Impacts on Mobility – Results and Implications, 2011) functionality, system design, use cases and impact area were the results from generating research questions and hypotheses, in a bottom-up approach. These factors will also be used in VRUITS for the comfort and mobility assessment of different VRUs. The factors are here elaborated (from the TeleFOT project):

1. **Function**: A functional description of the system (i.e. what it does) and the effect that the function may have on the different users and non-users in each assessment context regarding the users and non-users mobility and comfort, described in a simple model of the conditions and tasks.
2. **Design:** The implementation of the system (i.e. how it is designed), and the impact the system functionalities have on user-system interaction on the different users (and if necessary non-users), regarding mobility and comfort, in each assessment context.

3. **Use Case:** I.e. the context of use factors; site road environment, weather etc. and their relationship with consequences on mobility and comfort.

4. **Types of Impact:** The types of impact being considered on mobility and comfort on the different users and non-users in each assessment context.

A top-down approach based on the development of hypotheses will be used to check that nothing significant for a particular impact area is lost, based on a theoretical understanding of the factors that influence different impact areas. Based on the hypotheses, research questions will be worded so as to state the measure (e.g. journey length), the direction (e.g. longer/shorter) and the comparison conditions (e.g. system in use/system not in use).

Figure 21. **Mobility and comfort assessment model.**

Prior to the development of hypotheses it is determined in a more general stage on how to interpret the predicted impacts of the different ITS on different vulnerable road users from a mobility point of view and from an comfort point of view. Improved mobility means that the road users can make a journey following their own preferences, e.g. with efficient speed and route choice. Comfort means that they can use the mode of their choice, despite conditions, low level of stress and uncertainty, and a positive feeling of safety in relation to traffic. A third type of indicators so far included in the list; Compliance which means a more general term describing the relation between the user, the infrastructure, and the ITS. The following list of general hypotheses is developed from the earlier list of basic principles produced in the TeleFOT project, (Impacts on Mobility – Results and Implications. WP 4.4., 2011), but is in VRUITS divided into two groups of indicators; mobility and comfort:
Mobility

- Mobility improves as the number of journeys increases
- Mobility improves as the length of journeys measured in distance or as duration decreases (personal efficiency improves)
- Change in used modes improves or reduces mobility (if it is predicted that the road users will travel more often or less as vulnerable road user)
- Route choice either improves or deteriorates mobility based on user preferences (whether they choose a shorter/longer, or faster/slower route.). It can be assumed that if the user is (voluntarily) willing to change route, he/she considers the new route better.
- Mobility improves as management of time budget for travelling improves, e.g. as departure time of commuting is shifted later.

Comfort

- Comfort improves as willingness to travel in adverse conditions such as darkness or bad weather increases, or when the road users are more informed about adverse conditions
- Comfort improves as quality improves in terms of less stress and uncertainty or in form of a better feeling of safety in relation to traffic.

The developed research questions are based on previous work (DRIVE C2X FOT research questions and hypotheses and experimental design, Deliverable D42.1, 2011). The starting point is reflected by the two aspects Comfort and Mobility (even though there might be a theoretical overlap to some extent). These aspects are then divided into different sub-aspects, indicators, such as travel time, travel length etc. for mobility, and level of stress and level of uncertainty etc., for comfort. Each indicator is then tested if it is of interest at a specific location, if it is of interest for vehicle drivers (those that the VRUs sometimes interact with), if it is of interest for VRUs (i.e. pedestrian, bicyclist or PTWs), and finally if it is of interest for VRUs with special needs such as children, elderly, or disabled persons:

- First, subdivision of the terms Comfort or Mobility into research questions
- Is the question of importance when studying a specific ITS
- Is the question of importance when studying the driver in relation to a specific ITS
- Is the question of importance when studying VRUs in relation to a specific ITS
- Is the question of importance when studying VRUs with special needs in relation to a specific ITS.

The same set of research questions will be used for different ITS and VRUs; hence the results of the different assessments of effects are comparable for different ITS and VRUs. The structure when testing the different questions is as described in the tables below.

So far, the methodology on how to assess the effects if ITS on different VRUs mobility and comfort in specific conditions, has been described from a model point of view. The next step is to determine which methods to be used. Methods that generally are used in this field of study and generally are available are: Focus group discussions (results from D2.1 Technology potential of ITS addressing the needs of Vulnerable Road Users), Expert evaluations of mobility and comfort impacts (predicted results), Qualitative mobility and/or comfort impact assessment (i.e. collecting all known information on each system in relation to comfort and mobility), Behaviour observations (planned in VRUITS WP4 Improving ITS applications for VRUs, and WP5 Innovative ITS applications: adaptation and evaluation), and Automatic data collection, i.e. collecting data on e.g. speed.

The methods that will be used in VRUITS to assess mobility and comfort, some qualitative and some quantitative, will be used in a step-by-step application with different methods to assess mobility and comfort of different ITS on different VRUs. The selected methods to assess the effects are described in more detail in the next section.
At this level the proposed assessment methodology is comprised of a wide variety of research questions to potentially cover all aspects relevant for the aspects mobility, comfort and compliance of all potential ITS solutions.

Table 17. Structure of indicators.

<table>
<thead>
<tr>
<th>Aspect</th>
<th>Research question</th>
<th>A specific location/situation</th>
<th>A specific ITS</th>
<th>Vehicle driver</th>
<th>VRUs</th>
<th>Special VRU groups (children, elderly, disabled)</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comfort</td>
<td>Does the system affect environmental conditions (traffic noise levels, CO$_2$ emissions, odour emissions, etc.)?</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>ADC</td>
</tr>
<tr>
<td></td>
<td>Does the system affect the number of traffic conflicts between road user groups?</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>BO, ADC</td>
</tr>
<tr>
<td>Mobility</td>
<td>Is road user interaction affected?</td>
<td>(YES/NO)</td>
<td>(YES/NO)</td>
<td>(YES/NO)</td>
<td>(YES/NO)</td>
<td></td>
<td>(Q, TD, ADC)</td>
</tr>
<tr>
<td></td>
<td>Are trip characteristics affected? (number of trips/trip lengths/travel time)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Q, BO, ADC</td>
</tr>
<tr>
<td></td>
<td>Is route choice affected?</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>BO, ADC</td>
</tr>
<tr>
<td></td>
<td>Is speed of the motorised traffic affected?</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>BO, ADC</td>
</tr>
<tr>
<td>Compliance</td>
<td>Is walking/driving/riding against red light affected?</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>BO, ADC</td>
</tr>
<tr>
<td></td>
<td>Is giving right of way affected?</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>BO, ADC</td>
</tr>
</tbody>
</table>
Table 18. Structure of indicators focused on comfort.

<table>
<thead>
<tr>
<th>Aspect</th>
<th>Research question</th>
<th>A specific location or situation</th>
<th>ITS</th>
<th>Vehicle driver</th>
<th>VRUs</th>
<th>Special VRU groups (children, elderly, disabled)</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Is level of workload affected?</td>
<td>(YES/NO)</td>
<td></td>
<td>(YES/NO)</td>
<td>(YES/NO)</td>
<td>(YES/NO)</td>
<td>(YES/NO)</td>
</tr>
<tr>
<td></td>
<td>Does the function affect the stress of the driver?</td>
<td>(YES/NO)</td>
<td></td>
<td>(YES/NO)</td>
<td>(YES/NO)</td>
<td>(YES/NO)</td>
<td>(YES/NO)</td>
</tr>
<tr>
<td></td>
<td>Is the feeling of subjective safety affected?</td>
<td>(YES/NO)</td>
<td></td>
<td>(YES/NO)</td>
<td>(YES/NO)</td>
<td>(YES/NO)</td>
<td>(YES/NO)</td>
</tr>
<tr>
<td></td>
<td>Does the function support the user to travel in adverse conditions (weather etc)?</td>
<td>(YES/NO)</td>
<td></td>
<td>(YES/NO)</td>
<td>(YES/NO)</td>
<td>(YES/NO)</td>
<td>(YES/NO)</td>
</tr>
<tr>
<td></td>
<td>Is relevant information missing?</td>
<td>(YES/NO)</td>
<td></td>
<td>(YES/NO)</td>
<td>(YES/NO)</td>
<td>(YES/NO)</td>
<td>(YES/NO)</td>
</tr>
<tr>
<td></td>
<td>Is the usage satisfactory?</td>
<td>(YES/NO)</td>
<td></td>
<td>(YES/NO)</td>
<td>(YES/NO)</td>
<td>(YES/NO)</td>
<td>(YES/NO)</td>
</tr>
<tr>
<td></td>
<td>Does the usage support independent travel?</td>
<td>(YES/NO)</td>
<td></td>
<td>(YES/NO)</td>
<td>(YES/NO)</td>
<td>(YES/NO)</td>
<td>(YES/NO)</td>
</tr>
<tr>
<td></td>
<td>Does the system affect trip efficiency?</td>
<td>(YES/NO)</td>
<td></td>
<td>(YES/NO)</td>
<td>(YES/NO)</td>
<td>(YES/NO)</td>
<td>(YES/NO)</td>
</tr>
<tr>
<td></td>
<td>Does the system affect trip effectiveness?</td>
<td>(YES/NO)</td>
<td></td>
<td>(YES/NO)</td>
<td>(YES/NO)</td>
<td>(YES/NO)</td>
<td>(YES/NO)</td>
</tr>
<tr>
<td></td>
<td>Is the system reliable?</td>
<td>(YES/NO)</td>
<td></td>
<td>(YES/NO)</td>
<td>(YES/NO)</td>
<td>(YES/NO)</td>
<td>(YES/NO)</td>
</tr>
</tbody>
</table>

5.3 Step-by-step application of the mobility and comfort impact assessment method

The method for mobility and comfort impact assessment follows the steps and applies the tool described by Kulmala (2010). One should note, though, that the e-impact method was developed for assessing safety, and it was developed to assess the safety of vehicle drivers. To conduct the following assessment, two major specifics need to be addressed; the method is altered and developed to assess mobility and comfort, and the road users of interest are VRUs. The overall procedure of the method to assess mobility and comfort as adopted for VRUI TS project is presented below (Figure 22).
The first step of the impact analysis is to draw the system descriptions that explain the purpose of the system, i.e. the expected mobility and/or comfort effects and for which users the system has been developed. It should be noted that the expected effects can be either positive or negative. Then the relevant mobility and comfort mechanism are selected for each studied ITS.

The mechanisms refer to the earlier presented nine mechanisms which aim to cover the three aspects of road safety in systematic manner, but when assessing mobility and comfort number 3–4, 5 and 6–8 are of interest. The basis for the qualitative assessment are the questions stated in section 5.3 (Development of mobility and comfort methodology to take into account VRUs). The questions have been developed from the overall mechanisms 3–4, 5 and 6–8 regarding mobility, and to some respect comfort. In this phase the qualitative description of expected changes in mobility and comfort together with the estimation of, if possible numerical percentage, for the change in mobility and comfort will be done for each mechanism. Three different types of data or sources of estimation of numerical estimations will be used, see further description below.

In the next step a main classifying variable (link or intersection, road type, weather, etc.) is chosen for each system, called a basic variable to get an estimation of the exposure of a specific event. The functions of the tested systems are central when choosing classifying variable, for example some specific systems are designed for preventing accidents in intersections, or increasing VRUs mobility and/or comfort when travelling in intersections. The basic variable is used to weight the estimate when the effect estimates are applied to available data on mobility and comfort, to get an estimation of the effect on mobility and comfort at that specific event. The goal with the weighting is that the effect estimates indicated in percentage changes are multiplied with the share (%) of relevant mobility aspects and comfort aspects. Retrieving relevant data on mobility and comfort of VRUs is crucial for the level of detail of the results that can be achieved, this will be elaborated below. Choosing the basic variable is also critical as it links the total effect to the basic situation.

The impact estimates are based on an assumption of 100% penetration, meaning that the studied systems are fully installed in the studied transport system. The effect estimates are applied to selected target years by using the estimated mobility rates. In general, a linear development of the effects for
different penetrations is assumed. The aim is also to test the effect weighted according to different situational variable categories, to provide information on estimates that show in which circumstances the most substantial mobility and comfort benefits could be gained.

The assessment builds on the critical scenarios identified in T2.1 Identification of major critical situations for VRUs and the selected ITS from T2.3 Prioritization of ITS for Vulnerable Road Users. These have been reported in D2.1 Technology potential of ITS addressing the needs of Vulnerable Road Users. The procedure for assessing comfort and mobility follows the same order as for safety assessment. The work will be conducted in WP3 in VRUITS, Impact assessment. Specific details that are of interest when assessing mobility and/or comfort are emphasized below.

1. **System descriptions**
   The system descriptions (procedure described under chapter 4.2.1 regarding safety) are used in the assessment of comfort and mobility, examples of issues to be covered in the system descriptions regarding comfort and mobility are listed in the following:
   - Description of the purpose and technical performance of the system
     - informative/warning/intervening/controlling
     - stand-alone / cooperative x2x (v1i, v2v, i2vru, v2vru)
     - What kind of information is given to the user? How and when?
   - Description of the general mobility and/or comfort issue addressed with the system
   - Description of type of comfort aspects the system are addressing or affecting
   - Description of type of mobility aspects the system are addressing or affecting
   - Description of circumstances in which the system works or is assumed to work / does not work
   - Expectation of effects on the behaviour of the driver or VRUs; effects on mobility and/or comfort
     - Anticipated driver reactions; change in driver behaviour (direct and indirect effects; behavioural adaptation)
     - Change in VRU behaviour (direct and indirect effects; behavioural adaptation)
     - Interactions between the system and the user, interactions between the system and other applications
     - Interactions between the users of the system
     - interactions between users and non-users of the system; change in non-user behaviour

The above described comfort aspects will in further studies be aggregated as one parameter to describe comfort.

