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Table of contents

Revision and history chart .......................................................... iii
Table of contents ........................................................................... iii
Executive summary ......................................................................... 1
  1 Introduction ............................................................................... 2
  2 Assessment framework for socio-economic evaluation .............. 8
    2.1 General approach .................................................................. 8
    2.2 Methods for socio-economic impact assessment .................. 10
    2.3 Application of the methodology to the research needs of eIMPACT ........................................... 14
  3 Cost-benefit analysis as core element of the socio-economic evaluation methodology ........................................... 16
    3.1 General methodology of CBA ........................................... 16
    3.2 Information interfaces to other work packages .................. 30
      3.2.1 Functional descriptions of IVSS ................................. 31
      3.2.2 Market scenarios .................................................. 34
3.2.3 Impact assessment: safety ...........................................40
3.2.4 Impact assessment: traffic ...........................................43
3.3 Benefits of IVSS: Data framework for enabling European scale assessment .............................................49
  3.3.1 Traffic data ............................................................49
  3.3.2 Road safety data ......................................................63
3.4 Benefit of IVSS: Monetary evaluation of physical impacts ....69
  3.4.1 Monetary evaluation methods .......................................70
  3.4.2 Benefit categories/components .....................................71
3.5 Costs of IVSS .....................................................................91
  3.5.1 Assessment of costs and prices .....................................91
  3.5.2 Cost components and price derivation ............................92
  3.5.3 Determination of costs and prices ..................................95
3.6 Synthesis of CBA results: benefit-cost ratio and its interpretation ........................................................................98
4 Extension of methodological approach of CBA .........................101
  4.1 Analysis of wider economic impacts ..................................101
    4.1.1 Employment impacts .............................................101
    4.1.2 Income effects ......................................................102
    4.1.3 Effects on distribution of income .................................103
    4.1.4 Financial sustainability .............................................103
    4.1.5 Practicability and public acceptability .........................104
  4.2 Stakeholder analysis ....................................................106
    4.2.1 Conceptual basis .....................................................106
    4.2.2 Methods of stakeholder analysis .................................108
      4.2.2.1 Managerial investment appraisal ................................108
      4.2.2.2 Break even analysis ............................................109
      4.2.2.3 Financial analysis ..............................................111
      4.2.2.4 Input-Output-Analysis .......................................113
      4.2.2.5 Incidence analysis ..............................................117
5 Interpretation guideline for assessment results ......................123
6 Exemplary Calculation: ACC ..................................................127
References ................................................................................147
Annex 1 ..................................................................................155
Annex 2 ..................................................................................159
Annex 3  Glossary ....................................................................161
Executive summary

This deliverable provides the methodological framework for the socio-economic impact assessment of stand-alone and co-operative Intelligent Vehicle Safety Systems. It summarizes the work performed within the work packages 2100 (Evaluation Frame) and 2200 (Data collection and compilation for EU-25) of the eIMPACT project. This framework will guide all activities related to socio-economic impact assessment throughout the project. In particular, it will be applied to the cost-benefit analyses for a set of IVSS for the target years 2010 and 2020 in the EU-25, and to stakeholder analyses for selected systems.

The deliverable presents a comprehensive framework for socio-economic impact assessment which is based on the findings of the SEiSS study. The framework applies cost-benefit analysis as the most prominent economic assessment tool to prove the profitability of a measure on society level. Since relying on cost-benefit analysis will be not sufficient to safeguard the successful market deployment of IVSS, cost-benefit analysis is embedded in a wider framework. The overall society perspective will be complemented by stakeholder analyses for key interest groups (e.g. system users, OEMs and suppliers, insurance companies and public authorities).

The cost-benefit methodology is explained in detail, taking also into account the information interfaces to other work packages which deliver important input data for the cost-benefit assessment (e.g. safety impact, traffic impact). Furthermore, an overview is provided for the relevant data for performing an assessment on EU-25 level, describing the needs, the availability and the limits of the data. This section contains also the methodology for the cost assessment and the valuation rates for the benefit appraisal. Finally, the methodology is also exemplified by a case study.

The methodology of the stakeholder analyses makes use of managerial investment appraisal and break-even analysis in order to address the socio-economic impacts on users, OEMs, suppliers and insurance companies. Potential deployment support activities of public authorities will be analysed with respect to their budget incidence by means of financial analysis. Besides that, it is also explained how the wider economic impacts (production, income, employment) and the distributional incidence (which societal groups profit most from the technologies?) can be analysed.

The methodology makes also a proposal for the synthesis of the assessment results which lead to a decision path approach. The aim of this approach is to check analysis by analysis (starting from CBA and the user break-even analysis) whether there are constraints to a successful deployment of IVSS. With these results, the project provides valuable decision support to the eSafety groups and the Intelligent Car Initiative for the development of a future European IVSS roll-out strategy.
1 Introduction

Through an increase in road safety, more efficient traffic processes and a decrease in environmental intrusion, an eminent benefit for society can be expected because of IVSS. Such a positive benefit-cost-balance results from the first empirical studies about several systems which are conducted on a national or a regional level. On the EU-level, there is no such a socio-economic evaluation thus far. Such an evaluation is necessary in order to explore the potential of IVSS in a systematic way and if policy should encourage accelerated market penetration and deployment. Such a strategy of encouragement is the aim of the eSafety-program and the Intelligent Car Initiative of the European Commission.

Aim of the eIMPACT-project

The eIMPACT-project undertakes a comprehensive socio-economic impact assessment for selected (stand-alone and co-operative) IVSS-applications for EU-25. Thereby, different time horizons with different development perspectives are observed (2010, 2020). The scientific objectives and proposed approaches to meet them can be summarized as follows:

- Identification of most promising stand-alone and co-operative IVSS for full-scale impact assessment.
- Comprehensive market deployment analysis of IVSS.
- Assessment of IVSS safety impacts based on expert estimations and current accident figures.
- Assessment of IVSS traffic impacts based on microscopic traffic simulations.
- Development of policy options for facilitating market introduction of IVSS.
- Performing the cost-benefit analysis as core economic evaluation to judge different IVSS on a societal welfare basis.
- Extension and disaggregation of the cost-benefit analysis by the stakeholder perspective (system users and OEMs, insurance companies and the public) and wider economic assessment of IVSS (employment, income, distribution of income, financial sustainability).
- Overall economic evaluation by combination of results from cost-benefit analysis and stakeholder analysis with the aim of selecting IVSS-applications for accelerated deployment.

The eIMPACT-project is a follow up activity of the SEiSS-project (2005) which was subject to an exploratory study on the potential socio-economic impact of the introduction of IVSS. In this study, in which one partner of the eIMPACT-consortium has been involved, a methodological framework for the socio-economic assessment was worked out which demonstrates the workability of the approach and which was applied to several case studies of IVSS (eCall, lane depa-
ture warning, ACC). The eIMPACT-project is based methodologically on the SEiSS-study.

**Selected IVSS-applications**
Initially and in a first work step (D2), the IVSS-systems to be analysed for the eIMPACT-project were defined. All in all, twelve systems were chosen:

- Full Speed Range ACC
- Speed Alert Systems
- Emergency Braking
- Lane Keeping Support
- Lateral & rear monitoring, lane change aid and lateral collision warning (Lane Change Assistant)
- Intersection Safety
- Wireless Local Danger Warning
- Night Vision
- Collision Mitigation and Pre-Crash Protection of Road Users (Pre Crash Safety)
- eCall
- Driver Drowsiness Monitoring and Warning
- ESP/ESC

All twelve systems will undergo a cost-benefit analysis. For a reduced number of systems the CBA will be supplemented by stakeholder analyses. Potential candidates for that are ESP/ESC, Speed Alert Systems, and Wireless Local Danger Warning. A final decision on this matter will be provided before the stakeholder analyses will start.

With the socio-economic evaluation, it should be assured that only efficient IVSS are applied. The empirical measure of efficiency results from the decrease in traffic accidents, number of victims (i.e. fatalities and injured) from the improvement of the traffic flow and from the contribution to the wider economic benefits.

**Deliverable D3**
In D3, the methodological framework and the database for the eIMPACT-project are worked out. The steps in the socio-economic evaluation are explained, including the demonstration of the most important calculation steps, the linkage of derivatives and the concretization of the first results.

- First, a methodological framework is worked out for the evaluation. The methodological basis has already been established in the SEiSS-project. From this starting point, the methodology is developed further in order to meet the requirements of the eIMPACT project. Materially, the methodology covers the work steps safety
impact, traffic impact, cost-benefit analysis and stakeholder analysis.

- As a second element, the database is analysed. It is worked out which data is necessary for the socio-economic evaluation, which data sources are available for EU-25 and how their data quality has to be judged, where data is extracted from and which connections exist in the data structures of other EU-projects and from official statistics.

- In a third work step, first empirical figures are established. These are enhanced within eIMPACT and are completed with data material. In this respect, a first enrichment of the methodology with empirical data is already carried out here. That concerns especially data of traffic safety and of traffic flow. These show that the empirical requirements can be met. Partly, data still have provisional character, e.g. by only referring to one country.

- In another work step, the methodology and data is applied to a system. It tests the applicability and practicability of the methodology referring to a concrete IVSS. For instance, the cost-benefit analysis for an ACC-System is calculated. Therewith, every step of analysis is transferred into the ACC-example and the methodological capacity is checked. ACC was chosen because of information available on safety and traffic impacts. In addition, ACC is already available on the market so that comparable results are available. Market penetration rates are available and ACC has a good documentation. The example shows how calculation steps are constructed in the eIMPACT-project and which empirical results can be expected.

**Outline of the Deliverable**

Figure 1 provides the outline of the deliverable, divided into steps, on the following page:

- Initially, an assessment framework for the socio-economic evaluation is worked out (chapter 2). Hereby, the conceptual approach and the methods of impact assessment are explained. Different steps are shown in which the socio-economic evaluation runs. Hereby, it is stated that the methodology is based on the SEiSS-study.

- The core method of the evaluation is the cost-benefit analysis (chapter 3.1). It is a method of economic theory to clarify the macro-economic profitability of IVSS. The cost-benefit analysis makes use of the functions of IVSS, the market penetration ratios of IVSS and the impacts on safety and traffic (chapter 3.2).

- The benefits of IVSS depend on the avoidable accidents and the improvement of the traffic situation (chapter 3.3 and 3.4). To achieve this, the necessary data framework for EU-25 is worked out. These data have to be forecasted for 2010 and 2020. Regarding accident data, there is a cooperation between the EU-projects eIMPACT and TRACE in which TRACE should provide the data.
Interpretation Guidelines for Assessment Results

Cost-Benefit Analyses
Deliverable: Exemplary Calculation: ACC in Germany
eIMPACT-Study: Cost-Benefit Ratios for 12 IVSS-Systems
Sensitivity Analysis for Parameter Variations
Credibility of Results

Cost-Benefit Analyses
Wider Economic Impacts
Stakeholder Analysis

Employment
Income
Distribution of Income
Financial Sustainability
Practicability and Public Acceptability

Users
OEM and Manufactures
Insurance Companies
Public Authorities

Instruments:
Managerial Investment Appraisal
Break-Even-Analysis
Financial Analysis
Input-Output Analysis
Incidence Analysis

Figure 1: Workpackage Structure of Deliverable D3 (Own Figure)
• The costs of IVSS (production, equipment of infrastructure and operating and maintenance) are compared to the benefits. For the cost-benefit analysis, those costs have to be applied that express resource consumption for the manufacturing companies (chapter 3.5). The costs have to be distinguished from the market prices for the final users. The prices are included in the stakeholder analysis which investigates the impacts on users and OEM.

• The result of the benefit-cost-calculation illustrates a cost-benefit ratio where benefits are divided by costs (chapter 3.6). A cost-benefit ratio higher than 1 means that the system is macro-economically profitable. The cost-benefit ratio has to be interpreted in a way that every Euro invested in IVSS donates benefit amounting to the numerator. By means of cost-benefit ratios, those IVSS-actions can be chosen that lead to the highest benefit-cost-surplus. Through a sensitivity analysis, it can be checked to what extent the result “overbalances” if parameters are changed. If there is a low sensitivity, i.e. the results stay stable even if parameters are changed, the calculation gains credibility.

• An extension of the cost-benefit analysis takes place while wider economic impacts are added to the evaluation (chapter 4.1). Included are employment effects from the production of IVSS, increases in income for the employees, distributional and equity effects, affordability and financial sustainability effects and practicability and public acceptability effects. With regard to the wider economic impacts, a stepwise evaluation of IVSS is conducted. The economic core criterion is thereby the result of the cost-benefit analysis. The wider economic impacts complement the cost-benefit results by informing about further effects on the level of society. Since especially public authorities are interested in this information, these impacts are treated within the stakeholder analysis.

• For IVSS, there are several interested parties who have advantages and disadvantages from the systems and profit from that in a different way (chapter 4.2). Stakeholders include the system users, the manufacturers (OEMs and automotive companies), the insurance companies and the public authorities. The aim of the stakeholder analysis is to allocate benefits and costs of IVSS among the different interested parties. Therewith, it should make clear which specific impacts result from it for each stakeholder group. In this respect, the stakeholder analysis is a method of impact separation and disaggregation with which the economic impacts of IVSS can be allocated between the involved groups. The stakeholder analysis is an instrument of political communication. It is qualified to enhance the acceptance of IVSS among the affected groups. Therefore, it can stimulate the market penetration. The following methods are applied for the stakeholder analyses
  - managerial investment appraisal that tests the private-economic profitability for the OEM,
  - break-even analysis that detects the private benefits from the application of IVSS for the users,
  - financial analysis with which the financial revenue and expenditure flows resulting from IVSS and therewith the public budget impacts can be estimated,
- input-output-analysis that serves for the calculation of employment and income impacts from IVSS-application,

- incidence analysis with which the impacts on distribution of income are determined and furthermore the question of whether the “rich” or the “poor” profit more from IVSS is addressed.

The stakeholder analysis should be carried out within eIMPACT for selected examples of IVSS. Since stakeholder analysis requires economic in-depth data which is hardly available on EU-25 level, the geographical coverage has yet to be decided. As a contingency measure, the stakeholder analysis will be carried out for single countries. Together with the cost-benefit analysis, the stakeholder analysis constitutes the empirical basis for the evaluation and the choice of IVSS-applications.
2 Assessment framework for socio-economic evaluation

2.1 General approach

The final goal of the assessment methodology is to perform a socio-economic impact assessment of a set of Intelligent Vehicle Safety Systems (IVSS). Hence, a comprehensive standardised methodology is needed in order to come up with coherent results for the socio-economic impact of IVSS in pre-selected target years.

Generally, the evaluation process follows a multi-step procedure which can be explained in a simplified way as follows:

- The process starts with the IVSS market introduction.
- The use of the systems will influence road transport in terms of e.g. safety, efficiency and environmental friendliness. Besides that, there are also impacts beyond road transport to be considered, i.e. impacts on the general economy.
- In the next step, the impacts will be assessed in socio-economic terms (e.g. savings of accident costs, time costs).

The assessment scope is twofold: on society level and stakeholder level. The assessment on society level proves whether the use of a particular IVSS is profitable from the viewpoint of the society in general. The focus is on assessing whether the welfare of the society is improved or not, regardless of the fact who profits and who does not. The stakeholder analysis can overcome this shortcoming. It will do so by disaggregating the socio-economic impacts of IVSS to different groups which are key actors in the process of IVSS deployment.

Target years for the impact assessment are the years 2010 and 2020. The geographical scope refers to the EU-25. Moreover, the assessment itself has to be embedded in a realistic environment. Hence, comprehensive information is needed for the boundary conditions of the IVSS deployment:

- How is the system specified? Which functionalities does it have?
- How promising is the market perspective for the system?
- How is the general impact potential of the system against the background of traffic and safety performance in the EU-25?

This information has to be fully incorporated in the assessment process. It represents decisive information for the size of the socio-economic impact. It becomes also clear from Figure 2 that the information needs are substantial. The quality of input data and information is a crucial point for the success of the socio-economic impact assessment. Therefore, this deliverable deals to a considerable extent with information interfaces to other work packages (see chapter 3.2) as well as with data sources and content (see chapter 3.3).
Figure 2: General Approach of the Socio-Economic Impact Assessment (Own Figure)
2.2 Methods for socio-economic impact assessment

On the level of the overall society, the socio-economic impact assessment can make use of different methodological approaches. Depending on the goal dimensions (one goal / several goals) and the degree of impact appraisal, three methodological approaches can be broadly distinguished:

- Cost-benefit analysis (CBA),
- Cost-effectiveness analysis (CEA),
- Multi-criteria analysis (MCA).

Cost-benefit analysis

Cost-benefit analysis (CBA) represents the traditional and most prominent methodology for determining the worth, value and feasibility of a policy measure. CBA is based on welfare economics. Its benchmark is represented by the Kaldor-Hicks criterion: a policy measure is efficient when it makes some people better off without making other people worse off (This implies that winners can potentially compensate losers from their gain). In other words, the underlying question of CBA is whether it is profitable to the society to use productive resources (e.g. labour, capital) to achieve savings of resource consumption (e.g. savings of travel time, energy, casualties and environmental pollution). Both sides – the resource use (= costs) and the resource savings (= benefits) – are expressed in monetary terms and can be confronted to each other. This makes CBA a powerful tool for policy guidance since when the benefits exceed the costs (benefit-cost ratio > 1), it is evident that the policy measure is profitable from the society point of view. Using monetary values allows also a profitability ranking of different IVSS.

Obviously, cost-benefit analysis faces some limitations:

- The CBA framework does not take into account macro-economic impacts (e.g. productivity gains, growth and employment) and the distributional effects of IVSS.
- More generally, there is no room for stakeholder considerations in a pure CBA because it does not distinguish between who incurs the benefits and who bears the costs.
- A general problem of all assessment methods is that not all technology impacts are easily appraisable (e.g. level-of-service benefits, comfort benefits).
Figure 3: Methodological Approaches for Socio-Economic Impact Assessment (Own Figure)

Cost-effectiveness analysis

Cost-effectiveness analyses (CEA) aim at identifying the measure with the best goal achievement among different measures of equal costs. Alternatively, it will identify the measure with minimum costs which leads to a constant satisfying goal achievement. Hence, cost-effectiveness analysis is able to reflect multi-dimensional goals. The goal achievement is usually expressed by effectiveness indicators. These mostly physical indicators are often laid down in a specification sheet. In contrast to CBA, the different effectiveness indicators will not be transformed into monetary terms. This represents a substantial shortcoming of the cost-effectiveness analysis.

Multi-criteria analysis

Generally, multi-criteria analysis (MCA) aims at establishing preferences between options by referring to an explicit set of objectives. The objectives have to be identified by the decision making institution itself. Moreover, it is necessary that measurable criteria are defined to assess the extent to which objectives have been achieved. Scoring and weighting play also important roles within MCA.

With that, MCA techniques can be basically used for the identification of the most preferred option, a ranking of options, a selection of most promising options for further detailed assessment of a short-list or a distinction between acceptable and unacceptable options.

A crucial feature within MCA is the performance matrix (table of consequences). Each row stands for an option and each column describes the performance of the options against each criterion. The individual performance assessments are often numerical, but may also be expressed as ‘bullet point’ scores, or colour coding. The performance matrix may serve as the final product of the analysis within a basic form of MCA. Then, the decision makers are left with the task of assessing the extent to which their objectives are met by the entries in the matrix. Such intuitive processing of the data can be effective and fast. Otherwise, it may also lead to the use of unjustified assump-
tions, causing incorrect ranking of options. Hence, in an analytically more sophisticated MCA technique, the information in the base matrix is usually converted to consistent numerical values.

Scoring means that the expected consequences of each option have to be assigned to a numerical score which reflects the preference for each option under each criterion. Scoring scales which run from 0 to 100 are commonly used. In this case, 0 represents the least preferred option and 100 the most preferred option. The result is that the more preferred options have a higher score on the scale than less preferred options.

Weighting is assigned to each criterion of an option. The weight of a criterion expresses how important the criterion is. The weighting process can lead to the result that low scores of a criterion become more important if the weight for this criterion is higher than the weight of a criterion with a higher score. That means that with the weighting process compensatory effects are possible.

The main limitation of MCA is that the results of the weighting process give no indication whether an option adds more to welfare than it detracts. In contrast to CBA, there is no rationale, which leads to a final judgment that welfare is improved or not. Depending on the weighting scheme it may be the case that the best scoring option of the multi-criteria analysis is associated with a welfare loss. The MCA gives the decision maker the indication that an option is preferable within his assessment scheme, whereas it is not from an overall societal point of view.

Conclusion

Both appraisal methods, cost-benefit analysis and multi-criteria analysis, represent evaluation techniques which are appropriate for assessing the socio-economic impact of IVSS. Cost-effectiveness analysis is inferior to both methods since it stops on the level of effectiveness without subsequent appraisal and without aggregating the different effectiveness contributions of a measure.

Cost-benefit analysis is a widespread and standardized assessment method with clear assumptions and decision rules. Regarding the limitations of CBA, one might argue that MCA is already the more comprehensive approach than CBA because it incorporates the results of CBA. However, the CBA results will be blended with other effects (e.g. user comfort, spatial effects). The main problem is that these effects are amalgamated by a weighting scheme which depends at least on subjective judgment of the responsible decision makers. Hence, the limitations of CBA cannot be overcome by MCA in objective, trustworthy and reliable manner.

From an overall evaluation standpoint it can be concluded that CBA represents the preferable method for assessing IVSS. This refers to the undisputable methodological background of CBA. The absence of a weighting scheme leads to objective results. Moreover, the calculation procedure within CBA can be used for other evaluation methods in a wider assessment framework. Taking into account the limitations of CBA, the approach can be enlarged by evaluation procedures which are devoted to stakeholders such as users, OEMs and suppliers, insurance companies and public administrations. Such a frame-
work – traditional CBA and complementary analysis of e.g. productivity, employment and distribution – has been sometimes labelled as “twin approach” (Banister/Berechman 2003). This idea will be also applied here.
2.3 Application of the methodology to the research needs of eIMPACT

The assessment activities can be built on the sound methodological fundament which has been developed in the SEiSS study (Abele et al. 2005). This methodology refers mainly to cost-benefit analysis but it is not limited to it. Within SEiSS, core elements of a wider assessment framework, including stakeholder perspectives, have been outlined. This aspect has to be elaborated more comprehensively within the eIMPACT project. Moreover, it has to be accompanied by empirical assessment, at least for some of the twelve selected IVSS.

The stakeholder role becomes crucial for the success of IVSS deployment because of several factors:

- The costs for the investment in IVSS have to be borne by the users. In contrast, benefits apply on the level of the society, at least partially. Road safety can therefore be characterized as a merit good which is only insufficiently provided by purely market solutions.

- Some of the systems, especially the communication based systems, are characterized by the phenomenon of critical mass.

- The users represent the decisive group in the context of market penetration. Users have a different perspective on benefits and costs than the society. The stakeholder analysis has to consider this by analyzing the IVSS impacts also from a user perspective.

- Although the market introduction of IVSS offers business perspectives for OEMs and suppliers, there are also considerable risks. These risks are related to financial issues (payoff of high research and development costs, risk of callback campaigns) and legal constraints (e.g. product liability, tort liability).

- Insurance companies can potentially play an active role in the process of market introduction. Lowering insurance premiums can represent an incentive for users to buy IVSS. In this context, it has to be considered that insurances usually require ex-post proven reductions of accident frequencies and severities as a prerequisite for premium reductions. Hence, a hold up problem exists. It becomes clear that it is important to address insurance companies as a key stakeholder.

It is necessary to extend the assessment framework by incorporating assessment methods suitable for stakeholder analysis. The following figure provides an overview over the broader assessment framework. Besides the overall society perspective, the stakeholder concerns of public authorities will be also analysed in terms of wider economic impacts and distributional effects. The budget impacts of potential incentives provided for IVSS will be also assessed. Additionally, the role of system users, OEMs and suppliers as well as insurance companies will be investigated by break-even analyses.
Figure 4: Extended Framework for Socio-Economic Impact Assessment (Own Figure)
3 Cost-benefit analysis as core element of the socio-economic evaluation methodology

3.1 General methodology of CBA

Economic science provides several methodologies for assessing and quantifying the specific values of (potential) socio-economic impacts (see chapter 2.2). Besides the cost-effectiveness analysis (CEA), the cost-benefit analysis (CBA) is broadly-accepted as a sophisticated, objective evaluation instrument. In general, the CBA compares the potential economic benefits across a set of impacts with all relevant potential costs deriving from the implementation of a technology/measure. Since the CBA estimates benefits and costs in monetary terms by multiplying impact units by prices per unit, it can be used to assess the absolute efficiency of a technology/measure. Hence, the CBA aims at finding whether a proposed objective is economically efficient and how efficient it is. As a result of the analysis a quantitative relationship between benefits and costs is calculated. Although there are a number of indicators expressing the comparison between benefits and costs the most common is the benefit-cost-ratio (see chapter 3.6).

The economic CBA originates from welfare economics. The increase of the overall economic production potential is used as a standard for evaluating a technology/measure ("resource-oriented approach"). The costs of the regarded measure are confronted with this overall economic effect. The benefits are defined in terms of productive resources saved within an economy ("cost-savings approach"). Given this definition, the implementation and deployment of technologies/measures should demonstrate optimality, which at least means in economic terms allocative efficiency.

In theory, the principle of allocative efficiency is determined by the situation that by introducing any kind of technology/measure at least one individual is made better off and no individual is made worse off (Pareto optimum). Since the consequent application of this criterion is impractical due to the impossibility of identifying all winners and losers, a potential Pareto optimum – the Kaldor-Hicks criterion – is generally applied. This criterion considers a measure as acceptable if the amount by which some individuals gain is greater than the amount that others lose for suffering higher costs. Hence, it is important to reach a net-benefit which allows – in principle – losers to be compensated by winners of the measure. No actual cash transfer is required. A measure may therefore be considered efficient even if some individuals lose, as long it generates net benefits (Boardman et al, 1996, pp. 29-34). Consequently, social welfare may be enhanced by the redistribution of resources within society.

The Kaldor-Hicks criterion is commonly accepted and widely applied in welfare economics as well as in managerial economics. The criterion forms an underlying rationale for the cost-benefit analysis. However, it is supposed that the distribution of gains and losses to different individuals or groups is made transparent to the evaluator and to the political decision-maker. In this case the decision-maker could (at least theoretically) take the distributional effects of the measures...
evaluated into account, when making decisions about taxes, subsidies etc. and could compensate for the distributional effects of the individual measures. In the eIMPACT project, the issue of distributional effects are handled in a separate step – the distributional impact analysis.

In the assessment of economic efficiency of road safety technologies/measures the evaluation of accident savings plays an important role, because these technologies/measures specifically aim to reduce the number and severity of current accidents. Avoiding accidents and achieving mitigation represent the direct benefits of road safety technologies/measures. In addition, the benefits encompass other savings of resources used within an economy, which also have to be taken into account (see chapter 3.4.2). Relevant savings of resources in this context are changes in:

- time use,
- energy consumption (fuel),
- vehicle operating costs,
- greenhouse gas emissions (e.g. CO₂)
- emissions of various air pollutants (e.g. SOₓ, NOₓ, volatile organic compounds(VOCs)),

The costs of technologies/measures for road safety improvement comprise investment costs as well as operating and maintenance costs arising from the implementation of the technology/measure (see chapter 3.5.2).

---

**Figure 5:** Methodological Steps of CBA (Own Figure)
The evaluation instrument of the CBA is based on a well-defined **methodological process** for assessing the potential benefits and costs of safety technologies/measures for society. Figure 5 illustrates the basic evaluation steps for performing a full CBA. Within each step of the calculation procedure the figure distinguishes between the general task of the process step and the specific task in evaluating the implementation of IVSS.

In general the CBA consists of a four step process. These four **basic steps** can be characterized as follows:

- In the **first step** of the procedure the relevant alternatives that will be compared within the analysis have to be defined. For the CBA two cases are introduced:
  - The “with-case”, which means that a road safety technology/measure like IVSS will be introduced
  - The “without-case”, which assumes that there will be no implementation of the technology/measure to be evaluated

- The traffic impacts of the technology/measure determine, if the implementation leads to overall benefits or not, because the traffic effects determine how the economic factor resources of traffic are affected. Therefore, within the **second step** of the calculation process, the potential impacts of each case (without-case, with-case) have to be quantified. The following figure gives an overview over the overall impacts of safety technologies/measures on economic costs in case of IVSS.

---

**Figure 6: Impact Model of IVSS (Own Figure)**

Conceptually, the main effect of road safety technologies/measures is the reduction of hazardous situations which affects the number and/or the severity of accidents. As a consequence, accident costs can be lowered. Additionally, the effects of
each case on other traffic and safety indicators such as traffic flow and vehicle speed must be considered. Avoiding accidents is for example related to additional traffic effects, because the number of congestions due to accidents can also be lowered. Avoiding congestions then reduces time- and vehicle operating costs as well as emission cost for greenhouse gases, various air pollutants and noise. These effects depend on the concrete technical system characteristics.

For assessing the socio-economic impacts the direct and indirect effects on road safety as well as the non-safety impacts have to be addressed. As “side effects” the non-safety impacts may play a considerable role with respect to the overall economic benefits of IVSS:

- Substantial speed differences between vehicles in the road network cause frequent lane changes and overtaking manoeuvres. IVSS might lead to a reduction of the speed variances or variances in headways, so that the homogeneity of traffic flow is improved. This homogenization would mean that the number of congestions caused by unsteady driving could be avoided. In addition, the reduction of accidents lead to a higher homogeneity of traffic flow.

- More homogenous traffic flows improve the efficiency of the road network, i.e. more vehicles under given traffic conditions can pass through defined network compared to the without-case. Therefore an increase of the vehicle throughput on the road section is achieved leading to a higher road capacity.

- In road freight transport, the implementation of IVSS traffic can lead to improvements in transport organisation and possible cost savings for the transport industry. For example fleet management and route choice of transport industry could be affected, which can lead to modified volume of vehicle-kilometres. By decreasing of vehicle-kilometres, cost savings can be realized. Increasing vehicle-kilometres has a reverse effect.

- By influencing the individual driving behaviour of road users, IVSS might lead to lower fuel consumption. Lower consumption enables road users to reach direct cost savings and additionally reduces the emission costs of greenhouse gases and various air pollutants.

A specific characteristic of the CBA is that the technology/measure evaluated normally unfolds its traffic effects not in a direct way, but indirectly over the change of traffic parameters (e.g. vehicle-speed, vehicle distance, time to collision, number of accidents, fuel consumption) as intermediate variables. The parameters have a direct impact on the factor resources. However, each resource being affected by traffic processes has a different functional relation to the traffic parameters. Hence, the changes of traffic parameters caused by the implementation of a technology/measure affect differently the components of traffic amount (time, energy, accidents, and environment). The impact direction can be increasing or decreasing, there is even the possibility of an unchanged situation. Therefore the physical dimensions of the traffic impacts in terms of traffic parameter changes have to be
accurately examined for the with-case. The difference between
the values of each parameter between the without- and the with-
case is the benefit of the technology/measure in terms of physical
effects. This calculation of differences has to be done for every
year of the effectiveness or life-cycle of the technology/measure.

- The various traffic parameters are measured in different quantity
  units. Therefore, the parameters have to be transformed in mone-
tary units. Within the third step of the CBA process, the benefits
are calculated in monetary terms by valuing the annual physical
effects with standardized cost-unit rates. The annual benefits over
the effectiveness or life cycle of the technology/measure will be
summed up and then the total sum of benefits will be transformed
by the discount rate to one actual value of social benefit for the
starting date of the implementation. In addition to the monetariza-
tion of the physical benefits, the costs of the technology/measure
have to be determined. The costs comprise the costs to be borne
for implementation, operation and maintenance.

- The result of the economic evaluation is obtained in the fourth
  step by comparing economic benefits with costs. For this com-
parison several measures can be calculated. The most common
one is the benefit-cost-ratio according to which a technol-
ogy/measure is macro-economically profitable, if the calculated
ratio is greater than one. Another criterion widely used is the cost-
benefit difference which is defined as the difference between the
monetized benefits and the costs required to realize the measure
(see chapter 3.6).

In order to assess the socio-economic impacts of IVSS, a well-
defined set of input information and data has to be defined, com-
piled and analysed. The calculations within the CBA rely on four input
dimensions which are elaborated and provided in different work
packages (WP) within eIMPACT (Figure 7):

- All IVSS to be evaluated must be defined in a way that makes
  their safety and traffic functions clear. This is done in the techno-
logical specifications. The technology section provides a descrip-
tion and analysis of the systems considering possible interactions
between the systems and discusses their potential impact on road
safety by avoiding or mitigating accidents. Moreover, the impacts
on traffic flows are defined. Within the eIMPACT project the sys-
tem specifications are performed in WP 1100, whereas the safety
and traffic impact analysis is part of WP 3200 and 3300.

- Main input of all calculations is data which serves as a basis for
  statistical information and prediction. On the one hand, values for
various traffic (e.g. number of vehicle stock and newly-registered
vehicles, vehicle mileage) and accident parameters (e.g. numbers
of accidents, distribution of severity) have to be compiled and
analyzed. This is mainly the task of WP 2200. Moreover, general
accident statistics are provided by the Strep TRACE. On the other
hand, market data is necessary to illustrate the market penetra-
tion of IVSS. The market deployment and diffusion of IVSS is de-
determined by several factors (e.g. time and price of market intro-
duction, vehicle equipment rates, operating and maintenance
costs) which have to be taken into consideration. The responsibil-
ity for market data lies in the field of WP 3100 and WP 2300.
Besides technological specifications and data compilation, external parameters are considered in the CBA model. These parameters can be defined as values which could be used in scenarios, but which are not directly related to the IVSS. For example, the CBA calculations could be performed for several scenarios reverting to different fuel price forecasts which certainly will have an impact on the vehicle operating costs. The external parameters are elaborated in WP 2300.
value for the geographical and time focus of the analysis. On the other hand, data collection methods may be incomplete. If data or information is missing, assumptions or predictions can be made where comparable data is available.

As introduced before, the methodological approach of the CBA is based on four major steps. In addition, the input information and data essential for performing the socio-economic assessment of IVSS were introduced. The use of the input parameters can be shown in a detailed calculation process of the CBA of IVSS, i.e. showing at which step of the quantification which information or data is used as an input. For this overview a comprehensive, systematic step-by-step approach for a CBA is used. The total CBA-model consisting of 14 analytical steps is illustrated in figure 8 and described below.

Figure 8: Relevant Steps for CBA (Abele et al. 2005)
1 Technology and functions interaction matrix of IVSS
2 Assessment of function interaction
3 Collision probability for IVSS
4 Equipment rate for IVSS
5 Prediction for number of accidents for specific IVSS set-ups
6 Prediction for accident severity for specific IVSS set-ups
7 Calculation of accident costs
8 Prediction for congestions
9 Calculation of time costs
10 Calculation of vehicle operating costs
11 Calculation of emission costs
12 Aggregation of cost savings
13 IVSS-specific cost
14 Calculation of benefit-cost ratio

In the following the 14 steps of the CBA-calculation process are described in-depth step-by-step.

1 Technology and Functions Interaction Matrix (IVSS)
   The starting point for the CBA is a clear and common definition of the technologies and functions of the IVSS to be evaluated. In this context, IVSS is generally described as a technology that has a direct influence on safety. Therefore IVSS should be interpreted as functions. However, different functions may influence the same safety problem, making it necessary to define the areas of interaction comprehensively.

   The availability of technologies and functions of IVSS enables to predict market introduction from a technical point of view. Functions have to be described in parameters to define their effectiveness. Due to performance differences between systems from different OEMs or suppliers, the definitions have to be based on average parameters. In addition, it is assumed that a function keeps constant over time in its effectiveness but decreases in price. This assumption has to be reviewed after the interim results have been calculated.

2 Assessment of functions interaction
   The safety functions of IVSS may depend on each other or affect one another safety mechanism, effectiveness and accordingly safety impacts. These possible functions interactions have to be taken into consideration and analysed to ensure that there is no interference between the systems. The assessment of functions interaction is based on the time correlation approach for IVSS which reverts to the physics of accidents. This approach subdivides an accident into various time phases (Figure 9). The phases are:
• Prior to driving (planning and preparation of a trip),
• Driving (support of the driver by the vehicle in normal vehicle operation),
• Warning (the vehicle technology expects a dangerous situation, the driver is informed),
• Assistance (support of the driver by vehicle systems)
• Pre-crash (time directly before an unavoidable crash)
• Crash (with passive safety systems in operation)
• Post crash (after the crash)

Each above mentioned phase includes a different level of danger in terms of collision probability as well as a different support of the driver by a particular vehicle system.

