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TNO report for the European Commission

Impact of Information and Communication Technologies on Energy Efficiency in Road Transport- Final Report

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Summary

Background and aim of the study

The application of ITS is seen as very promising to address the negative consequences of road transport. However, the mechanisms which have an impact on the CO_2 emissions are very complex, while not much about this is known from existing studies.

Therefore, the EC commissioned this study, 'Impact of Information and Communication Technologies on Energy Efficiency in Road Transport', with the objective to perform an analysis on how ICT can contribute to reduction of emissions of CO_2 and possible other greenhouse gases (from here on called "CO_2 emissions") through innovative technologies. The study is intended to support the policy making process, by providing an assessment of the most important systems and models able to resolve some of the challenges related to clean and efficient mobility. The result will help to define DG INFSO's role in the ICT debate.

The study reviews three types of ICT-based solutions that can contribute to improved energy efficiency: Eco-solutions, Advanced Driver Assistance Systems, and Traffic Management solutions. As many studies are supported by simulation, the current study furthermore surveyed existing CO_2 emission models that are suitable to calculate the effects of ITS measures on CO_2 emissions. In addition, an assessment of aspects relevant to policy making was performed with regard to implementation and deployment of the most promising ICT based CO_2 reducing systems and services.

The main elements of the study were:

- Analysis of the benefits of ICT based eco-solutions, Advanced Driver Assistance Systems (ADAS) and traffic management solutions in achieving lower CO_2 emissions through both direct and indirect effects;
- Synthesis of the results, resulting in:
  - a ranking of the most promising systems and solutions examined;
  - a judgment of the usefulness of existing models to estimate the energy efficiency of the systems and solutions examined;
  - an estimation of the ease of implementation of the measures examined.
- Review the state of the art in CO_2 emissions modelling, creating an overview on the state of the art in CO_2 emissions modelling for road transport and conduct an assessment of the underlying models.

For ease of reading, the word "measures" will be used to cover eco-solutions, ADAS and traffic management solutions in this study. All work focused on application in the EU-27, while knowledge about world-wide activities such as in Japan and the United States is incorporated.

Overview of measures of the initial assessment

In total, over 50 systems have been assessed, as listed in Table 1. In the initial assessment, quantitative and qualitative information related to environmental impact and implementation issues of the systems and measures was collected from earlier

studies. This was summarized in a template for each of the systems, which are delivered to the EC with this report.

Table 1: List of systems considered in the initial assessment

Eco-solutions	ADA systems	Traffic management systems
Fuel-consumption/energy use indicators	Cruise Control (CC)	Real-time Traffic and Travel Information (RTTI) including multi-modal
Feedback and Pay As You Drive (PAYD) systems	Advanced/Adaptive Cruise Control (ACC)	Environmental zone access management
Gear shift indicator	Intelligent Speed Information (ISI)/Speed alert	Demand and access management
Active gas pedal	Stop-and-go / Full Speed Range Stop-and-Go	Road charging/Tolling
Map-enhanced eco-driving	Lane-departure warning/lane keeping assistant (LDWA)	Slot management
Automatic engine shutdown (PSA)/hybrid technology	Obstacle collision avoidance	Incident detection/eCall
Tyre pressure indicator	Emergency braking systems (EBS)	Traffic signalling optimization/ Homogenization
Fuel-efficient route choice	Electronic Stability Programme/Control (ESP/C)	Traffic light synchronization/Green waves
Remote diagnostics	Driver condition warning	Dynamic priority lanes for freight transport
Map-enhanced After-Treatment Control	Pre-Crash Protection of Vulnerable Road Users	V2I Heavy vehicle and public transport signal priorities
Map-enhanced Auxiliary Control	Lane Change Assistant (LCA)	Variable message signs
Map-enhanced (Advanced) Cruise-Control	Night vision	Emergency and bus lane allocation
Map-enhanced Hybrid-Electric Vehicle Energy Management	Cooperative ACC (CACC)	Reversible lanes due to traffic flow
Map-enhanced Fuel Saving Transmission Functions	Intelligent Speed Adaptation (ISA)	Dynamic navigation systems
Wheel Alignment Diagnosis	Integrated Full-Range Speed Assistant (IRSA)	Variable speed limits
	Curve speed warning	Cooperative Multi-modal traffic (information) system
	Cooperative Intersection Collision avoidance	Trip departure planning (freight)
	Local hazard warning / Wireless Local Danger Warning	Dynamic traffic light synchronization with actual traffic conditions
	Platooning	Parking availability and guidance
	Autonomous driving	
	Recommended Speed Profiles	
	Lane Keeping System	
	Congestion Assistant	