2. **Qualitative mobility and/or comfort impact assessment**
   During the next step the relevant mobility and/or comfort mechanisms are selected for each investigated IT system, selected in T2.3 Prioritization of ITS for Vulnerable Road Users. This includes description of expected changes in driver and VRU behaviour and the estimates are motivated with references found in literature if possible, and other evidence available. The basis for the qualitative assessment are the questions stated in section 5.3 (Development of mobility and comfort methodology to take into account VRUs), aiming to cover all aspects that can have an effect on the different road users behaviour. The questions has been developed from the overall mechanisms 3-4, 5 and 6-8 regarding mobility, and to some respect comfort. Examples of different kinds of evidence that will be used to test the questions are:
   1. Already available empirical evidence on mobility and comfort impacts of systems with partly similar functionalities
   2. Existing/earlier expert evaluations of mobility and comfort impacts (predicted results)
3. Indirect evidence on mobility and comfort impacts, which means more general assessment of the effects based on knowledge of VRU behaviour exposure, and effects of comparable systems.

Description of the mobility aspects of interest that can be addressed with the system:
- Mode of transport
- Route choice
- Travel distance
- Travel length
- Travel speed
- Time spent on travelling, duration
- Number of journeys
- Departure time/arrival time

Description of the comfort aspect of interest that can be addressed with the system:
- Workload related to travel
- Stress related to travel
- Uncertainty related to travel
- Travelling in adverse conditions (weather etc.)
- Feeling of safety in relation to traffic

3. Selection of systems for more detailed assessment

Based on the qualitative assessment the systems will be prioritised, in parallel with the safety assessment. The selection of systems for the final assessment will be done in a VRUITS workshop in June 2014, with experts in the field of traffic safety, ITS, traffic planning and vulnerable road users. The workshop will most likely follow the structure of a multicriteria analysis. The result from the workshop is a reduced list if ITS (less than ten systems) for further detailed quantitative studies.

4. A 5 step expert judgement process

The process for the collection of expert evaluations on mobility and comfort are described in more detail in chapter 4.2.4. The process starts with an expert evaluation conducted via an expert questionnaire focusing on safety, mobility and comfort. In the questionnaire the experts are asked to assess the effect of each specific system regarding safety, mobility and comfort. The questionnaire contains quantitative questions, but is also asking the experts to give qualitative descriptions of the effects. After that the process continues with a combination of expert judgements conducted by each partner involved in WP3. The estimates of the effects (literature review and other evidence) will be combined with the expert estimates based on which a numerical percentage value for the effect on mobility and comfort will be estimated for each mechanism. The result is presented in quantitative terms as far as possible.

The monetary assessment of the studied ITS in relation to the users regarding mobility and comfort, i.e. the users willingness to pay for the specific systems, will also be conducted in this phase. The data will be used in the CBA. The data collection will either be conducted via the expert judgment process, or a parallel process of users valuing the systems in monetary terms quantitatively.

5. Selection of main mobility or comfort category

One background variable will be chosen as the main classifying variable for each investigated system. Most often the main classifying variable is road type or location including a description of road and site conditions, or the VRUs. This is done since it is expected that the effect of the IT systems will vary according to the background variables.
6. **Calculation of effects for 100% equipment rate**

The effect estimates of mobility and comfort are applied to available mobility and comfort data (if any), so that the distribution of the main classifying variable (traffic environment, road type, transport mode, road user, weather or lightness) weights the estimate. In weighting, the effect estimate indicated in percent changes is multiplied with the share (%) of relevant mobility and/or comfort data. The calculations to obtain the changes in mobility and/or comfort will be carried out by an Excel tool which has originally been developed in eIMPACT project (Wilmink et al., 2008) for structuring the data and safety effect estimates. The tool will however be altered to fit to comfort and mobility data; this is central in the method development.

The data used will be limited on the EU level, to obtain results based on an EU context. As far as possible the result will be an impact assessment at EU-level, but also country-level assessments can be conducted for 1-2 countries, if these types of sources provide better data.

If no or scarce data on mobility and comfort is available, the results are presented as intervals or trends, based on assumptions of mobility and comfort, based on the data that do exist from specific countries, or specific circumstances, etc. The attempt is to make use of the best data available. Dependent on level of detail or quality of the data on mobility and comfort, some effects can be expressed in quantitative terms, but some results will likely be expressed qualitative.

7. **Calculation of effects for estimated penetration rates in 2020 and 2030.**

The target year estimates will be calculated by using the estimated penetration rates of the selected ITS for the years 2020 and 2030. In general, a linear development of the effects for the different penetrations is assumed (unless stated otherwise). The penetration rates and mobility and comfort trends will be estimated by T2.5 Scenarios development in the VRUITS project.

8. **Calculation of effects on mobility and comfort in numbers**

The impacts are described as far as possible in numbers for the listed mobility aspects and comfort aspects. In addition the effect is also weighted if possible to demonstrate in which circumstances, with which systems, the most substantial mobility and/or comfort benefits can be gained.

5.4 **Mechanisms to take into consideration for VRUs regarding mobility and comfort**

The nine ITS safety mechanisms presented by Kulmala (2010) form the framework for the safety impact assessment method focusing on vehicle drivers. The mechanisms have been studied and then updated to cover not only vulnerable road users, i.e. pedestrians, cyclists, mopeds and motorcyclists, but also in relation to mobility and comfort. Of the nine mechanisms number 6-8 are identified of interest when assessing mobility, and 1-4 are of direct or indirect interest when assessing comfort. Number 5 is of interest both from a mobility point of view, and also from a comfort point of view.

- **Mechanism 1. Direct modification of the task of road users by giving information, advice, and assistance or taking over part of the task.** This may influence their attention, mental load, and decision about for example choice of speed, or choosing to cross the street or not. The effects are direct consequences of the use of the system; and the outputs of the system appear in few milliseconds or seconds. Examples of effects by the system addressed by this mechanism are stress or workload, i.e. different aspects of comfort, in relation to the task of travelling.

- **Mechanism 2. Direct influence by roadside systems mainly by giving information and advice.** Without the possibility to control the road users’ behaviour, the impact of this influence is more limited than of the more active systems described under mechanism 1. In other aspects the impacts are similar as the ones described in mechanism 1. Example of such a system is intelligent traffic lights which are prioritising pedestrians and therefore the expected effect is increased comfort in relation to decreased waiting times for pedestrians.
− **Mechanism 3.** *Indirect modification of user behaviour.* The driver/rider/cyclist or the pedestrian will adapt to the changing situation, called behavioural adaptation, and these changes may show up later. It is hard to predict all types of behavioural adaptations. The modification of user behaviour can result in changes on how the users perceive their travel; i.e. change their opinion regarding the comfort of the travel undertaken.

− **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 road users, i.e. in this case the vulnerable road users, may for example change their behaviour by adapting to the changed behaviour of for instance vehicle drivers, or "active" vehicles (for example crossing a street and paying less attention than before, knowing that "all" vehicles are equipped with systems aiming to alert the driver of VRUs).

− **Mechanism 5.** *Modification of interaction between road users.* From a mobility point of view, and also from a comfort point of view of vulnerable road users, interaction between drivers and vulnerable road users is central. ITS will change the communication between equipped road users, and also non-equipped road users. The interaction can lead to that vulnerable road users are given priority to a lower or higher extent in the traffic environment, i.e. altering the mobility of vulnerable road users. It can also lead to a higher level of comfort due to more information, but also changing the way the different road users interact, leading to a lower level of comfort for vulnerable road users.

− **Mechanism 6: Modification of road user exposure.** This mechanism covers changes in the amount of travelling, i.e. more or fewer trips, or longer or shorter, trips due to the usage of the system (for example vulnerable road users with special needs that equipped with the system can move more freely, therefore more often, in the traffic environment)

− **Mechanism 7: Modification of modal choice.** Traffic information can lead to that travellers decide on shifting from traveling by car or public transport, to travel by foot or by bike.

− **Mechanism 8: Modification of route choice.** By route diversions, route guidance systems, vulnerable road users can be more enlighten regarding selection of routes to shorter, safer or more scenic locations. It should be noted that route changes also affect exposure, and the exposure changes can be taken into account also under mechanism 6.

### 5.5 Summary of methodology for mobility and comfort impact assessment

The aim is to develop a general methodology to study and assess mobility and comfort, a methodology that is developed to take into account the characteristics of mobility and comfort of VRUs. After that the methodology is applied to the eIMPACT method. The result is a procedure to assess mobility and comfort of VRUs in relation to the effect of ITS.

Based on the theory found in literature and method development in earlier projects a general mobility model and comfort model was created. The model summarises and enhances the differences between mobility and comfort, which forms the basis for the general mobility and comfort assessment in VRUITS. Research questions and hypotheses are generated based on the different factors or aspects described in the model, in relation to specific ITS. Functionality of the systems, system design, use cases and impact area are the base for the research questions and hypotheses, generated for the comfort and mobility assessment of different VRUs. Based on the hypotheses, research questions will be worded so as to state the measure (e.g. journey length), the direction (e.g. longer/shorter) and the comparison conditions (e.g. system in use/system not in use). Each research question is tested if it is of interest at a specific location, if it is of interest for vehicle drivers (those that the VRUs sometimes interact with), if it is of interest for VRUs (i.e. pedestrian, bicyclist or PTWs), and finally if it is of interest for VRUs with special needs such as children, elderly, or disabled persons.
The method for mobility and comfort impact assessment follows the steps and applies the e-impact method. The overall procedure of the method to assess mobility and comfort as adopted for VRUITS project is:

1. **System descriptions**
   The system descriptions are used in the assessment of comfort and mobility, examples of issues to be covered in the system descriptions regarding comfort and mobility are listed in the following:

2. **Qualitative mobility and/or comfort impact assessment**
   The relevant mobility and/or comfort mechanisms are selected for each investigated IT system.

3. **Selection of systems for more detailed assessment**
   Based on the qualitative assessment the systems will be prioritised, in parallel with the safety assessment.

4. **A 5 step expert judgement process**
   An expert evaluation conducted via an expert questionnaire focusing on safety, mobility and comfort. Followed by a combination of expert judgements conducted by each partner involved in WP3.

   **Selection of main mobility or comfort category**
   One background variable will be chosen as the main classifying variable for each investigated system. Most often the main classifying variable is road type or location including a description of road and site conditions, or the VRUs. This is done since it is expected that the effect of the IT systems will vary according to the background variables.

5. **Calculation of effects for 100% equipment rate**
   The effect estimates of mobility and comfort are applied to available mobility and comfort data (if any), so that the distribution of the main classifying variable (traffic environment, road type, transport mode, road user, weather or lightness) weights the estimate.

6. **Calculation of effects for estimated penetration rates in 2020 and 2030.**
   The target year estimates will be calculated by using the estimated penetration rates of the selected ITS for the years 2020 and 2030. In general, a linear development of the effects for the different penetrations is assumed (unless stated otherwise).

7. **Calculation of effects on mobility and comfort in numbers**
   The impacts are described as far as possible in numbers for the listed mobility aspects and comfort aspects.
6. METHODOLOGY FOR COST-BENEFIT ANALYSIS

Section 3.6 gives a general overview of Cost Benefit Analysis. In this chapter the focus is on the CBA of VRUITS. The chapter starts with an overview of the effects of VRUITS and how these can be expressed in monetary terms based on existing literature. The final section gives an overview of the results from other work packages that are needed for the CBA to be performed in T3.3.

6.1 Overview of issues relevant to make CBA specific to VRUITS

In section 3.6 the overall CBA methodology is described. Part of the CBA methodology concerns the monetisation of effects. In order to reach a conclusion regarding the contribution of a project to increasing society’s welfare, all welfare aspects of the project, positive and negative, must be expressed in terms of a common unit. The most convenient common unit is money. This means that in a CBA all welfare effects of a project should be measured in terms of their equivalent money value.

In VRUITS the effects of ITS services aimed at VRUs comprise effects in the field of:
- safety,
- mobility (travel time and travel costs),
- comfort,
- environment.

Below an overview is given of the monetary values of these effects that can be found in the literature.

Safety

Safety can be considered to be one of the most expected benefits for VRUs from the deployment of ITS that target their needs. The VRUITS project itself has been initiated due to the observation that despite the constantly declining rate in the number of accidents and consequently in injuries and fatalities in Europe, the same trend has not been observed for VRUs. The accidents involving VRUs appear to remain at the same levels (European Commission, 2012).

Regarding monetisation of the safety benefits from road accident prevention, a main point of discussion is how a human life is valued. Viscusi (2005) presents a short review of the aspects involved in human life valuation, as well as the methodological approaches applied to provide with monetary units corresponding to the value of a statistical life.

A main point of debate is the fact that while all human beings should in principle be valued as being equal, the economic impact of the loss of people with different productive capacity to society may differ. An example illustrating this statement is the fact that younger people are expected to have more future working years and thus to contribute more to society through their production, than people nearer or after the age of retirement. Another example would be that of the different expectation of lost productivity for casualties in different countries, due to the different levels of productivity of the respective economies.