Figure 9: Accident Phases and General IVSS Functions (PReVENT 2006)
As illustrated in above figure, IVSS perform in different phases of an accident. For the evaluation of IVSS, it is most important to eliminate any possible interactions between the different systems that could arise over time due to technological dependencies. Hence, separate evaluation results for each safety system are ensured. However, since technologically reasonable combinations of IVSS exist, a system bundle may also be assessed.
Collision Probability for IVSS

The performance of IVSS leads to an earlier warning information to the driver, better car stability, faster breaking or fewer driving faults. Hence, IVSS can be represented by time gains or contrary, time losses. In some cases it is rather difficult to correlate IVSS to time. This remains the case for ABS (ensuring steer ability while braking), ESP/ESC (preventing loss of traction through braking of specific wheels) and Safe (Adaptive) Speed (which limits the maximum speed to the physical limits of the vehicle combined with the specific road conditions). However, taking the physics of accidents into account, these overall time savings or losses will lead to a change in the number and severity of accidents related to the IVSS. Since each IVSS can moreover be related to different accident types (e.g. loss of control) correlation tables can be determined for different accident types and speeds for each safety system. These tables can be used to calculate the specific accident probability for each IVSS. Time gains achievable by the use of an IVSS will lead to a reduction in collision probability, no time savings translates into normal accident patterns. Such correlations should become the result of accident causation analyses providing a standardised basis for further calculation (refer to chapter 3.2.3).

Equipment rate for IVSS

The main goal of integrating the market perspective into the proposed model is to find a way of forecasting the penetration of IVSS within the vehicle fleet of the countries considered expressed as equipment rate. Within the socio-economic impact assessment the equipment rate has a threefold influence on the evaluation: The first is that vehicles which are equipped with IVSS as well as vehicles or other road users which are involved in crashes with those vehicles benefit from the advantages of the crash avoidance or crash mitigation effects of the IVSS. Therefore, only those vehicles which are equipped with IVSS influence the overall socio-economic impact. Secondly, some IVSS may need a certain equipment rate to fully exploit their potential benefits. For instance, co-operative systems need a minimum number of equipped cars for the technology to function correctly ("critical mass"). Thirdly, market penetration determines the total costs of IVSS which are confronted with the benefits generated. Thus, in total, a thorough analysis and estimation of the penetration of IVSS within the vehicle fleet is performed.

Prediction of numbers of accidents

Using the collision probability of an IVSS and its market penetration rate, and taking into account the vehicles’ driven mileage mostly available based on age of the vehicles, the corresponding number of accidents can be predicted. In this step the underlying collision probability developed in step 3 is linked to general accident data. The target figure is the number of accidents that can be avoided by using IVSS.
Prediction of accident severity

Besides the avoidance of accidents, IVSS largely influence accident severity for those accidents which are remaining. This assessment differentiates between fatalities and accidents with severely, slightly and uninjured persons. The more time for driver or vehicle reaction the IVSS provides, the lower the impact severity will be. Since the severity of an accident depends on the impact energy which directly corresponds to the impact speed, the time-related pattern used for step 3 can also be used to calculate the accident severity. In addition, the vehicle's energy absorption potential which is determined by the passive safety system installed adds to the accident severity. The absorption potential can be translated into additional time for the specific accident type resulting in accident mitigation. Analogous to the prediction of the collision probability, collision severity figures can be determined by accident causation analysis. These can be used to predict each IVSS’ potential for accident mitigation.

Calculation of Accident Costs

The calculation of accident costs combines the two IVSS impact dimensions of predicted number of accidents avoided (step 5) and the accident severity mitigation for the remaining accidents (step 6). Both impacts reduce casualties and – when translated into monetary units – accident costs due to a reduction of human and real capital damage caused. The direct accident costs associated with IVSS have to be calculated twice to reflect both the accident situation without using IVSS (“without”-case) and the situation when a specific IVSS is used in road traffic (“with”-case). In this context one has to bear in mind, that some IVSS are already introduced into the market (e.g. ESC). Although these systems feature a rather low market penetration nowadays (2006), their safety impacts and therefore their socio-economic benefits become effective. Consequently, the benefits which can be calculated for future years of evaluation by comparing the “with”- and “without”-case may include benefits proportionately effective already in 2006. In these cases, a correction of the future benefits has to be performed by subtracting the benefits that are already realised due to (low) market penetration in the year 2006. As a result, a “net benefit” can be derived which is the actual socio-economic benefits generated by the use of an IVSS in road traffic (“with”-case). This issue is addressed in Figure 10.

The comparison of accident costs between the “with”- and “without”-case gives the cost savings which are regarded as safety benefits in terms of resources saved within the society. These safety benefits become part of the aggregated benefits summarized in step 12. The accident costs are calculated using standardized and broadly-accepted cost unit rates for fatalities, severe and slight injuries.
Estimation of Congestion

The market deployment of IVSS results in a reduction of road congestion. Generally, there are two ways in which congestion may be reduced by safety systems:

1. Some IVSS, especially those which have an impact on longitudinal control of the vehicle, may reduce variations in acceleration. As a consequence, the traffic flow will be smoother and more homogenous. On the other hand, there could also be a negative effect on acceleration. The non-safety effect on congestion is due to changes in the traffic flow. In case of a high market penetration, IVSS could therefore contribute to measurable capacity changes in road infrastructure. The capacity effect influences congestion caused by high traffic volumes.

2. IVSS can contribute to an overall reduction in congestion due to the avoidance of accidents. Usually, road accidents impede the flow of traffic until rescue services have provided first aid to the accident victims and the police have documented the incident. This congestion caused by the accident is avoided resulting in savings of economic resources. Moreover, some IVSS influence accident severity or improve the efficiency of the rescue chain (e.g. eCall) so that the accident site can be cleared more quickly. This effect lowers the duration of the congestion.

In total, the IVSS induced avoidance of accidents and accident mitigation lead to a reduction of congestion as a side effect of safety improvements. This impact on road congestion has to be simulated within the socio-economic assessment.

Calculation of Time Costs

The reduction of road congestion due to the capacity effect of IVSS, which has been simulated in the previous step, results in a higher average speed on the road section affected. Consequently, an increased road capacity reduces both passenger and goods transport...
travel times. In most cases, time savings comprise a substantial part of the total economic benefit. Time savings are appraised with the opportunity costs of using one hour travel time alternatively, e.g. being productive. As with the assessment of accident costs, time costs calculations are based on two situations (with/without IVSS) which must be compared.

10 Calculation of Vehicle Operating Costs
In addition to time costs, vehicle operating costs are affected when the capacity effect influences the level of congestion. Vehicle operating costs comprise the fuel consumption of the vehicles on the one hand and a fixed cost term which reflects speed-invariant cost components (such as lubricant or tyre wear) on the other hand. Usually, IVSS only influence the fuel consumption component. Since fuel consumption functions \( FC = f(v) \) are usually U-shaped, the impact direction depends on the speed level. Therefore, the effect is not always positive, but it will be compensated for in most cases by smoother traffic flow due to lower variances in acceleration. A more homogenous traffic flow offers potential for fuel consumption reduction which result in lower vehicle operating costs. These can be directly attributed to the IVSS users. The changes of vehicle operating costs are calculated comparing the with- and without IVSS-case and using standardised cost rates.

11 Calculation of Emission Costs
Besides savings in vehicle operating costs, the reduction of road congestion also results in decreased emission costs due to the direct correlation between speed level and fuel consumption. Emission costs comprise the two different cost elements of CO\(_2\)-emission and emissions of pollutants such as NO\(_x\), CO and HC. Whereas the CO\(_2\)-emission costs represent the impact of fuel consumption on the greenhouse effect, damages to the environment caused by pollutants are reflected in the emission costs for each pollutant analysed. By aggregating the emissions of each pollutant weighted by its toxicity to NO\(_x\)-units, the total effect of pollutants is quantified. The damages to the global climate (CO\(_2\)) and the environment (NO\(_x\)-units) are monetized by using recent cost unit rates. The monetized effects are calculated for the with- and the without-case.

12 Aggregation of Cost Savings
In the previous steps 7 and 9 to 11 the traffic-related impacts of IVSS have been analysed and converted to monetary units by using cost unit rates. For each impact (e.g. accidents, time use, emissions) the cost savings have been calculated for the "with"-case (using IVSS) in comparison with the "without"-case (without IVSS). In this step the single savings in accident costs, time costs, vehicle operating costs and emission costs (CO\(_2\) and pollutants) quantified for the "with"-case are aggregated to a total sum of cost savings. These aggregated cost savings represent the total benefit of IVSS. Usually, the benefits are calculated on an annual basis, i.e. this value is interpreted as the benefits of using IVSS for one year.
Costs of IVSS

Each IVSS evaluated is connected to costs for its implementation and use. The investment costs are the most important cost element. They comprise the costs deriving from the safety system implementation into a vehicle as well as from infrastructural equipment and adaptation costs which may be necessary for the functioning of the IVSS (in the case of vehicle-infrastructure co-operative systems). In addition to the investment costs, IVSS induce operating and maintenance costs which are mainly borne by the users. All costs related to the implementation and use of the IVSS have to be calculated and aggregated to a value of total costs. Since benefits are calculated on an annual basis, the costs must also be converted to annual values. For this, the service life and the depreciation rate for the IVSS have to be taken into account. Moreover, due to the resource-based view of the cost-benefit analysis, all cost elements of IVSS have to be accounted for without taxes (e.g. VAT).

Calculation of Benefit-Cost Ratio

In the final step, the benefits arising from the use of IVSS are compared with the costs associated with the safety systems. Although several measures of efficiency can be used in performing a CBA, benefits and costs are mainly compared using the benefit-cost ratio. The benefit-cost ratio divides the aggregated benefits from step 12 (numerator) by the total costs of IVSS from step 13 (denominator), both on an annual basis. The value of the ratio indicates whether the implementation of IVSS is favourable from a socio-economic point of view (see chapter 3.6).

Following the illustrated analytical steps of the CBA, an absolute estimate of the benefits and costs associated with IVSS is provided. Hence, the calculation process ensures an objective evaluation of the main socio-economic impacts of IVSS. However, the implementation of a CBA requires a much higher differentiation and more detailed analysis of specific issues. For instance, the benefit calculations have to be performed for three different speed patterns of IVSS operation covering urban, rural and highway traffic. Moreover, the approach described must be performed separately for cars and heavy goods vehicles, since their different market deployment, vehicle mileage, safety systems relevance, accident path and cost figures call for separate calculations. In the end, the (weighted) average of the resulting benefit-cost ratios for cars and heavy goods vehicles for urban, rural and highway traffic equals the total benefit-cost ratio for an IVSS. Furthermore, it is important to perform the evaluation for both best- and worst-case scenarios to provide a range of benefit-cost ratios for each IVSS.
3.2 Information interfaces to other work packages

This chapter explains the interfaces between the work package 2300 (Cost-Benefit-Analysis) and other work packages. To perform the CBA information is required about the components of each IVSS, its market penetration for the considered years, and its impact on the safety and the traffic. Chapter 3.2.1 covers the functional descriptions of the IVSS. This is information about the components, and the way the IVSS work. 3.2.2 is dealing with the market penetration for the years 2010 and 2020 for each IVSS. The safety impact of each IVSS is the topic of 3.2.3 whereas 3.2.4 covers the traffic impact of the IVSS. Figure 11 shows the information interfaces to other work packages.

![Figure 11: Interfaces to other Work Packages (Own Figure)](image)

Before we start with the functional descriptions the 12 IVSS will be shortly explained. The first group of IVSS are the assistant systems for longitudinal control. Full Speed Range Adaptive Cruise Control (FSR ACC) is a system which holds autonomously the right time gap to the vehicle in front. Speed Alert warns the driver when he is driving faster than allowed. Emergency Braking is preparing the car for a crash when the crash is inevitable. Another group of IVSS are the assistant systems for lateral control. Lane Keeping Support helps the driver to keep the lane while Lane Change Assistant helps the driver to change the lane. Another system is an assistant for intersections called Intersection Safety. WILLWARN is a system that warns other vehicles when there is an obstacle, congestion etc. on the road. Nightvision helps the driver to see better at night. Collision Mitigation and Pre-Crash Protection of Road Users is a system which is preparing the car for a crash with vulnerable road users, i.e. pedestrians and cyclists. eCALL is sending an emergency call after a crash occurred. Driver Drowsiness Monitoring & Warning is warning the driver when he is not fit enough to drive along. The last system is ESP/ESC, which helps the driver to keep his vehicle under control by avoiding skidding in critical situations.

In chapter 6 there are example calculations which show the theoretical approaches discussed in the chapters. ACC is chosen as example IVSS. ACC has a safety and a traffic impact. Because ACC is available on the market there are comparable results procurable. Market penetration rates are available and ACC has a good documentation. The impact of ACC is content of several studies.
FSR ACC – a considered IVSS of eIMPACT – is the further development of ACC. So the conventional ACC, which is not part of the considered eIMPACT IVSS, is a good example IVSS.

3.2.1 Functional descriptions of IVSS

Characteristics of the IVSS

In the eIMPACT project, work package 1000 is responsible for the system specifications. The socio-economic impact assessment contains twelve systems, which can be divided into different groups (Table 1). Very important for the CBA are the characteristics “cooperation level”, “traffic simulation required”, “2010 and/or 2020”, and the “type of roads considered”. The characteristic cooperation is important for the costs of the systems. For a system which communicates with the infrastructure, the required road equipment and the costs for the maintenance have to be considered. For systems with likely traffic flow impacts, these effects have to be assessed by traffic simulations. Besides that, eIMPACT focuses on the years 2010 and 2020. But for several systems there is only the year 2020 relevant since they are not introduced to the market in 2010. One other characteristic is the question which types of roads have to be considered. Here, motorways, rural and urban roads represent the relevant road types. The last characteristic is whether the system is relevant for cars and trucks or only for cars as it is with night vision.

<table>
<thead>
<tr>
<th>IVSS</th>
<th>cooperation level</th>
<th>traffic simulation</th>
<th>time horizon 2010</th>
<th>time horizon 2020</th>
<th>type of road considered</th>
</tr>
</thead>
<tbody>
<tr>
<td>FSR ACC</td>
<td>stand alone</td>
<td>possible</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Speed Alert</td>
<td>v2i</td>
<td>possible</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Emergency Braking</td>
<td>stand alone</td>
<td></td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Lane Keeping Support</td>
<td>stand alone</td>
<td></td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Lane Change Assistant</td>
<td>stand alone</td>
<td></td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Intersection Safety</td>
<td>stand alone + v2i</td>
<td>possible</td>
<td></td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Wireless Local Danger Warning</td>
<td>v2i</td>
<td>possible</td>
<td></td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Nightvision</td>
<td>stand alone</td>
<td>possible</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Pre Crash Safety</td>
<td>stand alone</td>
<td></td>
<td>x</td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>eCall</td>
<td>v2i</td>
<td></td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Driver Drowsiness Monitoring &amp; Warning</td>
<td>stand alone</td>
<td></td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>ESP/ESC</td>
<td>stand alone</td>
<td></td>
<td></td>
<td></td>
<td>x</td>
</tr>
</tbody>
</table>

Table 1: The IVSS and their Characteristics (Own Figure)
The IVSS in the Process of an Accident

Figure 12 shows the IVSS in the process of an accident. The systems which are listed under the green arrow work before an accident happens. These systems help to avoid a dangerous situation. The systems listed under the yellow arrow help to avoid a forthcoming accident. The system listed under the red arrow is a special one. It is working when an accident is happening. Collision Mitigation and Pre-Crash Protection of Road Users is such a system. It has a subsystem called Mutual Adaption which is an airbag under the engine bonnet. The purpose of this system is to have a steeper angle of collision by accidents where pedestrians are involved. So Collision Mitigation and Pre-Crash Protection of Road Users is a system which is listed under the yellow and under the red arrow. The last arrow is painted grey. There, the accident has happened, so in this category there are all IVSS listed which work after the crash. Here it is the IVSS eCALL, which is able to set an emergency call.

![Diagram](image)

<table>
<thead>
<tr>
<th>CRASH</th>
<th>time</th>
</tr>
</thead>
<tbody>
<tr>
<td>FSR ACC</td>
<td>Emergency Braking</td>
</tr>
<tr>
<td>Speed Alert</td>
<td>Pre Crash Safety</td>
</tr>
<tr>
<td>Night Vision</td>
<td></td>
</tr>
<tr>
<td>Wireless Local</td>
<td></td>
</tr>
<tr>
<td>Danger Warning</td>
<td></td>
</tr>
<tr>
<td>Driver Drowsiness</td>
<td></td>
</tr>
<tr>
<td>Monitoring &amp; Warning</td>
<td></td>
</tr>
<tr>
<td>Intersection Safety</td>
<td></td>
</tr>
<tr>
<td>Lane Keeping Support</td>
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<tr>
<td>Lane Change Assistant</td>
<td></td>
</tr>
<tr>
<td>ESP/ESC</td>
<td></td>
</tr>
</tbody>
</table>

Figure 12: The IVSS in a Time-Flow (Own Figure)

Costs and Benefits of the IVSS

Work package 1000 provides the system specifications which are the common basis for all work packages working with the IVSS. It gives information about the components of the IVSS. With that, the system specifications deliver important information for the costs and the benefits. The system costs and the costs for the required road equipment when necessary can be derived from the system description. In the CBA there are the net market prices of the IVSS taken and the net prices for the adopted infrastructure. The net prices are delivered by the system descriptions.

In order to determine the benefits, it is important to know how the IVSS is working. The functional description specifies where a system will be applied, on motorways, rural or urban roads. Furthermore, the functional description gives information about the potential safety impact, i.e. which accident types are influenced by the system. However, the size of the impact is analysed by another work package which delivers their result to the work package 2300. So there is another indirect interface. This interface will be explained in 3.2.3.
IVSS with Traffic Impact

All systems will have likely traffic impacts. There is less congestion due to avoided accidents. Furthermore some of the systems will exhibit significant impacts on traffic flow. So therefore, those five systems will be analysed in-depth by traffic simulations. The simulations will show to what extent savings of travel time, on the time costs, operating costs, and on the costs for CO₂ and other emissions will be attainable. The work package which does the traffic impact needs information from work package 1000, and afterwards it delivers the results to work package 2300. So there is another indirect interface, too. This interface will be explained in 3.2.4.

System Bundles

The starting point for the eIMPACT assessment is that all systems will be analysed as a stand-alone system. However, this assumption does not consider the sub-additivity of the functional interaction of systems and the sub-additivity of system costs.

- There is a considerable problem with the assessment of the IVSS depending on their system specification. So it is possible, that a system has as a stand alone version a negative cost-benefit result but in a bundle with other IVSS a high positive result. This may happen when the first system has a negative cost-benefit result, but the other systems out of the bundle can use parts of the hard- and or software of the first system. That means a cost reduction for the further systems. There is a triangular matrix in Annex 1, which contains cost synergies of bundles out of two IVSS. Consider the first system out of a special bundle is ESP/ESC. ESP/ESC is a sensor which recognized situations in which the vehicle tends to jerk. With that information ESP/ESC can avoid skidding in critical situations. Consider the second system in this bundle is FSR ACC. In this case, ESP/ESC is a part of FSR ACC, so every vehicle which is equipped with FSR ACC is equipped with ESP/ESC. The cost synergy between ESP/ESC and FSR ACC is one hundred percent. Another example is a bundle Night Vision and Lane Keeping Support. Night Vision contains a near infrared, an image processing, and depending to the manufacturer a head-up display. Both systems have a high component overlapping. Both systems need an image processing and a camera. So both systems in a bundle have high cost synergies. The market price for the bundle will be lower than the sum of the market prices for each system.

- For combining different IVSS new calculations about the impact are necessary. The effects and costs of the individual IVSS can not be summed in general. When there are no synergies, then the costs of the pair is the summation of the individual costs. When there are synergies, the combination is cheaper than the sum of the individual systems. This fact can lead to a change in the CBA for this system bundle. So for combining systems an assessment of dependencies has to be made in all effects – costs and benefits, safety and traffic – for all possible respective meaningful bundles of IVSS.

However, a full-scale assessment of combined effects is not possible at the current stage of the project because of limited data and impact...
information. The number of possible bundles is high. There are twelve possibilities to create a bundle which consists of one IVSS, 66 possibilities for a bundle with two IVSS, 165 possibilities for a bundle out of three IVSS and so on. Hence, the working assumption of eIMPACT considers all systems as independent and treats them as stand alone applications. In the further development of the project the grouping of IVSS to system bundles will be examined.

3.2.2 Market scenarios

Determinants of the market penetration of IVSS

The potential safety impact of an IVSS depends ultimately on its market penetration rate and whether it is accepted and actually used by drivers. Whereas the proper use of the systems is affected by behavioural adjustments of the vehicle drivers, which are included in the safety impact assessment, different parameters influence the market penetration rate. Former studies analysed important concerns regarding the deployment of Advanced Driver Assistance Systems (ADAS) and Automated Vehicle Guidance Systems (AVG). The STARDUST project identified the following issues with a significant impact on varying levels of use (STARDUST 2004: 16):

- Legislation (mandatory or not)
- Infrastructure investments
- Combination with other applications
- Robustness of the systems in different traffic situations
- Liability issues
- Market needs (user acceptance, training, long term effect, maintenance).

Due to these factors, several stakeholders are involved in the market deployment process. Three stakeholders represent the main driving forces behind the market introduction of an IVSS.

Foremost, the users decide whether to accept a new system or not. The acceptability of individual users and the resultant willingness to pay for such a new system is based on numerous factors as full user cost, driver comfort, driver safety, travel time duration, available income, age and preference for technology use (ADVISORS 2003: 58). Legislation and liability issues address the public authorities and administrations.

Taking into account the overall welfare of the society, the political influence is another very important force to stimulate the market penetration. The representatives of society must consider new deployment strategies and the impact of the new systems on public spending in the course of the introduction of these systems, environmental effects (emissions, noise etc.), overall safety, full social implementation cost, network efficiency and acceptability (ADVISORS 2003: 58). In order to intensify the diffusion of IVSS, national and supranational authorities can intervene using promotion of various research activities, information campaigns and user trainings to point out the individual benefits of IVSS, legislative measures to standardise the safety equipment of vehicles or financial incentives like tax reductions and
investment premiums (RESPONSE 2 2004: 60+61, Carrotta 2006: 7ff.).

Finally, the market deployment of new systems is substantially affected by the strategies of the original equipment manufacturers (OEMs). Given that the introduction of new technologies is firmly correlated to R&D activities for safety systems, the OEMs are the main driving force for the market introduction and deployment. Before producers decide to launch a new system, they are interested in innovation cost, sales volume, internal spill-over effects, profitability and company status (ADVISORS 2003: 58).

In consideration of all these parameters recent studies identified four different scenarios, which are determined either by the financial risk of the OEMs and the usability of ADAS systems (RESPONSE 2 2004: 49ff.) or by a combination of the financial market introduction risk and the safety impact of an IVSS (Abele et al. 2005: 54). According to the SEiSS approach, the financial risk depends on the business risk (return on investment [ROI]), the liability risk (risk emerging from dysfunction or improper use of IVSS) and the cost of probable recall campaigns. The safety impact includes both the individual safety effect following a higher or lower crash avoidance probability or crash effects mitigation and the potential safety benefits for the general public. Both components were integrated in the below-mentioned coordinate system.

Figure 13: Driving Forces behind Market Introduction Determine Probable Diffusion Curves (Abele et al. 2005)

A main driving force and differentiated diffusion curve were derived from the scenarios displayed in each quadrant (Abele et al. 2005: 54-58). The major difference between these alternatives is the speed of diffusion. The scenario shown in the lower right remains empty, because if almost no safety impact of a new system and a high risk for the OEMs exist, nobody is interested to boost such a system. Scenario I or II are characterised by a potential political influence. Given that the financial risk is high, the OEMs are not the driving forces for market introduction. By virtue of positive aggregate benefits resulting from the high safety impact, an intervention on the part of the public authorities is very likely. Taking into account the feasibility and cost,
politics might use legislative or financial measures to push the market penetration. Depending on the design of legislative measures (only newly-registered vehicles or whole vehicle stock equipped with the new system), the speed of diffusion varies. Both scenarios result in a relative quick market penetration, but an upgrading of old vehicles fails mostly because of compatibility problems. Therefore, the scenarios shown in the left quadrants illustrate more realistic market deployment processes. In Scenario IV the OEM is the driving force and introduces the new system, since the financial risk is low. Scenario III shows an additional high safety impact for the individual consumer. Shortly after a new systems’ introduction, multiple OEMs will equip their vehicles with this new technology, because of a high demand of the costumers.

The most probable way of the diffusion of new technologies seems to be the last scenario. Therefore, the market diffusion is illustrated in the next figures exemplary. This scenario can be described as “cascade of innovation”. As soon as a new technology is available and ready for market introduction, it will be introduced in the highest vehicle segment. Drivers of luxury cars have usually the highest willingness-to-pay for new systems and therefore appreciate the new functions. After it has been introduced in the highest vehicle segment, the new IVSS will be introduced in the high end class. In this case, every second year the market deployment will be extended to a lower vehicle segment. Following this “cascade of innovation”, the penetration of the full market of new vehicles takes 10 years.

Figure 14: Market Deployment Process “Cascade of Innovation” (Own Figure)
Figure 15 shows the exemplary curve for the above described "cascade of innovation" for a system that is introduced in 2005 in the market:

![Diagram](image)

**Figure 15: Diffusion Curve: “Cascade of Innovation” (Abele et al. 2005)**

Starting from 2005, the vehicle stock increases steadily (upper black line), while the share of old vehicles without the system decreases more and more till 2019 (white area under the lower black line). This "cascade of innovation" displays a very small market penetration (blue area) during the first years, but after offering the new technology as a basic function in lower vehicle segments and imitations by other OEMs, the diffusions' speed increases rapidly and the share of newly-registered vehicles without system (white area inside) declines, that from a certain point (2015) every newly-registered vehicle contains the new system (Abele et al. 2005: 57). Implementation strategies with higher public support or mandatory equipment of vehicles can increase the market penetration significantly.

**Identification of penetration rates**

The preceding considerations about the influencing factors and the diffusion speed models provide a basis for the calculation of the equipment rate. The differentiated market penetration rates will be calculated in the context of work package (WP) 3100. Within this WP three scenarios (present situation, 2010 and 2020) will be analysed. These scenarios require further country specific information for the following indicators:

- vehicle stock per year for the market segments cars, trucks and possible sub segments
- newly-registered vehicles per year divided into sub-segments (e.g. small cars, luxury cars, sports cars / heavy goods vehicle, light goods vehicle)
- average service-life of vehicles / vehicle fleet age distributions
- time of market introduction for each IVSS
- share of new vehicles coming to market containing the IVSS divided into factory installed and/or retrofitted
• price range / standard device or optional extra

By means of this data, which will be obtained via literature review of earlier and ongoing EU projects (ADVISORS, HUMANIST, ADASE II, SafetyNET, AIDE, PREVENT etc.), a small-scale survey of OEMs and an expert workshop organised within the eIMPACT project, reliable and accepted estimations of the future penetration rates of both new vehicles and the whole fleet/market will be delivered for different vehicle types. These will describe the market penetration in 2006/2010/2020 for two different cases:

- Lower case (business as usual),
- Higher case (e.g. implementation support).

The first case is based upon the assumption that diffusion speed relies only on the influence of the producers and the customers. This situation would correspond to the above illustrated diffusion curve “cascade of innovation” if the new IVSS was implemented in the market segments successively. In the second case, public authorities support the market deployment with tax incentives, enhanced consumer and dealer awareness programs, more efficient enforcement, legislative measures etc., which lead to a much higher market penetration rate in 2010/2020. Finally, the resulting market penetration rates could be classified into different levels. According to the eSafety Forum, a possible way to classify the penetration rates could be a five level scale (eSafety Forum Working Group Road Maps 2005: 13):

- Very high 80 up to 100 %
- High 50 up to 80 %
- Medium 20 up to 50 %
- Low 5 up to 20 %
- Very low 0 up to 5 %

Thus, each system will have two different rates in 2006/2010/2020, which will determine the lower and upper limit of the estimated range of probable market penetration rates.

![Exemplary IVSS - EU 25](image)

Figure 16: Classification of Market Penetration Rates (Own Figure, cf. eSafety Forum Working Group Road Maps 2005)
Figure 16 demonstrates the grading of the rates according to the eSafety Forum method for an exemplary IVSS with a very low rate in 2006 (2.5 %) and a rate ranging between 16 and 65 % in 2010 or rather between 30 and 95 % in 2020.

But it has to be taken into consideration that these vehicle equipment rates do not necessarily express the share of vehicle kilometres driven by vehicles equipped with an IVSS. Generally, the greatest benefits of such a system are gained by drivers with the highest vehicle mileage per year. Those drivers are more exposed to the risk of an accident and from there are more aware of the advantages of the new technologies. After all, they possess a higher willingness to pay for new IVSS than the average driver and therefore, they buy vehicles with a new system first. In addition, a correlation exists between a vehicle’s age and the driven vehicle mileage. New cars drive more kilometres per year than older ones (COWI 2005: 36). Assuming that, the performance of an IVSS on roads can be described schematically as a monotonous increasing function with regressive growth (solid line in Figure 17). In contrast, the dotted line shows a constant growth of the performance. This results from the presumption that a linear correlation exists between market penetration and vehicle mileage.

![Figure 17: Correlation between Market Diffusion and IVSS Performance (Abele et al. 2005)](image)

Based on the regressive growth, a market penetration rate of 10 % represents almost 19 % of the driven vehicle kilometres in this diagram. That would mean, even an apparent low fleet penetration could have a significant safety impact. The correlation between vehicle mileage and market diffusion will be specified (linear or regressive) based upon empirical data from several European countries. Ultimately, the results will be integrated in the estimation of the fleet penetration rates and/or ranges.
3.2.3 Impact assessment: safety

Trisection of safety aspects

One very important factor for the evaluation of the social benefits of a new IVSS is the safety potential of each system. The safety potential can be affected by many factors including system function, technology reliability, Human Machine Interface (HMI) issues, behavioural adjustments by the driver and traffic conditions. These safety implications have been classified into three aspects (Carsten/Nilsson 2001: 226-227; Jagtman/Marchau/Heijer 2001: 5):

1. Functional Safety Level:
   This level covers all safety problems concerning the hardware and software design of each system. Technical reliability, the propensity for system malfunction and the potential to go into a dangerous and/or unanticipated system mode are the main parameters.

2. Driver Safety Level:
   HMI, which focuses on interaction between the user and the safety system, can induce behavioural adjustments by the driver. Studies discovered that the driver’s workload is heavily influenced by the technological design (buttons, screen, information and warning mode etc.) of the IVSS, which can lead to an over- or underload of drivers. Eventually, a workload alteration can cause a behavioural adjustment by the driver, e.g. the driver is no longer involved in the main task of driving due to an underload.

3. Traffic Safety Level:
   This aspect summarises the implications resulting from problems regarding the first two levels and outlines the interdependency between system, driver and the traffic environment. The system and driver activities are closely linked to the road infrastructure and other road users, Drivers without the new system and vulnerable road users can be affected from equipped vehicles both in a positive and a negative way.

Figure 18 demonstrates how all three levels are connected to each other.

Figure 18: Three Level of Safety (Own Figure, cf. Carsten/Nilsson 2001)
**Determination of safety impacts**

In eIMPACT the analyses of the safety impacts are focused on the two aspects: driver safety (or more precisely behaviour) and traffic safety. This work will be done in the work package Safety Impacts (WP 3300) and supported by the work package Traffic Impacts (WP 3200).

In order to determine the effectiveness of the selected IVSS, nine safety mechanisms identified by Draskóczy, Carsten and Kulmala (1998, Kulmala 2006) will be analysed. These mechanisms are the following:

1. Direct in-car modification of the driving task  
   Information, advice and assistance or taking over part of the driving task is provided by the system. This may influence driver attention, mental load and decision about action (e.g. choice of speed)

2. Direct influence by roadside systems  
   Roadside systems provide mainly information and advice. Consequently, the impact is more limited than the impact of the in-vehicle system.

3. Indirect modifications of user  
   Behavioural adaptation of driver to changing situations does often not appear immediately after a change but may shows up later and is hard to predict. It can appear in different ways (change of usage of the car, change of expectation of the behaviour of other road users, change of headway in a car following).

4. Indirect modification of non-user behaviour  
   Non-equipped drivers may change their behaviour for example by imitating the behaviour of equipped drivers. This adaptation is even harder to predict.

5. Modification of interaction between users and non-users  
   Communication between equipped and non-equipped road users, especially vulnerable road users, will be influenced by different communication habits of only equipped users.

6. Modification of road user exposure  
   Systems can have a large impact for example by changing travel pattern, modal choice, route choice etc.

7. Modification of modal choice  
   Demand restrains (area access, restriction, road pricing, area parking strategies), supply control by modal interchange and other public transport measures, travel information systems have influence on modal choice.

8. Modification of route choice  
   Route guidance, demand restraints by diversions, dynamic route information systems etc. can have an influence on the accident risk of different parts of the road network.

9. Modification of accident consequences
Intelligent injury reducing systems in vehicles can lower the severity of an injury by reducing the crash impact or the rescue time.

This type of analyses leads to systematic analysis which covers all circumstance, vehicle types of accidents (Rämä, Kulmala, Schirokoff 2006). In the analysis the structure in accident data will be used as a starting point. The relevant impact mechanisms will be described in detail qualitatively. The quantitative estimation of the safety effects will be based on the aggregated and classified accident data.

For the analysis, the classification of accidents will be based on environmental and situation-based factors in the CARE database. The selected structure was preliminary chosen to be as follows:

A. Road class
   • motorway, rural road and urban road

B. Vehicle Type
   • car and truck

C. Collision type
   • animal, chain or rear, frontal, lateral, parked vehicle, pedestrian, single vehicle accident, single vehicle accident with obstacle, single vehicle accident no obstacle, other and unknown.

D. Road surface conditions
   • normal (dry) and bad weather (fog or mist, rain, snow)

E. Lighting conditions
   • dark and light

![Safety Impacts Diagram](image-url)

**Figure 19:** The Structure of Accident Data and Analysis (Rämä, Kulmala, Schirokoff 2006)
The quantitative safety effects of IVSS are to be given as percent changes for each combination of above mentioned classes (Figure 19). Finally, the estimates of safety impacts will be provided in terms of % changes (with ranges) in the number of fatalities and injured persons for different market penetration rates. This result will be used as an input in cost-benefit analysis.

Within the cooperation with TRACE, these results will be compared with the system effectiveness measures found out by TRACE on a joint workshop.

### 3.2.4 Impact assessment: traffic

IVSS can potentially influence traffic flow on roads. This is especially beneficial in situations where road capacity approaches its limits. Therefore the impact of IVSS on traffic flow has to be considered. The traffic flow is described by three indicators: velocity, traffic density, and traffic volume.

#### Traffic Flow

The velocity gives information about the duration of the journey. The interval bounds are normally given by law, for example a minimum and a maximum velocity on motorways. The velocity is usually measured in kilometres per hour [km/h]. Velocity is abbreviated with V. The maximum theoretical velocity on the road is considered \( V_{\text{max}} = 250 \text{ km/h} \) because of the volunteer self-restriction of the big car manufactures. Due to driving ability limits, this theoretical velocity cannot be handled by most of the drivers without support. The velocity influences the consumption of fuel, the costs of operation provoked by abrasion, and the emission volume (CO\(_2\) and other). So every driver can determine his costs to a certain degree by adapting his velocity. Because of individual time costs there are individual optimum velocities for each driver. When the driver has high individual time costs, he will accept higher costs produced by a higher velocity to minimize his time costs for the journey. This leads to an interval of desired velocities mostly within the legal velocity interval of the road. Because the driver is not the only driver on the road, its own behaviour is influenced by the behaviour of other drivers. So the drivers are interacting. When there is a road without the chance to overtake, the slowest car of a queue decides the velocity.

Another important figure for the traffic flow is the traffic density, abbreviated with K. The traffic density measures the number of vehicles that can be counted on a particular section of road. This figure is normally stated in vehicles per kilometre [veh/km]. Considering the share of lorries on the road is zero, and a vehicle has a length of 5 metres, and the distance to the vehicle in front is about 1 metre, the theoretical maximum of traffic density \( K \) is \( 1000 / (5+1) = 166 \text{ veh/km} \) (rounded).

The last relevant figure which describes the traffic flow is the traffic volume, abbreviated with Q. It expresses the number of vehicles passing a special point during an hour [veh/h].

With these three variables, the traffic flow can be described. When the traffic volume is low, the measured velocities can be very high or very slow. So it is very important to have information about two char-
acteristics. Are the traffic volume and the velocity low, the traffic is disturbed. The German EWS (FGSV 1997) defines congestion as a traffic situation with velocities below 10 km/h on motorways or below 5 km/h else. A high traffic volume and a high velocity show that the drivers have low interactions and can choose their velocity in a legal interval. The highest theoretical traffic volume is for a bunch of vehicles driving along with a minimum gap to the vehicle in front with a velocity of 250 km/h. This refers to the idea of automated highways. In this theoretical extreme case the share of lorries on the road is zero and all vehicles are able to drive 250 km/h. Considering a minimum legal headway of 1.8 seconds the minimum gap to the vehicle in front is $\frac{250 \text{ [km/h]}}{3.6 \text{ [km/s/m*h]} \times 1.8 \text{ [s]}} = 125 \text{ m}$ which is exactly the halve “tachometer” in metres. The length of a vehicle is 5 metres. So the traffic volume Q is $\frac{250 \text{ [km/h]}}{(125 + 5) \text{ [m/veh]}} = 1923 \text{ veh/h}$. Table 2 shows the ranges of the figures.