Selection of systems for extended analysis

After the initial assessment of these systems, the most promising systems for CO_2 reduction on EU level were selected, based on a multi-criteria analysis. In this analysis, besides reported emission effects, traffic effects and implementation issues have been taken into account. Traffic effects include all effects relevant for CO_2 emissions, such as reduction in kilometres travelled, speed change, homogenization of traffic flow, traffic flow composition, or more efficient engine use. Examples of implementation issues are the current and forecasted use, measure costs, compliance issues, barriers for implementation, risks and involved stakeholders.

The multi-criteria analysis yielded the following selected systems for extended analysis:

- (Adaptive) Cruise Control
- Lane keeping assistant/emergency braking
- Platooning
- Eco-driver Assistance (including Energy-use Indicator and Gear Shift Indicator)
- Eco-driver Coaching (including Enhanced Map Data)
- Fuel-efficient route choice
- Automatic engine shutdown
- Tyre pressure indicator
- Pay As You Drive
- Congestion charging
- (Dynamic) Traffic signalling optimization
- Trip departure planning (freight)
- Slot management

An important part of the extended assessment was the estimation of the potential CO_2 reduction on EU27 level, by estimation of the (direct) CO_2 reduction of the system and the share of situations where the measure is effective. To assess the share of situations, an estimation was made of the distribution of total vehicle kilometres in the EU over motorways, rural roads and urban roads, as well as over types of traffic flow (free flow, heavy traffic or congestion) and vehicle types (percentage of heavy vehicles). These numbers were based on estimations in the eIMPACT project [2], in which different sources were used (e.g. the ProgTrans European Transport Report 2004 and 2006, the International Road Traffic and Accident Database and the Infras/IWW report on external costs of transport [3]. Furthermore, average emission factors derived from a large database with emission measurements of the TNO VERSIT+ emission model were used to make a rough estimation of the effect on CO_2 emissions.

The extended assessment had to deal with from many uncertainties regarding the effect estimation on CO_2 reduction, mainly because little information was available about CO_2 emissions and share of situations for most of the systems. The most important uncertainties for each system are listed in chapter 5.

Synthesis of the results resulted in a ranking of the most promising systems, an estimation of the ease of implementation of these measures and a judgment of the usefulness of existing models to estimate the energy efficiency of the systems and solutions examined.

Potential CO_2 reduction

The potential CO_2 reduction is based on the maximum possible use of the system, i.e. a 100% penetration rate of an in-vehicle system, or application on all suitable roads and areas.
Figure 1 gives an overview of the estimated potential CO_2 reductions per measure. This reduction is given as a percentage of the total CO_2 emission by road transport in the EU27.