To overcome this dilemma, in our approach, we distinguish between the value of life per se, which addresses the direct loss of welfare for the person involved in a traffic incident; this element is considered as being equal for all human beings, from the value of loss of productive capacity, which represents the indirect loss of productivity for the economy as a whole and is considered to differ for different groups of people and countries.

The FP6 research project HEATCO - Developing Harmonised European Approaches for Transport Costing and Project Assessment, has developed a proposal for harmonised guidelines for transport project appraisal. In this guideline, the suggestion made is that the components relevant to the valuation of accident risks are the following:
1. Valuation of lost quality of life (loss of welfare due to crashes)
2. Cost of loss of productive capacity (lost output)
3. Cost of property damage
4. Medical costs
5. Administrative costs

Subjective, safety impacts such as reduced mobility as a result of post-accident anxiety or increased mobility for vulnerable groups as a result of increased perceived safety are considered to be an element of the comfort assessment and therefore are not addressed in this section, but are rather regarded as an element of comfort and dealt with in the relevant assessment section.

There are multiple values to be found in literature on the cost of the respective elements that contribute to the cost of an accident. The most important factors, contributing also the most to the unit cost calculation of an accident, are the value of life per se and the value of productivity loss. Some countries have carried out studies specifying the Value of a Statistical Life (VoSL), mainly based on the Willingness to Pay principal (WtP), the SWOV fact sheets (SWOV, 2012a) indicate the VoSL for the Netherlands as being € 2.2 million (2001 prices). HEATCO (Bieckel et al., 2006) proposes VoSL units to be used for all EU countries based on the different level of prices for each country but indicates that where available, units produced by national surveys should be preferred.

On the other hand research performed by ICF Consulting and the Imperial College (2003) uses country-factors to address the difference between countries in the cost of goods and services. The ICF research uses similar factors to produce different unit values for the administrative, medical and property loss costs, as well as for the value of productivity loss. Another issue where the two research approaches also converge is the segregation of unit values for fatal accidents and accidents of different severity.

In the development of the current evaluation framework for the impact assessment task, we choose to keep to the same breakdown of components to be considered and separate the value of life per se from the value of productivity loss. Within this breakdown, unit values for accidents with fatalities and accidents with injuries of different extend or no health damage are distinguished. Moreover, as mentioned before the value of life per se will be considered equal for all European Member States. For the other cost elements of accidents (productivity loss, property damage, medical and administration costs), the difference in price levels between different countries is accounted for. Table 19 presents the EU-wide average unit costs for the different elements of the value of life per accident severity type. In this study, country specific values will be applied to monetise the benefits of accidents prevented from each category in different EU Member States.
Table 19. Table of accident cost components and accident severity types per 2020 in the EU member states (in 1000 €).

<table>
<thead>
<tr>
<th></th>
<th>Fatality</th>
<th>Severe Injury</th>
<th>Slight Injury</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Value of life per se</strong></td>
<td>€ 2103</td>
<td>€ 283</td>
<td>€ 23</td>
</tr>
<tr>
<td><strong>Loss of productivity</strong></td>
<td>€ 740</td>
<td>€ 28</td>
<td>€ 3.2</td>
</tr>
<tr>
<td><strong>Property damage</strong></td>
<td>€ 14</td>
<td>€ 5.5</td>
<td>€ 3.2</td>
</tr>
<tr>
<td><strong>Medical costs</strong></td>
<td>€ 10</td>
<td>€ 17</td>
<td>€ 1.4</td>
</tr>
<tr>
<td><strong>Administration costs</strong></td>
<td>€ 2.8</td>
<td>€ 0.5</td>
<td>€ 0.2</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>€ 2869.8</td>
<td>€ 334</td>
<td>€ 31</td>
</tr>
</tbody>
</table>

The value of life figures are based on HEATCO (Bieckel et al., 2006), adjusted for inflation and real growth per individual EU-27 member states, while the aggregated EU figures are weighed against the number of traffic deaths (in 2011) according to the CARE database. Since the HEATCO study does not make a clear distinction for the other cost elements of accidents, the rest of the values in Table 19 (loss of productivity, property damage, medical costs, administration costs) are derived from figures provided by the ICF in 2003 as this study makes a distinction to the different elements that comprise the value of the accident. Those figures have been as well adjusted for inflation up to 2020 (average historic European inflation rates of 1997-2012 extrapolated to 2020).

This table is an average of all traffic incidents so the figures on property damage include car-against-car crashes as well as accidents involving VRUs, of which the average property damage would reasonably be lower, however no easily accessible data are available on the property damage of accidents involving VRUs. Moreover, especially regarding accidents with fatalities and injuries, any effort to adjust property damage accordingly, although realistic, would have only limited impact to the overall costs of accidents examined. Table 20 summarises the assumptions considered in the safety impact monetisation methodology.

Table 20. Assumptions in safety impact monetisation.

<table>
<thead>
<tr>
<th>Assumptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>All human lives (per se) are valued the same</td>
</tr>
<tr>
<td>Difference in expected productivity output for different age groups</td>
</tr>
<tr>
<td>Same productivity output for different VRU groups (of same age)</td>
</tr>
<tr>
<td>Productivity taken as a proxy for all inhabitants of a country</td>
</tr>
<tr>
<td>Proper accounting of underreporting of accidents has been done</td>
</tr>
<tr>
<td>Accidents with different VRU types (pedestrians, cyclists and PTW) induce different property damage according to their severity</td>
</tr>
</tbody>
</table>

Mobility

Mobility impacts caused by the introduction of ITS applications have an impact on VRUs by lowering their perceived generalised transport cost. They also have an impact on other road users, by altering VRU participation in traffic and in accident generation which both affect traffic congestion levels. In the same line is the approach of eIMPACT (Benz et al., 2008), where mobility-related impacts are distinguished in direct and indirect; direct being the impacts of the ITS application on vehicles and driving behaviour, resulting in different driving characteristics. This has an impact on the number of trips and trip characteristics, ultimately yielding time or other benefits for road users. Impacts on congestion levels due to reduction of accidents are also calculated and defined as indirect impacts. A further impact

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2 Administration costs are the sum of insurance and police costs.
of changes in mobility levels of VRUs can be found in the impacts it may have on the health of individuals. This may be related to a change in productivity (less sick days, less early pensions) but also to a change in welfare of individuals (as a result of a healthier life) as well as an impact on healthcare costs. All this said, it can be realised that the impact of increased or decreased mobility of VRUs (and especially elderly people) can be considerable when taking all potential aspects into consideration. However there are inherit difficulties in introducing the monetisation of health-related impacts in the VRUITS assessment methodology related to the unavailability of relevant monetisation efforts and the complexity of assessing their impacts Therefore, health related impacts are not included in the current assessment methodology.

The effect on VRU mobility will be assessed in task T2.3. The time gains that derive from that can then be multiplied with the Value of Travel Time Savings (VTTS) units, depending on trip purpose and country. International literature (Bieckel et al., 2006; Litman & Doherty, 2009; Litman, 2013; European Commission, 2008) closely links the VTTS with the wage level in each country. Deliverable 5 HEATCO provides VTTS values for all Member States of the EU-25 following the proposal for a minimum proposed disaggregation of VTTS that should include different values for work/ non-work/ goods transport. Further disaggregation based on other transport elements such as income of traveller level, socio-economic status, length of journey, comfort and congestion level is recognised as meaningful. It is suggested that a more detailed approach that disaggregates VTTS by mode used or income level could bring in positive effects to the accuracy of the CBA. However, this more sophisticated approach requires a detailed VTTS split for the distinguished user groups and this could not be facilitated for an EU-28 level as for some EU Member States, the VTTS is defined in detail for different trip purposes and road users while for others this is not the case.

The VRUITS impact assessment methodology will disaggregate VTTS per country and trip purpose adopting the HEATCO values (Bieckel et al., 2006), as obtaining disaggregated data on VTTS per income level might not be feasible for the whole of Europe while also the element of data consistency is difficult to assure when drawing information from different national sources. Therefore, we account for the same VTTS for all VRUs when performing a trip with the same purpose in the same country. This approach of attributing to all VRUs the same VTTS has been also adopted by the Victorian Transport Institute CBA guidelines (Litman & Doherty, 2009) where cyclists and pedestrians are attributed the same VTTS values. However estimating the VTTS for non-motorised modes is difficult. This depends in principle heavily on the purpose of the trip, as well as the age and income of the road user. Most social cost-benefit analyses in the Netherlands (Goedhart et al., 2012) regard bicycling and pedestrian VTTS as being equal to that of the VTTS for bus/tram/metro users. The argument for this is that the average speed and costs for short trips with these modes is closest to the respective bicycle trip characteristics than those of other modalities (car, airplane, train, bus/tram/metro). In the VRUITS CBA methodology the VTTS for cyclists will be accounted as equal to the VTTS of short trips for bus users. This assumption is confirmed by the Victoria Transport Policy Institute (Litman, 2009) where the value of travel time savings for cyclists and standing bus passengers is estimated to be the same.

Below, in Table 21, the estimated VTTS values per country, mode of transport and trip purpose are displayed. The values are from HEATCO (Bieckel et al., 2006) with base year 2002, adjusted for inflation and extrapolated to 2020. In HEATCO, the values are categorised into short distance and long distance trips for the EU-25 countries. For this study, only the short distance values are accounted for, because only these trips are potentially replaced with VRU-modes trips. Long distance trips by bus, train or car are expected not to be affected by ITS applications for VRUs (as well as air travel). For the Member States that have been admitted to the Union since, the VTTS values will be estimated according to existing data. If these data are missing, the VTTS values of countries with similar economic and transport characteristics will be used after adjusting to reflect the difference between those countries.
Table 21  Estimated VTTS-values – passenger trips (€2020 nominal per passenger per hour, factor prices).

<table>
<thead>
<tr>
<th>Country</th>
<th>Commute</th>
<th></th>
<th>Business</th>
<th></th>
<th></th>
<th></th>
<th>Other</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Bus/VRU</td>
<td>Car, train</td>
<td>Bus/VRU</td>
<td>Car, train</td>
<td>Bus/VRU</td>
<td>Car, train</td>
<td></td>
</tr>
<tr>
<td>Austria</td>
<td>8.22</td>
<td>11.43</td>
<td>32.43</td>
<td>40.41</td>
<td>6.89</td>
<td>9.58</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Belgium</td>
<td>7.84</td>
<td>10.91</td>
<td>31.35</td>
<td>39.05</td>
<td>6.57</td>
<td>9.15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cyprus</td>
<td>8.11</td>
<td>11.28</td>
<td>24.08</td>
<td>30.00</td>
<td>6.80</td>
<td>9.46</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Czech Rep</td>
<td>5.88</td>
<td>8.18</td>
<td>16.29</td>
<td>20.31</td>
<td>4.92</td>
<td>6.86</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Denmark</td>
<td>8.67</td>
<td>12.07</td>
<td>36.02</td>
<td>44.88</td>
<td>7.27</td>
<td>10.12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Estonia</td>
<td>5.09</td>
<td>7.10</td>
<td>14.66</td>
<td>18.24</td>
<td>4.28</td>
<td>5.95</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Finland</td>
<td>7.76</td>
<td>10.79</td>
<td>32.14</td>
<td>40.06</td>
<td>6.50</td>
<td>9.05</td>
<td></td>
<td></td>
</tr>
<tr>
<td>France</td>
<td>11.20</td>
<td>15.58</td>
<td>31.63</td>
<td>39.42</td>
<td>9.39</td>
<td>13.06</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Germany</td>
<td>8.22</td>
<td>11.44</td>
<td>31.80</td>
<td>39.64</td>
<td>6.90</td>
<td>9.59</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Greece</td>
<td>7.09</td>
<td>9.86</td>
<td>22.18</td>
<td>27.63</td>
<td>5.95</td>
<td>8.28</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hungary</td>
<td>5.17</td>
<td>7.19</td>
<td>15.44</td>
<td>19.24</td>
<td>4.33</td>
<td>6.02</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ireland</td>
<td>8.58</td>
<td>11.94</td>
<td>34.11</td>
<td>42.50</td>
<td>7.20</td>
<td>10.02</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Italy</td>
<td>10.40</td>
<td>14.46</td>
<td>29.27</td>
<td>36.47</td>
<td>8.71</td>
<td>12.12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Latvia</td>
<td>4.65</td>
<td>6.47</td>
<td>13.39</td>
<td>16.69</td>
<td>3.90</td>
<td>5.44</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lithuania</td>
<td>4.54</td>
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<td>16.48</td>
<td>3.80</td>
<td>5.29</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Luxembourg</td>
<td>12.24</td>
<td>16.95</td>
<td>43.41</td>
<td>54.10</td>
<td>10.22</td>
<td>14.22</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Malta</td>
<td>6.67</td>
<td>9.29</td>
<td>21.29</td>
<td>26.52</td>
<td>5.59</td>
<td>7.78</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Netherlands</td>
<td>7.95</td>
<td>11.06</td>
<td>31.97</td>
<td>39.84</td>
<td>6.66</td>
<td>9.28</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Poland</td>
<td>5.05</td>
<td>7.03</td>
<td>14.70</td>
<td>18.31</td>
<td>4.23</td>
<td>5.89</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Portugal</td>
<td>6.84</td>
<td>9.52</td>
<td>22.08</td>
<td>27.52</td>
<td>5.73</td>
<td>7.98</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slovakia</td>
<td>4.71</td>
<td>6.55</td>
<td>14.12</td>
<td>17.59</td>
<td>3.96</td>
<td>5.49</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slovenia</td>
<td>8.22</td>
<td>11.44</td>
<td>21.46</td>
<td>26.75</td>
<td>6.90</td>
<td>9.59</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spain</td>
<td>8.71</td>
<td>12.12</td>
<td>25.51</td>
<td>31.79</td>
<td>7.30</td>
<td>10.17</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sweden</td>
<td>8.40</td>
<td>11.67</td>
<td>34.61</td>
<td>43.12</td>
<td>7.03</td>
<td>9.79</td>
<td></td>
<td></td>
</tr>
<tr>
<td>United Kingdom</td>
<td>8.52</td>
<td>11.87</td>
<td>33.14</td>
<td>41.29</td>
<td>7.14</td>
<td>9.95</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EU 25</td>
<td>8.68</td>
<td>12.07</td>
<td>27.19</td>
<td>33.89</td>
<td>7.27</td>
<td>10.12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Switzerland</td>
<td>11.47</td>
<td>15.97</td>
<td>37.67</td>
<td>46.92</td>
<td>9.62</td>
<td>13.38</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Transport cost benefits (beyond time savings) will be addressed as a function of the modal shift achieved and the different operating costs for the examined modes.