<table>
<thead>
<tr>
<th>Traffic figure</th>
<th>Abbreviation</th>
<th>Unit</th>
<th>Theoretical range</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>minimum</td>
<td>maximum</td>
</tr>
<tr>
<td>Velocity</td>
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</tr>
<tr>
<td>Traffic Volume</td>
<td>Q</td>
<td>veh/h*lane</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 2: Ranges of Traffic Figures (Own Calculations)

This example shows the theoretical limits for the velocity, traffic density and traffic volume. In reality these values are seldom measured. So the next calculation will draw a better picture of the reality. The assumptions are as follows: the share of lorries is 20 %. Each lorry has a length of 18 m and their driven velocity on average is 80 km/h. The passenger cars have a length of 5 m. There is no chance to overtake. The headway of each vehicle is 1.8 seconds. All vehicles are driving in a platoon. So the velocity on the road is 80 km/h, which means a distance to the vehicle in front of 40 m.

The length of a vehicle out of the described platoon is $20 \% \times 18 \text{ [m/veh]} + 80 \% \times 5 \text{ [m/veh]} = 7.6 \text{ m/veh}$. The traffic density K is $1000 \text{ [m/km]} / (7.6 + 40) \text{ [m/veh]} = 21 \text{ veh/km}$ at a driven velocity of 80 km/h and with an assumed distance of one metre at standstill 1 km / (7.6 + 1) [m/veh] = 116 veh/km (rounded). The linked traffic volume Q to the velocity of 80 km/h is $80 \text{ [km/h]} / (7.6 + 40) \text{ [m/veh]} = 1680 \text{ veh/h}$.

Connection between the Figures of the Traffic Flow

There is a connection between the velocity, the traffic density, and the traffic volume: $Q \text{ [veh/h]} = V \text{ [km/h]} \times K \text{ [veh/km]}$. This connection is displayed in graphs, so that there can be made a conclusion out of a known figure of that parameters to the other parameters. Such a theoretical graph is shown below (Figure 20).
In this theoretical graph there are two kinds of blue lines: continuous and dashed. The continuous blue line displays stable traffic situations. In stable situations the traffic is not disturbed. Consider there is no vehicle on the road. The first vehicle can choose its velocity. The traffic volume increases with every additional vehicle. Because there is more interaction between the vehicle drivers the average velocity decreases. The more vehicles are on the road the lower is the measured velocity. The drivers have to include the driving manoeuvres of other drivers as braking, changing the lane and so on. The traffic volume will increase till the maximum \( Q_{\text{max}} \) is reached. This point is the limit, the traffic volume equals the capacity of the road. The accordant traffic density is marked in Figure 20 with \( k \). So there is an optimal combination of velocity and traffic density where the traffic volume reaches its maximum.

**Condition of the Traffic Flow**

If the traffic volume is higher than \( Q_{\text{max}} \) the traffic is disturbed. In the graphs such situations are drawn with dashed blue lines. Driving is not safe anymore. The majority of the drivers do not keep the right distance to the vehicle in front. Single driving manoeuvres can lead to congestion. Distances which are too short, inattentive drivers or too hard braking manoeuvres are possibilities to affect congestion. So traffic volumes which are higher than the capacity are linked with lower velocities and lower realized traffic volumes.

A state of the art concept for analysing traffic performance is the “Level of Service” (LOS) concept, which divides the traffic situations into six categories (HCM 2000). The best category is marked with A. Here the vehicles have nearly no interactions. LOS D is the last category within the group of stable traffic. Increasing the traffic volume a little bit can lead to disturbed traffic situations. LOS E and F are used for instable traffic situations (the dashed lines in Figure 20). LOS E means a low velocity, lane changing manoeuvres are difficult. In-
Increasing the traffic volume a little bit can lead to congestion. LOS F describes congestion. Here short phases with very low velocities are alternating with congestion. The LOS categories are determined by the three variables traffic volume, traffic density, and velocity.

Germany uses a similar system (FGSV 2001) which is adapted to the German traffic condition (no speed limit). Germany is the only country within the EU 25 without speed limits so it makes sense to use the US LOS-system for Europe.

Benefits due to Traffic Impact

In a traffic forecast the traffic volume of a part of the infrastructure is determined. With this figure and knowledge of the kind of road (motorway, rural, urban, with speed limit, number of lanes) the other figures (velocity and traffic density) are associated and so can be determined. The fuel consumption and the emission exhaust are linked with the velocity (Figure 21), which is linked in turn to the traffic volume. If an IVSS has an impact on the linkage between velocity and traffic volume, a change in the fuel consumption and in the emission exhaust is possible. Thus, a feasible impact of the IVSS on the linkage between the traffic volume and the velocity is very important for calculating the benefits due to the change in the linkage. So this is another interface which has to be considered. The change in the linkage between velocity and traffic volume is linked again to the functional description of the IVSS and in turn has an impact on the CBA.

This impact may lead to time gains and to a change in the emission exhaust. Ideally the new traffic flow is harmonized, so that acceleration and deceleration processes can be reduced. This has a positive impact on the fuel consumption and on the ejected emissions. Figure 21 shows the linkage between the emissions and the velocity for a passenger car which is operated with petrol.

Figure 21: Linkage between Velocity and Emissions for a Personal Vehicle (Petrol) (Own Figure, cf. FGSV 1997)
Figure 21 contains four kinds of emissions: carbon oxide, hydrocarbon, nitrogen oxide, and sulphur dioxide. The last one listed in the figure, nitrogen oxide-equivalent is an artificial one which is introduced in the next clause. In absolute figures the output of carbon oxide is the highest. The curve shows that there is an optimal velocity which minimizes the carbon oxide output. The next highest output has the artificial emission nitrogen oxide-equivalent. Hydrocarbon and nitrogen oxide are changing their role as third highest emission. In phases of lower velocities the output of HC is higher than the output of nitrogen oxide. In phases with higher velocities HC remains on a low level while nitrogen oxide arises constantly. The lowest emission output has sulphide dioxide.

The artificial emission type was introduced to assess the emissions economically. The emission type with the highest absolute output is not necessarily the emission type with the highest effect on the environment. For example carbon oxide has the highest absolute output, but its toxicity per kilo is the lowest. 1 ton of carbon oxide is as toxic as 0.003 tons of nitrogen oxide-equivalent. So the nitrogen oxide-equivalent weighs the four emission types according to the toxicity. The weighing factors can be seen in Table 3. In Table 3 there is noted a fifth emission type – particles. Particles have to be included into nitrogen oxide-equivalent but they do not occur in engines powered with petrol. So this value is only relevant for diesel fuelled vehicles. Every emission type output is multiplied with its weighting factor and summed over all emission types. The result is the nitrogen oxide-equivalent. So its line is the most important one for assessing the environmental costs due to pollutants. The fuel consumption in dependence to the velocity is similar to the line for carbon oxide; the line for fuel consumption is U-shaped. Carbon dioxide is linked directly to the fuel consumption. The optimum velocity for a petrol passenger car is round about 60 km/h for the emissions and 70 km/h for fuel consumption and the output of CO2. The values for lorries which weighs more than 3.5 tons are between 60 and 70 km/h respectively round about 50 km/h.

<table>
<thead>
<tr>
<th>CO</th>
<th>HC</th>
<th>NOx</th>
<th>SO2</th>
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<tr>
<td>0.003</td>
<td>1.5</td>
<td>1</td>
<td>1</td>
<td>0.342</td>
</tr>
</tbody>
</table>

Table 3: Weighting Factors of the Emission Types (FGSV 1997)

Carbon dioxide is linked directly to the fuel consumption which is linked to the velocity. So it is possible to weigh the emission types nitrogen oxide-equivalent and carbon dioxide to calculate the optimal velocity with the lowest environmental effects. The weighing factors are the cost-unit rates (see also chapter 3.4.2). The optimal velocity ranges for passenger cars are between 60 and 70 km/h and for lorries with a legal weight over 3.5 tons between 50 and 60 km/h. So changes in the velocity in direction to the optimum velocity lead to a benefit and changes which lead in the opposite direction are producing higher costs.

Another result of harmonizing the traffic flow is a reduced possibility for congestion. This is in return very positive for time gains and the ejected emissions.
Traffic Impact of IVSS

The eIMPACT consortium has chosen five IVSS for traffic microsimulation modelling:

• Full Speed Range ACC,
• Intersection Safety,
• Night Vision,
• Speed Alert,
• Wireless Local Danger Warning.

For each of these systems it has to be specified, if the traffic flow will be affected, its direct impacts on the emission rate and its impact on congestion.

The work package 3200, which delivers the traffic impact, provides adjusted velocity - traffic volume - graphs for each of the five relevant IVSS. With these adjusted graphs it is possible to get an answer to the following questions by comparing the adjusted with the original graph:

• Are there harmonizing effects in the linkage between velocity and traffic volume?
• Will the IVSS reduce the number of congestion?
• Has the IVSS an impact on the ejected emissions?
• Has the IVSS an impact on time consumption?

For all the twelve systems the indirect traffic effects will be estimated. This involves estimating the reduction in congestion as a result of fewer or less severe accidents, which than can improve travel times.
3.3 Benefits of IVSS: Data framework for enabling European scale assessment

3.3.1 Traffic data

Objectives of the chapter

This chapter handles the relevant traffic data, which are necessary to conduct a cost-benefit estimation of the IVSS. The vehicle stock, the roadside equipment with a communication infrastructure, the vehicle mileage on the different road types, and the traffic condition on the roads are part of the relevant factors.

1. In eIMPACT twelve IVSS will be assessed. For calculating the costs of equipping the vehicle fleet with an IVSS, knowledge about the number of vehicles in the years 2010 and 2020 is necessary. So information is required about the vehicle stock for 2010 and 2020. Multiplying the vehicle stock with the penetration rate of the IVSS, the number of vehicles, which are equipped with the IVSS, can be calculated. These values can be multiplied with the average cost-unit rate to get the equipment costs of each IVSS for the years 2010 and 2020. For the first objective the vehicle stock for the years 2010 and 2020 is forecasted.

2. Some IVSS like Intersection Safety, Speed Alert, or eCall need special infrastructure equipment. These IVSS are communicating ones and therefore depend on information exchange with the road infrastructure. The communication between infrastructure and vehicles is done with the help of beacons. The beacons are able to communicate with the vehicles; they send information about the status of traffic lights or speed limits. Therefore the road equipment with beacons is important for these systems and costs have to be determined. The horizons for this issue are the years 2010 and 2020.

3. The third objective is to provide the traffic data for estimating the number of accidents, injuries and casualties for a situation without any IVSS penetration (without case). The accident rates are noted in accidents per million vehicle-kilometres. So the vehicle mileage for the years 2010 and 2020 is necessary for estimating the amount of accidents, injuries, and casualties in the without case (see also chapter 3.3.2). The risk of an accident on different road types varies (e.g. the risk of an accident on motorways is lower than on other road types). Thus, the knowledge of the distribution of driven vehicle kilometres on motorways, rural roads, and urban roads is important and data about this issue and the vehicle mileage will be gathered.

4. For calculating the traffic flow related benefits of the IVSS, statements about the traffic flow are essential. So for the assessment of FSR ACC requires information about the vehicle mileage and the distribution of the level of services. So with the knowledge about the effect of the IVSS on the traffic flow (changes in the linkage between traffic volume and velocity) and the distribution of the level of services, the benefits of the IVSS can be calculated. There are benefits from time gains through increased velocities, benefits from a reduction in fuel consumption due to a harmonized traffic flow, and benefits from avoided emissions due to
lower fuel consumption. This objective requires the determination of the level of services for the years 2010 and 2020.

For all objectives a literature review was done. For some categories the available data is not complete. In these cases, the missing data was estimated.

**Forecast of the vehicle stock for assessing the IVSS-costs**

The system costs of the IVSS depend on the average IVSS cost-unit rates and the total equipped vehicles. Therefore three kinds of information for the years 2010 and 2020 are required: the vehicle stock, the total penetration rate of each IVSS, and the average cost-unit rate for each IVSS.

Thus, the vehicle stock for the years 2010 and 2020 has to be estimated. Table 4 shows the vehicle stock for 2002 and 2010 based on ProgTrans European Transport Report 2004. The report includes data from all EU 25 member states. The figures for 2020 are calculated by using the growth rate given in the ProgTrans European Transport Report 2004; they will be updated by the figures from the ProgTrans European Transport Report 2006 when it is published. The total vehicle stock of the EU 25 countries increases by 23 % in the period from 2002 till 2020; the growth of the vehicle stock amounts to 20 % in the EU 15 member states and amounts to 49 % for the New 10 member states.

**Table 4: Vehicle Stock (mill. vehicles)**

<table>
<thead>
<tr>
<th>Year</th>
<th>2002</th>
<th>2010</th>
<th>2020</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passenger Transport</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total EU 15</td>
<td>190.6</td>
<td>211.1</td>
<td>227.9</td>
</tr>
<tr>
<td>Total New 10</td>
<td>22.2</td>
<td>27.8</td>
<td>33.7</td>
</tr>
<tr>
<td><strong>Total EU 25</strong></td>
<td><strong>212.8</strong></td>
<td><strong>238.9</strong></td>
<td><strong>261.7</strong></td>
</tr>
<tr>
<td>Goods Transport</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total EU 15</td>
<td>22.9</td>
<td>26.5</td>
<td>28.7</td>
</tr>
<tr>
<td>Total New 10</td>
<td>3.3</td>
<td>3.8</td>
<td>4.4</td>
</tr>
<tr>
<td><strong>Total EU 25</strong></td>
<td><strong>26.2</strong></td>
<td><strong>30.2</strong></td>
<td><strong>33.1</strong></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total EU 15</td>
<td>213.5</td>
<td>237.6</td>
<td>256.6</td>
</tr>
<tr>
<td>Total New 10</td>
<td>25.5</td>
<td>31.6</td>
<td>38.1</td>
</tr>
<tr>
<td><strong>Total EU 25</strong></td>
<td><strong>239.0</strong></td>
<td><strong>269.1</strong></td>
<td><strong>294.7</strong></td>
</tr>
</tbody>
</table>

Length of infrastructure technically equipped for infrastructure-to-vehicle communication

Some IVSS like Speed Alert or Intersection Safety need information from the road infrastructure, e.g. status of the traffic lights or speed limits. For these IVSS the infrastructure has to be equipped with communicating systems like beacons. The costs of these infrastructure equipments have to be added to the system costs of the accordant IVSS.

The IVSS Intersection Safety uses digital maps (which are not content of technical infrastructure equipment). Further, infrastructure sensing vehicles, pedestrians and cyclists is required (depending on the functionality). Thus, Intersection Safety can calculate the risk of an accident or the risk of violating a traffic light showing red or a stop
sign. If the risk is acute, the system can warn the vehicle driver. In the case of traffic lights, the traffic lights have to be able to send the current status as well as a near-term forecast. Hence, the vehicle knows the current status of the traffic light in front and the status for the next seconds. So, the intersections have to be equipped with sensors and beacons and – in the case of traffic lights – “open” signal controls, i.e. the current status and a short term forecast. For Intersection Safety it has to be decided, if the costs for the required technical infrastructure equipment have to be added to the system costs respectively with which rate. It is possible, that the technical infrastructure equipment is used for other things, so that there are no additional costs for Intersection Safety. For example, the sensors can be used for optimizing the traffic flow of the intersection or the beacons can be used for an optimizing of the public transport.

Speed Alert uses digital maps also. Hence, in the year 2010 there are no additional costs due to infrastructure equipment for Speed Alert. There is a second phase of Speed Alert possible. This system will be on market after 2010, so this phase is only relevant for the year 2020. In the second phase, Speed Alert takes broadcasts by traffic centers, Variable Message Signs (VMS) and beacons into account. VMS are traffic control devices. They are used to provide real-time travel information. Thus, Speed Alert has in the year 2020 additional effects due to variable and dynamic speed limits. The eSafety Forum estimates the equipment rates for the relevant VMS Dynamic Traffic Management systems and Local Danger Warning systems (eSafety Forum 2005). They assume that the length of the problematic road network is 70,000 km. In the case business as usual the equipped network with Dynamic Traffic Management systems is 18,900 km in the year 2020. The value for the implementation support case is 39,900 km. In 2003 the accordant length was 5,660 km. The number of Local Danger Warning systems is estimated for business as usual as 2,500. For the second scenario, the implementation support case, the figure is 3,700. The number before 2006 was 1,000 for both scenarios. The length of each system is 3 km with an average daily traffic of 30,000 vehicles. So the infrastructure costs of the VMS have to be added proportionate to the system costs of Speed Alert for the year 2020.

The IVSS eCall sends its message to a Public Safety Answering Point (PSAP). The costs for this PSAP have to be added to the system costs.

Traffic Data for the Estimation of the Number of Accidents, Injuries and Casualties

The EWS (FGSV 1997) is a standardised guideline for an economic appraisal of infrastructure investment. It provides information about the German accident rates for accidents with personal injury on motorways, rural roads and urban roads. Each of these three road categories are divided into several groups, e.g. motorways with four lanes or motorways with six lanes. Due to this division into groups, the accident rate per category is given in intervals. The accident rates for accidents with personal injuries on motorways are between 0.147 accidents per one million vehicle kilometres and 0.202 accidents per one million vehicle kilometres. On rural roads the range is between 0.187 accidents per one million vehicle kilometres and 0.512 acci-
On urban roads the accident rate for accidents with personal injuries are between 0.555 accidents per one million vehicle kilometres and 2.702 accidents per one million vehicle kilometres (FGSV 1997). These ranges are displayed in Table 5.

**Ranges for the Accident Rates with Personal Injuries for Germany**

<table>
<thead>
<tr>
<th>Road Type</th>
<th>From (accidents per one million vehicle kilometres)</th>
<th>To (accidents per one million vehicle kilometres)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motorways</td>
<td>0.147</td>
<td>0.202</td>
</tr>
<tr>
<td>Rural Roads</td>
<td>0.187</td>
<td>0.512</td>
</tr>
<tr>
<td>Urban Roads</td>
<td>0.555</td>
<td>2.702</td>
</tr>
</tbody>
</table>

Table 5: Ranges for Accident Rates with Personal Injuries for Germany (FGSV 1997)

The risk of accidents with fatalities depends also on the road type. In 2005 in Germany 31.3 % of all vehicle kilometres were driven on motorways. 12.3 % of all casualties died in accidents on motorways. On rural roads 52.2 % of all vehicle kilometres were driven, and 60.2 % of all accident victims were killed on rural roads. The remaining 16.5 % of the vehicle kilometres were driven on urban roads representing 27.5 % of all fatalities (Destatis 2006). These correlations are displayed in Figure 22.

![Figure 22: Share of Driven Vehicle Mileage Compared to the Share of Fatalities per Road Type in Germany (Destatis 2006)](image)

With these operating figures, the knowledge of the vehicle mileage for the year 2010 and 2020, and its distribution on the different types of roads, the number of accidents with personal injuries, the number of personal injuries, and the number of fatalities can be estimated.

Table 6 provides an overview of the current and forecasted vehicle mileage. The 2002 and 2010 data are based on the ProgTrans European Transport Report 2004. The figures for 2020 are calculated – as explained in the previous section – by using the growth rate given in the ProgTrans European Transport Report 2004. In total, vehicle mileage in the EU 25 member states is set to grow from about 3,200 billion km at present to about 4,000 billion km in 2020. The figures of the year 2020 will be replaced by the figures from the ProgTrans European Transport Report 2006 when it is published.
### Vehicle Mileage

<table>
<thead>
<tr>
<th></th>
<th>Year</th>
<th>2002</th>
<th>2010</th>
<th>2020</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>in Passenger Transport</strong></td>
<td>Total EU 15</td>
<td>2,390.9</td>
<td>2,680.3</td>
<td>2,931.5</td>
</tr>
<tr>
<td></td>
<td>Total New 10</td>
<td>210.1</td>
<td>275.7</td>
<td>342.1</td>
</tr>
<tr>
<td><strong>Total EU 25</strong></td>
<td></td>
<td>2,601.0</td>
<td>2,956.0</td>
<td>3,273.6</td>
</tr>
<tr>
<td><strong>in Goods Transport</strong></td>
<td>Total EU 15</td>
<td>504.9</td>
<td>591.2</td>
<td>667.3</td>
</tr>
<tr>
<td></td>
<td>Total New 10</td>
<td>63.2</td>
<td>76.0</td>
<td>86.7</td>
</tr>
<tr>
<td><strong>Total EU 25</strong></td>
<td></td>
<td>568.1</td>
<td>667.2</td>
<td>754.0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>Total EU 15</td>
<td>2,895.8</td>
<td>3,271.5</td>
<td>3,598.8</td>
</tr>
<tr>
<td></td>
<td>Total New 10</td>
<td>273.3</td>
<td>351.7</td>
<td>428.7</td>
</tr>
<tr>
<td><strong>Total EU 25</strong></td>
<td></td>
<td>3,169.1</td>
<td>3,623.2</td>
<td>4,027.6</td>
</tr>
</tbody>
</table>

Table 6: Vehicle Mileage in the EU (ProgTrans 2004, Own Calculations)

The last unknown figure, the distribution of the vehicle mileage has to be estimated for the years 2010 and 2020. The mileage can be provided on the road types motorway, rural and urban roads. On the one hand, this information is important for forecasting the casualties for 2010 and 2020. On the other hand, the mileage distribution will influence the effectiveness of the IVSS which are limited to a special type of road, e.g. Intersection Safety, which has no effect on motorways. In this case, its accident avoidance potential will be higher, the lower the share of the vehicle mileage on motorways is.

The database IRTAD (International Road Traffic and Accident Database) is used to estimate the distribution of the vehicle mileage for the EU 25 member states for the years 2010 and 2020, because IRTAD is the only database which provides information about this issue. The IRTAD database contains the categories vehicle kilometres in the total road network, vehicle kilometres on motorways, and vehicle kilometres on urban roads for the EU 25 member states for the period 1990 till 2004 (IRTAD 2006). The data for the vehicle kilometres on rural roads can be calculated with the data for the other categories. However, some data for urban traffic for EU 15 member states and data for the New EU 10 member states are missing.

The data concerning the vehicle kilometres in the total road network can not be taken directly from ProgTrans European Transport Report 2004, because its data are not comparable to the IRTAD-data. They differ significantly. Thus, the vehicle kilometres in the total road network have to be forecasted once more, this time with the IRTAD database to get congruent results for the distribution of the vehicle mileage. In the further process of the project the distribution of the vehicle mileage is combined with the absolute vehicle mileage data from ProgTrans European Transport Report 2006 when it is published.

The aim is to estimate the share of vehicle kilometres on motorways, on rural roads, and on urban roads for the years 2010 and 2020 based on the historical data given in IRTAD. Therefore the vehicle kilometres in the total road network, on motorways, and on urban roads are estimated for the years 2010 and 2020 with a linear regression approach for each country. The year will be the only independent variable in the regression approach. Thus, the function will be as follow: \[ \text{[mill. veh-km(t)]} = \text{constant} + a \cdot t \], where \( t \) is the year, and the constant and the gradient \( a \) have to be estimated. There are three
functions for each country, for the EU 15 and EU 25: one for vehicle kilometres in the total road network, one for vehicle kilometres on motorways, and one for vehicle kilometres on urban roads.

With this regression the share of the vehicle kilometres on motorways and on urban roads for the years 2010 and 2020 can be forecasted. The share of vehicle kilometres on rural roads equals the share of vehicle kilometres in the total road network minus the share of vehicle kilometres on motorways and the urban roads.

The first forecasted variable is the vehicle kilometres in the total road network. For this category IRTAD provides data for all EU 15 member states and for two member states of the New 10 EU members: Czech Republic and Slovenia. These countries represent 93.13 % of the vehicle kilometres in the year 2002 in the EU 25 based on the ProgTrans European Transport Report 2004 (ProgTrans 2004).

Data is missing from Cyprus, Estonia, Hungary, Lithuania, Latvia, Malta, Poland, and Slovakia. This gap in the data has to be closed in the further process of eIMPACT.

Thus, a linear regression approach with the year as independent variable was executed for 17 countries and the EU 15 on an aggregated level. The adjusted stability indices (adjusted R²) lie between 0.933 and 0.998. All results are significant to the 99.9 % confidence-level, so the results of the linear regression approach are trustworthy (see also Annex 2). With the regression equations the values for the vehicle kilometres in the total road network for the years 2010 and 2020 are calculated. Table 7 displays the results for the estimation for EU 15, Czech Republic, Slovenia, and the example country Germany. For the year 2004 the value from IRTAD is given to compare the results from the regression with the measured values.

<p>| Mill. Vehicle Kilometres in Total Road Network for Selected Member States and the EU 15 |
|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|</p>
<table>
<thead>
<tr>
<th>IRTAD (Observed Data)</th>
<th>Regression (Estimated Data)</th>
<th>2004</th>
<th>2004</th>
<th>2010</th>
<th>2020</th>
</tr>
</thead>
<tbody>
<tr>
<td>Germany</td>
<td>697,148</td>
<td>705,077</td>
<td>763,710</td>
<td>861,433</td>
<td></td>
</tr>
<tr>
<td>EU 15</td>
<td>3,228,162</td>
<td>3,226,308</td>
<td>3,632,297</td>
<td>4,308,946</td>
<td></td>
</tr>
<tr>
<td>Czech Republic</td>
<td>47,193</td>
<td>46,641</td>
<td>55,257</td>
<td>69,616</td>
<td></td>
</tr>
<tr>
<td>Slovenia</td>
<td>15,099</td>
<td>14,212</td>
<td>17,337</td>
<td>22,546</td>
<td></td>
</tr>
</tbody>
</table>

Table 7: Vehicle Kilometres in the Total Road Network for Selected Member States and EU 15 (IRTAD 2006, Own Calculations)

For example, the linear regression equation for the vehicle kilometres expressed in mill. veh-km in the total road network in Germany in the year t is 9,772,236 * t – 18,880,000. So for the year 2004 the vehicle kilometres in the total road network is estimated with 705,077 mill. veh-km. The value taken from IRTAD is 697,148 mill. veh-km. The value from the estimation for 2010 is 763,710 mill. veh-km and for 2020 the value is 861,433 mill. veh-km. Figure 23 displays the linear regression line for the vehicle kilometres in the total road network in Germany (red line) and the values based on IRTAD (blue rectangles).
The second forecasted variable is the vehicle kilometres on motorways. For this category IRTAD provides data for all EU 15 member states and for three member states of the New 10 EU members: Czech Republic, Hungary, and Slovenia. Malta and Latvia have no motorways.

There is data missing from Cyprus, Estonia, Lithuania, Poland, and Slovakia. The mentioned gap in the data has to be closed in the further process of eIMPACT. It has to be checked as well, if the assumption that Malta and Latvia will have no motorways in the years 2010 and 2020 is valid.

Thus, for 18 countries and the EU 15 on an aggregated level a linear regression approach with the year as independent variable was executed to forecast the vehicle kilometres on motorways. The adjusted stability indices lie between 0.721 and 0.997. All results are significant to the 98 % confidence-level (see Annex 2). The results for EU 15, Czech Republic, Hungary, Slovenia, and for the example country Germany can be seen in Table 8. The estimated values for the year 2004 can be compared with the given values from IRTAD.

| Mill. Vehicle Kilometres on Motorways for Selected Member States and the EU 15 |
|---------------------------------|---------------------------------|-----------------|-----------------|-----------------|
|                                 | IRTAD (Observed Data)           | Regression (Estimated Data) |
| Germany                         | 218,900                         | 221,584 | 251,351 | 300,962 | 221,584 | 251,351 | 300,962 |
| EU 15                           | 713,810                         | 722,836 | 844,923 | 1,048,400 | 722,836 | 844,923 | 1,048,400 |
| Czech Republic                  | 5,274                           | 4,966 | 6,489 | 9,026 | 4,966 | 6,489 | 9,026 |
| Hungary                         | 3,865                           | 3,865 | 4,932 | 6,709 | 3,865 | 4,932 | 6,709 |
| Slovenia                        | 2,866                           | 2,743 | 3,712 | 5,327 | 2,743 | 3,712 | 5,327 |

Table 8: Vehicle Kilometres on Motorways for Selected Member States and EU 15 (IRTAD 2006, Own Calculations)

As a result from the regression, the equation for the vehicle kilometres on motorways in Germany in the year t is: 4,961.107 * t – 9,720,474 [mill. veh-km]. The estimated value for the year 2004 is 221,584 mill. veh-km. The value taken from IRTAD is 218,900 mill.
The estimated value for 2010 is 251,351 mill. veh-km and for 2020 the value is 300,962 mill. veh-km.

With the vehicle kilometres in the total road network and the vehicle kilometres on motorways the share of vehicle kilometres on motorways can be calculated. Table 9 shows the shares. The values from the IRTAD data base for the year 2004 are also displayed to show the quality of the regression approach.

**Share of Vehicle Kilometres on Motorways for Selected Member States and EU 15**

<table>
<thead>
<tr>
<th></th>
<th>IRTAD (Observed Data)</th>
<th>Regression (Estimated Data)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2004</td>
<td>2004</td>
</tr>
<tr>
<td>Germany</td>
<td>31.4%</td>
<td>31.4%</td>
</tr>
<tr>
<td>EU 15</td>
<td>22.1%</td>
<td>22.4%</td>
</tr>
<tr>
<td>Czech Republic</td>
<td>11.2%</td>
<td>10.6%</td>
</tr>
<tr>
<td>Hungary</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slovenia</td>
<td>19.0%</td>
<td>19.3%</td>
</tr>
</tbody>
</table>

Table 9: Share of Vehicle Kilometres on Motorways for Selected Member States and EU 15 (IRTAD 2006, Own Calculations)

For the example country Germany the shares for the vehicle kilometres on motorways can be calculated as follow: for the year 2004 the share is 31.4 % (218,900/697,148), 32.9 % (251,351/763,710) in the year 2010, and 34.9 % (300,962/861,433) in the year 2020.

The third forecasted variable is the vehicle kilometres on urban roads. For this category IRTAD provides data for a sufficiently long time period for seven EU 15 member states only: Austria, Denmark, Finland, Germany, Ireland, the Netherlands, and Great Britain.

For the other eight EU 15 member states there is only data available for the years 2002 till 2004. The database for the member states of the New 10 is even worse. This gap in the data has to be closed in the further process of eIMPACT.

So the seven mentioned countries represent 47.5 % of the vehicle kilometres on urban roads in EU 15 (IRTAD 2006). For these countries a linear regression approach with the year as independent variable was executed to forecast the vehicle kilometres on urban roads. The adjusted stability indices lie between 0.01 and 0.998. The regression approaches for Austria, Finland, Germany, Ireland, and Great Britain seem to be trustworthy. The results from these five countries are significant to the 99 % confidence-level (see Annex 2).

The equation for the vehicle kilometres on urban roads in Germany in the year $t$ is: $1,327,667 - 599.95 \times t$ [mill. veh-km]. The estimated value for the year 2004 is 125,367 mill. veh-km. IRTAD has no empirical data for the year 2004. The estimated value for 2010 is 121,768 mill. veh-km and for 2020 the value is 115,768 mill. veh-km.

So urban roads have a share in the vehicle kilometres on urban roads of 18.0 % (125,367/697,148) in the year 2004, 15.9 % (121,768/763,710) in the year 2010, and 13.4 % (115,768/861,433) in the year 2020.

Because of a bad adjusted stability index and according significance levels over 0.05, the regression approaches for the other two countries, Denmark and the Netherlands, does not seem to be trustworthy.
So for these two countries a different linear regression approach was applied. Instead of the absolute figures, the share of the vehicle kilometres on urban roads has been used as input data for these two countries. This data set shows that there is a trend for a decreasing share during the time. This approach is satisfying. The adjusted stability index for Denmark is 0.939 and the value for the Netherlands is 0.765. The results are significant to the 99% confidence-level.

With knowledge about the share of vehicle kilometres on motorways and the share of vehicle kilometres on urban roads, the share of vehicle kilometres on rural roads can be determined to complete the distribution of vehicle kilometres. So the distribution can be calculated for seven countries yet: Austria, Denmark, Finland, Germany, Ireland, the Netherlands, and Great Britain. For the other countries of the EU 25 data is still missing and has to be collected or estimated in the progress of the project (for example on basis of the road network).

The distribution of the vehicle kilometres for Germany is as follows: The shares for the vehicle kilometres on motorways and on urban roads have been calculated as shown above. So the share of the vehicle kilometres on rural roads in the year 2004 is 50.6 % (1 – 31.4 % – 18 %), in the year 2010 the share of the vehicle kilometres on rural roads is 51.2 % (1 – 32.9 % – 15.9 %), and in the year 2020 the share of vehicle kilometres on rural roads is 51.7 % (1 – 34.9 % – 13.4 %). These values are displayed in Table 10.

<table>
<thead>
<tr>
<th>Distribution of Vehicle Mileage in Germany (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year</td>
</tr>
<tr>
<td>Motorways</td>
</tr>
<tr>
<td>Rural Roads</td>
</tr>
<tr>
<td>Urban Roads</td>
</tr>
</tbody>
</table>

Table 10: Distribution of Vehicle Kilometres in Germany per Road Type in Percentage (Source: IRTAD 2006, Own Calculations)

Traffic data for assessing the benefits of the IVSS, which have traffic impact

The IVSS which have traffic impact influence the vehicle operating costs, the travel time, fuel consumption and emission of CO\textsubscript{2} and pollutants. These effects are due to harmonized traffic flow and to adjusted connections between the traffic volume and the velocity. For the assessment of these effects, the velocity distribution for the EU 25 member states for the years 2010 and 2020 is necessary.

The vehicle operating costs depend on the driven velocity. There is a velocity which minimizes the fuel consumption. The CO\textsubscript{2} output is also directly linked to the velocity (see also chapter 3.2.4). The travel time is the shorter the higher the average driven velocity is.

The realized velocity depends on the traffic flow (traffic volume and traffic density). There are relations between the traffic volume and velocity respectively traffic volume and traffic density respectively traffic density and velocity (HCM 2000 and FGSV 2001) (see also chapter 3.2.4). These connections can be influenced by the IVSS which have traffic impact.

If the IVSS has a positive traffic influence, the connection will change. So the velocity will increase by a given traffic volume. This leads to a
greater traffic density by a given traffic volume. The velocity by a given traffic density will also increase.

There is a differentiation between stable traffic flow and instable traffic flow. Driving in a stable traffic flow means that a driver can choose his desired speed independently. The interaction between the vehicles is low. In this situation an IVSS can not influence the traffic flow. If the traffic flow is instable, choosing the velocity is not freely possible. Interaction between the vehicles is on a high level. Changing the lane is difficult. In such a situation the IVSS can influence the traffic flow. On the one hand, it can harmonize the traffic flow, which leads to less acceleration and deceleration procedures. This is positive for the fuel consumption and the emissions (pollutants and carbon dioxide). On the other hand, the IVSS can adjust the connections between the traffic flow, traffic density and velocity. This has a positive influence on the travel times and, depending on the new velocity, also a positive influence on the fuel consumption and emissions. In other words, traffic performance may change.

A state of the art concept for analysing traffic performance is the Level of Service (LOS) concept. The American Highway Capacity Manual (HCM) describes the LOS as a performance indicator for the motorist’s satisfaction with the trip. It is a qualitative measure which describes operational conditions within a traffic stream based on indicators such as velocity and travel time, freedom to manoeuvre, traffic interruptions, comfort, and convenience (HCM 2000).

LOS is divided into six groups for motorways and rural roads, and two groups for urban traffic. LOS A means there is no congestion; every driver can choose the velocity he prefers within the legal range. The LOS steps A to D address a stable, undisturbed traffic situation, LOS steps E and F refer to an instable, disturbed traffic situation. LOS F means congestion. In urban areas it is only differentiated between no congestion (B) and congestion (E). Every LOS step has limits for the according traffic volume, traffic density, and velocity. Table 11 displays an example for the connections between the level of service, traffic volume, traffic density, and the velocity for a two-lane motorway outside urban agglomeration without lorries and without speed limit.
<table>
<thead>
<tr>
<th>Level of Service</th>
<th>Average Velocity of Passenger Cars [km/h]</th>
<th>Traffic Density [veh/km]</th>
<th>Traffic Volume [veh/h]</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>&gt; 129</td>
<td>&lt; 9</td>
<td>&lt; 1051</td>
</tr>
<tr>
<td>B</td>
<td>&gt; 124</td>
<td>&lt; 17</td>
<td>&lt; 1901</td>
</tr>
<tr>
<td>C</td>
<td>&gt; 114</td>
<td>&lt; 24</td>
<td>&lt; 2581</td>
</tr>
<tr>
<td>D</td>
<td>&gt; 99</td>
<td>&lt; 33</td>
<td>&lt; 3091</td>
</tr>
<tr>
<td>E</td>
<td>&gt; 79</td>
<td>&lt; 46</td>
<td>&lt; 3401</td>
</tr>
<tr>
<td>F</td>
<td>&lt; 80</td>
<td>&gt; 45</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 11: Level of Service with the accordant Limits of Average Velocity, Traffic Density, and Traffic Volume for a two-lane Motorway outside Urban Agglomeration without Speed Limit and without Lorries (Source: FGSV 2001)

Since the application of IVSS has changed the relation between traffic volume and velocity, the borders of the LOS steps can change. So with the distribution of the LOS in the year 2010 respectively 2020 and the adjusted borders the benefits due to traffic impact can be estimated.