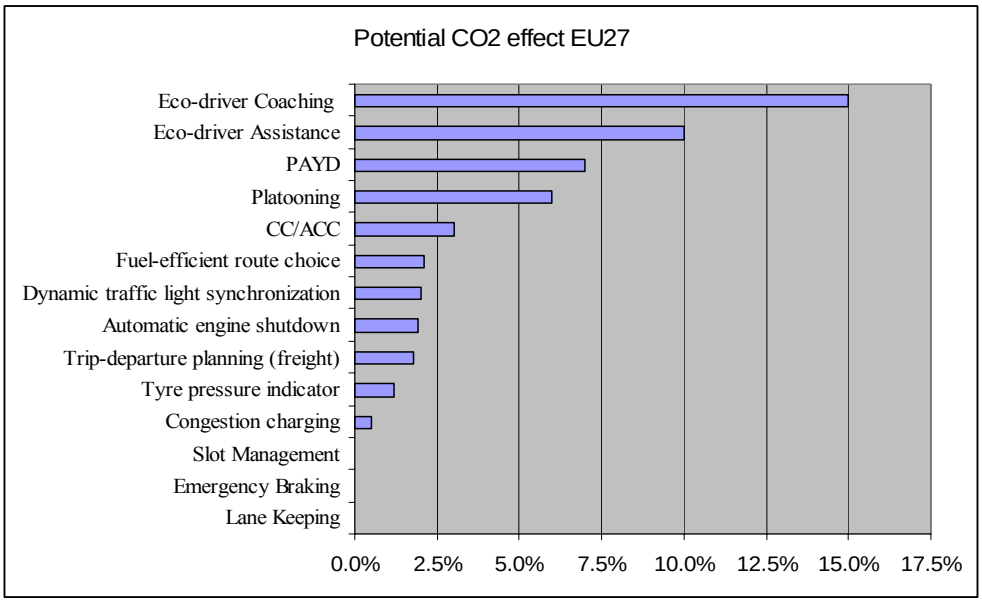

Figure 1: ranking of promising measures on potential CO2 effect

Since these numbers indicate what the maximum effect can be, for some measures, it will be easier to reach this potential effect than for others. This may depend on all kinds of implementation issues, as well as on the expected compliance of the driver for the measure. This is summarized in Table 2.

Table 2: Overview of potential CO_2 effects, ease of implementation, compliance and expected future use for promising measures

System	Potential CO_2 effect EU27	Ease of implementation	Compliance issue	Expected future use
Eco-driver Coaching	15%	Medium	Medium	Large
Eco-driver Assistance	10%	Easy	Medium/Hard	Large
PAYD	7%	Medium	Medium	Medium
Platooning	6%	Very hard	Hard	Small
CC/ACC	3%	Easy	Easy	Large
Fuel-efficient route choice	2%	Medium/hard	Medium	Medium
Dynamic traffic light synchronization	2%	Medium	No issue	Large
Automatic engine shutdown	2%	Easy	Easy	Large
Trip-departure planning (freight)	2%	Medium	Medium	Large
Tyre pressure indicator	1%	Easy	Medium	Large
Congestion charging	0.5%	Medium	No issue	Medium
Slot Management	0.05%	Hard	No issue	Small
Lane Keeping	0.008%	Easy	Easy	Large
Emergency Braking	0.007%	Easy	No issue	Large

Based on these results, the measures can be divided into the following groups:

Measures with a very large CO_2 reduction on EU27 level

- Eco-driver Coaching
- Eco-driver Assistance

The large effect is expected because the system enables driving in a more energy efficient manner (thanks to the support by a number of tools such as gear-shift indicator, speed profile recommendations, using enhanced map data) in all circumstances and on all road types. A barrier for implementation of the Eco-driver Coaching system is the use of map-enhanced information. For both systems, the effect is highly dependent on the willingness of the driver to comply with the most energy efficient driving style.

Measures with a large CO_2 reduction on EU27 level

- Pay As You Drive
- Platooning

The substantial effect of PAYD is due to the fact that the amount of vehicle kilometres driven will decrease significantly. This measure seems promising, however, existing examples in e.g. the Netherlands, U.S. and U.K., have shown that implementation is not easy, mainly because it is hard for insurers to achieve a profitable business case for this type of insurance.

The CO_2 reduction of platooning is mostly due to drag reduction. Technically, platooning seems feasible, but the large effect will only be reached for high penetration rates, and its implementation could also require infrastructural changes at e.g. on-ramps and weaving sections, which complicates the implementation. Therefore we expect this measure only to be applicable in a more distant future (more than 10 years from now).

Measures with a medium CO_2 reduction on EU27 level

- (Adaptive) Cruise Control
- Dynamic traffic light synchronization
- Fuel-efficient route choice
- Automatic engine shutdown
- Trip-departure planning (freight)
- Tyre pressure indicator

(Adaptive) Cruise Control has a relatively large effect on CO_2 reduction, since it is applicable on a large part of all vehicle kilometres driven, and homogenizes the traffic flow by driving with a more constant speed. Both CC and ACC are easy to implement and are already on the market.
Dynamic traffic synchronization can achieve a large effect on throughput and emissions in urban areas and can potentially be introduced in all urban areas. There are few barriers for implementation; however, introduction and maintenance are rather costly.
Fuel-efficient route choice is technically feasible, but depends on the availability of actual traffic information. Furthermore, there are compliance issues since the fuel-efficient route is not necessarily the fastest route.
Automatic engine shutdown reduces vehicle emissions and energy consumption during idling. Implementation is easy and the system is already on the market. There is almost no compliance issue, since the system works automatically (for most existing systems, the driver only needs to put the gear in neutral) and does not give discomfort to the driver. For electric vehicles, the system will have no benefit, since energy consumption for idling electric vehicles is already zero.
Trip-departure planning can offer large benefits in terms of kilometres driven and avoiding congestion and thereby to CO_2 reduction, mainly for freight operators and logistics firms. It is expected that almost all freight operators are going to use similar systems.
A tyre pressure indicator will reduce the number of vehicles driving with underinflated tyres, which will be beneficial for energy consumption and reduce CO2 emissions. It is estimated that at present possibly up to around 40% of the vehicles have underinflated tyres. There are almost no barriers for implementation. Tyre pressure monitoring systems will become much more common in the next few years.