The welfare benefit (travel time savings plus transport cost savings) for new users or new trips made by existing users will be assessed utilising the “rule of half” and thus considered to contribute to VRU welfare by half the rate than that of existing users/trips.

The indirect impacts on other users, such as the impact on accident-caused congestion levels can be calculated based on data on queuing costs due to road accidents. SafetyNet and Dutch statistical data (SafetyNet, 2007) provide an assessment of time costs due to accidents. Based on the expectation that fewer accidents would result in less accident-derived congestion, the value of derived congestion is calculated for accidents with fatalities or severe injuries. Of course the values used for calculating the VTTS should take into account the different value of travel time that should be applied in different countries and times of the day, accounting for congestion levels in each country.
In principle, the increased mobility of VRU groups should be taken into account as a potential cause of congestion, in which case the travel time losses of other users should also be considered. However, the examined VRU modes (cyclists, pedestrians, PTWs) have a small contribution to road congestion. Additionally the improvement of trip quality with these modes is more probable to also going to divert road users from cars and thus; these impacts can be disregarded. Finally, Table 22 presents the assumptions considered in the mobility monetisation methodology.

Table 22. **Assumptions in mobility impact monetisation.**

<table>
<thead>
<tr>
<th>Assumptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Travel time value is the same for all road users with the same trip purpose</td>
</tr>
<tr>
<td>All accidents of same severity, time of the day, type of road and country produce equal congestion</td>
</tr>
</tbody>
</table>

**Comfort**

Assessment and monetisation of comfort benefits for VRUs is a task that no research has dealt with before. This is one of the points that the VRUITS methodology intends to go beyond the state of the art. Usually, public transport operators provide approximate values to place a price tag on passenger comfort levels, but this mostly (if not exclusively) relates to the occupancy of the vehicles. When it comes to private transport, little relevant research is available. The Victoria Transport Policy Institute (Litman & Doherty, 2009), in its Cost Benefit Analysis Guideline for Transport policy appraisal, suggests that the value of time for a trip in high discomfort conditions should be accounted with 50% of the wage value of the individual making the trip, while in zero-discomfort conditions, this ratio drops to 25%. It is even noted that small walking or cycling trips can be perceived even as having a zero or even positive value of travel time in the case that the individual draws utility from the trip itself (i.e.: exercise). However this approach requires a comprehensive understanding of the relation of comfort levels to the value of travel time. A number of approaches to monetising comfort benefits are here analysed.

Due to the experimental nature of this research, multiple approaches to monetising the effect of comfort aspects on transport of VRUs can be proposed as no prevailing practice exists. The selected approach to be applied in the final VRUITS CBA methodology will be the one better fitting the data collection potential according to the scope of the VRUITS project. In the rest of this section 3 different methodological approaches to the monetisation of comfort benefits are described. Based on the availability of data as revealed later in the course of the VRUITS project, one of these approaches will be selected.
The first approach draws from a theoretical viewpoint and focuses on the transport demand and supply balance, as illustrated in Figure 23, by assessing what potential change in mobility is resulting from a combination of increase/decrease in trip costs and comfort, the comfort benefit can be then monetised. This is the case when the change in transport cost is known and the elasticity of transport demand is either given as a proxy value, revealed or estimated. The main drawback of this methodology is that it strongly relies on the elasticity values provided/retrieved from literature, a validation of which is difficult to achieve. Moreover, in real-life situations, and regarding the monetisation of comfort benefits, it is difficult to segregate the impact on mobility due to changes in comfort level, from the impacts on mobility caused by the other direct ITS impacts (i.e.: impact on safety, trip costs, etc.)

A second approach is established on the economist’s perspective of assessing willingness to pay (WTP). What is meant by this concept is that potential users are requested to state what is the amount they would be willing to pay for the increased comfort level provided by the use of the specific application. This approach is based on a stated preference subjective assessment method for defining the value of comfort. Subjective valuations of benefits are usually judged as not being capable of containing the benefits and costs that do not burden the potential user. However, as perception of comfort is a totally subjective matter, this methodology can be valuable for the case where placing a price tag on comfort levels alone is the goal. The WTP for a comfort-producing appliance should be further extrapolated to a passenger-km level in order to be able to calculate the final benefit.

This approach contains however a risk of double counting the effect of reduced costs of transport (either due to reduced travel time or operating costs) in the willingness to pay assessment. Therefore the user stated or revealed WTP due to the comfort, mobility and safety impacts of the ITS should be accounted for explicitly and separately. However, in the scope of the VRUI TS methodology, no extended survey on VRUs themselves regarding their WTP is foreseen. Instead the assessment of the ITS impacts is done by VRU and mobility experts. In this case, the assessment, by a third party, of the ITS

Figure 23. Impact of increase in comfort level.
impacts on the WTP of VRUs due to an expected change in comfort level alone can be a risky exercise and the reliability of the outcome can be debated. Finally, a third approach is founded on a more empirical basis. As suggested by the Cost-Benefit guidelines issued by the Victoria Transport Policy Institute (2005), the Value of Time (VoT) can be correlated to the trip purpose and the average wage level in each country. Specifically, for non-commuting trips, this value should be between 25% and 50% of the average wage (AW) level. This last approach is based on giving different price tags on the VoT depending on the level of comfort starting with 50% of the AW for extreme discomfort and gradually lowering it to 25% of the AW for very comfortable trip conditions. The assumptions used in this comfort monetisation methodology are summarised in Table 23.

Table 23. Assumptions in comfort impact monetisation.

<table>
<thead>
<tr>
<th>Assumptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>The valuation of the different aspects comprising the perception of comfort is subjective and depend only on individual VRU’s perception</td>
</tr>
<tr>
<td>The 25% - 50% of AW scale of the value of time depending on comfort levels needs validation</td>
</tr>
</tbody>
</table>

**Environment**

Although the primary focus of the VRUITS methodology is to assess the impacts of ITS applications on road users, and VRUs in specific, a (limited) estimation of the potential environmental benefits of these applications will be also performed focusing on the impacts on CO₂ emissions due to a change in the overall modal shift and passenger-km carried out per mode. The ITS applications might for example have an impact on emissions through a change in driving behaviour (i.e. smoother driving), resulting in less use of petrol that in turn results in lower CO₂ emissions. This means that other environmental benefits, (i.e. other type of emissions, change in noise levels etc.) are omitted from this CBA methodology. Overall, the introduction of various ITS applications aiming to alter the interaction of VRUs and other road users, will most probably have an impact on the driving characteristics of car users, which in turn will alter the environmental impacts caused by car drivers. However the estimation any potential impacts of this type can be very complex and thus exceeding the scope of this study.

The input for the monetisation of the environmental impact will be the mobility effects of the different scenarios. More specifically, the change in the travelled distance in kilometres per transport mode, type of vehicle, place and type of road will be used for a calculation of carbon dioxide emissions.

This analysis draws mainly from the fact that different modes of transport have different levels of carbon dioxide emissions. The implementation of the ITS will have an effect on people’s mobility behaviour and therefore on the carbon dioxide impact of their trips. To measure this environmental effect, the carbon dioxide emission factors of the various modes of transport – both the modes of the vulnerable road users and the modes that these people quit using – are needed as input for the calculation. Below, in Table 24, the average CO₂ emissions per passenger-kilometre per modality according to the EEA are displayed.

Table 24. European CO₂ emissions per passenger (gram per passenger kilometre) in 2011 (EEA, 2011).

<table>
<thead>
<tr>
<th>Mode</th>
<th>CO₂ emissions (gram per passenger kilometre)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passenger cars</td>
<td>120.13</td>
</tr>
<tr>
<td>Buses and coaches</td>
<td>36.94</td>
</tr>
<tr>
<td>Powered two-wheelers</td>
<td>66.63</td>
</tr>
<tr>
<td>Vans</td>
<td>157.67</td>
</tr>
</tbody>
</table>

The CO₂ emissions for each modality is steadily reduced every year: emission from passenger cars went down from 131 g/pk in 1995 to 120 g/pk in 2011, for two-wheelers these numbers went down...
even stronger: from 84 to 67. It can be assumed that this downward trend will continue into the future, especially when taking into account the EU ambitious emission targets for new passenger cars, which are set at 130g per vehicle kilometre for 2015, and 95g for 2020 (note that these are emissions per vehicle and not per passenger; as of 2010, the emissions per vehicle/km were still above 140g but dropping steadily every year). When extrapolating the values of the EEA to 2020, the emission values presented in Table 25 are obtained.

Table 25. Predicted European CO₂ emissions per passenger (gram per passenger kilometre) in 2020 (extrapolated data from EEA, 2011).

<table>
<thead>
<tr>
<th>Passenger cars</th>
<th>Buses and coaches</th>
<th>Powered two-wheelers</th>
<th>Vans</th>
</tr>
</thead>
<tbody>
<tr>
<td>113.97</td>
<td>31.22</td>
<td>56.86</td>
<td>146.15</td>
</tr>
</tbody>
</table>

The CO₂ emissions from cycling and walking are considered to be zero. Although there might be some lifecycle-emissions from the production and maintenance of bicycles, these effects are negligible compared to the emissions per kilometre of other modes of transport, moreover since the change in modal shift induced by the ITS will most probably not cause road users to change into modes they were never using before, but will most probably result in an increase of the use of VRU-modes in comparison to their use of the other modes they have available. Also with car transport the lifecycle-emissions are not taken into consideration, only the emissions from the fuel that the vehicles consume.

These emission factors are then multiplied with the change in the total travelled distance (in km) calculated for each mode. When the change in CO₂ emissions is known, a monetisation of the environmental impact can be made. The European Commission has produced guidelines for the calculation of the cost of CO₂ emissions, varying per year. The figures are based on the IMPACT study from 2008 (CE Delft, 2008), and the EC presented them in their report “Guide to Cost Benefit Analysis of Investment Projects” from 2008 (European Commission, 2008). These recommended values are displayed in Table 26. The central value of 2020 (40 euros per ton of CO₂ per 2020) is the value that will be used in this CBA.

Table 26 Central values (€/ton) of CO₂, recommended in eIMPACT (eIMPACT study, 2008).

<table>
<thead>
<tr>
<th>Year of application</th>
<th>Lower value</th>
<th>Central value</th>
<th>Upper value</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>7</td>
<td>25</td>
<td>45</td>
</tr>
<tr>
<td>2020</td>
<td>17</td>
<td>40</td>
<td>70</td>
</tr>
<tr>
<td>2030</td>
<td>22</td>
<td>55</td>
<td>100</td>
</tr>
<tr>
<td>2040</td>
<td>22</td>
<td>70</td>
<td>135</td>
</tr>
<tr>
<td>2050</td>
<td>20</td>
<td>85</td>
<td>180</td>
</tr>
</tbody>
</table>

6.2 Beyond the state of the art

The VRUITS methodology is initially relying on the foundation for ITS impact assessment laid by the eIMPACT methodology while it aims at going beyond the state of the art to achieve a full VRU-centric impact assessment. The main points where the VRUITS CBA methodology innovates are the following:

1. VRU-centric approach to assessing VRU-relevant ITS applications is defined as all relevant monetisation parameters (i.e.: value of life, value of time etc.) distinguish for different VRU users wherever possible.
2. Monetisation of comfort impacts for VRU users. This point goes beyond merely establishing a VRU-centric approach to the CBA, but also innovates in introducing comfort assessment in a CBA exercise for transport related effects.

3. The breakdown of the impact of ITS applications is quite sophisticated, including the cost of congestion saved by accident avertion, but furthermore, monetisation of the safety impacts accounts also for the element of property damage. This element, despite being marginal when fatal or accidents involving severe injuries are the case, can prove to be a significant cost factor for accidents where slight injuries or property damage alone are the case.

4. This exercise is based on the HEATCO FP6 research on drawing monetary units for the monetisation of the expected impacts. However, except from updating these factors, they will be expanded from an EU-25 to an EU-28 coverage.

6.3 Modifications of mobility and comfort methodology to take into account VRUs

This section gives an overview of the results from the previous sections: what additional information is needed (from other work packages) that serves as an input for the CBA to be performed in T3.3.