Forecasting the distribution of LOS for 2010 and 2020 is nearly impossible because of the lack of robust data (see below). Hence, the second best solution is to assume that the LOS distribution in 2010 and 2020 will be the same as in 2000. This implies that the road infrastructure (supply side) will grow adequately to cover with the transport demand (= vehicle kilometres). Table 12 shows the distribution of LOS for the year 2000. 12.0 % of the motorway network is congested and in another 4.4 % of the motorway network the traffic is disturbed. On rural roads the figures are lower. In 1.1 % there is congestion and in another 0.4 % the traffic is disturbed. On urban roads in 1.5 % the traffic is disturbed. So motorways have the highest potential for IVSS with traffic impact.

Distribution Level of Services Total EU 15 in the year 2000

<table>
<thead>
<tr>
<th>Level of Service</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>Sum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motorways</td>
<td>51.4%</td>
<td>14.7%</td>
<td>10.0%</td>
<td>7.5%</td>
<td>4.4%</td>
<td>12.0%</td>
<td>100%</td>
</tr>
<tr>
<td>Rural Roads</td>
<td>94.1%</td>
<td>2.4%</td>
<td>1.2%</td>
<td>0.8%</td>
<td>0.4%</td>
<td>1.1%</td>
<td>100%</td>
</tr>
<tr>
<td>Urban Roads</td>
<td>98.5%</td>
<td>1.5%</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>100%</td>
</tr>
</tbody>
</table>

Note: In urban areas there is just differentiated between LOS B and LOS E (congestion).

Table 12: Distribution of Level of Service 2000 (Infras/IWW 2004, Own Calculations)

As seen in objective three the vehicle mileage will increase in the period under review. So the assumption, that the distribution of LOS will remain on the level of the year 2000, is only valid if the infrastructure can handle the further vehicle mileage on the same level as in the year 2000. There is no assumption about the exact distribution of vehicle mileage in the years 2010 and 2020. If the vehicle mileage is only increasing in road sections with LOS step A, the growth of the vehicle mileage is not critical. On the other side, if the vehicle mileage is only increasing in road sections with LOS step F (congestion), the
growth of the vehicle mileage might be critically. In this case it depends on where the infrastructure is enlarged.

If the total infrastructure length is increasing the risk of degradation in the distribution of LOS is reduced.

Actually, a forecast of the length of infrastructure for the years 2010 and 2020 is a very difficult issue; the deployment of infrastructure is influenced by political decisions. The process between identification of infrastructure needs and realisation is characterised by large time lags. This means that in addition to the demand, the need for a certain section has to exist in the political mind. But the need alone brings no activity. The financing of the new section has to be allocated. This depends on the budget of the certain country respectively of the EU for sections partly financed by the EU. Moreover, the section has to be planned and built. Within this process unexpected budget restrictions, problems with planning processes especially unexpected exceptions in public hearings come up. Hence, it is difficult to forecast the infrastructure supply.

Practically, there are three alternatives to forecast the infrastructure length:

- National transport masterplans and TEN-T,
- Budgets for road infrastructure,
- Trend estimation of infrastructure length based on time series analysis.

One way of forecasting the infrastructure is to analyse the national masterplans for infrastructure construction. But these figures are not really trustworthy. For example in Germany it is obvious that the national masterplan is underfunded, i.e. there is not enough money to build all the sections which are planned for the duration of the masterplan from the year 2003 till 2015 (BVWP 2003). Another problem with the masterplans is that they cover only motorways and federal roads. A lot of the rural and all urban roads are not component of this masterplan. However the rural and urban roads have the biggest share in the total infrastructure length. So they seem to be the kinds of road infrastructure with the absolute biggest growth. Thus, taking the masterplan and interpolate respectively extrapolate the data to 2010 and 2020 will bring only a crude statement of a minimum level for the infrastructure. Hence, the analysis of national masterplans does not provide a solid picture of the infrastructure provision in 2010 or 2020.

Another possible way for forecasting the infrastructure length is analysing the budget for infrastructure. The problem is that infrastructure can be built completely new, it can be enlarged, or it can be maintained. All of these possibilities cost money. And as long as there is no information about the distribution of the funds (new development, enlarging and maintaining), no reliable statements can be made at least at EU-25 level.

Without information whether the infrastructure is enlarged where the vehicle mileage grows, a statement can not be made about the effectiveness of the infrastructure enlargement.

After considering all mentioned problems the best way seems to base the forecast on the time series for infrastructure. The base for the
time series is the data provided by IRF (IRF 2001, IRF 2005). The data covers all EU 25 member states. Because some data are not complete, the missing data was taken by a second data base, the International Auto Statistics (VDA 2001, VDA 2005). Both data bases have the same source, so there is no difference within the data. The newest available data for all EU 25 member states is from the year 2003. It will be completed by Latvian data based on Latvian State Roads (LAD n.d.).

Thus, the data set is complete for the period from 1994 till 2003 for all EU 25 member states. However, the forecast of the infrastructure length is challenging because this data set has three problems: The period of the data set is with ten years very short for estimating the values for the years 2010 and 2020; the data set has different classifications than used in eIMPACT; and the data is only consistent for motorways and the total network.

- The data bases from the IRF (IRF 2001, IRF 2005) and from the International Auto Statistics (VDA 2001, VDA 2005) are classified into four categories of the considered road types: motorways; highways, main or national roads ("A-level roads"); secondary or regional roads; and other roads (rural or urban). eIMPACT distinguishes between three categories — motorways, rural roads, and urban roads. Thus, the categories A-level roads and secondary or regional roads are combined to the new category "rural roads". The category other roads (rural and urban) can not be divided into the categories other roads rural and other roads urban because every EU 25 member state has a different definition of this category. For example France has a road infrastructure of 500,000 km in the category other roads (rural and urban). Portugal has 0 km in this category. So the used data set has three categories — motorways, rural roads, and other roads. The data is from the period 1994 till 2003 and covers the 25 EU member states.

- The other problem is that the data is not consistent in the categories rural roads and other roads. The reason in the inconsistency of the data base is that some country changes the definition of certain road sections. Some road sections were downgraded into another category. For example, Denmark decreases its A-level network from 3,751 km in the year 1997 to 780 km in the next year. In return the secondary or regional roads length increased from 7,050 km to 9,953 in the same period. This change is not problematic, because the categories A-level and secondary or regional roads are combined in the category "rural roads".

- The changes from the combined category rural roads to the category other roads is more problematic. Hungary’s rural road network decreased in the period 1996 till 1997 from 82,336 km to 52,813 km. The Hungarian other road network increased in the same period from 52,919 km to 134,952 km. Finland and Luxembourg even cancelled their complete other road network and changed it to rural roads.

- Another inconsistency is an abnormal change within one category. The length of the Spanish other road infrastructure increased from the year 1998 to 1999 from 175,000 km to 489,700 km. This change was not connected with another significant change in the category rural roads. Germany’s other roads length
decreased from the year 1998 to 1999 from 516,500 km to 91,076 km without a significant change in the category rural roads.

The mentioned problems affect the quality of the forecasting. Because of the different definitions and the definition changes which lead to abnormal changes in the infrastructure length of the categories rural roads and other roads, it seems to make sense to forecast only the categories length of motorways and length of the total road network.

The data for each year was aggregated for the two categories length of motorways and length of total road network for EU 15, New 10 EU, and EU 25. The chosen approach of the forecast is a linear regression, where the year is the independent variable. The estimation equation will be as follows: Length of infrastructure in the year \( t \) = constant + a * t, where the constant and the gradient a have to be estimated.

Thus, for the length of motorways and the length of total road network for EU 15, New 10 EU, and EU 25 the linear regression approach mentioned above was executed. For the length of the motorways the adjusted stability indices lie between 0.904 and 0.989. The results are significant to the 99.9% confidence-level, so the results of the linear regression approach are trustworthy.

For the length of the total road network the results of the linear regression approach are trustworthy as well. The stability indices lie between 0.534 and 0.751. The results are significant to the 95% confidence-level.

Table 13 displays the adjusted stability indices (adjusted \( R^2 \)), the F-values and the significance levels for the regression approaches.

<table>
<thead>
<tr>
<th>Category</th>
<th>EU 15</th>
<th>Total New 10</th>
<th>EU 25</th>
<th>F-Value</th>
<th>Significance-Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motorways</td>
<td>0.904</td>
<td>0.989</td>
<td>0.919</td>
<td>85.984</td>
<td>0.000**</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>797.844</td>
<td>0.000**</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>103.481</td>
<td>0.000**</td>
</tr>
<tr>
<td>Total</td>
<td>0.534</td>
<td>0.751</td>
<td>0.636</td>
<td>11.334</td>
<td>0.010*</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>28.150</td>
<td>0.001*</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>16.731</td>
<td>0.003*</td>
</tr>
</tbody>
</table>

* Significant to the 95% Confidence-Level.
** Significant to the 99.9% Confidence-Level.

Table 13: Adjusted Stability Indices, F-Values and Significance Levels for Linear Regression Approach (Own Calculations)

With the regression equations the values for the length of motorways and the length of total road network for the EU 15, the New 10 EU, and the EU 25 for the years 2010 and 2020 are calculated. There can be seen a trend for enlarging it. The motorway network will increase from 59,252 km in the year 2003 to almost 79,000 km in the year 2020. The length of the total road network increases from about 4,900,000 km in the year 2003 to about 6,600,000 km in the year 2020 (see also Table 14).
Thus, the probability that the infrastructure can handle the increase of the vehicle mileage is high. That means that the assumption, the distribution of level of services will remain on the level of the year 2000, is valid.

### 3.3.2 Road safety data

#### Importance of general Accident Data

The socio-economic assessment of IVSS mainly aims at calculating the benefits in terms of safety effects which can be expected from the market introduction and further deployment of the safety systems. The safety impacts are based on accident causation analyses identifying and quantitatively assessing the relevant safety mechanisms of IVSS, e.g. accident avoidance, changes in exposure and crash consequences (see chapter 3.2.3). In further calculations these impacts expressed as effectiveness in terms of percentage changes are combined with general accident data quantifying

- the total number of accidents,
- the number of casualties covered as fatalities, severe and slight injuries as well as
- the PDO (i.e. property-damage-only) accidents

differentiated between different collision types which are assigned to each IVSS. As a result, the safety impact in terms of accidents, fatalities and injuries avoided respectively mitigated are displayed for each IVSS. These results serve as input for the socio-economic evaluation. The accident data flow within this assessment is illustrated in Figure 24. As can be seen, the collection and compilation of road safety data is one essential part of the safety impacts as well as socio-economic assessment.
Figure 24: Accident Data Flow (Own Figure)

Besides evaluating the IVSS selected for the present situation, eIMPACT also performs a prospective assessment for the years 2010 and 2020. Moreover, the analyses are conducted on a EU-25 level. Thus, an up-to-date and prospective compilation of relevant road safety indicators has to be performed for each of the EU-25 countries.

Accident Data Provision

In contrary to the initial specification laid down in the project description of work (Technical Annex I), the collection and compilation of general accident data for further analyses is not in the field of activity of eIMPACT. A workable arrangement on the safety data provision has been arranged between the EC, eIMPACT and the STREP TRACE, a current European-funded project on traffic accident causation. The objectives of TRACE are to provide a scientific overview of the road accident causation issues in Europe. The project findings are based on the analysis of almost 50 accident databases (“TRaffic Accident Causation In Europe” (TRACE), Technical Annex 1 – Description of Work, October 2005). According to the agreement met, eIMPACT closely co-operates with TRACE in defining the accident data needed which finally will be compiled by TRACE. For quality reasons, this arrangement is reasonable, due to TRACE accessibility to more databases which comprise statistical data as well as in-depth information on accident causation (see Figure 25).

1 TRACE aims at using 12 sources of descriptive data, 28 sources of in-depth data and 7 sources of risk exposure data which are available across Europe.
In particular, TRACE will access the CARE database (Community database on Accidents on the Roads in Europe). This database at EU-15 level is based on an accident classification that will preliminary be used by TRACE and within the safety impact analysis of eIMPACT. The following differentiation of accidents is used in the eIMPACT safety impact assessment of IVSS and, consequently, in the socio-economic evaluation of the safety systems.

<table>
<thead>
<tr>
<th>Relevant Accident Item</th>
<th>Relevant Item values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collision type</td>
<td>chain or rear</td>
</tr>
<tr>
<td></td>
<td>frontal</td>
</tr>
<tr>
<td></td>
<td>lateral</td>
</tr>
<tr>
<td></td>
<td>parked vehicle</td>
</tr>
<tr>
<td></td>
<td>pedestrian</td>
</tr>
<tr>
<td></td>
<td>animal</td>
</tr>
<tr>
<td></td>
<td>single vehicle accident</td>
</tr>
<tr>
<td></td>
<td>do. with obstacle</td>
</tr>
<tr>
<td></td>
<td>do. no obstacle</td>
</tr>
<tr>
<td></td>
<td>Other</td>
</tr>
<tr>
<td></td>
<td>Unknown</td>
</tr>
<tr>
<td>Road class</td>
<td>motorway</td>
</tr>
<tr>
<td></td>
<td>rural road</td>
</tr>
<tr>
<td></td>
<td>urban road</td>
</tr>
<tr>
<td>Vehicle Type</td>
<td>car</td>
</tr>
<tr>
<td></td>
<td>truck</td>
</tr>
<tr>
<td>Road surface conditions</td>
<td>normal (dry)</td>
</tr>
<tr>
<td></td>
<td>bad weather (fog or mist, rain, snow)</td>
</tr>
<tr>
<td>Lighting conditions</td>
<td>dark</td>
</tr>
<tr>
<td></td>
<td>light</td>
</tr>
</tbody>
</table>

Table 15: Accident Classification Relevant in Safety Impact Analysis
The collection and compilation of general accident data using the CARE database is associated with various problems which have to be overcome. These restraints are highlighted in the following:

1. At present, CARE comprises accident data from 14 old EU-Member States excluding Germany. In the forthcoming years data from the Members States that joined the European Union in May 2004 plus Norway and Switzerland will be integrated in the database, so that an extension to all 25 EU Member States is achieved. However, since the database is presently limited to EU-15 (minus Germany), the existing data gaps have to be filled with accident data taken from other sources (e.g. databases, national surveys). In this context, comparability of data from different new Member States – definition, structure, quality and accuracy – is a continual problem which has to be taken into consideration.

2. Besides the problem of missing countries, the use of international and community databases such as CARE and IRTAD reveals other data gaps which are crucial in compiling general accident data. One essential issue is the problem of same base year due to years not (yet) available. Figure 26 illustrates this problem for the CARE data base comprising EU-15 data.

![Figure 26: Data Availability in the CARE Database by Country and Year (Own Figure)](image)

Hence, a base year has to be chosen for which general accident data is available for all countries. Otherwise, these data gaps could be filled by performing estimations on the further development of road accidents in those Member States for which no data are available for recent years (e.g. Luxembourg). However, this approach would increase the uncertainties of all analyses based on accident data.

3. The accident classification used within the CARE database being the main statistical source for European accident data was recently altered. Since then, the numbers of accidents and casualties (fatalities, injuries) are not differentiated between collision types (e.g. lateral collision, rear collision, frontal collision, side by side collision). Instead, the CARE database is using the item of...
"manoeuvres" of vehicles/drivers which has the following variable values:

- changing lane,
- overtaking,
- reversing,
- stopped/stopping,
- straight ahead,
- turning left,
- turning right,
- u-turn.

Any data collection for recent or past years based on CARE will be classified according to the new classification not distinguishing between collision types any more. Consequently, the changed data differentiation has to be taken into account in the compilation of general accident data.

Forecast of Road Safety Performance

One major challenge in collecting and compiling road safety data for further impact assessments (safety impacts, socio-economic impacts) is the forecasting of safety performance for the target years 2010 and 2020. Definitely, by nature, road accidents are unpredictable events. However, individual accidents are not random events without any factors determining their numbers and severity. In this context, research has identified various factors which make an accident more or less likely to occur. If the parameters that affect the road safety performance are known, the change of the existing pattern of accidents over time can be predicted. This approach would ensure the forecast of general accident data for the target years.

Main parameter directly determining road accident performance is the extent of road traffic participation which can be measured in vehicle mileage driven. Traffic participation – or transport demand in general – itself is determined by several factors. The following main factors influencing road safety performance indirectly can be identified (Ratzenberger, Ralf, Development of road safety and road safety determinants up until 2010, Federal Highway Research Institut (BASt), Bergisch Gladbach 2000):

- demographic situation (number of inhabitants, age distribution, migration trends),
- economic performance (gross domestic product),
- user prices for transport covering the prices in road transport (e.g. oil prices, road pricing) as well as in alternative transport modes (e.g. air fares, prices in public transport),
- infrastructural situation in all transport modes (development of network length, capacity and quality),
- vehicle stock (number of vehicles, distribution of vehicle categories),
• traffic participation pattern (e.g. average distance travelled, user behaviour in traffic),
• development of national and international policies (e.g. economic, transport and environmental policy).

Although all these factors more or less determine the number and severity of accidents, the central determinant of road safety is the vehicle mileage. Thus, the forecast of safety performance for the years of analysis 2010 and 2020 is based on this parameter. In combination with empiric data on the distribution of vehicle mileage on road categories on the one hand (chapter 3.3.1), and with the use of accident rates differentiating between number of accidents and casualties considering different road categories on the other hand, the road safety performance can be predicted (Figure 27).

Figure 27: Analytical Approach for Forecasting Road Safety Performance (Own Figure)

Key variables in predicting the numbers and severity of road accidents for the target years are the rates of accidents, fatalities and injured persons per 1 Mill. vehicle-km. These indicators differentiated between road classes (inside urban areas, outside urban areas, motorways) are calculated for each country for the years 1991 to 2005 resorting to the CARE database. Based on these calculations an extrapolation of the country- and road category-specific trends of road safety is performed up to the years 2010 and 2020. For this task the instrument of regression analysis is used. Given this analytical approach to forecast road safety performance in the EU-Member States, the necessary basis for a prospective safety and socio-economic evaluation of IVSS for the target years is laid.
3.4 Benefit of IVSS: Monetary evaluation of physical impacts

In order to calculate the potential benefits of a specific IVSS, it is not sufficient to estimate the number of avoided accidents, the lowering of the injury severity and the modification of the traffic flow. To determine the changes of economic resources of traffic by the use of IVSS, every benefit category has to be assigned to a monetary equivalent. From this it follows that every beneficial impact of an IVSS is expressed in terms of money, e.g. a fatality is valued at one million euros, a ton of CO₂ is stated at 60 euros etc. The different physical impacts are translated into the following economic resources components:

- accident costs
- time costs
- vehicle operating costs
- air pollutant costs
- CO₂-emission costs
- congestion costs

Uniform price level of cost-unit rates

These cost-unit rates differ more or less in each member state, because of varying economic conditions and evaluation approaches. Since the calculations in eIMPACT are designed for a common European point of view and to lower the calculation complexity, uniform cost-unit rates are used. Besides the elimination of regional differences, a consistent price level for the various benefit and cost components is required, to ensure the comparability of the identified cost-unit rates. In order to comply with the market price estimates of the implementation costs of the different IVSS (see chapter 3.5), the price level of the benefit categories has to be consistent. This means, that all cost-unit rates for the benefit categories rely on the price level of the beginning of 2006. For this reason, a couple of cost-unit rates have to be inflation-adjusted. The average annual harmonised index of consumer prices of the European Central Bank (HICP) for the period 1996 to 2005 provides the basis for the calculation (2.4%).

Finally, the specification of cost-unit rates for all physical impacts can be done with different evaluation methods. These methods are shown in detail in the following chapter. Afterwards, an in-depth look at the different cost-unit rates presents the determination of these important calculation parameters for the CBA.
3.4.1 Monetary evaluation methods

In contrast to the market price based estimation of the system costs, a direct market value can not be identified for every cost-unit rate of the benefit categories. Thus, the value of the resource savings has to be assessed via other principles. The following figure demonstrates the most common evaluation methods, which are used to monetize traffic effects:

![Evaluation Methods Diagram]

Figure 28: Different Cost-unit Rates Evaluation Methods (Own Figure, cf. Baum/Höhnscheid 2001)

The different methods can be classified into subjective and objective methods. The first kind is based upon varying individual preferences about the valuation of non-market goods. Contrary to this approach, the latter methods rely on more objective criteria, as market prices of other goods, which are examined as calculation substitutes depending on the disposed approach. The evaluation methods can be characterised more precisely as follows (Litman 2005: 4-2):

- **Willingness-to-pay Approach**
  This subjective method (also known as stated preference approach) infers costs by surveying a representative sample of society. People are asked about their valuation of the particular non-market good. Thus, individual preferences determine the amount, which people are willing to pay to avoid an accident or to adopt the crash consequences. The results of such surveys depend heavily on the way the questionnaire is designed and conducted.

- **Cost-of-damage Approach**
  The cost-of-damage approach (also known as human capital method) is based on the total estimated amount of economic losses caused by any physical impact. Generally, the losses are quantified via the decline of gross product. For instance, the costs of an accident include the vehicle damage, medical and emergency costs and lost productivity of killed or disabled per-
sons. Referring to net output definitions, the presumed future consumption of a person has to be removed additionally from the loss of gross output per person.

- **Cost-of-avoidance Approach**

A cost-unit rate can also be estimated based on the expenses to avoid a potential damage. For example, the amount to prevent an accident and/or to mitigate injury severity is considered by society as the minimum price of a physical impact. If both damage costs and avoidance costs can be determined, the lower of the two is usually used for analysis. A rational economic actor would prefer to prevent an accident if it was cheaper, but would accept the damages if accident avoidance had higher costs.

- **Market Data Divergence Analysis**

The market data divergence analysis (also known as hedonic pricing or revealed preference approach) derives the costs of non-market goods from their effect on market prices of related goods. For instance, the physical impacts lower the property value of houses on streets with heavy traffic or raise the wages of employees who are exposed to a higher risk or discomfort. The difference between property values or wages, which are influenced by the physical impacts, and otherwise comparable non-affected goods/wages defines the equivalent value of damage. By this approach the willingness-to-pay is estimated indirectly but in an objective way.

Finally, the used evaluation method defines the spread of costs related to the physical impacts. In general, willingness-to-pay approaches deliver higher cost-unit rates than cost-of-damage methods. They include values of non-market costs, such as pain, suffering and grief. An example of the different evaluation of cost-unit rates is given later within the specification of accident cost-unit rates.

### 3.4.2 Benefit categories/components

**Accident costs**

Associating a monetary value to the loss of human life or an injury may seem immoral and often provokes strong reactions on ethical groups. However, without a monetization of fatalities and injuries, road casualty reduction measures can not be weighted properly in relation to resource allocation. Resources are limited; therefore estimates of crash cost-unit rates by severity class can be used to ensure that best use is made of any investment through economic appraisal. Potential economic benefits of each IVSS can be estimated based upon predicted crash savings.

Foremost, a consistent framework of assessment criteria is required for the considered countries which include information about the following items:

1. Standardised definition of the considered accident impacts,
2. Common monetary evaluation method,
3. Uniform cost components included in the cost-unit rate.
1. The accident definition used in the different member states is in most countries (14 of 25) in line with the EUNET definition (Nellthorpe et al. 1998: 14):

- ‘fatality’ – death within 30 days for causes arising out of the accident
- ‘serious injury’ – casualties who require hospital treatment and have lasting injuries, but who do not die within the recording period for a fatality
- ‘slight injury’ – casualties whose injuries do not require hospital treatment or, if they do, the effects of the injuries quickly subside.
- ‘property-damage-only accident’ (PDO) – accident without casualties

Hence, further accident differentiations address to the mentioned categories.

2. The differences within cost-unit rates given by different evaluation methods can be huge. The possible differences are illustrated in the following table for cost-unit rates on the basis of the cost-of-damage approach and the willingness-to-pay approach for the U.S. in 1996. The comparison between both approaches displays only slight differentials for slight and serious injuries. Indeed, the willingness-to-pay cost-unit rates are higher than the cost-of-damage rates, but the difference is not substantial. On the other hand, for fatalities exists a huge deviation. The cost-unit rate of the willingness-to-pay approach is more than three times higher than the cost-unit rate based on resource losses.

<table>
<thead>
<tr>
<th>Accident Severity</th>
<th>Cost-of-damages</th>
<th>Willingness-to-pay</th>
</tr>
</thead>
<tbody>
<tr>
<td>Injury Level 1 (Minor)</td>
<td>$12,200</td>
<td>$13,418</td>
</tr>
<tr>
<td>Injury Level 2 (Moderate)</td>
<td>$39,759</td>
<td>$43,655</td>
</tr>
<tr>
<td>Injury Level 3 (Serious)</td>
<td>$114,771</td>
<td>$120,018</td>
</tr>
<tr>
<td>Injury Level 4 (Severe)</td>
<td>$202,141</td>
<td>$221,951</td>
</tr>
<tr>
<td>Injury Level 5 (Critical)</td>
<td>$685,781</td>
<td>$752,988</td>
</tr>
<tr>
<td>Fatality</td>
<td>$962,440</td>
<td>$3,580,536</td>
</tr>
<tr>
<td>Only property damage</td>
<td>$3,397</td>
<td>--</td>
</tr>
</tbody>
</table>

Table 16: Comparison between Cost-of-damage and Willingness-to-pay Approaches in U.S.A (NHTSA 1996)

Even though the willingness-to-pay method has replaced the cost-of-damage method as the preferred crash costing method in some high income countries (e.g. USA, seven EU countries), this method is extremely difficult to use. Willingness-to-pay approaches are based on the completion of complex questionnaires which relate to understanding risks and individuals’ stated willingness to pay to avoid a given hypothetical change in accident risk. In contrast, the cost-of-damage method fulfils the approach to illustrate only the economic losses.
Therefore, the latter method provides the most objective representation of accident costs. For this reason, the following determination of the accident cost-unit rate is accomplished based on the cost-damage approach.

3. The assembling of an accident cost-unit rate requires usually following cost components (Nellthorp et al. 1998: 14):

- medical and healthcare costs,
- costs of property damage,
- administrative and legal/court costs,
- costs of lost productive capacity (lost output),
- human cost (pain, grief and suffering) valuation.

The first category can be called direct restoration costs, which includes actual and future costs necessary to restore the health of the accident casualty. The following categories present indirect restoration costs which arise in the course of administrative and legal issues related to an accident. This includes replacement costs for the damaged vehicles. The resource losses are the reduction in economic net product resulting from the fact that injured or killed persons are not able to work for a certain period. At least, human costs describe a subjective value of individual accident related suffering, pain and grief. Figure 29 gives a detailed overview of the different cost components included in accident cost-unit rate.
Finally, the monetary evaluation of human costs is intimately connected with willingness-to-pay approaches, given that the subjective cognition of stress correlated to accidents is different. In many countries an amount reflecting such costs is added to the total costs for each severity of crash. While all other cost components are based upon the cost-of-damage approach, human costs are usually calculated with the willingness-to-pay approach. Figure 30 displays the percentage for each injury level (MAIS: maximum abbreviated injury scale) in the U.S.A. In this study, the economic costs are supplemented by values for “intangible” consequences which were as quality-adjusted life years (QALYs) estimated. A QALY stands for a health outcome measure that assigns a value of 1 to a year of perfect health and 0 to death. Therefore, the QALY loss is determined by the duration and severity of the health problem. Ultimately, the monetized QALYs were added to the sum of economic costs. With the exception of MAIS 2, the proportion of human costs increases with growing injury severity. Based on this evaluation approach, the costs for a fatality contain over 70 % human costs. Because of varying shares of human costs in different countries using additional willingness-to-pay methods to complete the determination of traffic accident costs, it has to be underlined that only costs calculated through gross product losses will be considered.

![Figure 30: Distribution of Comprehensive Accident Costs in U.S.A. for the year 2000 (Blincoe et al 2002)](image)

The accident cost-unit rates for EU member states vary to a high degree. Table 17 gives an overview of the costs per accident impact of selective EU 25 countries for the different severity classes. The values, for instance, of traffic fatalities differ between 227,547 € (Spain) and 1,752,000 € (Finland). Additionally, there are clear differences to be observed between the different regions in Europe. All countries in the North/West region, except Denmark, use cost-unit rates higher than 1,100,000 € per fatality. On the other hand, the Eastern Countries have much lower values between 221,530 € and 896,981 € per fatality. The average value in the Eastern region is nearly the half of the Northern/Western value. In the South region, the values are even lower. Here, the value ranges between 227,547 € and 485,477 € per fatality.
### Table 17: Costs per Accident Impact (Costs/Casualty) in € 2005 in EU 25 and in Factor Prices (Bickel et al. 2005, Tiehallinto 2005, Own Calculations)

The main reason for the broad range of values lies in the different evaluation technique. The countries using willingness-to-pay approaches (e.g. Finland: 1,752,000 € per fatality) exhibit noticeable higher values than the countries calculating gross product losses (Denmark: 692,143 €). For objective reasons, only cost-of-damage approaches are considered for the determination of the accident cost-unit rate. In order to identify an average value for EU 25, the above listed cost-of-damage rates show still a broad range across all regions (Germany: 1,199,780 € per fatality; Slovak Republic: 221,530 € per fatality).

Therefore, accident cost-unit rates are proposed which were already used in past European projects based on a cost-of-damage approach (see Table 18). These cost-unit rates are proposed as a harmonized value for including accident costs in the benefit calculation of the different IVSS.

### Table 18: European Cost-unit Rates for Accident Evaluation in Euro per Casualty (cf. EC 2003)

<table>
<thead>
<tr>
<th>Type of Accident</th>
<th>Cost-unit Rate per Casualty</th>
</tr>
</thead>
<tbody>
<tr>
<td>With Fatalities</td>
<td>1,000,000 €</td>
</tr>
<tr>
<td>Severe Injuries</td>
<td>135,000 €</td>
</tr>
<tr>
<td>Slight Injuries</td>
<td>15,000 €</td>
</tr>
</tbody>
</table>
Furthermore, each accident with casualties is accompanied by property damage. These additional costs have to be added to the above proposed harmonized values in order to complete the benefits calculated in the CBA. Property damages represent a real economic resource loss for the overall society. After reviewing prior EC studies and international literature, it is assumed that the value of property damage in the course of a crash with fatalities accounts 12,000 € per crash. For injury crashes an average value of 3,500 € per crash is used (cf. ICF Consulting 2003, Blincoe et. al 2002, Bureau of Transport Economics 2000).

If reliable data about property damage only accidents is available, the value of these kinds of accidents will be considered in the benefit calculation additionally. The value of property damage only is examined from the data delivered in Table 17. Based on the fact, that property damage only accidents are calculated with a cost-of-damage approach (Bickel et al. 2005: 48), an average value of 3,630 € per accident for EU 25 is assumed.

**Travel time costs**

The safety impact is the most important impact regarding the use of IVSS. Nevertheless, some systems have an additional traffic impact which changes the driven velocity of the vehicles. A better flow of traffic means also saved time for the vehicle’s driver. These travel time costs and the benefit of time cost savings vary widely depending on factors such as the type of trip (leisure time, working purpose) traveler and travel condition. Independently from the subjective or individual assessment of time most of travel/transport time represents from an overall economic standpoint costs. Travel time costs refer to the value of time spent in travel. Therefore, it includes costs to businesses of time by their employees, vehicles and goods, and costs to consumers of personal unpaid time spent on travel. For a complete efficiency analysis the effects of IVSS on the travel/transport time have to be incorporated. In order to be able to evaluate the time in monetary terms, the concept of opportunity costs is used.

Figure 31 on the next page shows the proceeding how time costs can be calculated. Vehicle-kilometres and vehicle-speed determine the amount of travel time. Alongside the traffic variables length of relevant network section and the vehicle-speed, the number of vehicles, which are equipped with IVSS, and also the number of vehicles, which are affected by IVSS, play an important role for the effects on travel time. Finally, the product between amount of travel time per vehicle and time cost-unit rate provides the overall time costs.
Figure 31: Procedure for Calculating Time Costs (Abele et al. 2005)

The time cost rate itself depends on the travel purpose and the vehicle type. Table 19 shows the various components, which have been integrated in the calculation the time cost rates. Travel time savings for passenger transport journeys can be divided in labour and leisure time. To passenger car journeys for working purposes, provision costs for the car have to be added. In contrast, the values of freight time savings usually include labour costs, interest charge of the capital investment, depreciation of the capital investment, garage costs and general cost.

<table>
<thead>
<tr>
<th></th>
<th>Labor costs and expenses of the drivers</th>
<th>Labor costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freight transport</td>
<td></td>
<td>Expenses</td>
</tr>
<tr>
<td>Provision costs</td>
<td></td>
<td>Interest charges of the capital investment</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Depreciation of the capital investment</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(50% independent of vehicle-kilometres)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Garage</td>
</tr>
<tr>
<td></td>
<td></td>
<td>General costs</td>
</tr>
<tr>
<td>Passenger transport</td>
<td>Time costs</td>
<td>Time costs for one labour-hour</td>
</tr>
<tr>
<td>Provision costs</td>
<td></td>
<td>Time costs for one leisure-hour</td>
</tr>
<tr>
<td></td>
<td>Commercially used passenger cars</td>
<td></td>
</tr>
</tbody>
</table>

Table 19: Components of Time Costs (Own Figure)

On the basis of previous table, cost-unit rates are normally worked out for the different vehicle types. The following tables represent the cost-unit rates for time depending on passenger and freight transport for selected countries in the EU.
### Table 20: Vehicle Travel Time Savings for Freight Transport in Euro per Vehicle-hour (2005) (Bickel et al. 2005, Tiehallinto 2005, Own Calculations)

As in Table 20 can be seen, the value of travel time savings in freight transport varies in the different countries. The Netherlands has the highest value of 38.23 €/vehicle-hour. In contrast, Portugal’s value lies under 10 €/vehicle-hour. The only eastern country (Lithuania) displays a slightly higher value (11.92 €/vehicle-hour). Besides regional differences (southern and eastern countries: low values vs. northern/western countries: high values), also within the north/west states big differentials are apparent. The value of Finland is only a third of the value used in the Netherlands. In order to calculate the benefits on an European base, it is therefore proposed to use an average value of 22.33 €/vehicle-hour for heavy goods vehicles.

### Table 21: Vehicle Travel Time Savings for Passenger Transport in Euro per Person-hour in Factor Prices (2005) (Bickel et al. 2005, Tiehallinto 2005, Own Calculations)

However, in passenger transport, the cost-unit rates for the sample countries vary a lot more. The lower limit for person-hours is Lithuania with 7.71 €/person-hour. UK presents the upper limit with 33.09 €/person-hour. The north/west countries display considerably higher values than the eastern countries representative Lithuania. The same correlation is identified for the time value of non-work journeys. Finland has the highest cost-unit rate which is nearly four times higher than Lithuania.

- **Belgium**: 33.50
- **Finland**: 18.94
- **France**: 29.74
- **Germany**: 24.48
- **Lithuania**: 11.92
- **Netherlands**: 38.23
- **Portugal**: 9.13
- **UK**: 12.78

### Table 21: Vehicle Travel Time Savings for Passenger Transport in Euro per Person-hour in Factor Prices (2005) (Bickel et al. 2005, Tiehallinto 2005, Own Calculations)

<table>
<thead>
<tr>
<th>Country</th>
<th>VTTS for Passenger Cars in €/Person-Hour in Factor Prices (2005)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Work</td>
</tr>
<tr>
<td>Austria</td>
<td>11.06</td>
</tr>
<tr>
<td>Finland</td>
<td>23.59</td>
</tr>
<tr>
<td>Germany</td>
<td>21.42</td>
</tr>
<tr>
<td>Lithuania</td>
<td>7.71</td>
</tr>
<tr>
<td>Netherlands</td>
<td>24.41</td>
</tr>
<tr>
<td>Portugal</td>
<td>24.41</td>
</tr>
<tr>
<td>UK</td>
<td>33.09</td>
</tr>
</tbody>
</table>

1For non-work trips the VTTS value is lowered by 30 % to reflect the fact that small time savings are not discernible
2Values reflecting VTTS for average private road vehicles
3Non-work values based on commuting trips
4Work value reflects VTTS for the driver
higher than the used value in Lithuania. Therefore, average values of 20.81 €/person-hour for working time and of 4.41 €/person-hour for non-working time are assumed for all EU 25 countries. In order to calculate the travel time savings per vehicle, these values have to be multiplied by the assumed average vehicle occupancy (working time: 1.4 persons per vehicle; non-working time: 1.6 persons per vehicle). Additionally, the value for work journeys in passenger cars has to be complemented with average provision costs (1.28 €/vehicle-hour). Following from this, the average value for working time is 30.41 €/vehicle-hour and 7.06 €/vehicle-hour for non-working trips. Assuming that one third of all passenger car journeys are carried out because of working purposes and the other two third of the trips serve a private purpose, an average value of travel time savings for passenger cars can be derived (14.84 €/vehicle-hour).

**Vehicle operating costs**

Basically, vehicle operating costs can be divided into two different components. The first component is fixed for every vehicle type and represents basic vehicle operating costs. These basic vehicle operating costs include depreciation of vehicles, solid lubricant costs, repair and maintenance costs, tyre wear costs etc. In fact, these costs depend on the vehicle mileage but they are also independent on the vehicle’s velocity. Because it is assumed, that the traffic effects of the considered IVSS influence only the vehicle’s velocity and not the vehicle mileage, further calculations exclude those basic vehicle operating costs and concentrate on costs dependent on the velocity. This second cost component contains the fuel costs, which are calculated by the product of fuel consumption and fuel price. Finally, the fuel consumption depends on vehicle-kilometres, vehicle speed, vehicle type, and road design. The functional correlation between all aspects can be described as follows:

\[
FC_{vt} = \frac{1}{10} \cdot \Phi_{vt} \cdot FP
\]

with:

\[
\Phi_{vt} = c_0 + c_1 \cdot v^2 + \frac{c_2}{v}
\]

\(FC_{vt}: \) fuel costs for various vehicle-types (vt)

\(vt: \) passenger cars, trucks < 3.5 tons, trucks > 3.5 tons, semi-trailer, coaches, regular bus

\(\Phi_{vt}: \) fuel consumption factor for various vehicle-types

\(FP: \) fuel price

\(c_i: \) vehicle-type specific fuel consumption parameters, i = 0 to 2

\(v: \) vehicle speed (km/h)

The applied fuel consumption factors consider two main technical relations:

- fuel consumption increases disproportionately at high speeds, because of increased air resistance,
- fuel consumption depends at very low speed on the reciprocal value of speed (otherwise, for \( V = 0 \) km/h rises the specific fuel consumption approximately infinitely).

Besides the fuel consumption factors (for further information see chapter 3.7), the fuel price is necessary to determine the total variable vehicle operating costs. The monetization of estimated fuel consumption savings is rather easier than, for instance the determination of a travel time cost-unit rate, because fuel costs can be evaluated with market prices. Unfortunately, the fuel price is highly correlated with the volatile crude oil price. Figure 32 shows the development of the crude oil price and the average net fuel price in Germany for the last 15 years.

![Figure 32: Trend of Crude Oil Prices and Average Net Fuel Prices in Germany between 1991 and 2005 (Nominal Values) (Aral Fuel Price Database 2006/OECD 2006)](image)

Within the framework of a macroeconomic analysis the consumption of productive resources is relevant only. Therefore, a net fuel price, the price paid at the gas station lowered by the mineral oil tax and value-added tax, has to be used. Figure 32 indicates that the average net fuel price in Germany has correlated with the average crude oil price in recent years. The crude oil price itself varies due to different supply and demand circumstances. The shortage of oil production by the OPEC (Organization of Petroleum Exporting Countries) at the start of 1999 caused a doubling of crude oil prices. An expansion of oil production contingents in 2000 lead to a temporarily price decrease. Figure 32 points out that net fuel prices followed this trend in
the same degree during this period. Today’s high crude oil price (around 60 US-$ per barrel) is primarily caused by a still increasing demand from China and the Middle-East countries (IEA 2006: 5). To the growing oil demand adds only a slow rising oil production. Recent studies come to different conclusions regarding the future oil price development. DG TREN differentiates a “World Baseline” scenario (extrapolation of recent economic trend and rising oil production) and a “Soaring Oil Price” scenario (combination of much higher growth in Asia and relatively less abundant resources). Depending on the considered scenario, the future crude oil price differs substantially (2030: 62 US-$ per barrel contrary to 99 US-$ per barrel) (DG TREN 2006: 6 et seqq.). A recent study for the German Federal Ministry of Economics and Technology expects in its reference scenario a decline of oil prices in 2010 (34 US-$ per barrel) and 2020 (46 US-$ per barrel) (EWI/Prognos AG 2006: 14). Nevertheless, in a pessimistic scenario of this study the oil price will stay at the current level (2010: 60 US-$ per barrel; 2020: 68 US-$ per barrel).

It is quite evident, that oil price estimations are afflicted with high uncertainties. The future oil price can be substantially higher or lower than today’s price. While in the near future a price decrease seems very likely, many experts forecast a stabilisation of oil prices on a relatively high level. Thus, oil price estimations are not carried out and the fuel costs will be maintained on the price level from 2005. Considering the crude oil price level from 2005 (54 US-$ per barrel) an average net fuel price can be derived. Figure 33 shows the average net prices and taxes of premium petrol (Euro-Super 95) and diesel in the year 2005 for all 25 EU member states. Significant differences in gross fuel prices can be identified which are almost exclusively caused by varying tax rates. Member states with high gross prices for gasoline and diesel like United Kingdom, Germany, the Netherlands and Italy have also the highest tax rates in Europe. By contrast, new member states in Eastern Europe which exceed the European minimum taxation of fuels (petrol: 0.359 € diesel: 0.302 €) only slightly exhibit gross prices 30 to 40 Eurocents lower than the countries with a high taxation of fuels (European Council 2003). However, the net fuel prices range more or less in the same price area (10 Eurocent between the highest and lowest petrol and diesel prices). Hence, the average net fuel prices in the EU 25 listed below provide a good basis for calculations within the CBA:

- premium petrol: 0.386 € per litre,
- diesel: 0.433 € per litre.

For the private based evaluation process within the breakeven analysis the gross fuel price is relevant. Therefore, the average net fuel prices have to be adjusted by the average tax portion which results in the following gross fuel prices:

- premium petrol: 0.925 € per litre,
- diesel: 1.010 € per litre.
Figure 33: Net Prices and Taxes of Premium Petrol (Euro-Super 95) and Diesel in Euro per Litre Fuel for EU 25 Member States (2005 Nominal Values) (Eurostat 2006)

Air pollutant costs

The combustion of fossil fuels in the transport sector causes emissions of several air pollutants. These air pollutants burden the environment to an increasing degree. The elevated concentrations of air pollutants in the atmosphere affect the health of human beings, the natural and built environment in a negative way. The effects can be differentiated in two components with diverse directions of action:
1. Direct emissions, which spread spaciously in the atmosphere and thus are independently of the distance to the source of emissions.

2. Indirect emissions and secondary emissions, whose imission load is strongly connected to the source of pollutant output. Indirect emissions are life-cycle emissions and secondary emissions are generated by chemical reactions in the atmosphere. A typical secondary emission is ozone, which is a result of the photo oxidation of NO\(_X\), CO and VOC and causes smog.

The different air pollutants in the transport sector can not only be classified in direct and indirect emissions, they also vary in their harmful impact on the local or regional environment. Following compilation explains the direct impairment of the environment caused by every air pollutant (Weinreich 2003: 65-70):

- NO\(_X\) (nitrogen oxide): This pollutant aggravates through effects of nitrate aerosols asthmatic conditions and damages crop production and waters through nitrogen input. It also reacts with the oxygen in the air to produce ozone which is also an irritant.

- CO (carbon monoxide): Product of the incomplete combustion of carbon-containing compounds. It is an odourless gas with serious toxicity.

- HC (hydrocarbon chemicals): A group of chemicals containing hydrogen and carbon which often contribute to air pollution in the shape of OC’s or VOC’s (Volatile Organic Compounds). In urban pollution, these components - along with NO\(_X\) and sunlight- all contributes to the formation of tropospheric ozone. Hydrocarbon vapours are often carcinogenic.

- SO\(_2\) (sulfur dioxide): SO\(_2\) provokes acid rain, which causes damages of buildings, acidification of grounds and soiling of water bodies. As sulfate aerosols, it contributes to respiratory disease.

- PM (particulate matter, focused on PM\(_{2.5}\), particles with an aerodynamic diameter less than 2.5 micrometer): Inhaling of particulate matter can induce asthma, lung cancer, cardiovascular issues, and premature death.

Now, all above mentioned impacts have to be monetized. The valuation of air pollutant effects is based upon on the damages caused by air pollutant emissions. Figure 34 presents exemplary the impact pathway for the quantification of air pollutant costs. First, transport activity generates air pollutant emissions through combustion of fossil fuels. Then after chemical conversion the concentration and/or deposition of these pollutants burden the local or regional environment. To estimate the impact on varying receptors (humans, flora, buildings, ecosystems etc.), auxiliary variables for the estimation of the pollution from direct emission are required. In order to differentiate the pollutant impact for certain areas, data concerning the land development structure, the site and population density for the examined route networks have to be collected.
Valuation of Air Pollutant Emissions

![Valuation Pathway of Air Pollutant Emissions](Own Figure)

Via models containing several factors as air dispersion, weather conditions, number and characteristics of buildings in the examined area the air quality is measured (as pollutant concentration in the air in g/cm³). In a next step, the impacts of certain pollutant concentrations on human health, agricultural and forestry production as well as soil-ing and corrosion of building material are determined. As a result of these damages, the utility of the receptor of the pollution diminishes. Finally, these welfare losses are monetized, for instance health impacts are valued with production losses from sickness and increased mortality. In most of the European countries, the resulting cost-unit rates are based on damage costs (Bickel et al. 2005: 169).

The determination of the emitted pollutant quantities is carried out similarly to the algorithm used to identify the fuel consumption. Different emission factors are calculated considering the vehicle speed and varying emission parameters depending on vehicle type and pollutant (FGSV 1997):

\[
EF_{FG,j} = c_0 + c_1 \cdot V^2 + c_2 / V
\]

with
- \( EF \) ... emission factor (in g/[km*vehicles])
- \( V \) ... vehicle speed (in km/h)
- \( c_0, c_1, c_2 \) ... parameter depending on vehicle type and emission
- \( FG \) ... index for the various vehicle types
- \( j \) ... index for the emission

In addition, all different kinds of emissions are transformed by toxic factors to a standardised unit of nitrogen x-oxide. In respect of the
toxic factors (see Table 22), the standardised nitrogen x-oxides expressed in g/(km*veh) are transformed to t/(km*veh). After all, the traffic impact caused by the use of the IVSS (change of speed) can be valued with a cost-unit rate of €/tonne NO₅.

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>NOₓ</th>
<th>CO</th>
<th>HC</th>
<th>SO₂</th>
<th>PM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Toxic Factor</td>
<td>1.0</td>
<td>0.003</td>
<td>1.5</td>
<td>1.0</td>
<td>0.342</td>
</tr>
</tbody>
</table>

Table 22: Toxic Factors for Standardisation of Nitrogen X-Oxide (FGSV 1997)

Cost-unit rates in different European countries feature a wide range of values for NOₓ-emissions. Table 23 shows both the lower limit and the upper limit of values expressed in costs per tonne of pollutant emitted regarding urban and non-urban roads.

<table>
<thead>
<tr>
<th>Road Type</th>
<th>Width of Cost-Unit Rates in € 2005 / tonne NOₓ in EU 25 and in Factor Prices</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban roads</td>
<td>864 - 6,084</td>
</tr>
<tr>
<td>Non-Urban Roads</td>
<td>338 - 2,027</td>
</tr>
<tr>
<td>No Differentiation</td>
<td>316 - 4,972</td>
</tr>
</tbody>
</table>

Table 23: Width of Cost-Unit Rates in € 2005 / tonne NOₓ in EU 25 and in Factor Prices (Bickel et al. 2005, Own Calculations)

The values for the certain road type differ to a high degree due to different valuation approaches applied (avoidance or damage cost), different impacts included (health damage, losses in forestry, damage to water supply etc.) and different monetary values applied for the impacts (Bickel et al.: 171). Nevertheless, cost-unit rates on urban roads are substantially higher which accounts for an increasing toxicity of several pollutants in urban areas. Because of worse dispersion and transport possibilities of air pollutants (especially carcinogenic pollutants) in high-density areas, the resulting damages for human health and buildings rise. Apparently, the cost-unit rate on urban roads is nearly three times as high as on non-urban roads. To come to an European average value, the following considerations can be made:

Non-urban road costs → factor 3 → urban road costs

For each category it is an approximately medium value assumed. Further calculations are carried out with a cost-unit rate of 1050 €/tonne NOₓ for non-urban roads, and a cost-unit rate of 3150 €/tonne NOₓ for urban roads.
**CO₂-emission costs**

The global climate change is predominantly caused by anthropogenic emissions of green house gases. These kinds of emissions occur as a by-product of combustion of fossil fuels. Because green house gases have no direct toxic effects which can cause health problems at certain spots, the green house effect is examined separately from other pollutants. The emission of carbon dioxide (CO₂) and other green house gases - like methane (CH₄) and nitrous oxide (N₂O) - are by-products of fuel consumption of conventional combustion engines. Because of the fast growing transport volume and the fuel dependency of the transport sector, traffic is already a major source of anthropogenic emissions (about one fourth of the total CO₂ emissions in the EU). Due to the fact, that the traffic sector plays a minor role in emitting methane (2002: 0.3 % in Germany) and nitrous oxide (2002: 8.2 % in Germany), these gases are not accounted in further calculations (DIW 2005: 305). Despite a much higher effectuality on the climate change of methane (CO₂-equivalent 21) and nitrous oxide (CO₂-equivalent 310), CO₂ emissions are responsible for 95 % of the traffic-induced green house effect (Weinreich 2003: 108).

Whereas a sufficient estimation of other physical impacts can be carried out with the above mentioned evaluation methods, the determination of external effects induced by CO₂-emissions is associated with some difficulties. Given that the dimension of damage caused to the environment will become apparent in the future and the correlation between CO₂-emissions and climate change is afflicted with uncertainty, an exact quantification of damage costs is ex ante nearly impossible. Nevertheless, previous studies tried to estimate the future climate change costs. These estimates of external marginal damage costs display a wide range of CO₂ costs per tonne (see Table 24):

<table>
<thead>
<tr>
<th>Study</th>
<th>Marginal Damage Costs [Euro (1995) / tonne CO₂]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nordhaus (1991)</td>
<td>0.1 - 16.6</td>
</tr>
<tr>
<td>Fankhauser (1995)</td>
<td>2.3 - 16.1</td>
</tr>
<tr>
<td>Hohmeyer and Gärtner (1992)</td>
<td>201.1</td>
</tr>
<tr>
<td>IPCC (1996)</td>
<td>1.3 - 31.4</td>
</tr>
</tbody>
</table>

Table 24: External Marginal Damage Cost Estimations of Climate Change in Euro (1995) per tonne CO₂

Interaction between climate change and population growth, change of resource disposability etc. were to a large extent disregarded in the first studies from Nordhaus and Fankhauser. Nordhaus’ calculation established the minimum value of marginal damage costs which influenced also the lower limit of first IPCC estimations. In contrast, Hohmeyer and Gärtner considered the influence of climate change on agriculture and therewith the increase of starvation caused by insufficient food supply. The included monetized casualties lead to much higher marginal damage costs which present the upper limit of estimations. Recent estimations of the costs of carbon dioxide range between the lower and upper limit of past estimated values. Based upon new cognitions about the increase in temperature in the course of the
climate change, the Stern Review assesses the value of a tonne CO$_2$ at 85 US-$ or 64 € (2006 price) (Stern: XVI). After all, average costs or prevailing carbon prices can differ from the above mentioned values representing marginal damage costs. Even if marginal costs will rise in the future, the use of new technologies, learning and experience - driven through innovation policy - could lead to falling average costs.

On this account, it seems appropriate to establish a market based assessment approach. Since the beginning of 2005, an emissions trading scheme (ETS) for the industrial sector has been implemented. In order to fulfil the European burden adopted in the Kyoto agreement, companies, for instance of the power industry, get CO$_2$-emission allowances (EUA) from the government which are tradable on an European market (European Parliament and Council 2003: 32). Previously, policymakers have determined the total supply of allowances for the first period of the EU ETS from 2005-2007 through the National Allocation Plans (NAPs). Figure 35 displays the price development of the last six months. After an increase up to 18 €/EUA in June, the price stabilised around 16 €/EUA till September. Based on the current price level (10.50 €/EUA), a forecast of the future value of carbon dioxide is required in order to calculate the benefits of the IVSS. However, it has to be considered that this market is heavily influenced by policy and regulatory issues which determine the amount and the duration of emission allowances. Nevertheless, a study of DG TREN estimated the value of carbon dioxide per tonne in prices of the year 2000 at 15.3 € in 2010 and at 28.1 € in 2020 for a reduction scenario which keeps the emissions on the Kyoto level for the whole period under consideration (DG TREN 2004: 141). This study analysed also two more scenarios with higher emission reduction aims. For a reduction of 8.6 % CO$_2$-emissions from the 1990 levels in 2020 a value of 43.6 € was calculated. An even higher value (60.3 €) was assumed for 12.8 % reduction compared to the 1990 levels in 2020. Facing the current discussions and information about the climate change and its economic impact and based on the presumed figures, a uniform cost-unit rate of 60 € per tonne CO$_2$ is derived for the whole period under consideration. This price seems to be realistic facing the uncertainties of future global and/or European agreements, but takes into consideration that further measures against global warming are becoming more and more necessary.

The CO$_2$-emission is under the assumption of a complete oxidisation of carbon directly correlated with the fuel consumption. Due to physical characteristics of the different kinds of fuels, following emission factors are in use:

Petrol: 3.12 kg CO$_2$ per kg petrol,

Diesel: 3.15 kg CO$_2$ per kg diesel.
Congestion costs

The accident cost-unit rate, as mentioned above, usually contains only cost components directly linked to the vehicles and persons involved in a crash. First and foremost, this covers reproduction costs and resource losses. Albeit, this assessment approach includes the bulk of costs related to an accident, another cost component is neglected. Crashes on motorways are regularly accomplished by congestion caused by a temporarily reduction of road capacity (e.g. blocking of a lane on a motorway). Congestions lead to time losses, higher fuel consumption, higher air pollution and CO₂-emissions. Therefore, these effects have to be considered as additional accident costs. Otherwise, the danger arises, that the possible benefits occurring in an economic evaluation of road safety measures are underrated.

Available studies feature a broad range of values for congestion costs in the course of accidents. Table 25 illustrates the results of three selected studies about travel delay costs per accident. Blincoe et al. identified different cost-unit rates for each injury level which rise with increasing severity level. The same correlation is evident for the results of the other studies. Apparently, the different cost-unit rates reflect the proportion of police and/or rescue time at the crash scene depending on the accident severity. The estimates of ICF Consulting mark the upper limit for fatal and injury accidents. In contrast, Parry’s analyses resulted in travel delay costs for a fatal injury accident of nearly 5000 € and for an injury accident of about 900 €. Only the
American studies covered congestion travel delay cost caused by property damage only (PDO) accidents.

### Average Congestion Costs Caused by Accident Type in € per congestion (2005 price)

<table>
<thead>
<tr>
<th>Study</th>
<th>Fatal Injury Accident</th>
<th>Serious Injury Accident</th>
<th>Slight Injury Accident</th>
<th>PDO Accident</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blincoe et al. (2002)¹,⁵</td>
<td>12,824</td>
<td>1,539</td>
<td>1,285</td>
<td>1,409</td>
</tr>
<tr>
<td>Parry (2004)³,⁵</td>
<td>4,967</td>
<td>991</td>
<td>885</td>
<td>824</td>
</tr>
</tbody>
</table>

¹ Estimates are classified in MAIS (Maximum Abbreviated Injury Scale by victims); adjusted to: MAIS 0 to 1 = slight injury, MAIS 2 to 4 = serious injury, MAIS 5 to 6 = fatal injury
² No differentiation between slight and serious injury
³ Original severity classes adjusted to: disabling injury = serious injury, evident and possible injury = slight injury
⁴ PDO means "Property Damage Only", cost on a per damaged vehicle basis, adjusted with the average number of involved vehicles in a crash in the USA for the year 2000 [1.439] (Blincoe et al.:28)
⁵ Original unit-costs on per person basis, adjusted with number of fatalities [1,15] or injuries [1,36] per accident (ICF Consulting:11)

Table 25: Average Congestion Costs Caused by Accident Type in Euro per Congestion (2005 price) (Blincoe et al. 2002, ICF Consulting 2003, Parry 2004, Own Calculations)

However, the estimates include only travel delay costs during a congestion caused by crash. Calculations of the Institute for Transport Economics at the University of Cologne identified an average cost-unit rate of 14,791 € (2005 price) per congestion. The value includes besides travel delay costs additional fuel cost, pollutant cost and CO₂-emission cost per congestion caused by a crash in the region of Stuttgart. Though, the cost-unit rate is not differentiated between fatal, injury and PDO accidents.

Therefore, the upper limit of the estimates provides the basis for further calculations. Values of 15,500 € for congestions due to accidents with fatalities, 5,000 € for congestions due to accidents with personal injuries and 1,000 € per congestion due to PDO accidents are assumed for the whole period under consideration. Considering the fact, that the estimates of ICF Consulting do not contain additional fuel cost, pollutant cost and CO₂-emission cost, these cost-unit rates seem to be relatively conservative.

**Survey of cost-unit rates**

Table 26 provides all cost-unit rates which will be used to calculate the potential benefits of the investigated IVSS. The cost-unit rates are constant for the whole period under consideration. Nevertheless, further sensitivity testing could lead to modified values.
### Cost-unit rates of varying benefit components

<table>
<thead>
<tr>
<th>Designation</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Accident cost</strong></td>
<td></td>
</tr>
<tr>
<td>fatality</td>
<td>1,000,000 € / casualty</td>
</tr>
<tr>
<td>serious injury - property damage</td>
<td>12,000 € / accident</td>
</tr>
<tr>
<td>slight injury - property damage</td>
<td>135,000 € / casualty</td>
</tr>
<tr>
<td>slight injury - property damage</td>
<td>3,500 € / accident</td>
</tr>
<tr>
<td>slight injury - property damage only</td>
<td>15,000 € / casualty</td>
</tr>
<tr>
<td>slight injury - property damage only</td>
<td>3,500 € / accident</td>
</tr>
<tr>
<td>property damage only</td>
<td>3,630 € / accident</td>
</tr>
<tr>
<td><strong>Travel time cost</strong></td>
<td></td>
</tr>
<tr>
<td>freight transport</td>
<td>22.33 € / vehicle-hour</td>
</tr>
<tr>
<td>passenger transport</td>
<td>14.84 € / vehicle-hour</td>
</tr>
<tr>
<td><strong>Fuel price</strong></td>
<td></td>
</tr>
<tr>
<td>premium petrol</td>
<td>0.386 € / litre</td>
</tr>
<tr>
<td>diesel</td>
<td>0.433 € / litre</td>
</tr>
<tr>
<td><strong>NOX-equivalent</strong></td>
<td></td>
</tr>
<tr>
<td>non-urban roads</td>
<td>1,050 € / tonne NOX</td>
</tr>
<tr>
<td>urban roads</td>
<td>3,150 € / tonne NOX</td>
</tr>
<tr>
<td><strong>CO2-emission cost</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>60 € / tonne CO₂</td>
</tr>
<tr>
<td><strong>Congestion cost after accident</strong></td>
<td></td>
</tr>
<tr>
<td>with fatality</td>
<td>15,500 € / congestion</td>
</tr>
<tr>
<td>with personal injury</td>
<td>5,000 € / congestion</td>
</tr>
<tr>
<td>with property damage only</td>
<td>1,000 € / congestion</td>
</tr>
</tbody>
</table>

Table 26: Cost-unit Rates of Varying Benefit Components (2005)
3.5 Costs of IVSS

3.5.1 Assessment of costs and prices

In the socio-economic assessment of IVSS the costs of the systems to be evaluated have to be compared with the benefits the systems generate for the society or for specific stakeholder groups. Hence, the costs of IVSS have to be elaborated by compiling information and data. In this context, existing studies and available databases show that there is no sharp definition of costs. In most cases, economic assessment refers to system costs. In some studies, the system costs are broken down to production costs, i.e. the costs induced by manufacturing the systems, operating and maintenance costs of the systems as well as infrastructure (adaptation) costs. However, the position of system costs offers room for interpretation as is illustrated by the dotted lines in Figure 36. The definition and consequently the level of system costs (in Euro) largely depends on the steps along the value chain of IVSS production that are taken into consideration when accounting for costs of IVSS.

Figure 36: Costs and Prices of IVSS along the Value Chain (Own Figure)

Moreover, in some studies even a distinction between (production and system) costs and prices of IVSS is not performed. In fact, values for costs of IVSS on the one hand and system prices realised in the market are often mixed. From a methodological point of view, a clearer distinction between costs and prices is essential for the socio-economic assessment (Figure 37):

- The cost-related items play an important role in an assessment which focuses on resource consumption. The underlying question is which resources a society must spend to provide a good, in this case an IVSS. This resource consumption is valued in monetary terms. In so far, it is just relevant that there are costs because of the resource consumption; the question who bears the costs is irrelevant within this approach. The cost-benefit analysis being the instrument for this type of socio-economic assessment is dependent on cost information and data for calculating the efficiency of each IVSS by comparing benefits and costs.

- The price of an IVSS is what the end user faces when purchasing the system in the market-place. Hence, price determines to a large extent the market penetration of the IVSS. Price information is relevant for any user-related assessment. Stakeholder analyses
such as break-even analyses for users and OEMs are based on price information. Moreover, analyses of political or economic measures for facilitating the market deployment of IVSS will rely on price data. Certainly, prices are cost-based, at least to a large extent. Normally prices are much higher than costs because they include profit margins. But the relation between prices and costs may not be so straightforward due to other parameters such as the users’ willingness-to-buy, the OEM marketing strategy, the risks of market introduction (e.g. likelihood and costs of call-back campaigns) and intangible values of a system (e.g. comfort value such as stress reduction).

As illustrated, the conceptual distinction between costs and prices of IVSS is necessary for covering the different approaches within a comprehensive socio-economic assessment. Therefore, bearing this distinction in mind, a complete double set of information on costs and prices for each IVSS to be evaluated has to be come up with. This data set has to be based on clear definitions of costs and prices which is performed in the following chapter.

### 3.5.2 Cost components and price derivation

Within the socio-economic impact assessment of IVSS the welfare-economics-based cost-benefit analysis measures all relevant costs and benefits in monetary terms. Hence, in general, the cost-benefit analysis can be used to assess the absolute efficiency of a measure (by monetizing all costs and all benefits) which aims at finding whether a proposed objective is economically efficient and how efficient it is. For determining this absolute efficiency the definition of costs for IVSS is an important factor.

Each IVSS features its own level of costs. The costs of IVSS are mainly technology-specific; they are determined by the automotive technology and system components used for the specific intelligent safety application, e.g. sensors, cameras, communication systems in
case of co-operative IVSS. These technological components can be labelled as “cost drivers”. For cost-benefit calculations the total costs related to an IVSS have to be determined. Within this assessment methodology these safety-system-specific total costs are called “system costs”. They mainly consist of the vehicle- and infrastructure-related investment costs on the one hand and operating as well as maintenance costs on the other hand (Figure 38).

![Cost Categories Used in the Assessment Methodology (Own Figure)](figure38.png)

**Figure 38: Cost Categories Used in the Assessment Methodology (Own Figure)**

**System production and vehicle implementation costs**

Each IVSS consists of several „key-enabling components“ ensuring the technical operability of the system. Hence, an IVSS bears costs for the manufacturing of various system components and their assembly to the complete IVSS. These costs are labelled as system production costs. The production and assembly of the systems is the automotive suppliers’ business. The supplying companies manufacture the systems and sell them to automobile manufacturers for vehicle installation. Consequently, the so called “cost price” the car manufacturers pay to the suppliers include a profit margin for the supplying industry. Besides the activity-related additional costs (e.g. marketing, service) on the suppliers’ side, the manufacturers are confronted with further costs due to their added-value of which the vehicle implementation costs mainly supplement to the total costs. This whole production and added-value process is completed with the sale of the automobile to the end customer at a certain market price which also includes a IVSS-related profit margin for the automobile manufacturer (besides a profit margin for the car itself).

This step-by-step definition of cost components can be illustrated by the value chain running from the suppliers purchasing of inputs for producing IVSS to the marketing of vehicles equipped with IVSS by the automobile manufacturers (Figure 39).
**Figure 39: Cost Components and Market Price along the Value Chain (Own Figure)**

**Infrastructure equipment and adaptation costs**

Besides vehicle-related investments some IVSS also require investments into infrastructure equipment. ECall is one such system where an infrastructure outside the car is required to ensure the connection to assistance services. In addition, potential infrastructural adaptations have to be taken into consideration (e.g. technical modifications). Such additional costs directly tied to co-operative IVSS must be included in calculations when performing a cost-benefit analysis. Concerning co-operative systems accessing infrastructure equipment, it is furthermore important to include the infrastructure costs which are borne by private organisations (e.g. OEMs, service provider) as well as those costs which are covered by public authorities (e.g. state, province, city).

**Operating and maintenance costs**

Being active parts of the vehicle once installed, IVSS add mass to the vehicle and consume energy for their safety functions. Consequently, the installation and use of IVSS lead to increases in the vehicle fuel consumption which is directly correlated to higher costs. For instance, studies showed that cars using Daytime Running Lights (DRL) on average consume an additional 0.2 litres of fuel per 100 km driven (VDA 2003: 189 f). Given this correlation the need for calculating operating costs becomes obvious.

Depending on a IVSS’ components, complexity and robustness, a more or less extent of system maintenance may be required. Currently, IVSS are built for the lifetime of the vehicle. The maintenance costs therefore involve mere fault repair. This might be different for other systems, particularly infrastructural installations and equipment.
3.5.3 Determination of costs and prices

The determination of costs and prices of IVSS is crucial for the socio-economic assessment using the cost-benefit analysis and different stakeholder analyses (e.g. break-even analysis). For some systems (e.g. eCall) data on costs and prices are directly available due to up-to-date studies or databases, e.g.

- ECORYS Nederland BV, COWI, ECN, Ernst & Young Europe, Consultrans, Cost-benefit assessment and prioritisation of vehicle safety technologies, Interim Report, October 2005,
- Federal Highway Administration, United States Department of Transportation (Editor), Intelligent Transportation Systems: Benefits, Costs and Lessons Learned, 2005 Update, Washington, D.C. May 2005,

For most of the IVSS cost and price information available is very rare. Therefore an expert workshop has been organised within the eIMPACT project with the aim of getting reliable and accepted data on market acceptance and penetration as well as on costs and prices of the 12 IVSS selected for socio-economic assessment. Within the workshop the following essential conventions have been developed for determining costs and prices of IVSS:

1. Since costs and prices highly depend on the technical “key-enabling components” installed in the systems their determination has to be based on well-elaborated system specifications. In this context a common understanding has been achieved in the workshop so that broadly-accepted cost and price data could be developed.

2. From the automotive industry’s point of view the main indicator for costs is the “cost price” defined above as the price the vehicle manufacturers pay to the suppliers (including the supplier’s profit margin). Hence, the cost data compiled and agreed on in the expert workshop all refer to this cost price. According to this cost definition an adaptation has to be performed for further economic assessment to take into account the resource consumption due to various additional steps along the value chain.

3. In the long-run IVSS become more and more common in the market. Increasing market volumes (which are subject matter of the market penetration scenarios) are linked to higher production volumes. According to empirical studies, so called economies of scale in production arise when production volume increases. Economies of scale result in lower average production costs (Figure 40). Consequently, it can be assumed that the costs for IVSS will decrease over time.
4. The consumer price of each IVSS paid by the end user can be derived from the cost price by using a proportion of end prices to costs. The experts in the workshop quoted a rule of thumb stating the end user price on average is about three-times the cost price. Hence, a price estimate can be given for each IVSS although there are merely cost data available (and vice versa). However, one should keep in mind the increase in uncertainty of evaluation results due to this procedure.

The following figure illustrates above summarized issues on the determination of costs and prices of IVSS.
For the socio-economic impact assessment of IVSS, their costs and prices differ for cars on the one hand and for heavy duty vehicles on the other hand. Moreover, they also differ according to vehicle model and for OEMs, where they might be part of marketing strategies. Nevertheless, due to the complexity of this issue, average costs and prices are presumed for all vehicles regardless of model and OEM. The presumed costs and prices are subject to level changes over time. Regarding the different cost components defined, only the investment costs consisting of system and vehicle implementation costs as well as infrastructural costs (see figure 8) are considered to change, giving us different figures for 2010 and 2020. Maintenance and operating costs are considered stable costs over time.
3.6 Synthesis of CBA results: benefit-cost ratio and its interpretation

In general, the welfare-economics-based cost-benefit analysis (CBA) aims at finding whether a proposed objective – in this case different IVSS – is economically efficient and how efficient it is. For this purpose, the CBA measures all relevant costs and benefits in monetary terms of resources saved within an economy. In the final stage of the CBA process, the benefits and costs of the different IVSS are compared leading to a prioritization of safety systems to be implemented from the society’s point of view: The IVSS are ranked according to their values and relations of benefits and costs; the most highly ranked system should be selected. This selection offers the highest overall level of benefit relative to the costs of implementation, and ensures that the available resources are used in the most effective manner. Thus, the CBA can be used to assess the absolute efficiency of IVSS.

Various measures of efficiency are used to perform a comparison between benefits and costs on society level. Most common are the net present value (defined as difference between the monetized benefits and the costs required to realize the measure), the internal rate of return (defined as the interest rate that makes the net present value equal to zero) and the cost-benefit ratio. The cost-benefit ratio (C-B R) is the most broadly-accepted measure for comparing social benefits and costs. It is defined as

\[
C - B \quad R = \frac{\sum_{t=1}^{T} B_t (1 + i)^t}{\sum_{t=1}^{T} C_t (1 + i)^t}
\]

with

\begin{align*}
\text{C-B R} & = \text{cost-benefit ratio} \\
\text{t} & = \text{time horizon defined} \\
\text{B}_t & = \text{estimated value of benefits for the year t} \\
\text{C}_t & = \text{estimated value of costs for the year t} \\
i & = \text{discount rate}
\end{align*}

The value of the ratio indicates whether the implementation of IVSS is favourable from a socio-economic point of view. A C-B R of more than “1” indicates that benefits exceed the costs. Thus, the introduction of the IVSS would be beneficial to society. Furthermore, the value of the C-B R expresses the absolute rentability of the IVSS which can be interpreted as the socio-economic return for every monetary unit (e.g. Euro, US-$) invested in the implementation of the IVSS. For example, a C-B R of “3.5” would show that 3.5 monetary units can be gained for society for every monetary unit provided for the investment evaluated. Setting absolute, monetized values of benefits and costs into relation, the C-B R is a reliable indicator of efficient resource allocation.
The calculations of benefits and costs of IVSS depend on a variety of factors. In particular, these influencing factors are:

- Data related to IVSS (e.g. safety impact, costs and prices),
- Demand data (e.g. market penetration, changes in fuel prices, changes in prices of goods and services),
- Traffic Data (e.g. status-quo and forecast of traffic volume, vehicle-kilometres and number as well as severity of accidents) and
- Model Parameters (e.g. discount rate, cost unit rates).

Due to their nature of being input data for the CBA, these factors consequently determine the Cost-Benefit Ratio as the final result of the CBA calculation process. It therefore makes sense to perform the economic evaluation of each IVSS for more than one case, i.e. for various scenarios referring to different paths of the IVSS implementation. With other words, different “with”-cases have to be accounted for. For this, sensitivity analyses are performed.

The purpose of the sensitivity analyses is to select the “critical” variables and parameters of the socio-economic assessment. Critical variables are those whose variations, positive or negative, compared to the value used as the best estimate in the base case, have the greatest effect on the results of the CBA and consequently on the C-B R. In eIMPACT, the market penetration of IVSS is determined as being the major influencing factor for the assessment. This issue is taken into consideration by elaborating different market scenarios which have been developed in a scenario expert workshop (see chapter 3.2.2). Due to the uncertainty of predicting market penetration rates for IVSS for the years of analysis (present, 2010, 2020), three scenarios per year have been worked out for each IVSS (“business as usual”-scenario, “implementation support”-scenario, scenario of technological potential). The sensitivity analyses of B-C R are based on these market scenarios. Moreover, the sensitivity calculations will broach the issue of further parameters influencing the result of the CBA (e.g. safety impact).