6.3.1 Scenarios

In section 3.6 it is described that in order to establish the effects of VRUITS two scenarios are needed: the Business as Usual scenario and the ‘with’ project scenario. Since the effects of new ITS services will be established for each new service separately there will be more than one ‘with’ project scenario needed. These will be established in T2.5 and must result in:

- Elaborate description of the scenarios: what is the goal of the ITS service in each of the ‘with’ project situations, what does the service comprise, who are the stakeholders;
- Time frame for the CBA (depending on when ITS services can be introduced and the expected lifetime of the new technologies);
- Determination of the scope of the CBA: is it the EU-27 or the EU-28.

6.3.2 Benefits

The traffic effects of the new ITS services determine the benefits. This means that in a first step the traffic effects of each ITS service have to be established by comparing the BAU scenario with the scenario in which we assume the new ITS service is implemented.

The direct effect of a new ITS service aimed at increasing safety for VRUs is the reduction in the number and/or severity of accidents (safety impacts). This in turn results in lower accident costs (less people injured, less casualties, less damage costs to vehicles and infrastructure).

Less accidents also have (indirect) benefits for the other road users since congestion costs due to accidents will be lower resulting in lower transport costs (reduction in time- and vehicle operating costs). Also (indirect) positive environmental benefits can result due to the lower transport costs (less emissions).

Besides the effects mentioned above, the new ITS services can also improve the comfort level of VRUs during their trips (comfort impact). This can also be seen as a direct benefit of the ITS service.

As a second order effect of the new ITS services ‘new’ traffic could arise: VRUs that would not travel in the BAU scenario, decide to make a trip if the new ITS service is introduced. This means more traf-
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Assessment methodology

fic and possibly an increase in accidents compared to the BAU scenario. The above mentioned positive benefits of the new ITS services can be (partly) offset by these effects.

Another second order effect can be a change in transport modalities due to increased safety and reliability of certain transport systems. This can also result in a change in the number of kilometres travelled per transport mode thereby changing transport costs and environmental costs.

This means that in the determination of the effects we have to separate traffic effects into effect for the current users, the new users and the ‘shifting’ users. Although it is expected that only marginal effects will result from new and shifting users, from a theoretical point of view we have to make a distinction because the effects for new and shifting users are valued in a different way than the effects for current users. Therefore in the questionnaire asking experts for the effects of new ITS services a distinction is made between the effects for these three types of users.

**Safety benefits**

Introducing ITS services for VRUs will result in a change in the absolute numbers of:

- Accidents by type of vehicle (resulting in changing material costs),
- Fatalities (by type of VRU),
- Injuries (severe or slight by type of VRU),

In each of the EU-countries. Because the safety impact assessment does not distinguish between severe and slight injuries, the CBA will not receive the injuries split by severe and slight from the safety impact assessment. The CBA may develop a simple formula to split the injuries up into severe and slight injuries. The change in these absolute figures will have to be determined in T3.1.

Based on these absolute figures the monetised benefits can be established using unit-cost rates. These unit cost rates will be based on literature analysis (see section 6.1). In order to calculate the accident costs per type of VRU, detailed information regarding the types of vehicles involved in the accidents is needed as well as the number of fatalities or injuries by type of VRU (pedestrians, cyclists and PTW).

**Table 27. CBA safety input requirements from other VRUITS tasks.**

<table>
<thead>
<tr>
<th>Input needed from previous Tasks (T3.1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distinguishing per age group, VRU type and country. Distinguish effects for current users, new users and users that change mode</td>
</tr>
<tr>
<td>Change in number of accidents per type of accidents (fatalities, severe injuries, light injuries or only property damage),</td>
</tr>
<tr>
<td>Change in number of fatalities</td>
</tr>
<tr>
<td>Change in number of severe and slight injuries</td>
</tr>
<tr>
<td>Trend-line of accidents for the following N years (this results from Task 2.5)</td>
</tr>
</tbody>
</table>

**Table 28. Safety input requirements from T3.1 research.**

<table>
<thead>
<tr>
<th>Data needed from research</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value of life per se</td>
</tr>
<tr>
<td>Value of productivity loss (per age group and country)</td>
</tr>
<tr>
<td>Country-factors to assess difference in value of life</td>
</tr>
<tr>
<td>Administration and medical costs of accidents (for different countries and accident severity)</td>
</tr>
<tr>
<td>Property damage per VRU type and accident severity</td>
</tr>
</tbody>
</table>
Mobility benefits

The mobility impacts comprise several aspects. First the benefits for road users via the expected reduction in transport costs if road safety increases due to the new ITS service (reduction in congestion costs - travel time - and vehicle operating costs). The magnitude of this indirect mobility impact will differ depending on the conditional variables of the accidents prevented, such as time of trip (peak vs off-peak period) and per type of accident (fatal accident or accident with severe or only slight injuries).

A second mobility impact comprises the increased welfare as a consequence of the generation of trips for VRUs that would otherwise not travel. The benefits of this mobility impact will not be taken into account since it is assumed that these additional benefits will (for the greatest part) be offset by the costs that have to be made for these trips. Another effect of generated trips that are made on the road is that they can lead to increased transport costs for current road users (increase in congestion costs and vehicle operating costs). Increased costs for current road users can also be expected in case that a modal shift from other modes to road occurs (for instance from foot or public transport).

A third mobility impact that can arise is that due to the new ITS service the transport of VRUs is done in a more efficient way due to a better route choice (resulting in less km travelled and as a result lower transport costs in time and money) or a higher average speed (also resulting in changed transport costs).

The mobility impacts will be calculated in T3.2. Travel time savings due to more efficient transport can be calculated based on the change in average speed and length of trips. For the CBA, travel time savings per year are needed by type of user (VRU type or other), country and purpose of trip (business, commuting, other). Additionally, cost savings are expected due to a change in trip costs due to either a modal shift in favour of cheaper modes or due to a smoother traffic flow as a result of accidents reduction. For the CBA, the change in trips made per mode and accidents occurred, by severity of incident is needed as an input.

Table 29. CBA mobility input requirements from other VRUIS tasks.

<table>
<thead>
<tr>
<th>Input needed from previous Tasks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distinguishing per trip purpose, VRU type, time of trip (peak/off-peak) and country</td>
</tr>
<tr>
<td>- Change in number of trips</td>
</tr>
<tr>
<td>- Change in trip length and average speed (if possible or relevant)</td>
</tr>
<tr>
<td>- Change in modal split</td>
</tr>
<tr>
<td>- Change in number of accidents (per accident type and accident location)</td>
</tr>
</tbody>
</table>

Table 30. Mobility input requirements from T3.1 research.

<table>
<thead>
<tr>
<th>Data needed from research</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Value of time (per VRU group, trip purpose and country)</td>
</tr>
<tr>
<td>- Cost of transport</td>
</tr>
<tr>
<td>- Accident-induced queuing time (per time of accident and location)</td>
</tr>
</tbody>
</table>

Comfort benefits

Comfort benefits can be monetised as part of the generalised costs to transport. Although it is easy to comprehend that increased comfort levels decrease the perception of transport generalised costs (i.e. more pleasant and thus probable to make a long trip in a more comfortable car) and research on the levels and effects of transport comfort, as well as on the perceived price of comfort have been done when public transport is at stake, this research has come across nearly no attempt to monetise com-
fort aspects of transport beyond public transport and especially when non-mechanised means of transport are concerned.

In section 6.1, a methodological approach to monetise comfort benefits for VRUs has been proposed, where the perceived comfort benefit of each VRU group is assessed by establishing their willingness to pay. In principle this approach will be used, it is however still under discussion in which task the questions to VRU-users regarding their willingness to pay will be asked. Using this approach the following information is needed:

**Table 31. CBA comfort input requirements from other VRUITS tasks.**

<table>
<thead>
<tr>
<th>Input needed from previous Tasks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distinguishing trip purpose, VRU group and country</td>
</tr>
<tr>
<td>Aggregated comfort level for VRUs for the situation before and after the use of the relevant ITS application</td>
</tr>
<tr>
<td>The number of trips or km per type of user (current user, new user or users that change mode) per VRU</td>
</tr>
<tr>
<td>The willingness to pay for the changed comfort level due to the new ITS service per trip or km</td>
</tr>
</tbody>
</table>

**Environmental benefits**

The environmental impacts comprise the change in:

- the absolute numbers of emissions (tonnes of CO\(_2\), NO\(_x\), PM)
- noise pollution

Since it has been elaborated earlier that the primary focus of this CBA exercise is to capture mainly VRU-related impacts, the environmental benefits do not concern a main priority to this study. This CBA will therefore only focus on the possible impacts regarding CO\(_2\) emissions.

In order to quantify the change in emissions the following information is needed:

**Table 32. CBA environmental input requirements from other VRUITS tasks.**

<table>
<thead>
<tr>
<th>Input needed from previous Tasks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distinguishing by type of transport mode and country</td>
</tr>
<tr>
<td>Mobility impacts. The change in the total number of km per mode</td>
</tr>
</tbody>
</table>

**Table 33. Environmental input requirements from T3.1 research.**

<table>
<thead>
<tr>
<th>Data needed from research</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emission factors per km per mode of transport</td>
</tr>
<tr>
<td>Monetary values for CO(_2) emissions (not differentiated per EU country)</td>
</tr>
</tbody>
</table>

**6.3.3 Costs of ITS**

The costs of the ITS services comprise:

- Investment costs
- Installation costs
- Operating and maintenance costs (yearly costs)

The investment costs comprise the costs that are made for the ITS service: communication system, sensors, hardware, software etc. These costs have to be known with and without VAT since the latter is only a shifting of money between the private and public sector. For the stakeholder analysis we
need to known the costs with VAT as this is the value the stakeholders perceive, for the overall CBA the costs without VAT are used. It is at this point important to stress that securing consistency of the values used regarding the inclusion (or not) of VAT, especially when assessing benefits derived from the willingness to pay principle which are assuming inclusion of VAT. It is possible that investment costs decrease in the future due to economies of scale in production. If this is the case it must be determined how the investment costs will evolve during the CBA time horizon.

Some ITS services also require installation resulting in installation costs. These additional costs (whether paid by the public or private sector) also have to be taken into account and need to be known with and without VAT.

Finally the operating and maintenance costs of the ITS services need to be taken into account (with and without VAT). It will depend on the type of ITS service if these costs will arise. If for example the use of additional devices in the car will result in an increase in fuel consumption, these additional costs have to be taken into account. The operating and maintenance costs comprise also replacement costs if the device has to be replaced during the time horizon of the CBA. As a result the operating and maintenance costs between different ITS services can differ substantially.

The CBA is based on constant prices, i.e. maintaining the same price levels as from the start of the project. This means that the costs of the project do not have to take into account increasing costs due to inflation.

The table below gives an overview of the costs data needed. These will be collected in T3.3 by a technical partner.

**Table 34. Cost data needed for the examined ITS applications.**

<table>
<thead>
<tr>
<th>Overview of costs needed for each ITS service</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Investment costs with and without VAT</td>
</tr>
<tr>
<td>- Installation costs with and without VAT</td>
</tr>
<tr>
<td>- Operating, maintenance and replacement costs (yearly costs, with and without VAT)</td>
</tr>
</tbody>
</table>

6.3.4 **Overview of input needed for the CBA**

Figure 24 gives an overview of what data on impacts/effects are needed from each task in order to be able to perform a CBA for the impacts of ITS applications on the different VRU groups.
Figure 24. CBA methodology framework and data input from other VRUITS tasks.

Once the impacts/effects are estimated, they will be monetized using unit-cost rates.
7. SUMMARY AND CONCLUSION

This deliverable presents a comprehensive and sound methodology to assess the qualitative and quantitative safety, mobility and comfort effects of ITS on vulnerable road users and the translation of these impacts into socioeconomic indicators via social cost-benefit analysis (CBA). The CBA will determine not only the potential benefits that could be enjoyed by VRUs, but also the benefits to society as a whole.

The method to be used in the VRUITS project to assess the safety, mobility and comfort impacts of ITS on vulnerable road users is based on the method introduced by Kulmala (2010), which was developed for the assessment of safety impacts of ITS for cars. The method is based on the idea that safety measures influence safety by affecting one or several of the factors contributing to exposure, accident risk, and accident consequences. In order to be sure that all possible impacts will be covered, the method utilizes a set of nine mechanisms via which ITS can affect road user behaviour and thereby road safety, mobility and comfort. Since this method was developed only to assess the safety impacts of ITS for cars some parts of the method were enhanced and adjusted to take also into consideration the vulnerable road users. The main modifications of the method for the purposes of VRUITS project are: i) nine mechanisms have been updated to cover VRUs i.e. pedestrians, cyclists, moped riders and motorcyclists, ii) the safety impact assessment tool will be updated to include more detailed information on accidents involving VRUs, iii) accident types and circumstances like age, road layout and lighting are considered in more detail when relevant for VRU and when feasible and iv) the expert judgement process will be used to enhance the value of estimates for the nine mechanisms.

The impact assessment process, to take place later in the project, will start with comprehensive system descriptions of several ITS that are relevant for VRU. The descriptions will provide clear understanding on the systems under assessment, their functioning and anticipated user reactions. Next, the relevant mechanisms (out of the nine mechanisms mentioned before) are selected for each investigated ITS. This phase includes description of expected changes in driver and VRU behaviour and documentation of the expected effects on safety, mobility and comfort based on existing literature and other evidence available. The result will be a qualitative assessment for the selected systems for safety, mobility and comfort. Based on the qualitative assessment the systems will be prioritized and the 7–10 most promising ITS will be selected for more detailed assessment. The more detailed assessment includes a 5 step expert judgment process which will be used to enhance the value of the assessments by making the estimates for the nine mechanisms more transparent, reliable and objective.