The results of the CBA of IVSS in terms of the C-B R are most important for every kind of decision-maker interested in the evaluation of IVSS before deciding on market introduction, deployment or promotion of the safety systems. Thus, the results should be presented in a way that is both comprehensive and coherent. Therefore a standardised table is used to present the CBA-results for each IVSS using ranges in the C-B ratio. The following table summarizes the results of a CBA for a fictive example.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Costs (in Mill. €)</td>
<td>230 - 245</td>
<td>275 - 315</td>
<td>300 - 310</td>
</tr>
<tr>
<td>Range of C-B ratio:</td>
<td>0.8 - 0.9</td>
<td>1.4 - 1.8</td>
<td>3.1 - 3.6</td>
</tr>
<tr>
<td>Result:</td>
<td>Poor</td>
<td>Acceptable</td>
<td>Excellent</td>
</tr>
</tbody>
</table>

Table 27: Standardised Presentation of CBA-results for IVSS (fictive example)
Table 27 presents ranges of benefits and costs to take account of the different IVSS market penetration scenarios developed. As a consequence, ranges of C-B R are given which illustrate the variance of evaluation results. In this context, classes for CBA results are introduced to expose a grading of the results. The following classes are used in the table:

- $0 < C-B\ R < 0.99$: The C-B R is rated “poor” (red) showing that a socio-economic inefficiency of IVSS is given,
- $1 < C-B\ R < 2.99$: The C-B R is rated “acceptable” (yellow) meaning that the social benefits associated with the implementation of a safety system exceed the costs up to almost three-times which can be labelled as an acceptable absolute efficiency,
- $C-B\ R > 3$: The C-B R is higher than “3” indicating an “excellent” (green) result of the socio-economic assessment. The IVSS evaluated as “excellent” should be in first line for market deployment.

Based on these value classes of CBA results, a first evidence and valuation of the results can be illustrated. Moreover, in case quick estimations or preliminary calculations regarding the socio-economic efficiency of IVSS are performed, the interim results can be presented using these C-B R classes instead of exact C-B R values. This would allow for additional, more accurate calculations in the proceeding without having to revise the preliminary results.
4 Extension of methodological approach of CBA

4.1 Analysis of wider economic impacts

The cost-benefit analysis considers resource savings which emerge from IVSS (amongst other things fewer accidents, traffic jams) and contrasts these benefits with costs that are related to IVSS. In this respect, the evaluation is made for each IVSS-project specifically. Next to these actual welfare gains from resource savings, other economic impacts arise from IVSS which also have to be used for the evaluation of social benefit. They are important for evaluation and political acceptance and serve as an argument for the deployment of IVSS. Since the analysis of economic impacts requires economic in-depth data which is hardly available on EU-25 level, the geographical coverage is still to be decided.

The following issues belong to the wider economic impacts:

- Employment impacts from the deployment of IVSS,
- Income impacts which come up in national economy,
- distributional and equity effects which refer to income distribution,
- affordability and financial sustainability effects,
- practicability and public acceptability analysis.

The extension in evaluation of projects was established in research literature of the Anglo-American area. It has found explicit consideration in the „Transport Analysis Guidance (TAG)“ of the Department for Transport in U. K. in 2004. The wider economic impacts captures the impacts which are not included in the Appraisal Summary Table (Department for Transport, 2004).

The supporting analysis is operated in addition to the cost-benefit analysis and rounds off the spectrum of evaluation. Therefore, an extended circle of information is provided for evaluation and selection of IVSS. Thereby, a stepwise evaluation of IVSS-applications can be conducted. In the first step a reasonable safety contribution is secured. Among the remaining systems, the economical core criterion is the result of the cost-benefit analysis. It shows if projects are self-internal-rentable and generates the central orientation for the encouragement-worthiness of IVSS. The wider economic impacts supplement the basis of evaluation. They show if other positive or negative aspects accrue. The treatment of wider economic impacts is carried out in the stakeholder analysis and there especially with the benefits for public.

4.1.1 Employment impacts

From politics’ point of view, employment impacts are the most interesting macro-economical impact that emerges from IVSS. Employment impacts are an important criterion that is queried by poli-
tics within certain tasks. Employment impacts originate through multiple impulses:

- Direct primary employees result from the production of IVSS and from the construction of necessary additional information infrastructures.
- Indirect primary employees evolve because the producers have to use intermediate inputs (goods and services) on the first step which creates employment on previous steps.
- Secondary employment impacts come up because incomes rise on the primary step which again makes consumption expenditures increase and causes employment in consumer goods industry. It is controversial if these secondary impacts should be counted to the employment impacts. In the calculations within this study, secondary impacts are factored out in order to avoid an inflation of employment impacts.

The employment impacts are acquired out of the production impacts which represent the first step of the macro-economical functional chain. What has to be identified is the gross production value from the enhancement of final demand for IVSS. Here, also the indirect impacts, i.e. intermediate inputs, have to be taken into account next to the direct ones. This requires the use of an input-output-table. These tables present the integration of goods and services flows between the economic sectors of a national economy. For each economic sector it is analysed which goods and services in which quantity serve as an input to the production of this sector and which goods and services in which quantity are produced in this sector. The input-output-analysis is displayed with the methods of stakeholder analysis.

The inference from production impacts to employment impacts is made through multiplication of production impacts by sectoral labour coefficients. These specify for each economic sector how many employees are needed to create a specific output of gross domestic product. They are the reciprocal value of labour productivity. They are published in official statistics.

### 4.1.2 Income effects

A second important core value of wider economic impacts are income effects which result from the production of IVSS for the economy as a whole. They are an indicator of welfare effects which emerge from the application of IVSS: The macro-economical income is composed of wages of dependant employees, corporate profits and interest on invested capital.

The initial point for the quantitative evaluation of the income effect is the gross production value of IVSS. Through subtraction of intermediate inputs, one receives the gross domestic product. After subtraction of depreciation, the net production value results. Therefore, taxes are subtracted and subventions are added. This leads to national income which is at disposal of the payment of wages, corporate profits and interest on capital.
4.1.3 Effects on distribution of income

For the political acceptance of IVSS and therefore for the implementation chances of IVSS, the social effects possess substantial relevance. The social effects address the fact that the costs of a measure burden certain social classes, while others benefit from the measures. In such an analysis it is examined how the effects of IVSS affect the income distribution of the user groups. It should be answered which income groups – the “rich” or the “poor” – benefit from IVSS. The political acceptability rises if the systems contribute to a better social balance and lower income groups derive the larger benefits from such systems.

The aim of politics is to ensure – next to efficiency – also equity. That is justified by the fundamental task of the state to effectuate a financial adjustment between population groups with high and low income. Beyond that, pragmatical considerations are adduced. It appeared again and again that certain tasks could not be realised because of disadvantageous distribution effects in spite of a high macro-economical efficiency. Therefore, it is important to know which distribution effects come from IVSS. So far, there are no empirical insights to this.

IVSS unfold distributional effects. For the users, benefits evolve from lower accident costs and improved traffic conditions. Thereby, the income situation of users is improved. The other way around, income losses result from the costs that have to be brought up for IVSS. The consequences for the relative income position are due to the difference between benefits and costs depending on the income group. If population groups with low income are charged by IVSS relatively stronger than groups with high income, one alludes to a “regressive” distribution effect. If the groups with a higher income are charged relatively stronger, a “progressive” effect is on hand. Aim of the analysis is to identify which social group is involved with which share in financing of the fleet equipment with IVSS and which social group profits from the thereby effected benefits in the form of resource savings.

The empirical evaluation of the distribution effects is carried out in the so-called “incidence analysis” (see chapter 4.2.2.5). Incidence means the final resting place of benefits and costs of IVSS. Based on this method, an empirically based statement can be made about how benefits and costs of IVSS are distributed through income groups.

4.1.4 Financial sustainability

To the wider economic impacts belong also the fiscal effects which result from the application and the deployment of the IVSS. Financial sustainability is a criterion with which it can be controlled if public revenues from IVSS cover the related expenditures and if in this respect a financial balance is reached. Thereby, the impacts on the public budget are investigated.

For public decision makers, it is an important aspect that the financial budget equalisation is checked. If revenues exceed expenditures, politics get an impulse to realise an action and to launch IVSS. If the other way around public deficits are connected with
that, a rather sceptical attitude results. In this respect, public decision makers often disengage from social benefit-cost-criteria and put budget effects in the foreground.

For the examination of the question if financial sustainability is reached, the financial flows that come from IVSS have to be captured and contrasted.

On revenue side, higher tax revenues are generated. These result from higher prices for vehicles with IVSS and the higher value added tax connected with that. Because IVSS make profits of the OEM rise, also income and corporate tax rise. Because IVSS make a higher employment possible, revenues from wage tax rise. Finally, higher tax revenues arise because as a result of a decreased resource absorption in traffic and environment, the gross domestic product increases.

Increasing expenditures respectively public tax losses evolve due to the fact that with the introduction of IVSS, possibly tax decreases, grants and subsidies are granted as an impulse for the deployment of IVSS. Besides that, increasing expenditures result from information and communication infrastructures by public authorities in order to make the IVSS work.

The estimation of future revenues and expenditures is made within financial analysis (chapter 4.2.2.3). In existing analyses of IVSS, public expenditures are partly considered. But there is an estimation about potential revenue increases missing that should be related to macro-economical dependences between economic activity and tax revenues. Likewise, there are statements missing about the total budget effect of IVSS.

4.1.5 Practicability and public acceptability

The evaluation of IVSS includes the question in how far the systems fit the requirements of practicability and acceptability. These criteria belong to the wider economic and political impacts. They represent conditions on that IVSS can be implemented into practice. Regarding a recommendation for the application and deployment of IVSS, these criteria also have to be considered. In doing so, restrictions in effectiveness and practicability are marked. They can be opposed to a deployment strategy of IVSS. The implementation concept then has to be accompanied by actions that reduce these barriers. Therefore, additional actions are necessary to make the implementation strategy practicable. Such actions should be inserted in the strategic concept of IVSS implementation.

Practicability and public acceptability depend on the following factors which should be investigated with regard to the chances of an implementation of IVSS (Department for Transport in the U.K., 2004).

- **Feasibility.** The analysis of feasibility explains how high the probability is that IVSS are implemented and deployed. Thereby, technical and legal issues have to be considered as well as political aspects and questions of financability.
• **Enforcement.** To be determined is in how far an IVSS strategy requires supporting tasks in order to enhance their enforcement and acceptance.

• **Area of interest** ("breadth" of decision). For the conceptuation of an IVSS strategy, it has to be clarified which groups have interests in IVSS and how extensive the strategy should be. This affects among other things the spatial dimension of the tasks (e.g. road categories), which role local authorities and other bodies play and which interests the automotive industry pursues.

• **Complexity** ("depth" of decision). A complexity is evident in a strategy if it requires the coaction of multiple factors. IVSS have such a complexity. A technical complexity is given because IVSS demand the coaction of different technologies. A complexity of impacts exists as IVSS not only influence the event of the accident, but also the traffic flow. Within the IVSS there are a lot of organizations involved (OEMs, public authorities etc.) which form a further complexity.

• **Time-scale.** The time-scale plays an important role for development, implementation and market penetration. It decides when the effects of IVSS can be expected. Likewise, the analysis provides a statement about the question if political impulses should be given for the enhancement of market penetration.

• **Phasing.** The phasing concerns the question which time progress of an IVSS strategy should be chosen by the political decision makers. There are options between an earlier implementation and a quick launch or waiting till later phases when certain developments have taken place. Crucial is here the technical development status and how far the technologies are available sufficiently and assuredly.

• **Partitioning.** Within the strategy of IVSS implementation, it has to be clarified if it can be divided into time segments and into a series of simple, small portions. It has to be questioned if the implementation should be carried out step by step or en bloc. The IVSS strategy is affected by that because either only new vehicles should be equipped with IVSS or also end-of-life vehicles in a retrofitting.

• **Complementarity.** The question of complementarity references on if tasks are independent from each other or complement one another. Certain actions only make sense if they are operated in conjunction with other actions. Regarding IVSS there is the problem of complementarity in connection with a partly necessary supplementation with the communication infrastructure of roads.

• **Conflicts.** During the development of an IVSS strategy, it has to checked if the action stands in conflict with other actions that possibly have to be made. For IVSS, it has to be investigated if there are conflict potentials here. A preferably conflict-free strategy should be generated. A consistent policy is essential for an effective strategy.
During the design of an implementation strategy for IVSS, the requirements of practicability and public acceptability should be considered. Recommendations to this are developed within the scope of the policy options. Thereby, it should be warranted that a preferably high acceptance and market penetration of IVSS is reached. The conditions mentioned are the assumption for effectiveness and success of the IVSS strategy.

4.2 Stakeholder analysis

4.2.1 Conceptual basis

The socio-economic evaluation of IVSS with the aid of benefit-cost-analyses displays the profitability of the systems for all economies in the EU-25 and in this respect brings out an aggregated result. This result can help to judge collectively if IVSS are worth for an economical enhancement.

Apart from the total macro-economic balance it must be seen that there are several stakeholders of IVSS who have advantages and disadvantages from these systems and who benefit differently from that. They either find the implementation of IVSS positive or negative and thus influence the political decision of deployment. In order to indicate arguments and reactions of these stakeholders, it is necessary to identify the specific consequences of IVSS for these groups. In research literature such a specification of the benefit-cost-balance is called "stakeholder analysis" (Abele et al. 2005: 90/91).

Concerning IVSS, different stakeholder groups are to be observed who all have an individual specific concern for these systems.

- **Users** of IVSS consider the private-economic profitability of the systems. As a result of the use of IVSS, car drivers’ costs rise (purchase and maintenance). For their purchase decision it is essential if these costs are exceeded by the benefits. Those consist of favourable insurance premiums due to fewer accidents, vehicle operating cost savings and time savings as well as higher benefits of comfort. By comparison of individual-private benefits and costs arises the private profitability of IVSS which has a determining influence on users’ willingness to pay and on the market penetration of the systems.

- For the **manufacturers** (OEMs and automotive companies) the question of commercial profitability of IVSS emerges. Development of systems, production and equipment of vehicles with IVSS depend on that. Costs consist of costs of development, manufacturing and production for vehicles. Costs face revenues that were realised on the market and that determine profits. The effects on private profitability are different. Higher prices for vehicles as a consequence of the equipment with IVSS reduce sales and profitability. Contrariwise, IVSS stand for an increase of quality of the vehicle which can increase sales. Furthermore, the producers take the technical and economical risks which are associated with IVSS. If technical malfunctions appear, it means a damage of image for the producers and therewith a detraction of profit as well as higher costs for possible product recalls.
Insurance companies have interest in IVSS because thereby their business case is influenced. IVSS reduce accident frequency and severity which lessens the sum of damage to be regulated. This firstly denotes an increase of profitability, but the decrease of damage also opens tolerances for reductions of premiums. By this, the business volume would be depleted as fewer expenditures face fewer revenues. The fact that there is a willingness to lower premiums in the insurance industry becomes evident through the example of the insurance company Allianz in Germany which in the year 2006 implemented reductions in premiums for motor trucks in case certain driver assistance systems are installed.

Public authorities have various interests in IVSS. For state and society, benefits are gained through a diminishment of traffic costs by the use of IVSS, among other things lower accident costs or less emissions of CO₂ and pollutants. A second component of benefits consists in higher tax revenues. These result from production and sales of IVSS (for example higher VAT). Higher revenues from general taxes (for instance income and wage tax, consumption taxes) arise because IVSS help to avoid accidents, so resources can be saved whereby a higher economic growth emerges. But for the government possibly also higher costs evolve if for example by an encouragement of the market penetration of IVSS expenditures respectively tax losses (e.g. through reduction of motor vehicle tax) occur. Possibly state expenditures also arise since certain communication infrastructures have to be built up for IVSS. Losses in growth can be generated if there are cost escalations for society through the mandatory utilisation of defined IVSS. The equipment costs for all car drivers would be imposed on the whole society.

It is the aim of the stakeholder analysis to subdivide and allocate benefits and costs of IVSS on the various groups of interest. By this it should be pointed out to every group which specific impacts result from it for them. Insofar, the stakeholder analysis is a method of separation and disaggregation with which the economic effects of IVSS are subdivided on the involved groups. Basis of the allocation are the cost-benefit analysis and the analysis of wider economic effects. This empirical basis is dissected by specific methods in a way that a statement about stakeholder effects becomes possible. Partly, separate calculations in addition to the cost-benefit analysis are carried out. Input-output-analysis, managerial investment appraisal, break even analysis, financial analysis and incidence analysis belong to the applied methods. The stakeholder analysis gives differentiated information about the involvement of different groups and the (dis)advantages from the applications of IVSS. It is an instrument of political communication and able to convince the affected groups of the application of IVSS and by that to broaden acceptance and market penetration.
4.2.2 Methods of stakeholder analysis

4.2.2.1 Managerial investment appraisal

For the manufacturers of a product a managerial investment appraisal shows if the fabrication of a product is economically profitable for the enterprise. This approach follows “classical” investment theory with the net present value method which contrasts expected, aggregated and discounted returns and costs of a production with the costs of the investment. If the net present value is higher than 0, the project is being declared as profitable. The higher the capital value, the more profitable a project is.

\[
NPV = -A_0 + \frac{E_1 - K_1}{(1+i)} + \frac{E_2 - K_2}{(1+i)^2} + \ldots + \frac{E_n - K_n}{(1+i)^n}
\]

with

- NPV = net present value,
- \(A_0\) = initial expenditures for investments,
- \(E\) = revenues of the current period,
- \(K\) = costs of the current period,
- \(i\) = discount rate.

The net present value method is adequate in order to find out about the profitability of the production of IVSS for the OEM and their private-economic benefit. Before the decision about production is made by the OEM, initial costs and future expected returns and costs for IVSS are opposed.

The managerial investment appraisal is not included in the cost-benefit analysis, but must be carried out in addition. Instead of macro-economical benefits, only private revenues of enterprises are being focused on. Also costs are not equal to costs of society but to private costs of the manufacturers.

Revenues result from market penetration and the sold amount of IVSS. This amount must be multiplied with the attainable market price per IVSS. Decisive are the market prices and not the generated costs of production. Market prices are fixed through the chosen pricing strategy of the producers. Costs particularly consist of production costs for IVSS. Costs for research and development are added.

Investment calculations are normally accomplished by manufacturers before the market implementation of IVSS. They must include uncertainties regarding both revenue- and cost-side of the calculus.
4.2.2.2 Break even analysis

The break even analysis is a method of business administration used to determine from which production output an investment is getting profitable for the producer. Therefore, benefits and costs in dependence of output are put in contrast. Then the extent of output is being investigated which just brings benefits to the same level as costs. So the point is being determined where neither profits nor losses occur (=break even point). With lower output, costs are higher than benefits (=losses), with higher output, benefits are higher than costs (=profits).

The break even analysis is used within the scope of the stakeholder analysis in order to find out about the private-individual benefits and costs of users and to clarify if IVSS are profitable for users and OEMs. Benefits and costs of users are being examined in dependence of the covered vehicle mileage per year. It is assumed that benefits and costs are linear to the vehicle mileage. A low vehicle mileage means relatively high fixed costs and little benefit for IVSS, so that a loss occurs. A high vehicle mileage results in high benefits and low costs which is followed by a profit. In the break even point, benefits equal costs.

Figure 42: Break-Even Diagram for System Users (Own Figure)

In the chart, the break even analysis is operated for one year. A user with vehicle kilometres as shown in A (40,000 km) realises maximum net savings (= benefits) of IVSS, demonstrated by the green triangle. At the level of 10,000 km per year, the break even point is reached.

The private-individual benefits of the user accrue from the following cost savings:

- savings regarding avoided accident costs which are not covered by insurances,
- savings through rebates in insurance premiums due to smaller accident risks with IVSS,
• savings of motor vehicle operating costs because of improved traffic conditions with the use of IVSS,
• time savings through a better traffic flow,
• benefits of comfort for users.

In contrast to that, there are the following private-individual costs for IVSS to be seen:
• investment costs for IVSS,
• costs of operation and maintenance for IVSS.

The benefit and cost components used in the break even analysis are partly also present in the cost-benefit analysis. The difference is that in the cost-benefit analysis only the real benefits and costs are included, while the break even analysis considers the effective monetary savings and expenditures. This means in particular that in the break even analysis the flows of benefits and costs including taxes (fuel tax, value added tax) are calculated, while in the cost-benefit analysis taxes are treated as transfer payments and do not contribute to the parameters.

For the final assessment it is necessary to convert the costs and benefits into present value. At this stage the definition for which time period the BEA should be accomplished is relevant:
• If the BEA is performed on an annual basis then only the expenditure for IVSS has to be discounted to identify the present value. The other benefits and cost components represent annual values; therefore they have not to be discounted.
• If the BEA is performed for example for the average age of the vehicle fleet, then all future benefits and costs have to be discounted to identify the present value.

Discounting to get the present value can be done by the annuity factor. The annuity factor is given as:

\[
a = \frac{q \cdot (1 + q)^n}{(1 + q)^n - 1}
\]

with
\[
a = \text{annuity factor},
q = \text{interest rate divided by 100},
n = \text{economic service life of IVSS}.
\]

The choices of the interest rate and the life-cycle have a decisive influence on the amount of the annual benefits and costs. Therefore, it has been proposed that an average market interest rate and an average life-cycle are used, which can be expected as representative for the whole economic service life of IVSS. Then, the annual costs for the user of IVSS are the sum between annualised investment costs and discounted operating maintenance costs.

Furthermore, the break even analysis provides information about the willingness to pay of IVSS-users. The willingness to pay is limited by the prices for IVSS charged by car manufacturers which
may not be higher than the benefits for the users. A surcharge on benefits via benefits of comfort is allowed. In this respect, the price limit for IVSS is defined by the break even analysis.

4.2.2.3 Financial analysis

The financial analysis is an instrument which quantifies the financial impacts of an IVSS-application on revenues, expenditures and fiscal cash flow for a public authority. Public authorities have a strong interest in projects with regard to fiscal budget effects. The budget effects are of significant meaning for the political acceptance because negative influences on the financial situation are a barrier of application. Aim of the financial analysis is to resolve if public expenditures which are transacted for a project can be refinanced from revenues. Thereto, cash flows are established which result from IVSS.

The financial analysis is an additional calculation to the benefit cost analysis and considers monetary flow that is not included in CBA. CBA observes only real benefits and costs but no transfers as represented by cash flows. The financial analysis is only a matter of public’s revenues and expenditures. These are an important information for politicians who want to know which financial burdens result from a project and if these burdens are covered by revenues.

Also for the implementation of IVSS the question of budget effects comes up, i.e. revenues and expenditures for public authorities (Figure 43).

Tax revenues ensue from the following flows:

- The investment costs for IVSS raise prices for these systems. Manufacturers face higher volumes of sales and for this reason an increase of value added tax.
- Higher prices mean higher profits for manufacturers so that the income tax or the corporation tax rises.
- In the production, IVSS lead to more employment and income of employees which results in higher wage taxes.
- The higher incomes causes an increase of consume expenditures and therewith a higher value added tax and higher consumption taxes.
- The application of IVSS generates a saving of productive resources (among other things less accidents, less time costs, less motor vehicle operating costs). That makes the potential gross domestic product rise. Macroeconomic growth is connected with higher tax revenues.
Potential increases of public expenditures affect the following circumstances:

- A drop of tax revenues occurs if the implementation of IVSS is induced by financial incentives (tax reduction).
- Expenditure increases for public authorities arise if for the technical operability of IVSS certain infrastructures of information have to be established.
- Expenditure increases can also result from the emergence of administrative costs for the implementation of IVSS.

The financial analysis means a confrontation of public revenues and expenditures. If actions of encouragement which require money should be warranted over future years, financial means per year have to be discounted to the present value.

For the determination of tax effects, average rates of taxation are evaluated for income, wage and corporation tax; then they are multiplied by the tax assessment basis (profit, sum of salaries). Additional receipts from value added tax result from additional volume of sales of IVSS producers multiplied by the average value added tax rate.

The increases of expenditures respectively the decreases of revenues of public authorities are detected by multiplication of tax remissions per vehicle by the rate of market penetration with IVSS. Possible additional expenditures on infrastructure for IVSS must be estimated from case to case.
4.2.2.4 Input-Output-Analysis

The input-output-analysis is an instrument with whose help the number of employees who are needed for the production of the demanded IVSS can be determined. Employment is an important core factor political decision makers gear the worthiness of enhancing IVSS to. It is in this respect a crucial parameter for stakeholder analysis of public institutions. Employment effects do not emanate from cost-benefit analysis but must be investigated in an independent calculation with the input-output-analysis.

Value adding process

The employment effects caused by demand for IVSS result from the production of the systems. Demand for IVSS is here captured as an impulse that causes employment effects on all levels of the value-added process for IVSS (Holub, Schnabl, 1994: 16). The employment effects from the handling of IVSS are restricted to cost of repair after accidental damages and are very low. Hence, a calculation of the resultant employment effects is passed on.

Initially, employment effects arise at the manufacturers of the systems. But for the production of the systems, intermediate inputs from other companies are needed which on their part receive services and products from other companies and so on. That is why the production of IVSS not only causes employment effects at the level of producers of the systems but for all companies involved in the value-added process (Figure 44).

The production value of an adding value level is composed of received intermediate inputs and own adding value. From these increases in production, employment growth on all levels of adding value evolves.

The diverse effects are classified as follows:

- The effects which are originated at the level of the producers of the demanded products (here: production of IVSS) are called primary direct effects.
- Primary indirect effects are effects at companies on preceding steps of the production process (here: production of inputs for IVSS).
- Secondary effects are caused by consumption of incomes which evolved from the rise of production on the primary level. They will not be considered in the following.
Input-Output-Table

For the identification of the economic sectors being involved in the value-added process of a product, input-output-tables which are published by official statistics are suitable. Input-output-tables give a detailed overview over flows of goods and services on a value basis between different sectors within economy. They consist of three quadrants: in the first quadrant, the matrix of intermediate input is shown; in the second quadrant, the matrix of final demand is located; and in the third quadrant, the matrix of primary expenditures can be found (see table 1).

The matrix of intermediate input shows the linkage of inputs between different sectors of economy. In the schematic construction of an input-output-table as shown in table 1, an economy of two sectors is assumed for reasons of reduced complexity. While the rows list the output of a sector, the columns itemise the input that is needed for the creation of the output. According to this example, sector 1 delivers goods and services amounting to 80 units to the own sector and amounting to 90 to sector 2. However, sector 2 produces 150 units for sector 1 and a total amount of 30 for itself. All in all, sector 1 has an output of intermediate inputs in the amount of 170, sector 2 generates an intermediate input of 180. Sector 1 receives intermediate inputs of 230 units, sector 2 is being supplied with 120.
Table 28: Schematic Construction of an Input-Output-Table (Own Figure)

A part of both sectors’ produced goods and services is also manufactured for the final demand. The linkage of the producing sectors with final demand is shown in the matrix of final demand. It is attached right of the matrix of intermediate input in the second quadrant. Final demand is e. g. formed by consumption expenditures of private households, public consumption expenditures, gross investments of other enterprises as well as exports of goods and services. In the exemplary input-output-table (see Table 28), sector 1 produces next to intermediate inputs of 170 units also other products and services amounting to 210 units for the final disposal, thereof 110 for private consumption and 100 for export. The total output of sector 1 thus accounts for 380 units. All in all, the displayed 2-sector-economy produces amounting to 600 units.

In the third quadrant of an input-output-scheme expenditures are shown which are needed next to intermediate inputs for the production of goods and services, namely primary expenditures. All those services count as primary expenditures which are being rendered by the primary factors of production, i. e. incomes from dependent work, net profits respectively incomes of self-employees as well as depreciation. Beyond that, imports and indirect taxes are ranked among primary expenditures.

Because input-output-tables represent a closed circulation system, sector 1 has to receive a total input of 380 units in order to be able to render an output of that amount. Besides 230 units intermediate inputs, the supply of primary expenditures of 150 units is therefore needed. This supply is made up of employee wages (100) and imports (50). If intermediate inputs are added, the total production value (380) comes out.
By their construction of direct structural connections within an economy, input-output-schemes are the basis for different model calculations. Within the framework of this appraisal, it is to be analysed how a change in demand for goods for the last disposal – in this case the change of demand for IVSS – influences the production values in various branches of production of an economy.

**Input coefficients**

The increases in production on the first level of intermediate inputs – caused for example by an enhancement of the production of IVSS – can be calculated by creation of input coefficients on basis of input-output-tables. The input coefficients indicate with which proportions the different intermediate inputs and primary expenditures contribute to the production value of a sector. They are reckoned analogical to the values from Table 28 as follows:

<table>
<thead>
<tr>
<th>Sector</th>
<th>Sector 1</th>
<th>Sector 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sector 1</td>
<td>80 / 380 = 0.21</td>
<td>90 / 220 = 0.41</td>
</tr>
<tr>
<td>Sector 2</td>
<td>150 / 380 = 0.39</td>
<td>30 / 220 = 0.14</td>
</tr>
<tr>
<td>Production Value</td>
<td>380</td>
<td>220</td>
</tr>
</tbody>
</table>

Table 29: Calculation of Input Coefficients (Own Calculations)

An input coefficient of 0.39 for sector 2 as the producer of intermediate inputs and sector 1 as the receiver of intermediate inputs indicates that 39% of the production value of sector 1 (= 380) are based on intermediate inputs by sector 2. For an increase of production in sector 1 in 100 units, goods and services of sector 2 amounting to 39 units and of sector 1 amounting to 21 units must thus be applied on the first level of intermediate input.

All in all, the production value rises – through an increase of demand for goods of sector 1 in 100 units – by 160 units in consideration of the first level of intermediate input:

\[
\begin{align*}
100 & \quad \text{Primary Direct Increase of the Production Value in Sector 1} \\
+ 21 & \quad \text{Primary Indirect Increase of the Production Value in Sector 1} \\
+ 39 & \quad \text{Primary Indirect Increase of the Production Value in Sector 2} \\
160 & \quad \text{Total Increase of the Production Value of the First Level of Intermediate Input}
\end{align*}
\]

If analysis was limited to primary direct production effects as well as to primary indirect production effects of the first level of intermediate input, the calculation would be finished. Yet the producers of intermediate inputs themselves receive intermediate inputs from different sectors which again need intermediate inputs and so on.

For the calculation of production effects of an impulse of demand with inclusion of all levels of intermediate input, i.e. with inclusion of primary direct and all primary indirect increases in production, also schemes with inverse coefficients are released next to input-output-schemes. Inverse coefficients are based on the input coefficients mentioned above. In matrix notation, the matrix of inverse coefficients is (Statistisches Bundesamt: 2003):

\[
\text{Inverse Coefficients (Statistisches Bundesamt: 2003)}
\]
\[ C = (I-A)^{-1} \]
\[ I = \text{identity matrix} \]
\[ A = \text{matrix of input coefficients} \]

In order to identify the increase in added value of the particular sector, the calculated production values must therefore be multiplied by the sectoral share in added value which likewise can be deduced from the input-output-schemes. Then, one obtains the effects of increasing demand on macro-economical added value.

**Sectoral labour coefficients**

The employment effects through demand for IVSS that have to be detected can subsequently be acquired on basis of production enhancement (production value or added value) with the help of sectoral labour productivity:

\[ P_J = \frac{O_J}{E_J} \]

\[ P_J = \text{labour productivity of sector J} \]
\[ O_J = \text{output of sector J} \]
\[ E_J = \text{number of employees in sector J} \]

As output \( O_J \), the factor must be chosen that also handles the quantification of increases in production (production value or added value). The number of employees in a certain sector ascribable to the increase in demand is then calculated as follows:

\[ \Delta E_J = \frac{\Delta O_J}{P_J} \]

\[ \Delta E_J = \text{number of employees necessary to yield the modified output } \Delta O_J \]
\[ \Delta O_J = \text{modification of the outputs of sectors J} \]
\[ P_J = \text{labour productivity of sectors J} \]

**4.2.2.5 Incidence analysis**

The incidence analysis is an instrument that can identify social impacts of IVSS on the distribution of income. There are two distribution effects: On the one hand, there is a deprivation effect on income through acquisition costs; on the other hand, IVSS have an allocation effect on income through resource savings. The analysis of effects is
carried out in a differentiated way with income groups, i.e. with recipients of high and low incomes. The incidence analysis derives from public finance theory and is applied to distribution effects of public projects. Thereby, “incidence” stands for the final resting place of an action, i.e. it is investigated which income group profits from the action and which income group the action is financed by. It makes a statement about the social compatibility of IVSS.

The incidence analysis is an additional calculation of the cost-benefit analysis. In the cost-benefit analysis, some factors are included (e.g. external benefits and private items of IVSS) that address the incidence analysis. But the determining thing is the continuation by the incidence analysis while a differentiation of benefits and costs in terms of income groups occurs. By that, a statement is made about which income group – the rich or the poor – benefits more or is charged more from IVSS. The result of the incidence analysis is here an important criterion for public authorities which have to consider the social balance of its decisions.

**Households’ expenditures for IVSS**

In the framework of incidence analysis, the first step is to put the acquisition expenditures for IVSS into relation to total expenditures of a private household. The total expenditures of private households with their purposes of usage are investigated for selected years by samples of income and consumption of official statistics. In this calculation, the share of expenditures for IVSS in household incomes on the different income categories is detected. Furthermore, it can be specified which share expenditures for IVSS have in expenditures for motor vehicles. Since the data refer to monthly expenditures, investment costs for IVSS have to be transformed into monthly expenditures. The calculation steps of the evaluation of shares of IVSS and the change in relative motor vehicle costs of an IVSS are shown schematically in Table 30.

<table>
<thead>
<tr>
<th>Income per Household and Month (Euro)</th>
<th>Expenditures for Motor Vehicles (Euro)</th>
<th>Share of Expenditures for Motor Vehicles in Households’ Net Income without IVSS (%)</th>
<th>Relative Surplus Burden because of IVSS as measured by Household Income</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 30: Expenditures of private households for motor vehicles related to household income and change in relative motor vehicle costs referring to the purchase of an IVSS (Own Figure)
From the changes in share of expenditures for motor vehicles it can be deduced which group of income recipients is charged more or less by the purchase of IVSS. Thereby, a statement on regressive or progressive distribution effects is possible.

**Willingness to purchase IVSS subject to income**

In the second step, it has to be clarified empirically how high the willingness to purchase IVSS is subject to the income of the households. That leads to determination of which income group is involved in financing expenditures for IVSS predominantly. The empirical correlation is built here in two steps: First, the willingness to pay for IVSS is appraised subject to the expenditures for the purchase of a passenger car. Second, the connection between choice of the purchased passenger car and income level is found out.

- The dependence of willingness to pay for IVSS on the purchased passenger cars leads to the assumption that drivers of upper class vehicles have a high willingness to pay for technical innovation. This is shown in Figure 45 which illustrates willingness to pay subject to different vehicle segments. The higher the value of a vehicle, the higher is the willingness to pay for IVSS.

![Figure 45: Willingness-to-pay for New Vehicle Technologies in Dependence of Passenger Car Segments (McKinsey & Company, Technische Universität Darmstadt – Institut für Produktionsmanagement, Technologie und Werkzeugmaschinen, Verband der Automobilindustrie (VDA), HAWK 2015 – Knowledge-based changes in the automotive value chain, Frankfurt 2003)](chart)

- The influence of income on the choice of the purchased passenger car is characterised by a positive correlation: the higher the income, the higher the expenditures for a purchase of a passenger car.
As a result, groups of persons with a high income will have a relatively higher share in expenditures for IVSS than those with lower income.

**Distribution of benefits of IVSS to the income groups**

Within the scope of incidence analysis, a third step shows which income groups benefit most from IVSS. That is important for the question if IVSS have progressive or regressive effects. If recipients of high incomes have the benefits, IVSS work reggressively. If recipients of low incomes have the benefits, IVSS function progressively.

Regarding benefits of IVSS, internal and external benefits have to be distinguished. Internal benefits arise for the users of IVSS and are the equivalent to the expenditures. The internal benefits have no distribution effect because the bearers of benefits and expenditures are identical. To internal benefits belong saved motor vehicle operation costs, internal accident costs and the enhancement of driving comfort.

External benefits accrue for a third party or for society. They execute a distributional effect. They consist of saved time costs, fuel savings for vehicles without IVSS, savings of CO₂-emissions, savings of pollutants and external (i.e. uninsured) accident costs.

Problematic about this division is the category of saved accident costs. Property damages are regarded by the causer and the victim of an accident as internal costs because they are paid by the accident causer or his or her insurance. Also personal injury costs of the accident victim are internal costs because they are borne by the accident causer’s third party liability insurance. Only the personal injury costs of the accident causer are incurred by private or compulsory insurance, employers’ liability insurance associations or the like so that they represent external costs. These have to be considered in the incidence analysis.

Crucial for the distribution effects of saved costs is the question which income groups are affected by the benefits of IVSS. For this, empirical investigations have to be conducted. For a first approximation, the following hypotheses can thereby be valid:

- For external accident cost savings, a regressive effect with disadvantages for recipients of low incomes could be assumed. IVSS are predominantly used by above average earners. The external benefits in terms of personal injury costs of the accident causer are passed on to total population via compulsory insurance systems. However, it must be considered here that the recipients of high incomes also have to pay higher dues to compulsory health insurance and by that should profit disproportionately high from the cost savings. This argues for an effect that is neutral concerning income distribution and that has no impact on the relative income position.

- The saved time costs because of IVSS do not affect society in total but only road users. For the distribution of time savings, mileages subject to income have to be known. There are empirical evidences from Germany about this (Deutsches Institut für Wirtschaftsforschung (DIW), Infos, Institut für angewandte Sozialwis-
senschaft, 2002). According to them, the mileages of households with higher income are clearly higher than those of recipients of low incomes.

<table>
<thead>
<tr>
<th>Net Household Income (Euro)</th>
<th>Average yearly Mileage per Household (km)</th>
<th>Share in all Households in Germany (%)</th>
<th>Share in yearly Mileage in Germany (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 900</td>
<td>5,757</td>
<td>12.20</td>
<td>3.63</td>
</tr>
<tr>
<td>900 - 1,499</td>
<td>10,158</td>
<td>22.28</td>
<td>11.70</td>
</tr>
<tr>
<td>1,500 - 1,999</td>
<td>15,987</td>
<td>19.36</td>
<td>16.00</td>
</tr>
<tr>
<td>2,000 - 2,599</td>
<td>22,468</td>
<td>17.51</td>
<td>20.33</td>
</tr>
<tr>
<td>2,600 - 2,999</td>
<td>27,721</td>
<td>8.75</td>
<td>12.53</td>
</tr>
<tr>
<td>3,000 - 3,599</td>
<td>30,137</td>
<td>7.96</td>
<td>12.40</td>
</tr>
<tr>
<td>&gt; 3,600</td>
<td>37,942</td>
<td>11.94</td>
<td>23.41</td>
</tr>
</tbody>
</table>

Table 31: Distribution of total mileage on household groups regarding income (Deutsches Institut für Wirtschaftsforschung (DIW), infas Institut für angewandte Sozialwissenschaft; 2002)

The mileage shares have to be equated with the distribution of benefits through time savings with IVSS. The distribution of advantages through time savings benefits households with high income disproportionately. That is why households with less than 900 Euro monthly income constitute about 12 % of households in Germany. But these participate in yearly mileages in road traffic with only 4 %. The other way around, the highest income group participates with 23 % in total yearly mileage in Germany although only circa 12 % of households belong to it.

This effect is even enforced due to the fact that the monetary value of time savings is not constant. The individual time value of persons depends, in addition to other factors, also on income. The time value rises with increasing income.

As a result, it can be recorded that the time savings of IVSS are neutral regarding the distribution of income. The burden of costs is borne disproportionately high by the recipients of high incomes who also benefit from time savings disproportionally high.

- The savings in CO₂-emissions of IVSS reduce global warming and insofar globally provide undifferentiated benefits. These benefits are distributed equally between different income groups. Given the fact that IVSS are in relatively bigger parts financed by groups of persons with high income, a progressive distribution effect results from which the recipients of lower incomes profit relatively more.

- The savings in pollutant emissions of IVSS work comparably progressive like the benefits from CO₂-savings. This is mainly valid for the avoidance of spatially undifferentiated effects of pollutants (e.g. on vegetation). From this, the entirety of population profits in equal parts. Beyond that, pollutant emissions cause damages on the close environment of the emission sources (e.g. human beings and buildings). Persons living in the near proximity of frequently used roads therefore can profit from pollutant savings disproportionally. These are rather the recipients of lower incomes. The distribution effect is therefore neutral or progressive.

Total incidence of IVSS
All in all, the total incidence of distribution effects of IVSS is shown (table 4). The distribution effect of expenditures for IVSS as a reason for decreasing income faces the distribution of benefits as a reason for increasing income, the total distribution balance and the shares of the different components of benefit in total benefit of IVSS.

<table>
<thead>
<tr>
<th>Distribution of expenditures</th>
<th>Distribution of benefits from IVSS</th>
<th>Total distribution effect</th>
<th>Share in total benefit from IVSS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time savings</td>
<td>Increasing involvement of strong income groups</td>
<td>Neutral</td>
<td></td>
</tr>
<tr>
<td>External fuel savings</td>
<td>Increasing involvement of strong income groups</td>
<td>Neutral</td>
<td></td>
</tr>
<tr>
<td>Savings in CO₂ and pollutants</td>
<td>Proportional</td>
<td>Progressive</td>
<td></td>
</tr>
<tr>
<td>External accident costs</td>
<td>Increasing involvement of strong income groups</td>
<td>Neutral</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 46: Distribution effects of IVSS (Own Figure)**

Because of the hypotheses-like relations, incidence statements evolve in table 4 which should be investigated separately within the scope of the project. The example examined here uncovers a wide neutrality or a progression of the distribution effects of IVSS. Therefore, IVSS do not lead to a distribution effect that is opposed to the social aim.
5 Interpretation guideline for assessment results

The socio-economic assessment performed in eIMPACT aims at a comprehensive evaluation of selected IVSS by using different broadly-accepted analytical methodologies. For decision-making, the individual results of the various assessment tools have to be incorporated into an overall socio-economic evaluation of the safety systems. Hence, the outcomes of

- the cost-benefit analysis,
- the macroeconomic impact analysis,
- the distributional impact analysis,
- the break-even analysis and of
- the financial analysis

have to be accounted for in a synthesis of results. In general, this synthesis can be performed using the three following alternative approaches (Figure 47):

**Socio-economic Impact Assessment**

<table>
<thead>
<tr>
<th>Society Perspective</th>
<th>Stakeholder Perspective</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost-Benefit Analysis</td>
<td>Macroeconomic Impact Analysis</td>
</tr>
<tr>
<td>Distributional Impact Analysis</td>
<td>Break-Even Analysis</td>
</tr>
<tr>
<td>Financial Analysis</td>
<td></td>
</tr>
</tbody>
</table>

**Synthesis Alternative 1**

Independent Overview of Individual Assessment Results

**Synthesis Alternative 2**

CBA-Results as Core Element with Other Assessment Results as Satellite Results

**Synthesis Alternative 3**

Consideration of Individual Assessment Results in a Common Decision Path Approach

**Figure 47: Basic Alternatives for Synthesis of Results (Own Figure)**

1. One approach of result synthesis is giving an independent overview of the individual assessment results for IVSS. This overview displays the different evaluation outcomes side-by-side. Hence, a relationship between the results or even a consolidation of the results is not established.

2. Alternatively, a synthesis can be achieved on a base level by the taking CBA-results as the core element of the assessment approach. This stresses the importance of the profitability proof whereas the results of the other individual assessment methodologies are considered as satellite results.

3. The development of a common step-by-step “path of decision” is the most progressive approach for a feasible result synthesis. The results of the analytical methodologies used are combined by es-
establishing a sequence of results. This decision path approach considers the importance of each individual evaluation result within the whole socio-economic assessment.

Each of the three different approaches for result synthesis features advantages as well as disadvantages. Whereas the independent overview of the individual assessment results (approach 1) actually offers no benefit in comparison to the single treatment of each result, the introduction of a satellite system of results (approach 2) gives the decision-maker a further developed synthesis of results which underlines the importance of the CBA using it as a core element. The consideration of the individual assessment results in a common decision path approach (approach 3) combines the practicability for the evaluators with the benefit for the decision-maker who gets hold of a comprehensive, yet comprehensible orientation. Thus, the synthesis of assessment results in eIMPACT is based on this decision path approach.

The decision path approach for the synthesis of the different assessment results aims at giving an overall evaluation and orientation to the decision-maker. The approach clearly defines a sequence of decision rules to be followed in the socio-economic assessment (Figure 48).

The CBA is the core element of the socio-economic assessment developed in eIMPACT. Hence, the results of the CBA are the main results of the assessment and should be taken as basis for decision-making. In order to take the results of the additional methodologies used for evaluating IVSS (analysis of macroeconomic and distributional impacts, break-even and financial analysis) into consideration, each evaluation result has to be reviewed regarding the direction of the IVSS´ impact evaluated, i.e. the algebraic sign of the effect (e.g. the overall effect on employment). If one of the impacts appears to be a negative effect (e.g. job losses), the IVSS should be considered as “problematic” from a societal point of view or even eliminated.

In case all impacts linked to an IVSS are positive, the system is further compared with other safety systems. As a consequence, a choice or at least ranking of the safety systems has to be performed to ensure priorisation. For this aim, the decision path approach pro-
vides a hierarchy of results for consideration based on the importance of each evaluation methodology for the overall socio-economic assessment (Figure 49).

1. Objective: How does the IVSS contribute to resource savings?

2. Objective: Where is the profit threshold (break-even point) for the IVSS-users and OEM?

3. Objective: What volume of financial costs and revenues of the IVSS are borne by public authorities?

4. Objective: What volume of macroeconomic impacts can be expected from the IVSS?

5. Objective: How does the IVSS-related distribution of incomes among the members of society look like?

Figure 49: Hierarchy of Results for Consideration within the Decision Path Approach (Own Figure)

1. The approach primarily takes into account how the IVSS contribute to resource savings. The resource savings are calculated within the CBA. From the society’s point of view, the safety system should be introduced, promoted and deployed which have a benefit-cost ratio higher than “1”. According to the methodology of the CBA, the higher the benefit-cost ratio, the higher the efficiency of the IVSS.

2. If two or more systems are valued (almost) equally within the CBA, the benefits and costs to be borne by IVSS users and OEMs being one group of stakeholders are taken into consideration in the next step of the synthesis. Hence, the overall assessment is based on the results of the break-even analysis. Since the objective of the break-even analysis is the determination of the break-even point where the expenditures for IVSS are reimbursed by their benefits, the IVSS with the lower break-even point should be concentrated on in decision-making.

3. The financial impacts on public authorities are accounted for next. The volumes of financial costs and revenues of the acting institution have to be compared between the IVSS evaluated. The safety system which revenues exceed its costs should be approved. In case that the revenues of more than one IVSS exceed the financial costs, the IVSS with the higher ratio of revenues to costs should be promoted.

4. If the financial impacts of the different IVSS evaluated feature a similar impact level, the decision path approach considers the systems’ macroeconomic impacts afterwards. The IVSS with the wider economic impacts expected in terms of volume should be chosen by the decision-maker.
5. The result synthesis of socio-economic assessment is completed by the consideration of the findings of the distributional impacts analysis. Here, the income effects of each IVSS allocated to the individual society members are compared with the desired distributional effects from a society’s viewpoint.

The decision path approach described offers a sound and comprehensive synthesis of socio-economic assessment results for IVSS by following a sequence of decision rules. Since decision-making is primarily based on the traditional CBA, its key importance is illustrated within this approach. However, the impact assessment results for different stakeholder groups (system users, OEMs, insurance companies, public) are additionally taken into consideration and endorse the CBA by a sequence of results which is based on the individual importance of the different state-of-the-art evaluation methodologies applied in eIMPACT. Each individual evaluation outcome therefore contributes to the overall socio-economic assessment of IVSS.
6 Exemplary Calculation: ACC

**Functional description for the example ACC**

In this deliverable an example IVSS shall make the CBA process evident. As example system the *Adaptive Cruise Control (ACC)* was chosen. ACC is a system which measures the time gap to the vehicle in front and compares it with the headway. The headway is a function which contains the velocity of the vehicle, the difference speed of the vehicle and the vehicle in front, and the time gap between them. When the time gap is too small, ACC delays the vehicle with a maximum deceleration of 2.5 m/s². When a harder braking manoeuvre is required, ACC warns the driver through a message on the display, by audio or by haptic signals. ACC works currently for velocities above 30 km/h. Extended versions such as FSR ACC are able to operate at any speed.

ACC can relieve the driver from his driving task. Hence, ACC represents a comfort system. Regarding safety impacts, ACC helps to prevent rear end and chain accidents and to mitigate their consequences. Vehicles moving in opposite direction and obstacles are not considered by ACC. Curves with a low radius can not be considered as well.

The technical description mentions the required components for ACC. ACC is based on ESP/ESC, needs a speed control and an automatic drive. These are systems which every vehicle owner can buy for his car without having an ACC. So the new component of ACC is a sensor (radar). Depending on the manufacturer there has to be built in a new HMI. This information is relevant for the system costs used for CBA. For this conceptual case study, the net price for ACC is estimated – in conformity with the SEiSS study – to 400 Euro in 2010 and 240 Euro in 2020.

ACC is defined as a comfort issue. The system relieves the driver. ACC can reduce rear end and chain accidents. This information is relevant for the benefits.

There are three more interfaces between the functional descriptions and the CBA. But these are indirect interfaces, i.e. there is an interface between work package 1000 and another work package which has an interface to the CBA. These interfaces are the *market scenarios* (see also 3.2.2), the *impact assessment: safety* (see also 3.2.3) and the *impact assessment: traffic* (see also 3.2.4). They need for their calculations information from work package 1000.

**Market Penetration ACC**

ACC systems are already on the market, but they are only available for upper segment vehicles so far. Though it was introduced in different markets several years ago (Japan 1995, Europe 1998, USA 2000), its market penetration is still on a very low level. A recent study estimated an aggregated fleet penetration rate of 1 % for cars in 2006 (COWI 2005: 83). Based on the prediction in the SEiSS study, it is furthermore presumed that the market penetration rate will rise even if a business as usual scenario is implied (see Table 32 below). In
2010, an estimated share of 3% of all cars will be equipped with ACC. This rate will have increased to 8% in 2020. However, the increase is comparatively moderate due to a supposed high consumer price per unit (2010: 750 €, 2020: 400 €). Hence, financial incentives by public authorities can provide a chance to stimulate the market penetration. Such a public promotion implied, a second scenario with implementation support is generated (eSafety Forum Working Group Road Maps 2005: 58). This scenario assumed, the market penetration rate will increase to 4.5% in 2010 and 15.2% in 2020 respectively. Table 32 exhibits the values of these penetration rates for 2010/2020 as well.

<table>
<thead>
<tr>
<th>ACC (EU-25)</th>
<th>Market Diffusion Rate in %</th>
<th>Equipped cars in million</th>
<th>ACC Performance in % of total veh-km</th>
</tr>
</thead>
<tbody>
<tr>
<td>No specific incentives</td>
<td>1.0% 3.0% 8.0%</td>
<td>2.27 7.17 20.93</td>
<td>2.0% 5.9% 15.3%</td>
</tr>
<tr>
<td>Focused incentives to promote rollout</td>
<td>1.0% 4.5% 15.2%</td>
<td>2.27 10.75 39.76</td>
<td>2.0% 8.9% 27.9%</td>
</tr>
</tbody>
</table>

The eSafety Forum Working Group Road Maps estimated fleet penetration rates for an ACC system with additional safety functions. The values are re-assessed without these functions and adjusted to the ACC system presented in the SEiSS study.

<table>
<thead>
<tr>
<th>Table 32: Market Diffusion, Equipped Cars and Performance in % of Total Veh-km of ACC (SEiSS 2005, COWI 2005, eSafety Forum Working Group Road Maps 2005, Own Calculations)</th>
</tr>
</thead>
</table>

The public support will be able lift the penetration rate in each year, but as shown in Figure 50, it will not be enough to reach a higher diffusion level. Though nearly 40 million cars will be equipped in the implementation support scenario, the penetration rate will not reach a medium diffusion level in 2020.

<table>
<thead>
<tr>
<th>ACC - EU 25</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very high</td>
</tr>
<tr>
<td>High</td>
</tr>
<tr>
<td>Medium</td>
</tr>
<tr>
<td>Low</td>
</tr>
<tr>
<td>Very low</td>
</tr>
</tbody>
</table>

![Figure 50: Classification of Market Penetration Rates (Own Figure, cf. eSafety Forum Working Group Road Maps 2005)](image)

Taking the performance in percentage of the total vehicle kilometres in consideration, a fleet penetration rate of 8% in 2020 will represent more than 15% of the driven kilometres. The implementation support scenario with a diffusion rate of 15.2% will contain nearly one third of all driven kilometres.
Safety Impact ACC

The time correlation of the majority of the IVSS can be helpful to estimate the safety potential of each system (Abele et al. 2005: 44ff.). Depending on in which driving or accident phase a system works (e.g. during a pre-crash phase: emergency brake by Emergency Braking or night vision for standard driving), time savings gained from the system’s use can enable the driver to minimise the crash risk or the crash consequences. These time savings or losses can be matched to the different accident/collision types. For example, Enke investigated the time correlation for collisions at intersections, collision with oncoming traffic and rear end collisions (see Figure 51).

Figure 51: Collision Probability Related to the Shift Forward of Driver Reaction (Enke 1979)

The collision probability decreases with every millisecond the driver or the vehicle has in addition to react earlier or faster. After a standardisation of these time gains for different crash phases, speeds, and accident types, such graphs could be derived from accident causation analysis. The green line is an example for a positive time saving of 500 milliseconds. On average for all three illustrated collision types, this would halve the crash probability for collisions at intersections, collisions with oncoming traffic and rear end collisions. A similar study investigating the accident probability of hazard warning systems underlined the correlation of shift forward of driver reaction and collision probability (Widodo, A./Hasegawa, T. 2000).

But not only can a crash risk be lowered, even if an accident occurs, the use of IVSS can mitigate the crash consequences. The accident severity decreases according to cascade model. That means, fatalities would be shifted to severe injuries and severe injuries would be reduced to slight injuries. The final calculation on accident severity should be made for impact speed based on time patterns, so that the available individual time gains or the energy absorption potentials related to speed can be transformed into the remaining impact speed. The collision severity probability can be illustrated against the impact
speed of a vehicle (Figure 52). By the means of such curves, the specific accident severity impact of each IVSS can be determined on a standardised basis, these curves should be calculated in cooperation with accident causation analysis experts.

![Figure 52: Accident Severity Based on Impact Speed (Own Figure, cf. Hannawald et al. 2005)](image)

In order to estimate the safety impact of ACC, the relevant accident types have to be assigned. ACC influences chain or rear end collisions, which are a frequent type of accident on European roads. An in-depth study of rear end collisions for ten countries of EU-15 (SWOV 2003) based on the CARE database has shown that those accidents account for an average of 13 % of all accidents. In several studies an ACC safety potential was identified. Table 33 delivers insight to the varying results of those studies.

<table>
<thead>
<tr>
<th>Study</th>
<th>Percentage change in the number of rear end collisions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Malatterre/ Fontaine (1993)</td>
<td>-45</td>
</tr>
<tr>
<td>Farber/Paley (1993)</td>
<td>-50</td>
</tr>
<tr>
<td>Chira-Chavala/Yoo (1994)</td>
<td>-52</td>
</tr>
<tr>
<td>Asher/Galler (1997)</td>
<td>-50</td>
</tr>
</tbody>
</table>

The results suggest a safety potential of an average of 50% avoided rear end collisions. The safety potentials in the studies were not differentiated in the above mentioned direct and indirect mechanisms. Therefore, potential indirect effects which are maybe not included in these numbers, could lower the effectiveness of ACC.

An alternative way to estimate the safety potential is given in the SEiSS study with the time savings model. According to Figure 51, the time gains for ACC can be derived. The estimated time savings enable the driver to react faster and better, because ACC operates in the driving, warning and assistance phases. Less vehicle speed can lead to crash prevention or at least to a reduced crash impact, which determines the injury severity. Using ACC, the driver could gain up to 0.5 seconds due to early warning. But it has to be considered that the system does not detect all problems and is not permanently used. Regarding all problems mentioned in the SEiSS study, an aggregated attainable time savings of 0.2 seconds is estimated (Abele et al. 2005: 114). Thereby, 25% of all rear end collision can be avoided. In addition, the time savings have an influence on the crash impact and therefore on the severity of accidents which can not be avoided. Based on the assumptions in the SEiSS study, a speed reduction of 10 km/h translates into a shift in the accident severity cascade. It is assumed, that 20% of accidents can be shifted down a severity class: 20% fatalities become severe injuries and 20% of severe injuries become slight injuries. A shift from slight injuries to no injuries is excluded. By the means of these effectiveness rates and the accident data, the total number of fatalities, severe and slight injuries can be calculated.

ACC and its impact on the traffic

The physical impacts of ACC are not limited to safety impacts. As ACC maintains the distance to a preceding vehicle, it can also contribute to traffic flow effects. The gap between vehicles can be expressed either in terms of distance or time. Assuming a velocity of 120 km/h (this is equivalent to 33.33 m/s), a headway of 1.2 s and no gap at standstill, the distance between the vehicles amounts to 40 m (headway: 1.2 s). Obviously, this is less than the legally recommended safe distance (headway: 1.8 s). For instance in Germany, most of the measured headways lie between 1.0 s and 1.2 s. In almost 40% of all cases the headway is even measured below 0.9 s (IKA 1995).

Empirical measurements from different European member states show that there is a tendency to apply short headways or distances respectively. The study by Ellinghaus and Steinbrecher (2000) defines distances as hazardous when the gap is smaller than a fourth of velocity, e.g. when the velocity is assumed with 120 km/h, distances below 30 m will be classified as hazardous. Figure 53 shows the share of hazardous distances for three countries (Germany, France and Italy) and two traffic environments (conurbation, outside conurbation). Obviously, the distances in real traffic are smaller in conurbation than outside of it. This holds true at least for France and Italy. In Germany however, the share of hazardous distances outside conur-
bation is significantly higher than in France and Italy. This effect may be due to a different driving style and risk perception.

![Figure 53: The Share of Hazardous Distances for Germany, France and Italy (Ellinghaus and Steinbrecher: 2000). Note: The Lower End of the Bars Represent the Minimum Value and the Upper End of the Bars the Maximum Value.](image)

Several studies have investigated the traffic impact of ACC. The most common variables that were investigated are the impact of ACC on capacity (throughput, in vehicles/hour), on average travel time and on the standard deviation of travel time. Table 34 provides an overview over the results of selected studies from the past 15 years. Although the results are different concerning the size of impacts there are some general conclusions which can be drawn. The capacity effect of ACC depends largely on the equipment rate and the headway settings. The impact is positively correlated with the equipment rate: the higher the penetration, the higher the impact. Concerning the direction of the impact, it can be stated that for smaller headways than 1.2 s positive capacity effects were found. Furthermore, travel time tended to be higher whereas its standard deviation tended to be smaller. This illustrates that in situations when traffic will not be faster, the traffic flow will become more homogeneous.
## Target Variables

<table>
<thead>
<tr>
<th>Authors</th>
<th>Headway setting</th>
<th>Equipment rate</th>
<th>Target Variables</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Capacity (Throughput)</td>
<td>Travel time average</td>
</tr>
<tr>
<td>Broqua (1991)</td>
<td>1.0 s</td>
<td>20%</td>
<td>X</td>
<td>+6%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>40%</td>
<td>X</td>
<td>+13%</td>
</tr>
<tr>
<td></td>
<td>2.0 s</td>
<td>20%</td>
<td>X</td>
<td>-6%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>40%</td>
<td>X</td>
<td>-13%</td>
</tr>
<tr>
<td>Minderhout/Bovy (1999)</td>
<td>1.0 s</td>
<td>10%</td>
<td>X</td>
<td>0%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>20%</td>
<td>X</td>
<td>+2%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>50%</td>
<td>X</td>
<td>+4%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>100%</td>
<td>X</td>
<td>+4%</td>
</tr>
<tr>
<td></td>
<td>1.2 s</td>
<td>10%</td>
<td>X</td>
<td>0%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>20%</td>
<td>X</td>
<td>-1%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>50%</td>
<td>X</td>
<td>+1%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>100%</td>
<td>X</td>
<td>+1%</td>
</tr>
<tr>
<td>Benz et al. (2003)</td>
<td>1.0 s</td>
<td>10%</td>
<td>X</td>
<td>+0.6%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>20%</td>
<td>X</td>
<td>+1.3%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>40%</td>
<td>X</td>
<td>+2.7%</td>
</tr>
<tr>
<td>Van Arem et al. (1996)</td>
<td>1.0 s</td>
<td>20%</td>
<td>X</td>
<td>+0.5%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>40%</td>
<td>X</td>
<td>+0.9%</td>
</tr>
<tr>
<td></td>
<td>1.5 s</td>
<td>20%</td>
<td>X</td>
<td>+1.6%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>40%</td>
<td>X</td>
<td>+4.0%</td>
</tr>
<tr>
<td></td>
<td>1.0 s</td>
<td>20%</td>
<td>X</td>
<td>-0.8%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>40%</td>
<td>X</td>
<td>-2.2%</td>
</tr>
<tr>
<td></td>
<td>1.5 s</td>
<td>20%</td>
<td>X</td>
<td>-1.3%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>40%</td>
<td>X</td>
<td>+1.0%</td>
</tr>
<tr>
<td>Marsden et al. (2001)</td>
<td>1.2 s</td>
<td>20%</td>
<td>X</td>
<td>-0.7%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>40%</td>
<td>X</td>
<td>+1.7%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>70%</td>
<td>X</td>
<td>+2.3%</td>
</tr>
<tr>
<td></td>
<td>1.5 s</td>
<td>20%</td>
<td>X</td>
<td>-0.1%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>40%</td>
<td>X</td>
<td>+0.7%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>70%</td>
<td>X</td>
<td>+2.6%</td>
</tr>
</tbody>
</table>


Following these effects, the impact to the emission ejection will be positive because of reducing abnormal accelerations or decelerations. Due to the harmonizing impact the number and the heaviness of congestion will be reduced. The higher the penetration rate, the higher is the traffic impact.
Against the research background of eIMPACT – European scale impact assessment of IVSS – the upcoming question is whether the results will be valid for the traffic situation in different European countries. There are different infrastructure layouts (e.g. lane width, hard shoulder), speed limits and also driving attitudes. This makes it difficult to scale up simulation results to the European level.

On the other hand, the investigation of traffic impact needs the support from micro simulation. Typically, the simulations are built on real traffic measurement data of smaller scale road networks which however are representative for traffic situations on motorways, rural or urban roads in Europe.

Hence, this general procedure is also proposed for eIMPACT. The real measured situation represents the without-case. The with-case will be simulated taking into account the functional specifications of the system and the legal framework.

In order to calculate this demonstrational case study it is assumed that the road capacity is increased by 0.3 % in the year 2010 respectively 0.6 % in the year 2020. Due to this increase of the road capacity the fuel consumption, the emission ejection of carbon dioxide and of other emissions can be reduced. The example calculation for ACC will be done in the next section.

System Benefits ACC

ACC makes use of the numbers and effects which have been described in particular in the sub-chapters of 3.2. and 3.3. This information represents the basic set of data for the case study which is computed here. ACC has a safety impact and a traffic impact. Hence, there are benefits due to a reduction in accidents, benefits due to a reduction in operating costs, and benefits due to a reduction in the emissions (pollutants and carbon dioxide).

Reduction in Accidents

In a first step the accident data for the case status quo is estimated for the years 2010 and 2020 for the example country Germany. Due to the fact that ACC is already on the market, the estimated values have to be corrected in a second step. The effects due to ACC have to be extracted and summed to the accident data. The result is the accident data for the years 2010 and 2020 for the case that no vehicle is equipped with ACC. In the last step the absolute reduction potential of ACC for avoided accidents with personal injuries, for fatalities, severe injuries and slight injuries for the accordant penetration rates for the years 2010 and 2020 is estimated.

In the last years traffic is continuously getting safer (BMVBW 2004, BMVBS 2005):

- The annual reduction rate of the fatalities is 3.5 % for the period 1992 till 2003.
- The annual reduction rate of the severe injuries is 2.9 % for the same period. This trend proceeds even for the years 2004 and 2005.
The number of accidents with personal injuries decreases to 336,619 or to 0.57 accidents with personal injuries per one million vehicle kilometres.

The number of fatalities decreases to 5,361 or to 15.93 fatalities per one thousand accidents in the year 2005. In the year 2004 the value was 17.22 fatalities per one thousand accidents.

The number of fatalities decreases by 3.5% on average during the last years (BMVBW 2004). In the year 2005 there were 5,361 fatalities. Given the decrease rate of 3.5% per year, in the year 2010 there are 4,487 fatalities and in the year 2020 there are 3,142 fatalities. The number of severe injuries decreases by 2.9% on average during the last years (BMVBW 2004). In the year 2002, there were 88,382 severe injuries. Given the decrease rate of 2.9% per year, in the year 2010 there are 69,843 severe injuries and in the year 2020 there are 52,037 severe injuries.

The number of slight injuries depends on the figure slight injuries per fatality. This figure has a significant trend. Despite of continuous road safety improvements this figure is increasing during the time. Hence, a linear regression with the time as only independent variable is done to calculate the ratio for the years 2010 and 2020. The adjusted R-square is 0.817. The F-value is 57.929, so the regression equation is significant to the 0.999 level. For the year 2010 the result of the linear regression is a ratio of 75.258 slight injuries per one fatality. So the number of slight injuries is 337,683 (4,487 * 75.258). The ratio for the year 2020 is 97.209 slight injuries per one fatality. The total number of slight injuries in the year 2020 is 305,431. The increase in the trend is due to safer vehicles and due to other safety systems. Safer vehicles and the accordant safety systems avoid accidents and therewith fatalities and injuries. The other benefit is that accidents, which can not be avoided, are not as severe as without the technical progress. The result is a shift from fatalities to severe injuries and from severe injuries to slight injuries. But there is no shift from slight injuries to uninjured. This is due to the fact that accidents with uninjured are not in injury accidents any longer. Thus, the number of slight injuries per fatality increases.

The last unknown figure is the number of accidents with personal injuries. This figure can be calculated by using the ratio injuries per accident. This ratio is constant during the last years. In the middle, 1.3118 injuries occur per one accident with personal injuries. The number of injuries can be calculated by summing the values for slight injuries and severe injuries. In the year 2010 there are 407,526 injuries. This value has to be divided by 1.3118 to get the total number of accidents with personal injuries. The result is 310,662. The accordant value for the year 2020 is 272,502 accidents (357,468 / 1.3118). So the number of accidents is decreasing during the time. This trend is due to safer vehicles and it is approved by the literature (BMVBW 2004, BMVBS 2005).

The number of accidents with personal damage and the number of casualties are displayed in Table 35. These values are valid for the assumption that the market penetration of ACC in the years 2010 and 2020 equals the market penetration of the year 2005 (status quo).
Table 35: Number of Accidents and Number of Casualties - Scenario Status Quo (BMVBW 2004, Own Calculations)

<table>
<thead>
<tr>
<th>Year</th>
<th>2010</th>
<th>2020</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accidents with Personal Damage</td>
<td>310,662</td>
<td>272,502</td>
</tr>
<tr>
<td>Fatalities</td>
<td>4,487</td>
<td>3,142</td>
</tr>
<tr>
<td>Severe Injuries</td>
<td>69,843</td>
<td>52,037</td>
</tr>
<tr>
<td>Slight Injuries</td>
<td>337,683</td>
<td>305,431</td>
</tr>
</tbody>
</table>

After forecasting the accident data for the years 2010 and 2020 for the status quo, the forecasted values have to be corrected by the safety impact of ACC. This step is in particular relevant for systems which are already widely penetrated in the market. Actually, this is not the case for ACC. For demonstrational reasons the correction factor will be also applied here. There is a minor but however considerable car penetration rate with ACC that has already been realised in 2005. This fleet penetration with ACC systems falsifies the measured accident data. This means that parts of the accident reduction potential of ACC had already been realised in 2005. It is assumed, that there exists a linear functional relation between vehicle kilometres driven with vehicles that are equipped with ACC and avoided accidents. This means that 25 % of the accidents, which could be avoided if all vehicle kilometres are covered with vehicles equipped with ACC, are avoided, if 25 % of the vehicle kilometres are covered by cars equipped with ACC.

As seen in chapter 3.2.3 the relevant accident group for ACC is rear end collisions. The potential of ACC is considered as a 25 % reduction in the number of accidents within this group. Further, the number of remaining fatalities can be shifted by 20 % to severe injuries and the number of remaining severe injuries can be shifted also by 20 % to slight injuries.

Regarding Table 32, the penetration in Germany in 2005 is equivalent to 2 % of all driven vehicle kilometres. So the number of rear end collisions can not be reduced by 25 % due to ACC in the future, because some vehicles had been equipped with ACC in the year 2005. This means that about 0.5 % (0.02 * 25 %) of the rear end collisions were already being avoided at that time. By extending the penetration rate from 1 % to 100 %, a further 24.5 % accident reduction (25 % - 0.5 %) could be achieved. The potential in avoiding fatalities and severe injuries for the remaining accidents can be calculated similar. In 2005 about 0.4 % (0.02 * 20 %) of fatalities due to rear end collisions are shifted to severe injuries. The value for the shift from severe injuries to slight injuries is also 0.4 %. So by a penetration rate from 100 %, a further 19.6 % reduction in fatalities and severe injuries can be achieved.

The values for 2005, 2010, and 2020 have to be corrected by a correcting factor. The correcting factor depends on the share of the relevant accidents, on the reduction potential, and on the performance rate of equipped vehicles. In the year 2005 the share of the relevant accidents (rear end collisions) was 23.524 %. This figure is considered as constant during the time. The reduction potential for accidents is 25 % and the performance rate 2 %. The correcting factor for the number of accidents with personal injuries is
1 / (1 – 23.524 % * 25 % * 2 %) = 1.001. This correcting factor is also valid for slight injuries.

The number of accidents for the without-case (without ACC) for the year 2010 is 311,028 and for the year 2020 the accordant value is 272,823.

The reduction potential for fatalities consists out of 25 % accident reduction and a shift of 20 % from the class casualties to severe injuries. So its total reduction potential is 40 % (1 – (1 – 25 %) * (1 – 20 %)). The accordant correcting factor is 1.002.

The number of fatalities for the without-case for the year 2010 is 4,496 and for the year 2020 the value is 3,148. The difference which is due to ACC is 9 fatalities for the year 2010 and 6 fatalities for the year 2020. 62.5 % of the avoided fatalities (25% / 40%) have no injuries because their accident has been avoided. The other 37.5 % of the avoided fatalities is shifted to the severe injuries. That means for the year 2010 that three severe injuries are due to the mitigation impact of ACC and two in the year 2020. Hence, these values have to be removed from the number of severe injuries in the with-case. After that, the new value is multiplied with the correcting factor 1.002. The result is the number of severe injuries for the without-case. For the year 2010 the new value is 69,972 and for the year 2020 the new value is 52,134. The difference is 132 severe injuries in 2010 and 99 severe injuries in 2020. Also 37.5 % of the difference is the shift to the slight injuries. That are 50 accident victims for the year 2010 and 37 casualties for the year 2020. These values have to be removed from the slight injuries. After that, the new values for slight injuries have to be multiplied with the correcting factor for the accidents to get the number of slight injuries for the without-case. The new values are 338,031 for the year 2010 and 305,754 for the year 2020. The results are displayed in Table 36.

<table>
<thead>
<tr>
<th>Year</th>
<th>2010</th>
<th>2020</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accidents with Personal Damage</td>
<td>311,028</td>
<td>272,823</td>
</tr>
<tr>
<td>Fatalities</td>
<td>4,496</td>
<td>3,148</td>
</tr>
<tr>
<td>Severe Injuries</td>
<td>69,972</td>
<td>52,134</td>
</tr>
<tr>
<td>Slight Injuries</td>
<td>338,031</td>
<td>305,754</td>
</tr>
</tbody>
</table>

Table 36: Number of Accidents and Number of Injuries – Scenario Without-Case (Own Calculations)

With this new accident data the reduction potential of ACC can be calculated. A quarter of all rear end accidents can be avoided with ACC. The share of rear end accidents is 23.524 %. The performance rate of the vehicles equipped with ACC is estimated with 5.9 % in the year 2010. 1,080 accidents can be avoided (311,028 * 23.524 % * 25 % * 5.9 %). The number of accordant avoided fatalities is 16. The value for avoided severe injuries is 243 and the number of avoided slight injuries is 1,173. In the year 2020 the performance rate of vehicles equipped with ACC will be 15.9 %. The number of avoided casualties is 29, the value for avoided severe injuries is 470 and the number for avoided slight injuries is 2,752. Altogether, 2,455 accidents can be avoided.
In addition to the directly avoided accidents there is a shift from fatalities to severe injuries and from severe injuries to slight injuries. The shift rate is assumed to be 20% for both cases. The number of fatalities which can be shifted to the class of severe injuries can be calculated as follow: The difference of fatalities in the with-case and the directly avoided fatalities has to be multiplied with the share of rear end accidents, with the performance rate of ACC, and with the shift-potential. The shift potential for the case fatalities to severe injuries for the year 2010 is 12 and for the year 2020 it is 22. The shift potential for the direction severe injuries to slight injuries can be calculated similar. The accordant value for the year 2010 is 191 and for the year 2020 the value is 361. These values have to be corrected by the values from the shift fatalities to severe injuries. So the total reduction in severe injuries due to reduced accident severity has to increase by the complete shift. So there are 191 more slight injuries in the year 2010 and 361 more slight injuries in the year 2020.