In the final phase of the assessment the changes in the number of accidents will be calculated with an Excel tool when feasible. If possible, the results will be provided in the number of avoided injury accidents, injuries and fatalities. If no sufficient statistical data is available concerning the accident types the ITS aims to prevent, the results will be based on more qualitative assessment of the safety effects made by experts. The impacts of ITS on mobility and comfort will be presented by a numerical percentage value for the change in mobility and comfort which will be estimated based on literature and expert estimates.

The outputs of the impact assessment will be translated into socioeconomic indicators via social cost-benefit analysis (CBA). The CBA method considers benefits in the field of safety, mobility (travel time and travel costs), comfort and environment. The relevant components related to the safety are: i) valuation of lost quality of life (loss of welfare due to crashes), ii) cost of loss of productive capacity (lost output), iii) cost of property damage, iv) medical costs and v) administrative costs. The most important factors, contributing also the most to the unit cost calculation of an accident, are the value of life per se and the value of productivity loss.

ITS have a mobility impact on VRUs by lowering their perceived generalised transport cost. They also have an impact on other road users, by altering VRU participation in traffic and in accident generation which both have an effect on traffic congestion levels. Thus, mobility-related impacts are distinguished
in direct and indirect; direct being the impacts of the ITS on vehicles and driving behaviour, resulting in different driving characteristics and ultimately number of trips and trip characteristics, producing time or other benefits for road users. Impacts on congestion levels due to reduction of accidents are also calculated and defined as indirect impacts.

The assessment and monetisation of comfort benefits for VRUs is a task that no previous research has dealt with. In the VRRUITS project this will be conducted by connecting comfort level with value of time. Finally, an estimation of the potential environmental benefits of ITS will be performed focusing on the impacts on CO₂ emissions due to a change in the overall modal shift and passenger-km carried out per mode.

The safety, mobility and comfort impact assessments will make use of the VRU categorisation that is consistent with the literature and with experts’ findings on the level of protection, fragility of VRUs and task competency. These facets are relevant for whether VRUs can use the ITS applications and the consequences of doing so. The categorisation differentiates the VRUs by mode of travel (pedestrian, cyclist, moped, and motorcycle) and age (7-12, 13-17, 18-64 and 65+).

Data quality and availability will determine how the quantitative impact assessment later in this project will be carried out. Task 2.5, Scenario Development, will collect this data. Task 2.5 is on-going as this deliverable is completed. Data on mobility and especially comfort is lacking. It appears that no European-wide data is available. Data at the country level for some countries may be available. In this case, quantitative analyses will be carried out for these countries. The quantitative safety impact assessment also must address issues with respect to underreporting.
8. REFERENCES


CARE (2009), EU roads accident database


D2.2 Assessment methodology


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Appendix A. VRU categorisation from a safety standpoint

A.1 Limited external protection

External protection in this context is the extent that road users are protected against accidents. For instance, pedestrians and cyclists are more vulnerable than drivers of trucks and cars because of limited or absent external protection. (Methorst, 2003) identifies several groups of VRU’s. A modified version of his classification\(^3\) is used here and is shown in Table A-1.

\begin{table}[h]
\centering
\begin{tabular}{|c|c|}
\hline
No. & Group \\
\hline
1 & Pedestrians \\
3 & Cyclists \\
4 & E-bikes \\
5 & Slower mopeds \\
6 & Faster mopeds \\
7 & Motorcyclists \\
\hline
\end{tabular}
\caption{VRUs categorized by external protection.}
\end{table}

Two groups need further discussion: e-bikes and mopeds.

\textit{E-bikes}

An electric bicycle known by the term e-bike, is a bicycle with an integrated electric motor which assists cyclists in providing power. (European union, 2002) defined e-bikes as "Cycles with pedal assistance which are equipped with an auxiliary electric motor having a maximum continuous rated power of 0.25 kW, of which the output is progressively reduced and finally cut off as the vehicle reaches a speed of 25 km/h or if the cyclist stops pedalling". Advantages of using e-bikes are no emissions, no noise very limited energy use, low cost use, avoids congestion, parking problems...etc. (Engelmoer, 2012).

Even though e-bike is beneficial in many aspects, it has some disadvantages with road safety. Elderly people using the e-bikes experience problems in controlling the bike, this is mainly due to the heavier weight of the bike and the less physical capability of the elderly people (Innovatie-support, 2010), these problems are common at stop and go situations, e.g. at a traffic light. Another contributing factor to their safety is the sharing of a lane by e-bikes and bicycles, as the average speed of an e-bike is higher than a bicycle; this speed difference could be a variable in traffic accidents.

As a result of failing strength and a deteriorating condition, e-bikes are common among elderly people, particularly for the age group 50+ (Roetynck, 2010). Other users of e-bikes are people who suffer from ailments such as asthma, rheumatism, arthritis, Multiple Sclerosis, lung diseases, heart diseases, muscle diseases and obesity, it is a lot easier for this group to use e-bikes since cycling can be quite difficult.

\footnote{We have removed the category special vehicles (like skates, autoped, wheelchair) because this group is heterogeneous (hence hard to handle) and for most vehicle types rather small. We have lumped pedestrians with walking aids with pedestrians; the subcategory of pedestrians with walking aids is to some extent covered by the task competency criterion below.}
**Mopeds**

Faster moped and slower-moped (just like motorcyclists) riders have relatively a higher risk of getting involved in an accident, which is primarily due to the higher speed of mopeds when riding over a cycle lane and the vulnerability of the rider. A study, commissioned by the Swedish National Road Administration (Schoon, 2004), looked out the safety aspects of mopeds and made a comparison throughout several European countries, this study is identifies the classification, use and regulations of mopeds in Europe. Two types of mopeds are identified, slower mopeds (also referred as lighter mopeds) where maximum vehicle speed is around 25 km/h and faster mopeds (also referred as mopeds) where a maximum vehicle speed is 45km/h.

In most countries, the minimum legal age for riding a moped differ strongly and depend on the type of moped, generally the legal driving age is lower than for regular motorcycles and cars. The legal ages, compulsory helmet use and speed limit for 15 countries are shown in Appendix E. In almost of the European countries helmet use is compulsory, the Netherlands is the only country without compulsory helmet use for the light-moped, however this may probably change.

In most EU countries, within the built-up area the light-mopeds must use the cycle lanes and the faster mopeds must use the roads, outside the built-up area, only in Belgium and the Netherlands it is not allowed for either type of moped to use the road if bicycle lanes are present. It should be noted that this study was made in 2004 and some countries may have different regulations after this period, for instance some cities in the Netherlands are trying to ban mopeds from the cycle path (DutchNews, 2014).

**A.2 Task competency**

According to the definition by (Wegman & Aarts, 2006), task competency/capability is the ability of performing one or more task aspects as a road user. Task competency differs between individuals (e.g. novice road users, elderly road users, disabled road users, fatigued ‘average’ road users or road users under the influence of alcohol or drugs and road users who are less skilful because of social or cultural circumstances. Methorst (2003) classified road users based on their competency into the groups shown in Table A-2.

<table>
<thead>
<tr>
<th>No</th>
<th>Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Preschool children</td>
</tr>
<tr>
<td>2</td>
<td>Elementary school (4–8 yrs old)</td>
</tr>
<tr>
<td>3</td>
<td>Elementary school (9–11 yrs)</td>
</tr>
<tr>
<td>4</td>
<td>Special schools</td>
</tr>
<tr>
<td>5</td>
<td>Secondary school</td>
</tr>
<tr>
<td>6</td>
<td>Young people 16–17 years</td>
</tr>
<tr>
<td>7</td>
<td>Young people 18–25 years</td>
</tr>
<tr>
<td>8</td>
<td>Handicap-lost function</td>
</tr>
<tr>
<td>9</td>
<td>Limited stamina</td>
</tr>
<tr>
<td>10</td>
<td>Limited perception</td>
</tr>
<tr>
<td>11</td>
<td>Mentally handicapped</td>
</tr>
<tr>
<td>12</td>
<td>Motor handicapped</td>
</tr>
<tr>
<td>13</td>
<td>Foreigners</td>
</tr>
<tr>
<td>14</td>
<td>Addicted/homeless</td>
</tr>
</tbody>
</table>
VRUITS will use a modified version of this classification, which is purely based on age. The reasoning behind the choice of age groups is presented in the “task competency” column. The categories are based on physiological (e.g., cognitive and physical abilities of children) and cultural differences (e.g., children going to school accompanied or alone) between age groups. The EU countries may have some cultural differences, but physiological factors will largely be the same in different countries. All in all, and in part to keep the analysis manageable, it is assumed that there will not be very big fluctuations among the EU countries.

The groups 8–12, corresponding to people with limited abilities, are not explicitly included in this classification to keep the number of groups limited. These groups have a large overlap with the group of elderly. Moreover, many of the people with these problems choose modes of travel which cause them minimum difficulty from the disorder, such as the car, a four-wheeled moped, a taxi or some form of transport for disabled people. Due to their heterogeneous nature the special schools group is not included in the modified version of the classification. The groups of foreigners and addicted/homeless are not included as they are assumed rather small and very heterogeneous. For instance, in the Netherlands addicts and homeless people represent less than 0.09% of the population.

Table A.3. Modified version of Task competency classification.

<table>
<thead>
<tr>
<th>No</th>
<th>Age</th>
<th>Education level</th>
<th>Task competency</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0–4</td>
<td>Preschool children</td>
<td>− Are almost always transported by an adult&lt;br&gt;− Attention is very selective and momentary&lt;br&gt;− Not able to estimate risks</td>
</tr>
<tr>
<td>2</td>
<td>4–8</td>
<td>Elementary school</td>
<td>− Knowledge of and insight into traffic still limited&lt;br&gt;− Peripheral perception and direction of sound still developing&lt;br&gt;− Typically supervised by an adult</td>
</tr>
<tr>
<td>3</td>
<td>9–11</td>
<td>Elementary school</td>
<td>− Knowledge of insight into traffic still limited&lt;br&gt;− Basic knowledge of rules, but not easy to handle rules&lt;br&gt;− May be walking or cycling without adult supervision</td>
</tr>
<tr>
<td>4</td>
<td>12–15</td>
<td>Secondary school, pre-moped age</td>
<td>− Not good knowledge of traffic rules-cycling speed and control increasing&lt;br&gt;− Typically not supervised by an adult</td>
</tr>
<tr>
<td>5</td>
<td>16–17</td>
<td>Secondary school, post-moped age</td>
<td>− lack of vehicle skill on moped&lt;br&gt;− Interferences with riding task (e.g. smartphone.)&lt;br&gt;− Not supervised by an adult</td>
</tr>
<tr>
<td>6</td>
<td>18–25</td>
<td>Young adult</td>
<td>− limited car driving skill&lt;br&gt;− Often looking at the wrong things</td>
</tr>
<tr>
<td>7</td>
<td>65+</td>
<td>Elderly</td>
<td>− visual acuity and hearing decline concentration,&lt;br&gt;− with increasing age need more time than actually given.</td>
</tr>
</tbody>
</table>

A.3 Fragility

With increasing age, people become more physically fragile, their bones become more brittle, broken bones and wounds take longer to heal, if they are involved in an accident, they are more likely to be injured and they take longer to recover, the extent of their injury is more likely to be severe. In addition, there are also disorders (diseases of the bones, muscles and blood) that can give people reduced stamina (resilience). Children fall into the fragile for their reduced muscle strength. Table A-4 shows the road user groups which are grouped as VRUs due to their fragility. As they are classified by age, they can be combined with the task competency groups from the previous section.
## Table A-4 VRUs categorized by fragility

<table>
<thead>
<tr>
<th></th>
<th>VRUs categorized by fragility</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Elderly</td>
</tr>
<tr>
<td>2</td>
<td>Children</td>
</tr>
</tbody>
</table>

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**Note:**

Elderly and Children are categorized based on their fragility from a safety standpoint.
Appendix B. Methodologies to assess safety impact

B.1 Safety mechanisms

This approach methods identifies factors contributing to a crash, and then employs direct or indirect methods to estimate the effect of an ITS on these factors. Simple approaches may consider factors such as exposure and severity, see e.g. (Joksch, 1972), or target population and effectiveness, as mentioned above. A more detailed subdivision of safety impacts of ITS is given by the so-called nine safety mechanisms (Draskóczy, 1998). These mechanisms are:

1. Direct in-car modification of the driving task,
2. Direct influence by roadside applications,
3. Indirect modification of user behaviour,
4. Indirect modification of non-user behaviour,
5. Modification of interaction between users and non-users,
6. Modification of road user exposure,
7. Modification of modal choice,
8. Modification of route choice,

The first five address accident probability and to some extent severity too, the next three address exposure and the final one addresses severity related to post-crash modifications (i.e. timeliness of the emergency service response to mitigate injury severity). The boundaries between the mechanisms are not sharply defined, and some safety aspects can be listed under several headings. For example, an application that mitigates crashes could have its effects listed under mechanism 1 or 9. However, this is not really problematic, because the purpose of this structure is not so much to define precisely the categories of safety effects, but rather to help the researcher to be complete in listing all potential effects.

This methodology requires the classification of various variables to calculate the overall safety modification factor. The variables are grouped into collision scenario variables (CSVs) and situational variables (SVs). European accident statistics are used to group the following CSVs and SVs.