<table>
<thead>
<tr>
<th>Year</th>
<th>2010</th>
<th>2020</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accidents with Personal Damage</td>
<td>1,080</td>
<td>2,455</td>
</tr>
<tr>
<td>Fatalities</td>
<td>16</td>
<td>29</td>
</tr>
<tr>
<td>Severe Injuries</td>
<td>243</td>
<td>470</td>
</tr>
<tr>
<td>Slight Injuries</td>
<td>1,173</td>
<td>2,752</td>
</tr>
</tbody>
</table>

Table 37: Number of Casualties Avoided due to Accident Avoidance (Own Calculations)

After calculating the avoided accidents and the avoided casualties due to the direct avoided accidents, and calculating the potential of ACC due to the shifting effect, the total potential of ACC has to be calculated. The number of avoided accidents is 1,080 in the year 2010 and 2,455 in the year 2020. The total number of avoided fatalities in the year 2010 is 28 (16 due to avoided accidents and 12 due to a shift from fatality to severe injury). The accordant value for the year 2020 is 51. The total number of severe injuries is 422 (243 due to avoided accidents and 191 due to a shift from severe injuries to slight injuries corrected by 12 due to a shift from fatalities to severe injuries). The accordant value for the year 2020 is 809. And the last figure is the total number of slight injuries. The value for the year 2010 is 982 (1,173 due to avoided accidents corrected by 191 due to a shift from severe injuries to slight injuries). The accordant value for the year 2020 is 2,391. Table 39 displays the results.
Table 39: Aggregated Safety Impact of ACC for the Years 2010 and 2020 (Own Calculations)

<table>
<thead>
<tr>
<th>Year</th>
<th>2010</th>
<th>2020</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accidents with Personal Damage</td>
<td>1,080</td>
<td>2,455</td>
</tr>
<tr>
<td>Fatalities</td>
<td>28</td>
<td>51</td>
</tr>
<tr>
<td>Severe Injuries</td>
<td>422</td>
<td>809</td>
</tr>
<tr>
<td>Slight Injuries</td>
<td>982</td>
<td>2,391</td>
</tr>
</tbody>
</table>

In order to assess the socio-economic benefits, the safety impact has to be evaluated using cost-unit rates which represent different levels of severity. These cost rates are taken from chapter 3.4.2. They are multiplied with the safety impact which is calculated above.

The monetary assessment of ACC safety impacts leads to considerable benefits. They account for 113.9 million Euro in the year 2010 respectively 227.4 million Euro in the year 2020. Figure 54 shows the distribution of the safety benefits among different components. Nearly 25 % of the total benefits can be attributed to the reduction of fatalities. Another 50 % are due to the reduction of severe injuries. The remaining 25 % of benefits are distributed among the reductions in slight injuries (13 %), in property damages (6 %), and in congestion (6 %).

Figure 54: Socio-Economic Benefits of ACC due to the Safety Impact (Own Calculations)

**Reduction of operating costs**

The IVSS ACC has a traffic impact. As shown in chapter 3.2.4 the road capacity is increased by 0.3 % in the year 2010 and by 0.6 % in the year 2020. The average velocity is not influenced by ACC. This is the result of a literature review (chapter 3.2.4). The linkage between the traffic volume Q, the traffic density K and the velocity V is $Q = K \times V$. So the density has to grow with the same growth rate as the capacity for a constant velocity. This means that the range of realized headways between the vehicles has to decrease. Lower headways lead to a higher traffic density. There are more vehicles on one kilometre road. So the distances expressed in metres between the vehicles decrease. This is the case when the velocities are harmonized, which is due to ACC. ACC holds autonomously the correct headway to the vehicle in front. Hence, there are less accelerating and decelerating processes due to headways, which are too short. These processes are very energy-intensive. So the main traffic impact of ACC is a reduction of the fuel consumption due to the harmo-
nizing of the velocities. This reduction of fuel consumption is assessed in this chapter.

The IVSS ACC works for velocities above 30 km/h. Its effect on the traffic flow can be measured in traffic situations where the traffic volume is near the capacity. There the traffic flow is not stable anymore, it is disturbed. In these situations the drivers have high interaction among each other. Headways which are too short and inattention can lead to a traffic break down, which can be avoided by using ACC because ACC holds the correct headway autonomously. Thus, ACC influences the traffic within the Level of Service steps LOS E and LOS F, which stand for disturbed traffic situations. ACC has no impact on urban roads, because the velocity within LOS E on urban roads is below 30 km/h. So the relevant road categories for ACC are motorways and rural roads.

For calculating the benefit due to fuel consumption several input data is necessarily. The total vehicle mileage for Germany for the years 2010 and 2020, its share on motorways and rural roads for the years 2010 and 2020, and the share of LOS step E and step F for motorways and rural roads are important to determine the relevant vehicle kilometres. These data are taken from chapter 3.3.1. Further, the share of the considered vehicle groups on the vehicle kilometres is essential. This share has to be divided into the following groups: passenger car petrol, passenger car diesel, light goods vehicle, heavy goods vehicle, and semi-trailer (Table 40). By multiplying these figures the relevant vehicle kilometres for motorways and rural roads for the relevant LOS steps E and F for each vehicle category for the years 2010 and 2020 can be determined.

<table>
<thead>
<tr>
<th>Year</th>
<th>2010</th>
<th>2020</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passenger Car Petrol</td>
<td>54.37%</td>
<td>47.37%</td>
</tr>
<tr>
<td>Passenger Car Diesel</td>
<td>29.00%</td>
<td>36.00%</td>
</tr>
<tr>
<td>Light Goods Vehicle</td>
<td>1.33%</td>
<td>1.33%</td>
</tr>
<tr>
<td>Heavy Goods Vehicle</td>
<td>4.99%</td>
<td>4.99%</td>
</tr>
<tr>
<td>Semi-Trailer</td>
<td>10.31%</td>
<td>10.31%</td>
</tr>
</tbody>
</table>

Table 40: Distribution of Vehicle Mileage of Vehicle Categories on the relevant Road Network (FGSV 1997, UBA 2003)

The relevant vehicle kilometres for each road type, the LOS steps E and F, and the vehicle categories have to be multiplied with the average fuel consumption of each group. This is done for the without-case (without ACC) and for the with-case. The difference of both values is the potential for ACC with a penetration rate of 100 %. In a last step, the penetration rate of ACC has to be considered. The vehicles which are equipped with ACC have a higher average driving performance. So the performance rate in percentage to the total vehicle kilometres is taken as weighing factor. These factors are taken from chapter 3.2.2. The calculation is displayed graphically in Figure 55 on the next page.
The average fuel consumption for each group has to be estimated. As shown above there are 80 groups: year 2010 and 2020, motorways and rural roads, LOS step E and F, 5 vehicle categories, and the without-case and the with-case. For each group the average fuel consumption has to be calculated. The fuel consumption depends on the velocity. The EWS (FGSV 1997) provides such a function for each vehicle category. Hence, the distribution of the measured velocities for the years 2010 and 2020 is important. This distribution is only available on an aggregated level. The Level of Service (LOS) distribution provides a classification of vehicle kilometres in several velocity groups. The relevant groups are the steps E and F. In these steps, the traffic is disturbed, so these groups are the potential for ACC. The velocity limits between each LOS step are not influenced by ACC. The limits are mainly determined by the traffic volume or the traffic density. The traffic volume and the traffic density are increasing by the same factor, so the velocity which is linked to the traffic volume and the traffic density remain constant. The limits depend also on the type of road (motorway or rural road, number of lanes, and so on).

For calculating the fuel consumption for the relevant LOS steps E and F, the linkage between fuel consumption and velocity from the EWS (FGSV 1997) is taken. The formula is the same as for the emissions (for the graphical course see chapter 3.2.4, figure 12).
The impact function (1) is:

\[ f_{veh-cat,t}(v) = rf_{veh-cat,t} \left( a_{veh-cat} + b_{veh-cat} \cdot v^2 + \frac{c_{veh-cat}}{v} \right), \]

with

- \( a, b, \) and \( c \): coefficients depending on the vehicle category
- \( rf \): reduction factor to display the technical progress depending on the vehicle type and the year \( t \) – the values for 2010 are from the EWS (FGSV 1997), the values for 2020 are estimated
- \( t \): year 2010 or year 2020
- \( veh-cat \): passenger car petrol, passenger car diesel, light goods vehicle, heavy goods vehicle, semi-trailer

The result of each function is expressed in g/km. For velocities below 20 km/h the formula equals:

\[ f_{veh-cat,t}(v) = \min \left( d_{veh-cat,t}, a_{veh-cat} + b_{veh-cat} \cdot v^2 + \frac{c_{veh-cat}}{v} \right), \]

with

- \( d \): coefficient depending on the vehicle category and the year \( t \)

ACC works only for velocities above 30 km/h indeed, but it can avoid congestion due to short distances and due to inattention. So it seems to be practicable to consider even velocities below 30 km/h.

In the without-case (without ACC) there are a lot of accelerating and decelerating processes. These processes are very energy-intensive. The function from the EWS handles only the fuel consumption for a constant velocity. To simulate a traffic flow with accelerating and decelerating processes, it is assumed that the velocity distribution within the LOS steps E and F equals a rectangular distribution. So every velocity has the same share. This assumption reflects the accelerating and decelerating processes. For calculating the average fuel consumption within a LOS step for the without-case, the integral of formula (1) respectively (2) has to be taken:

\[ \int_{\text{lower}}^{\text{upper}} f_{veh-cat,t}(v) dv = rf_{veh-cat,t} \int_{\text{lower}}^{\text{upper}} \left( a_{veh-cat} + b_{veh-cat} \cdot v^2 + \frac{c_{veh-cat}}{v} \right) dv = \]

\[ F_{veh-cat,t}(\text{upper}) - F_{veh-cat,t}(\text{lower}), \]

with

- \( g \): constant. In this case \( g \) equals zero.
- \( \text{upper} \): upper velocity border of the LOS step
- \( \text{lower} \): lower velocity border of the LOS step

The integrals of each group have to be divided by the accordant velocity range of the LOS step to get the average fuel consumption per
veh-km within the LOS step for each group. For LOS step F formula (2) has to be considered, because the lower velocity limit of step F is standstill.

In the with-case (with ACC) the accelerating and decelerating processes are reduced. The average velocity remains constant. To simulate this traffic flow it is assumed that every vehicle drives with the same velocity – the average velocity. Further, it has to be considered that the speed limit for heavy lorries is 80 km/h. Formula (1) is taken to calculate the average fuel consumption for the with-case. Therefore the average velocity of the LOS step is used.

The velocity limits for the LOS steps E and F depend on the type of road – motorway or rural road – and on the character of the infrastructure – speed limit and number of lanes. Another impact is the grade, the share of heavy lorries and – for rural roads – the curviness. The assumption for the grade is below 2 %, the share of heavy lorries is 15.3 % (see table 104), and the curviness is below 75 gon/km.

In the next step the limits for LOS step E and F for motorways and rural roads have to be determined. The lower velocity limit for LOS step F is standstill. So the upper limit of LOS step F, which equals the lower limit of LOS step E, and the upper limit of LOS step E have to be designated. For rural roads there is only one type of road mentioned in the HBS (2001): two lanes with a speed limit of 100 km/h. For a share of heavy lorries of 15.3 % the upper limit of LOS step F respectively the lower limit of LOS step E is 57 km/h. The upper velocity limit of LOS step E is 63 km/h. That means that the average driven velocity on rural roads within LOS step F equals 28.5 km/h \((0+57)/2\) and 60 km/h for LOS step E.

For motorways there are different types of motorways mentioned. There are motorways with three or two lanes, with speed limit of 80 km/h, 100 km/h, 120 km/h, or without speed limit, in urban or rural areas. For calculating the velocity limits of LOS step E respectively the upper limit of LOS step F, only the motorways with speed limits above 80 km/h in rural areas are considered. For these motorways the average limit is calculated. The upper limit of LOS step F respectively the lower limit of LOS step E for motorways lies between 75 km/h and 80 km/h depending on the speed limit and the number of lanes. The average limit is assumed with 78 km/h. The upper velocity limit of LOS step E lies between 87 km/h and 100 km/h. The average limit is assumed with 94 km/h. So the average driven velocity on motorways is 39 km/h within LOS step F and 86 km/h within LOS step E. The limits and average velocities are displayed in Table 41.
Table 41: Velocity Limits and Average Velocity for LOS Step E and F for Motorways and Rural Roads (HBS 2001, Own Calculation)

<table>
<thead>
<tr>
<th></th>
<th>Without-Case</th>
<th></th>
<th>With-Case</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lower Limit</td>
<td>Upper Limit</td>
<td>Average Limit</td>
</tr>
<tr>
<td><strong>Motorways</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LOS F (km/h)</td>
<td>0</td>
<td>78</td>
<td>39</td>
</tr>
<tr>
<td>LOS E (km/h)</td>
<td>78</td>
<td>94</td>
<td>86</td>
</tr>
<tr>
<td><strong>Rural Roads</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LOS F (km/h)</td>
<td>0</td>
<td>57</td>
<td>28.5</td>
</tr>
<tr>
<td>LOS E (km/h)</td>
<td>57</td>
<td>63</td>
<td>60</td>
</tr>
</tbody>
</table>

The lower and upper limits of the LOS steps E and F for motorways and rural roads are the lower and upper bounds for the integrals. The limits are adopted in formula (3) and the result is divided by the velocity range of the LOS step. The result is the average fuel consumption in g/km for the without-case for each group. For the with-case, the average velocity is adopted in formula (1) to get the average fuel consumption in g/km. So the difference between the fuel consumption of the without-case and the with-case is the potential per kilometre for each group.

The potential of ACC in fuel reduction can be calculated as follow: The total vehicle mileage of the year 2010 respectively 2020 has to be multiplied with the share of motorway vehicle kilometres respectively with the share of rural road vehicle kilometres and with the share of LOS step E and F within the road categories. These values have to be multiplied with the share of each vehicle category based on the vehicle kilometres. The results are the relevant vehicle kilometre for each group. These values have to be multiplied with the potential per kilometre for each group. This is the difference of the average fuel consumption of each group for the without-case and the average fuel consumption of each group for the with-case. The result of this calculation is the potential of ACC for a penetration rate of 100% for each vehicle group and for the years 2010 and 2020. There is in each case one group for reduction of petrol for the year 2010 and 2020. This is the total potential of ACC for a reduction of petrol. All the other groups are for a reduction of diesel for the years 2010 and 2020. These groups have to be summed up for the years 2010 and 2020. The result is the total potential of ACC for diesel reduction for the years 2010 and 2020. So in the last step, these total potentials have to be multiplied with the performance rate of ACC of the accordant year to get the potential in a reduction of fuel consumption for the estimated ACC equipment rates of the years 2010 and 2020.

After estimating the potential of ACC expressed in tons of fuel, the potential has to be assessed economically. Therefore, the reduction has to be multiplied with the cost-unit rates given in chapter 3.4.2. Table 42 displays the results. The benefits due to a reduction in operating costs account for 10.1 million Euro in the year 2010 respectively 26.8 million Euro in the year 2020.
Table 42: Potential of ACC in Reducing the Fuel Consumption and the Benefits in Euro (Own Calculation)

Reduction in emissions (pollutants and carbon dioxide)

There are two types of considered emissions. On the one hand there is carbon dioxide, which is linked directly to the fuel consumption, and on the other hand there are pollutants which are expressed in NOx-equivalents.

The output of carbon dioxide can be determined by multiplying the petrol consumption in kg with 3.12 respectively the diesel consumption in kg with 3.15. The potential in the fuel consumption for ACC is estimated in the chapter above. These values have to be multiplied with the cost-unit rates for the years 2010 and 2020. They are taken from chapter 3.4.2. The results can be seen in Table 43.

The pollutants are also reduced due to harmonized velocities. The pollutants are linked with the velocity in the same manner as the fuel consumption. So the calculation of the benefits due to a reduction in pollutants is similar to the one for fuel consumption above. The only difference is, that the coefficients rf, a, b, c, and d in formula (1) respectively (3) changes. They are taken from the EWS (FGSV 1997). The reduction factor rf for the year 2020 is estimated.

The potential in reducing pollutants has to be multiplied with the cost-unit rate for NOx-equivalent for the year 2010 respectively 2020. These cost-unit rates are taken from chapter 3.4.2. Table 43 shows the results. The benefits due to a reduction in emissions account for 3.9 million Euro in the year 2010 respectively 10.1 million Euro in the year 2020.

Table 43: Potential of ACC for Emissions Reduction and its Benefits expressed in Euro (Own Calculation)
Summary of the benefit side

ACC has three benefit groups. ACC avoids accidents and due to this effect ACC avoids casualties, injuries, material damage and congestion. Further, ACC reduces the fuel consumption and it reduces the emission outcast. All these effects are assessed above. Thus, the total benefit of ACC is the sum of the three mentioned effects. This sum is displayed in Table 44.

<table>
<thead>
<tr>
<th>Year</th>
<th>Safety Impact (Mill. EUR)</th>
<th>Saved Operating Costs (Mill. EUR)</th>
<th>Saved Emission Costs (Mill. EUR)</th>
<th>Total Benefit (EUR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>114</td>
<td>10</td>
<td>4</td>
<td>128</td>
</tr>
<tr>
<td>2020</td>
<td>227</td>
<td>27</td>
<td>10</td>
<td>264</td>
</tr>
</tbody>
</table>

Table 44: Total Benefit of ACC for Germany (Own Calculation)

The benefits have to be faced with the costs of ACC. The costs are determined in the next clause.

System Costs of ACC

As stated in chapter 3.2.2, the system costs per unit equals 400 Euro in 2010 and 240 Euro in 2020. The average economic lifetime of a vehicle in Germany is estimated with 12 years. For both years the annuity is calculated and multiplied with the equipped vehicle stock. The discount rate was estimated as 3 %. The annuity for the year 2010 is 40.18 Euro and the annuity for the year 2020 is 24.11 Euro. The vehicle stock in the year 2010 equals 50.36 million vehicles (ProgTrans 2004). So in the year 2010, there are 1.5108 million vehicles equipped with ACC. That means total systems costs of 60,711,247 Euro. The accordant value for the year 2020 is 102,558,126 Euro.

Benefit-Cost Ratio for ACC

After calculating the benefits and the costs of ACC, the benefit-cost ratio can be determined. In the year 2010 the benefit-cost-ratio is 2.1. Its value for the year 2020 is 2.6. The main reason for the improvement in the benefit-cost ratio to 2.6 is the fact that the system costs have been significantly reduced till the year 2020. The benefit-cost ratio above 1 illustrates that market deployment would be beneficial from society’s point of view. Table 45 shows the benefit-cost ratios.

<table>
<thead>
<tr>
<th>Year</th>
<th>Benefits</th>
<th>Costs</th>
<th>Benefit-Cost Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>128</td>
<td>61</td>
<td>2.1</td>
</tr>
<tr>
<td>2020</td>
<td>264</td>
<td>103</td>
<td>2.6</td>
</tr>
</tbody>
</table>

Table 45: Benefit-Cost Ratio for ACC (Own Calculations)
References

**Abele, J. et al. (2005):** Exploratory Study on the potential socio-economic impact of the introduction of Intelligent Safety Systems in Road Vehicles, SEiSS-Study, Teltow.


**Bickel, P. et al. (2005):** HEATCO, Developing Harmonised European Approaches for Transport Costing and Project Assessment, Deliverable 2, State-of-the-art in project assessment.


Eurostat (2006): Environment and energy, petroleum products, half year prices.


Mineralölwirtschaftsverband (2006), MWV-Prognose 2025 für die Bundesrepublik Deutschland, Hamburg.


WDT (Wisconsin Department of Transportation) (2000): Intelligent Transportation Design Manual
### Annex 1

**IVSS System Synergies (Cost-side)**

<table>
<thead>
<tr>
<th>System</th>
<th>Subsystems</th>
<th>ESP</th>
<th>eCALL</th>
<th>Full Speed Range ACC</th>
</tr>
</thead>
<tbody>
<tr>
<td>ESP</td>
<td>ESP</td>
<td>-</td>
<td>-</td>
<td>ESP is component of ACC</td>
</tr>
<tr>
<td>eCALL</td>
<td>eCALL</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Full Speed Range ACC</td>
<td>FSR ACC Tempomat ESP</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>System</th>
<th>Subsystems</th>
<th>Collision Avoidance</th>
<th>Speed Alert</th>
</tr>
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<tbody>
<tr>
<td>ESP</td>
<td>ESP</td>
<td>ESP is component of</td>
<td>-</td>
</tr>
<tr>
<td>eCALL</td>
<td>eCALL</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Full Speed Range ACC</td>
<td>FSR ACC Tempomat ESP</td>
<td>~ 100% component overlapping</td>
<td>improvement of FSR ACC (Speed Alert sets speed limit)</td>
</tr>
<tr>
<td>Emergency Braking</td>
<td>ACC Adaptive Brake Lights Obstacle Warning Emergency Braking</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Speed Alert</td>
<td>Speed limit/advise detection module Speed advise and warning module Speed advise management module</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>System</td>
<td>Subsystems</td>
<td>Night Vision</td>
<td>WLDW</td>
</tr>
<tr>
<td>------------------</td>
<td>------------</td>
<td>--------------</td>
<td>-----------------------------------------------------</td>
</tr>
<tr>
<td>ESP</td>
<td>ESP</td>
<td>-</td>
<td>WLDW can use ESP information</td>
</tr>
<tr>
<td>eCALL</td>
<td>eCALL</td>
<td>-</td>
<td>+ Car2Car Communication</td>
</tr>
<tr>
<td>Full Speed Range ACC</td>
<td>FSR ACC Tempomat ESP</td>
<td>+ Camera: improve object detection day/night vice versa: + radar improve object classification of NV</td>
<td></td>
</tr>
<tr>
<td>Emergency Braking</td>
<td>ACC</td>
<td>object and relevance classification is improved, would help, vice versa: + radar improve object classification of NV</td>
<td></td>
</tr>
<tr>
<td>Speed Alert</td>
<td>Speed limit/advise det. Speed advise and warn. Speed advise managem.</td>
<td>updated road signs for Speed Alert (camera)</td>
<td>when someone is driving much lower than the official speed limit vice versa: map data will be improved because of efficiency</td>
</tr>
<tr>
<td>Night Vision</td>
<td>Near IR image processing (Head-up Display)</td>
<td>-</td>
<td>earlier information to WLDW (NVWarning)</td>
</tr>
<tr>
<td>WLDW</td>
<td>?ESP ?other sensors</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>System</td>
<td>Subsystems</td>
<td>Driver Drowsiness Monitoring &amp; Warning</td>
<td>Intersection Safety</td>
</tr>
<tr>
<td>-------------------------</td>
<td>-----------------------------</td>
<td>----------------------------------------</td>
<td>---------------------</td>
</tr>
<tr>
<td>eIMPACT 14.12.2006</td>
<td>Deliverable D3 V 1.0 157</td>
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<table>
<thead>
<tr>
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<th>ESP</th>
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<th>Full Speed Range ACC</th>
<th>Emergency Braking</th>
<th>Speed Alert</th>
<th>Night Vision</th>
<th>WLDW</th>
<th>Driver Drowsiness Monitoring &amp; Warning</th>
<th>Intersection Safety</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>ESP</td>
<td>eCALL</td>
<td>FSR ACC Tempomat ESP</td>
<td>ACC</td>
<td>Speed limit/advise det.</td>
<td>Near IR image processing (Head-up Display)</td>
<td>?ESP ?other sensors ?</td>
<td>Driver Drowsiness Monitoring &amp; Warning</td>
<td>Radar, 3D-Laser, Camera Wireless communication with traffic lights Data Fusion Module</td>
</tr>
</tbody>
</table>

- ESP
- eCALL
- FSR ACC
- Tempomat
- ESP
- ACC
- Adaptive Brake Lights
- Obstacle Warning
- Emergency Braking
- Speed limit/advise det.
- Speed advise and warn.
- Speed advise managem.
- Near IR image processing (Head-up Display)
- ?ESP
- ?other sensors
- ?
- Driver Drowsiness Monitoring & Warning
- Radar, 3D-Laser, Camera Wireless communication with traffic lights Data Fusion Module
<table>
<thead>
<tr>
<th>System</th>
<th>Subsystems</th>
<th>Lane Keeping Assistant</th>
<th>Lane Change Assistant</th>
</tr>
</thead>
<tbody>
<tr>
<td>ESP</td>
<td>ESP</td>
<td>LKA has a low cost ESP</td>
<td>both ESP</td>
</tr>
<tr>
<td>eCALL</td>
<td>eCALL</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Full Speed Range ACC</td>
<td>FSR ACC</td>
<td>+ mono camera for object</td>
<td>sensors are not the same, both ESP</td>
</tr>
<tr>
<td>Temppomat</td>
<td>ESP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Emergency Braking</td>
<td>ACC</td>
<td>+ mono camera for object</td>
<td>sensors are not the same, both ESP</td>
</tr>
<tr>
<td>Adaptive Brake Lights</td>
<td>Obstacle Warning</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Emergency Braking</td>
<td>ACC</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Speed Alert</td>
<td>Speed limit/advise det.</td>
<td></td>
<td>maybe map data gives information where it is hard to leave the lane, this would improve the safety margins of Lateral Safe</td>
</tr>
<tr>
<td>Speed advise and warn.</td>
<td>Speed advise and warn.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Speed advise managem.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Night Vision</td>
<td>Near IR image processing</td>
<td>high component overlapping.</td>
<td>-</td>
</tr>
<tr>
<td>(Head-up Display)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WLDW</td>
<td>?ESP</td>
<td>slightly improvement of</td>
<td>-</td>
</tr>
<tr>
<td>?other sensors</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Driver Drowsiness Monitoring &amp; Warning</td>
<td>Driver Drowsiness Monitoring &amp; Warning</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Intersection Safety</td>
<td>Radar, 3D-Laser, Cam.</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Wireless com.</td>
<td>Data Fusion Module</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lane Keeping Assistant</td>
<td>Lane Keeping Support</td>
<td>-</td>
<td>with LKA actuator in LKA, LCA gets a convening system</td>
</tr>
<tr>
<td>Lane Change Assistant</td>
<td>Lateral and Rear Monitoring</td>
<td></td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Lateral Collision Warning</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lane Change Assistant with integrated BS</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Annex 2

Results of the Linear Regression Approach for Estimating the Vehicle Mileage of the Different Road Types

The linear regression equation for the vehicle mileage of the road types has the form:

\[ y = \text{constant} + a \times t, \]

where:
- \( y \): vehicle mileage expressed in mill. vehicle kilometres
- \( t \): year

Adjusted \( R^2 \) for the Vehicle Mileage of the Total Road Network

<table>
<thead>
<tr>
<th>Country</th>
<th>constant</th>
<th>( a )</th>
<th>Adjusted ( R^2 )</th>
<th>F-Value</th>
<th>Significance Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Austria</td>
<td>-3517242</td>
<td>1795.661</td>
<td>0.998</td>
<td>9111</td>
<td>0.000</td>
</tr>
<tr>
<td>Belgium</td>
<td>-3397751</td>
<td>1743.379</td>
<td>0.985</td>
<td>919</td>
<td>0.000</td>
</tr>
<tr>
<td>Denmark</td>
<td>-1924438</td>
<td>985.429</td>
<td>0.986</td>
<td>817</td>
<td>0.000</td>
</tr>
<tr>
<td>Finland</td>
<td>-1534109</td>
<td>790.5</td>
<td>0.947</td>
<td>252</td>
<td>0.000</td>
</tr>
<tr>
<td>France</td>
<td>-18206477</td>
<td>9367.857</td>
<td>0.971</td>
<td>473</td>
<td>0.000</td>
</tr>
<tr>
<td>Germany</td>
<td>-18878484</td>
<td>9772.236</td>
<td>0.969</td>
<td>437</td>
<td>0.000</td>
</tr>
<tr>
<td>Greece</td>
<td>-7341012</td>
<td>3714.714</td>
<td>0.994</td>
<td>856</td>
<td>0.000</td>
</tr>
<tr>
<td>Ireland</td>
<td>-2584896</td>
<td>1311.214</td>
<td>0.933</td>
<td>98</td>
<td>0.000</td>
</tr>
<tr>
<td>Italy</td>
<td>-28124010</td>
<td>14265.04</td>
<td>0.976</td>
<td>569</td>
<td>0.000</td>
</tr>
<tr>
<td>Luxembourg</td>
<td>-412117</td>
<td>207.893</td>
<td>0.988</td>
<td>1110</td>
<td>0.000</td>
</tr>
<tr>
<td>Netherlands</td>
<td>-5327837</td>
<td>2725.919</td>
<td>0.978</td>
<td>570</td>
<td>0.000</td>
</tr>
<tr>
<td>Portugal</td>
<td>-7443218</td>
<td>3755.25</td>
<td>0.997</td>
<td>4962</td>
<td>0.000</td>
</tr>
<tr>
<td>Spain</td>
<td>-16132315</td>
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<td>0.983</td>
<td>510</td>
<td>0.000</td>
</tr>
<tr>
<td>Sweden</td>
<td>-1659718</td>
<td>865.411</td>
<td>0.882</td>
<td>105</td>
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</tr>
<tr>
<td>Great Britain</td>
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<td>6894.346</td>
<td>0.973</td>
<td>511</td>
<td>0.000</td>
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<td><strong>EU 15</strong></td>
<td><strong>-1.32E+08</strong></td>
<td><strong>67664.88</strong></td>
<td><strong>0.996</strong></td>
<td><strong>3958</strong></td>
<td><strong>0.000</strong></td>
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<td>0.986</td>
<td>696</td>
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<tr>
<td>Slovenia</td>
<td>-1029644</td>
<td>520.886</td>
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<td>233</td>
<td>0.000</td>
</tr>
</tbody>
</table>

All results are significant to the 99.9 % confidence-level.
Adjusted $R^2$ for the Length of Motorways

<table>
<thead>
<tr>
<th></th>
<th>constant</th>
<th>a</th>
<th>Adjusted $R^2$</th>
<th>F-Value</th>
<th>Significance Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Austria</td>
<td>-981628</td>
<td>499.157</td>
<td>0.995</td>
<td>2580</td>
<td>0.000</td>
</tr>
<tr>
<td>Belgium</td>
<td>-1665317</td>
<td>847.657</td>
<td>0.984</td>
<td>871</td>
<td>0.000</td>
</tr>
<tr>
<td>Denmark</td>
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<td>501.214</td>
<td>0.983</td>
<td>829</td>
<td>0.000</td>
</tr>
<tr>
<td>Finland</td>
<td>-462136</td>
<td>233.075</td>
<td>0.976</td>
<td>576</td>
<td>0.000</td>
</tr>
<tr>
<td>France</td>
<td>-7838834</td>
<td>3972.411</td>
<td>0.995</td>
<td>2617</td>
<td>0.000</td>
</tr>
<tr>
<td>Germany</td>
<td>-9720474</td>
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<td>0.983</td>
<td>804</td>
<td>0.000</td>
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<td>Greece</td>
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<td>186.961</td>
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<td>0.011</td>
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<td>0.988</td>
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<td>3726</td>
<td><strong>0.000</strong></td>
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All results are significant to the 97.5% confidence-level.

Adjusted $R^2$ for the Length of Urban Roads

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<th>Adjusted $R^2$</th>
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<th>Significance Level</th>
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<tr>
<td>Austria</td>
<td>-760755</td>
<td>388.4</td>
<td>0.998</td>
<td>9079</td>
<td>0.000*</td>
</tr>
<tr>
<td>Denmark</td>
<td>271747</td>
<td>-128.3</td>
<td>0.067</td>
<td>2</td>
<td>0.200</td>
</tr>
<tr>
<td>Finland</td>
<td>-2833086</td>
<td>1428.6</td>
<td>0.818</td>
<td>64</td>
<td>0.000*</td>
</tr>
<tr>
<td>Germany</td>
<td>1327667</td>
<td>-600.0</td>
<td>0.785</td>
<td>23</td>
<td>0.005*</td>
</tr>
<tr>
<td>Ireland</td>
<td>-446230</td>
<td>226.5</td>
<td>0.910</td>
<td>61</td>
<td>0.001*</td>
</tr>
<tr>
<td>Netherlands</td>
<td>-160860</td>
<td>95.4</td>
<td>0.010</td>
<td>1</td>
<td>0.368</td>
</tr>
<tr>
<td>Great Britain</td>
<td>-1959095</td>
<td>1073.5</td>
<td>0.598</td>
<td>22</td>
<td>0.000*</td>
</tr>
</tbody>
</table>

* Results are significant to the 99% confidence-level.

Adjusted $R^2$ for the Share of Urban Roads

<table>
<thead>
<tr>
<th></th>
<th>constant</th>
<th>a</th>
<th>Adjusted $R^2$</th>
<th>F-Value</th>
<th>Significance Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Denmark</td>
<td>13.298</td>
<td>-0.006</td>
<td>0.939</td>
<td>140</td>
<td>0.000</td>
</tr>
<tr>
<td>Netherlands</td>
<td>16.462</td>
<td>-0.008</td>
<td>0.765</td>
<td>24</td>
<td>0.003</td>
</tr>
</tbody>
</table>

All results are significant to the 99.5% confidence-level.

The linear regression equation for the share of urban roads has the form:

\[ y = \text{constant} + a \times t, \text{ with} \]

\[ y: \text{ share of urban roads} \]

\[ t: \text{ year} \]
### Annex 3  Glossary

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Adjusted R square/ Adjusted stability index</strong></td>
<td>This statistical figure measures the relation between the measured variance and the real variance. The range lies between 0 and 1, where 0 is bad and 1 means that the model reflects the reality perfectly.</td>
</tr>
<tr>
<td><strong>Cost-benefit-analysis</strong></td>
<td>Cost-benefit analysis (CBA) is an economic technique for project appraisal. CBA is a process of weighing the total expected benefits against the total expected costs of one or more actions in order to choose the best or most profitable option.</td>
</tr>
<tr>
<td><strong>Cost-effectiveness analysis</strong></td>
<td>Cost-effectiveness analysis (CEA) refers to the consideration of decision alternatives in which both their costs and consequences are taken into account in a systematic way. The consequences are often expressed in non-monetary effectiveness indicators.</td>
</tr>
<tr>
<td><strong>“Cost-price”</strong></td>
<td>The so called “cost price” is the price for automotive products which the car manufacturers pay to their suppliers being the producers of these products. The “cost price” comprises the production costs as well as a profit margin for the supplying industry.</td>
</tr>
<tr>
<td><strong>CRM</strong></td>
<td>Customer relationship management (CRM) covers methodological tools used by companies to manage their relationships with clients. Information on existing and potential customers is stored and analysed to be used for further processes (e.g. marketing).</td>
</tr>
<tr>
<td><strong>F-Value</strong></td>
<td>The F-Value is a statistical figure which gives information about the goodness of the model. The higher the F-Value the better is the model.</td>
</tr>
<tr>
<td><strong>Headway</strong></td>
<td>Function which contentes the velocity of the vehicle, the difference speed of the vehicle and the vehicle in front, and the time gap between them.</td>
</tr>
<tr>
<td><strong>MAIS</strong></td>
<td>(Maximum) Abbreviated injury scale (AIS) is a standardised injury classification divided into different body parts and injury severity. The classification varies from 0 (unhurt) to 6 (fatal). Maximum means the highest injury severity level by victims.</td>
</tr>
</tbody>
</table>
Multi-criteria analysis  Multi-criteria analysis (MCA) describes any structured approach used to determine overall preferences among alternative options, where the options accomplish several objectives. Corresponding to the objectives, indicators are identified. The measurement of indicators is often based on the quantitative analysis (through scoring, ranking and weighting) of a wide range of qualitative impact categories and criteria.

QALY  Quality-adjusted life years (QALYs) are a measure to assess the value of one year of life in relation to the state of health. Each year in perfect health is assigned the value of 1.0, whereas a value of 0 stands for death. Changes of life expectancy, which is weighted with life quality parameters, are compared to (additional) medical costs and indirect costs e.g. resulting from productivity losses.

Significance level  The significance level describes the potential of being wrong. A significance level of 0.005 means that in 5 out of 1,000 cases the assumption is wrong.

TRACE  TRACE ("TRaffic Accident Causation In Europe" (TRACE)) is a current European-funded project on traffic accident causation. The objective of the TRACE project is to provide a global overview of the road accident causation issues in Europe and possibly overseas, based on the analysis of available databases which include accident, injury, insurance, medical and exposure data. TRACE aims at identifying, characterising and quantifying the nature of risk factors, groups at risk, specific conflict driving situations and accident situations as well as at estimating the safety benefits of a selection of technology-based safety functions.

Value chain  The concept of the value chain describes the generic value-adding activities of an organisation which comprise primary activities (e.g. inbound logistics, production) as well as support activities (e.g. administrative management, research and development). The value chain model is a broadly-accepted analysis tool for strategic planning. Its objective is to maximise value creation while minimising costs.

VAT  Value added tax (VAT) is an indirect sales tax which is intended as a tax on consumption of goods and services.