Collision scenario variables (CSVs):

1. vehicle type host (passenger car/goods vehicles),
2. vehicle type target (passenger car/goods vehicles),
3. collision type (9 categories, defined in the accident statistics):
   4. collision on the road with pedestrian,
   5. collision on the road with all other obstacles,
   6. collision besides the road with pedestrian or obstacle or other single vehicle accidents,
   7. frontal collision,
   8. side-by-side collision,
   9. angle collision,
   10. rear collision,
   11. other accidents with two vehicles,
   12. All other collisions.

The type of target vehicle is important because it will impact both the detection rate and the severity of the consequences of a collision.

Situational variables (SVs):

1. road type (motorway/rural/urban),
2. weather conditions (normal/bad),
3. lighting conditions (light/dark),
4. Location (intersection/not intersection).

This means there are in total $3^1*2^2=24$ situations and 28 collision configurations\(^4\), for $24*28=672$ possible scenarios. Some of these may be unlikely or impossible (e.g. frontal collision on a motorway), but the total number remains large.

These mechanisms were used in eIMPACT and in PReVAL (Wilmink et al., 2008) (Scholliers et al., 2008). For a given ITS, safety modification factors were determined for each of the 9 mechanisms and an overall safety modification factor for the ITS was defined as the product of these 9 factors. Optionally, this calculation is done for each scenario separately, with scenario dependent safety modification factors. The overall safety modification factor is computed as the weighted average of these scenario dependent factors, where the weights are the frequencies of the scenario in accident statistics. Thus the weights can be determined if these frequencies can be retrieved from the accident database used.

This approach needs 672 (scenarios) * 9 (mechanisms) = 6 048 safety modification factors, which can be a daunting task to determine. Therefore, eIMPACT made the simplifying assumption that each CSV and SV influences the safety impact independently of all others. Hence, its influence can be represented by a modifier for each value of the CSV or SV and each mechanism, and the number of parameters to determine reduces to 9 safety modification factors for one “special” scenario (called the reference scenario), and 15 * 9 = 135 modifiers to cover all other scenarios, for a single function. Some further reduction may be possible, for example by taking the same modifiers for all mechanisms for all scenarios except the special one, which will reduce the number to 9 + 15 = 24 modifiers per function.

The assumption of independence has not been validated. External validation checks the assumption against data and is only possible with sufficient accident statistics with and without the application. Such data is rare (ESC is one of those rare examples), and often numerous circumstances have changed over the (long) deployment period of the application, which makes such data hard to interpret. Internal validation checks whether the assumption is justified by proven cause-effect relations, and also seems hard to accomplish. Face validation is the weakest form of validation and checks whether the assumption is reasonable in the light of general expectations on the model. While generally speaking it seems reasonable to assume that the CSVs and SVs modify risk independently, one can also easily imagine a function for which it is not true – for example, night vision (not present in interactIVe) may be very effective in the dark on rural roads, but hardly have any effects at all on other road types or when it is light. Thus, the assumption is hard to justify and is mostly made to ease the calculations.

Advantages of this method are:
- It can be systematically applied to functions not yet on the market,
- It is all encompassing,
- It covers both intended and unintended effects,
- It has limited data needs besides detailed accident data, It requires relatively little effort,
- It is transparent in the sense that it documents clearly what the breakdown of safety effects is.

Disadvantages of this method are:
- For most mechanisms it is not easy to obtain modifications factors. Those factors may come from various sources such as data, expert opinion and/or literature review,
- Treating all situations can be a time consuming,
- Validation is difficult for systems not yet on the market.

---

\(^4\) This number is slightly less than $2^2*9=36$ because in single-vehicle collisions there is no choice of target vehicle. There are 5 collision types with 2 vehicles and 4 types with 1 vehicle, leading to $2^2*5 + 2^1*4 = 28$ collision configurations.
B.2 Accident reconstruction

This approach reconstructs accidents based on the data logged in an in-depth accident database and then assesses what would have happened if a particular ITS had been present. The method has been used in the TRACE and the interactIVe project (Karabatsou et al., 2007) (Willemsen et al., 2011) and the study of Busch (2005). The method applied consists of a number of steps:

1. Reconstruction of the pre-crash phase based on accident data for each accident under consideration. The accident data is obtained from an in-depth accident database which typically contains data from the moment of the accident or later, but no data on the pre-crash phase. To assess the effectiveness of ITS, typically the pre-crash phase is important, and hence this phase is reconstructed until some starting time point a few seconds before the accident, based on the available data and using physical models of the movement of the vehicles. Data is obtained for accidents, where the ITS has not been not present. So, this reconstruction can be seen as a reference case.

2. Construction of a hypothetical alternative evolution in the presence of the ITS. This evolution originates from the situation at the starting time, but may follow another path than the reference case due to the actions of the ITS. This construction requires a model of the functioning of the ITS and its influence on the driver behaviour. It leads to a difference in the physical parameters of the accident (e.g. the collision speed change) between the alternative and the reference.

3. Transformation of the change in physical parameters to a change in physiological parameters, e.g. fatality risk. This yields the safety impact of the ITS on the accident under investigation.

4. Scaling up of the safety impact to the target population, e.g. the national level. This step has to account for deployment scenarios as well as the representativeness of the in-depth accident database.

Advantages of this method are:
- It will provide a highly detailed analysis of the safety effect of the ITS on real world accidents,
- Its case by case approach allows further inspection into the mechanisms by which an ITS prevents or mitigates crashes,
- It can be applied to functions which are not currently available in the market.

Disadvantages of this method are:
- The analysis requires access to detailed accident data, which may be non-existent or incomplete or non-representative,
- The reconstruction may be sensitive to model assumptions or inaccuracies in the data. In particular, assumptions need to be made regarding driver behaviour,
- The method analyses only the effect on accidents that have occurred, which is not the full effect of the ITS on driving behaviour. E.g. Some ITS may induce the driver to take more risks than he would have done without it. This is called risk compensation and it is neglected completely by this method,
- The method assumes that future accident scenarios will be similar to past accident scenarios (represented in the accident database),
- The analysis requires significant effort, as each accident from the database is treated individually,
- It requires specialized software tools,
- Validation is difficult.
B.3 Black box statistical analysis

The neural network based evaluation called “The black box” statistical analysis has been applied in the TRACE project. Neural network is designed to operate as a multilayer, feed-forward network, using the supervised mode of learning. Using this approach the potential effects with respect to reduction of accident consequences in given accident configurations can be calculated.

By means of a neural network a link between the input parameters (e.g. collision type, weather condition) and the output (severity level) is determined. Besides to the input and output layer, there is the hidden layer (Figure B-1).

This hidden layer consists of different neurons nodes, which contain the information on how input parameters affect output parameters. In order to determine this information, the neural network is trained with a dataset (in TRACE 70% of the recorded accident has been used). Afterwards, the rest of the data are used in order to test and validate neural network (Karabatsou et al., 2007).

Figure B-1: Neural network architecture used in TRACE (Pappas, Stanzel, Page, & al., 2008).

The approach is divided in the following eight basic steps:

1. Acquire knowledge for the safety functions of passenger cars to be evaluated,
2. Selection of the modelling parameters (parameters that affect the safety impact of the function),
3. Accident data collection according to the selected parameters,
4. Design neural network architecture for predicting the severity level of different accident configurations based on the available data,
5. Define the relevance of safety function to accident configurations,
6. Estimate the influence of a safety function on different accident parameters,
7. Using the neural network calculate the effectiveness of the safety function on the level of severity,
8. Estimate the effectiveness of the studied safety function based on the calculation of the injury severity mitigation (in percentage) (Pappas, Stanzel, Page, & al., 2008).

Advantages of this method are:
Assessment methodology

B.4 FOT data analysis

This approach uses FOT data to assess safety. The size of a FOT is too small to record significant numbers of (serious) accidents. Hence assessment methods use data on near accidents or risky events and translate that data into an estimate on safety.

One approach is the Event Based Approach, followed for example in (Dingus et al, 2006) (Sayer et al, 2010); it identifies events that are thought to be crash related, and then compares the frequency of these with and without the ITS. These events are thought to be potential precursors of a crash, but they occur much more often than crashes and can be identified from the FOT data. If one assumes that the ratio of the frequency of crashes is the same as the ratio of the frequency of these crash related events, then the safety impact of the ITS can be deduced.


The method assumes that it is possible to determine the incidence of crash related events in crash situations from an accident database. The method calculates the number of avoided crashes \( N_a \) as follows:

\[
N_a = N_{wo}(C) \cdot \sum_i P_{wo}(S_i | C) \cdot \left(1 - \frac{P_{w}(C | S_i) P_{wo}(S_i)}{P_{wo}(C | S_i) P_{wo}(S_i)}\right)
\]

Here the event of a crash is denoted by \( C \), and \( N_{wo}(C) \) is the number of applicable crashes without the application, which is obtained from an accident database. The crash related events are denoted by \( S_i \). The probability \( P_{wo}(S_i | C) \) is the fraction of crashes preceded by event \( S_i \) and has to be obtained from the accident database. The ratio \( P_{w}(S_i) / P_{wo}(S_i) \) is called the exposure ratio and is the frequency with which events occur with the system ("w") compared to without ("wo"). This can be measured from the FOT, using CAN and video data. The ratio \( P_{w}(C | S_i) / P_{wo}(C | S_i) \) is called the prevention ratio and measures the ability of the system to prevent crashes after a crash related event has occurred, relative to the case without the ITS. This ratio is determined using simulation of simple traffic scenarios.

The relation between the number of avoided crashes and the corresponding reduction in fatalities is obtained by estimating the severity of each conflict type, possibly depending on a further subdivision, for example by the impact speed of the crash.
Tarko (Tarko, 2011) has developed a similar method that calculates safety benefits in terms of avoided crashes using extreme value theory. It is based on measured data regarding conflicts of various types and on the assumption that the probability distribution of conflict severity is a Pareto distribution, including crashes as the most severe conflicts. By matching this distribution to the data one obtains the estimated number of crashes as a function of the measured number of conflicts of varying severity.

This method, therefore, produces an estimate of the number of expected crashes without use of an accident database, and in an absolute setting, that is, not as a comparison between “with” and “without” cases. It is event based although severity is taken into account, and it relies on the assumption that the severity parameter is Pareto distributed.

In the euroFOT project, detailed data is collected on the everyday driving of hundreds of normal drivers, with and without ITS. Two methods were used for assessing the safety impacts (Faber et al, 2011). The first method is the Event Based Approach, which is mostly applicable to applications that warn for dangerous situations.

The second method, Aggregated Based Approach, applies to applications that impact driving continuously in time, such as Adaptive Cruise Control. This method is a refinement of the NHTSA approach that associates a risk to every recorded data point of a trip, based on collected data on the state of the driver, the vehicle and its surroundings (van Noort, 2011). This removes the arbitrary distinction between risky and non-risky situations and replaces it by a smooth risk scale. The risk calculation itself is done with a simulation of simple traffic scenarios, while the exposure is calculated directly from the FOT data. Comparison of these risks between the cases with and without the ITS leads to an estimate of the safety impact of the ITS.

Advantages of this method are:
- It is based on data measured under natural conditions,
- It can capture both intended and unintended effects. In this sense it is not biased towards a certain assumption on the effect of the ITS, if the crash related events are setup correctly,
- It provides a statistically valid assessment if the FOT is set up correctly, that is, if drivers, traffic situations, etc. are representative.

Disadvantages of this method are:
- It relies on the assumption that there is a relation between crashes and crash related events,
- It requires FOT data,
- Validation is hard.

### B.5 Effectiveness methodology using a tree approach

The basis of the effectiveness methodology is a tree structure capturing all relevant accident conditions, see Figure B-2. The effectiveness methodology procedure is:

1. The relevant conditions are placed in the different levels of the tree,
2. Information from accident databases is used to fill the tree with casualty data. This shows under which condition the most injuries/fatalities were inflicted,
3. The extent to which the ITS measure will be effective for VRU protection are estimated and put in the tree. This could for example be represented by the percentage of VRUs that did not die or did not get injured as a result of the countermeasure,
4. By multiplying the numbers of step 2 with the percentages of step 3 the reduction of the number of fatalities or injured people is estimated.

Within step 1 (the specification of the branches), two intermediate processes are applied. Firstly it is determined how many trees are necessary. For example an individual tree could be generated for bicyclists and pedestrians. In step 2, the trees are branched for relevant conditions such as road type,
weather conditions VRU age and car deceleration, and the number of accidents, fatalities etc. is determined for each branch and leaf. Within these steps all individual characteristics can be applied that distinguish the functional group of VRU mentioned previously. Then the safety effect of the system is determined separately for each of the leaves, and subsequently aggregated to an overall safety impact.

The casualty data that represents the accident scenario information is often derived from in-depth accidents databases (i.e. the German In-Depth Accident Study (GIDAS) project) including vehicle and VRU velocities.

In step 3, the effectiveness of a measure is determined. It can be investigated by applying a variety of methodologies. For passive systems such as passenger friendly bonnets, data can be derived from kinetic impact tests. For active ITS applications for which it is more difficult to acquire real life test data (e.g. pedestrians detection systems), one may use expert judgment, or the proposed system algorithm, sensing models and driver behavior can be integrated in a simulation environment.

In step 4, all the information from step 1 to 3 is applied to estimate the effectiveness of an ITS. For example the research of Lindman et al. (2010) concluded that an Auto Brake function in all vehicles would lead to a decrease of around 24% in pedestrian fatalities for crashes where pedestrians were struck by the front of a car.

Advantages of this method are:
- It can be applied to functions not yet on the market,
- Assessing the safety impact of a safety function is straightforward once the accident database is mapped in a tree.

Disadvantages of this method are:
- Accident database is required which maybe incomplete or nonexistent,
- It doesn’t cover both intended and unintended effects,
- Validation is hard.

Figure B-2: Schematic representation of the effectiveness approach
Appendix C. Some examples of case studies assessing the effects of ITS countermeasures

Gårder et al. (2013) outlines different methods for how the safety can be assessed for a countermeasure that still does not exist, such as is often the case when assessing Intelligent Transportation Systems (ITS). The target of ITS devices is often to aid the road user in becoming aware of an upcoming hazard. Therefore, the theory of awareness of risk is outlined, and then an approach to calculate the effect of an ITS measure is discussed based on an estimate of the effect of different subcomponents of the system’s functionality.

A case study of the effect of backup warning systems is also presented. This system was developed primarily to aid drivers when parallel parking, but it can also be used to detect pedestrians, playing children, and other objects behind a car. Some drivers have used such backup warning systems for over a decade whereas many drivers still have never driven a car with such an aid. Renowned traffic safety experts in Europe, Israel and North America as well as Finnish taxi drivers (experienced drivers having used such a system) and engineering students at Aalto University in Espoo, Finland, were asked to directly and indirectly using the step-by-step methodology assess the effectiveness on such a system in reducing backup crashes of different types. When using the step-by-step methodology, estimates were given of how reliable such a system would be, how likely drivers would be to perceive an alarm from the system, to comprehend what the danger was, to react in time and take the correct action.

The students were also asked to form groups and come up with new estimates after discussing the estimates in the first round.

The conclusion of this study is that three groups (experts, taxi drivers and students) on average came up with very similar safety estimates when basing the analysis on individual (personal) step by step estimates; that roughly 40 crashes would happen if all vehicles had backup warning systems rather than 100 without such a system. That is that the system would improve safety by about 60%. A second round estimates by the students was thought to possibly be a ‘better’ estimate than the first round estimates, and that may certainly be the case. However, the second round final estimates, using the step-by-step methodology, among the Aalto students is that the effect is, based on their average estimates, around an 80% improvement of safety.

One conclusion is that using direct assessment of the effect on safety leads to much smaller benefits than the step analysis according to the experts and a somewhat greater benefit according to the taxi drivers. Students had in their first round almost the same estimates when doing step-by-step assessment as direct assessments; in their second round, that uniformity was lost. One reason that step-by-step estimates and direct estimates may lead to different results is that adaptation and new behaviour may lead to new types of crashes occurring (possibly still with young children playing behind cars) and that the step-by-step methodology as used here did not include such effects. In other words, one should also consider market penetration rates as well as the risk that there are behavioural adaptations leading to other types of crashes when making assessments like these. If a more comprehensive approach like the one suggested by Kulmala (2010) our conclusion is the following these mechanisms are taken account of. Whether direct assessments or step-by-step assessments gets closer to the truth is impossible to say without knowing the truth, i.e. having access to extensive crash data from a system fully implemented. However, what we can say is that the step-by-step analysis came up with more similar results than the direct estimates did when we compare the averages for different groups surveyed. Because of less variance and more transparency, we recommend the step-by-step process based on individual (personal) estimates.

Leden et al. (2013) present the results of two expert questionnaires focusing on the potential safety and mobility benefits to child pedestrians of targeted types of Intelligent Transportation Systems (ITS).
Five different types of functional requests for children were identified based on previous work. The first expert questionnaire was structured to collect expert opinions on which ITS solutions or devices would be, and why, the most relevant ones to satisfy five different functional requests of child pedestrians. The five different functional request areas, or needs, of child pedestrians when assessing suitable ITS solutions or devices to improve children’s safety and mobility in urban traffic:

1. Environmental adaptation (using ITS to change driver behaviour to child pedestrian limitations)
2. Guidance (leading or navigating the pedestrians)
3. Danger alerts or information (about risks)
4. Confidence and security enhancements (to feel safe enough to leave home and walk)
5. Contact systems (to get in touch with others and/or being localized).

Based on the first questionnaire, fifteen problem areas were defined. In the second questionnaire, the experts ranked the fifteen areas, and prioritized related ITS services, according to their potential for developing ITS services beneficial to children. Information on about three dozen of road safety programs, guidelines and standards and about 150 measures addressing the issue of child pedestrian safety was provided.

Winkelbauer et al. (2012) prepared a comprehensive list of currently applied and potential PTW safety measures, also providing relevant information on each of the measures. "Measure" was generously interpreted and some of the items go beyond what is normally considered a "measure". Technical standards and legal provisions, research activities and methods are included just as well as road safety programs, visions and real hands-on measures like campaigns.

The "list of measures" was collected by two sources. On the one hand, 2BESAFE partners were asked for input and have delivered a total of 130 answered questionnaires describing measures, standards, guidelines and programs. On the other, numerous road safety programs were analysed and all measures proposed within these programs were added to the "List of Measures".

At a later stage, more detailed descriptions for all measures were collected and all measures were rated by expert judgment so that a type of evaluation of the measures was performed that could indicate each measure’s effectiveness taking into account several factors that contribute to a measure being successful.
## Appendix D. Example of a Function Description

This appendix presents the template for a function description needed for the impact assessment. It is partially filled in for the Intersection Safety function.

### Intersection Safety Extended

#### ITS DESCRIPTION PAPER

<table>
<thead>
<tr>
<th>I. GENERAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. VRU/s addressed:</td>
</tr>
<tr>
<td>2. System name:</td>
</tr>
</tbody>
</table>

#### II. DESIGN / INTENT OF THE SYSTEM

| 3. System Road User: | Vehicle and VRU |
| 4. Level of “warning”: (Informative/ advisory / warning / intervening) | Warning |

#### 5. Cooperation level: (e.g., stand-alone; I2ru; vru2v; etc); What components are necessary for the system? (in-vehicle, infrastructure)

- I2V; I2V and I2VRU

#### 6. Functional System Description (describe what the system does, where and how is it intended to operate? Describe interactions with vehicle, roadside or VRU-carried components. What is provided: information, warning? What is the reaction, and who reacts?)

Intersection Safety assists the driver and VRU in avoiding common mistakes which may lead to typical intersection accidents. It covers these functions: left and right turn assistance and vehicles arriving perpendicular to VRUs at intersections.

For left- and right-turning assistance, RSU detects the VRU, communicates this to the vehicle which is turning right or left into the path of the VRU. The vehicle driver is informed, gets a warning or the vehicle begins to brake, depending on the urgency of the situation. The roadside infrastructure also informs the VRU of a dangerous situation by e.g. flashing lights. And / or making a sound.

The second function identifies a dangerous situation in which the vehicle drives perpendicular to the path of the VRU. The RSU detects the VRU crossing the intersection. The RSU informs the vehicle about the presence of the VRU. The RSU also informs the VRU (via flashing lights/ sound) about the presence of the on-coming vehicle.

#### 7. Technical System Description (identify the major technical components needed for system operation, range / area that the function covers, technical limitations)

- **Detection**
  - of VRU by RSU, supplemented by in-vehicle system;
  - of vehicle by RSU and / or by communication of vehicle to RSU;

- **Actuation**
  - car: by-vehicle system;
  - VRU: by roadside infra (flashing lights / sound).

- **Issues**
  - RSU: can be a camera or radar
  - Synchronization of the RSU and vehicle

Where should the intelligence be? Safety-critical situation requires fast idenfication of dangerous situations:

- Path prediction of VRU
- Path prediction of vehicle
- Identification and seriousness of potential conflict

Communication: short range communication (IP/G5)

#### 8. Road user groups that the system affects (Specify the parties involved: who or what informs/ detects;
who or what is actively informed, who or what communicates; who are the intended beneficiaries of the system? Specify which road users are affected: vehicle drivers, PTWs, pedestrians, bicyclists, and the sub-groups regarding age; adults, children or elderly, and disabled persons)

9. Safety: Describe the type of accidents the system aims to prevent and / or the type of accident consequences the system aims to mitigate
Accident type:
Type of host vehicle (pedestrian, bicycle, car, truck motorcycle):
Type of target vehicle:

10. Comfort: Describe the type of mobility and / or comfort issues the system aims to address and / or the situations the system aims to mitigate

11. Circumstances in which the system works or is assumed to work or not work

<table>
<thead>
<tr>
<th>Lighting: dark/daylight/artificial light</th>
<th>Works</th>
<th>Does not work</th>
</tr>
</thead>
<tbody>
<tr>
<td>Road type: urban/rural/motorway</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Speed range</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weather: normal/adverse.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Road configuration: section/intersection</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Specific characteristics of the system user: age, disabilities, etc</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Specific characteristics of other involved parties</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

III. EFFECTS

12. Circumstances where system is expected to be most effective:
Choose list in #11

13. Expected effects on the behaviour of the involved road users

- Anticipated driver reactions; change in driver behaviour (direct and indirect effects; behavioural adaptation)
- Anticipated reactions of (other) VRU; change in (other) VRU behaviour (direct and indirect effects; behavioural adaptation)
- Interactions between the system and the user, interactions between the system and other applications
- Interactions between the users of the system
- Interactions between users and non-users of the system; change in non-user behaviour

14. Expected Safety Impacts (positive and negative, qualitative and quantitative):

- Number of fatalities
- Number of severe injuries
- Number of slight injuries
- Number of accidents

15. Expected Mobility and Comfort impacts (positive and negative, qualitative and quantitative):

Mobility:
- Number of journeys
- Length and duration of journeys
- Mode of travel
- Route choice
- Departure time/arrival time

Comfort:
- Workload related to travel
- Stress related to travel
- Uncertainty related to travel
- Travelling in adverse conditions (weather etc)
- Feeling of safety in relation to traffic

16. Potential adverse effects of system on Road users:

<table>
<thead>
<tr>
<th>IV. DEPLOYMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>17. Costs of the system components:</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>18. Challenges to deployment:</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>19. Development status: when will the system be on-market?</th>
</tr>
</thead>
<tbody>
<tr>
<td>☐ Now</td>
</tr>
<tr>
<td>☐ 2015</td>
</tr>
<tr>
<td>☐ 2020</td>
</tr>
<tr>
<td>☐ 2025</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>V. OTHER</th>
</tr>
</thead>
<tbody>
<tr>
<td>20. Additional information:</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>21. References</th>
</tr>
</thead>
<tbody>
<tr>
<td>21.a. Reference of function description (a project where the system is prototyped, or a commercially available product):</td>
</tr>
<tr>
<td>eIMPACT, D4</td>
</tr>
<tr>
<td>NHTSA: CICAS (<a href="http://www.its.dot.gov/cicas/">http://www.its.dot.gov/cicas/</a>)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>21.b. References of research dealing with the impact of the system:</th>
</tr>
</thead>
</table>

| 21. c. Contact information (of the person who filled in the template): |

Informative: a message that purely informs, such as an alternative route.

Advisory: a message that advises the traveller to do something, eg, drive at a certain speed

Warning: a message that indicates that a potentially dangerous may occur

Intervening: a system that actually takes action autonomously but temporarily, such as automatic braking.
### Appendix E. Mopeds Legislation data from different European countries

**Table E-5: Mopeds Legislation data from different European countries (Schoon, 2004)**

<table>
<thead>
<tr>
<th>Legislation countries for: LM: Light mopeds M: mopeds</th>
<th>Min. age</th>
<th>Compulsory test</th>
<th>Speed limit</th>
<th>Compulsory helmet use</th>
<th>Registration plates</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Theoretical</td>
<td>Practical</td>
<td>Within the built-up area</td>
<td>Outside the built-up area</td>
</tr>
<tr>
<td>Austria M</td>
<td>15</td>
<td>Yes</td>
<td>No</td>
<td>45</td>
<td>45</td>
</tr>
<tr>
<td>Belgium LM M</td>
<td>16</td>
<td>Yes</td>
<td>No</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>Denmark LM M</td>
<td>16</td>
<td>Yes</td>
<td>Yes</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>Finland M</td>
<td>15</td>
<td>No</td>
<td>No</td>
<td>45</td>
<td>45</td>
</tr>
<tr>
<td>France M</td>
<td>14</td>
<td>Yes (school test)</td>
<td>Yes (3 hours)</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>Germany LM M</td>
<td>15</td>
<td>Yes</td>
<td>No</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>Italy M</td>
<td>14</td>
<td>Yes</td>
<td>Yes</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Luxembourg M</td>
<td>16</td>
<td>Yes</td>
<td>Yes</td>
<td>30</td>
<td>40</td>
</tr>
<tr>
<td>Netherlands LM M</td>
<td>16</td>
<td>Yes</td>
<td>No</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>Norway M</td>
<td>16</td>
<td>No (intention to do it)</td>
<td>No</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>Portugal M</td>
<td>16</td>
<td>Yes</td>
<td>Yes</td>
<td>45</td>
<td>45</td>
</tr>
<tr>
<td>Spain M</td>
<td>14</td>
<td>Yes</td>
<td>No</td>
<td>45</td>
<td>45</td>
</tr>
<tr>
<td>Sweden LM M</td>
<td>15</td>
<td>No</td>
<td>Yes</td>
<td>25</td>
<td>25</td>
</tr>
</tbody>
</table>