Measures with a small CO_2 reduction on EU27 level

- Congestion charging
- Slot Management

These measures have less CO_2 reduction on EU27 level than the measures presented above, because they are applicable in fewer situations.
Congestion charging as considered in this study is only applicable to large cities. It has already been implemented in London, Stockholm and Milan, and has shown that, locally, a substantial effect on throughput and emissions can be achieved.
The same holds for slot management; especially on important corridors where it is important that the traffic can be controlled (e.g. tunnels), the measure can be useful. Large-scale implementation does not seem to be feasible.

Regarding safety systems that only have an indirect effect on CO_2 emissions by avoiding incidents and subsequent queue formation: Our effect estimation has shown that these systems have a much lower potential regarding CO_2 reduction. Of course, it is still worthwhile to stimulate the use of these systems for improving traffic safety.

The estimations of the presented CO_2 effects are based on the vehicles of today. When the measures are applied in future years, the effect in absolute terms will be smaller, since the vehicles will become cleaner and more energy efficient already by 'normal' technological developments.
For each of the selected systems, implications for electric vehicles were addressed. In general, measures that are effective on the energy efficiency of conventional engine vehicles are also beneficial for electric vehicles, however, the effect may be smaller, since electric vehicles are already capable of more energy efficient driving, especially at low speed.

Finally, it can be noted that the effects of most of the presented promising measures are independent of each other, such that the total effect, when used together, is the summation of the separate effects. It can therefore be recommended to stimulate the deployment of a combination of the promising systems and measures.

Evaluation of CO_2 models

In addition to the assessment of ICT measures, a quick scan has been performed related to the existing CO_2 emission models and their suitability to assess the impact of proposed ICT based measures. It was found that CO_2 models exist with different levels of detail, ranging from more generic traffic situation models to very detailed vehicle design models. For a proper (virtual) evaluation, each category of measures sets its own model requirements.

Traffic management measures influence the traffic intensity and the amount of congestion. These measures can be evaluated using traffic situation based CO_2 emission models. To ensure a good resolution, such models should contain a large variety of traffic situations. This is not the case for most of the models currently available. In the future, models like HBEFA will be extended and might provide the possibility to import traffic situations.

Advanced driver assistance systems affect the driving behaviour, and can best be evaluated using instantaneous emission models like DIVEM or the most recent version of VERSIT+. Both microscopic traffic simulations output and empirical GPS data can serve as input for the emission models. To be able to generate representative results, the emission model used should contain a sufficiently large emission database. In addition, it should be noted that traffic simulations do not automatically deliver realistic output in terms of speed-time profiles that can serve as input for the emission models.

Eco solutions affect the drive-train characteristics and / or driving behaviour. Therefore an (virtual) evaluation can be performed with an engine power demand model like PHEM or VeTESS. In general, vehicle design models are suitable, but too detailed. However, most power demand models only contain limited emission data, with the risk that the models do not provide results representative for a certain vehicle category.

It can be concluded that numerous CO_2 models exist which generally are methodologically sound. However, only a few are based on a reasonably large emission dataset. Experimental data on both real world traffic emissions and driver behaviour will be valuable for the further development and validation of these models.

In addition, a CO_2 emission model alone is not able to evaluate the effects of each measure directly. Often these models are used in a chain of models, as for instance a traffic simulation model is needed to calculate the effect of the measure on the traffic parameters like average speed, the amount of congestion and the traffic volumes. For a reliable and accurate result the complete chain should provide accurate results. Therefore it is noted that:

- In case traffic simulation models are used, these models should generate realistic speed-time profiles to ensure accurate input for the emission models.
- Extrapolation of the CO_2 model results towards national, regional or European scale is needed. This is an important part of the study, which can significantly influence the results. Currently, as in this study, this is done via an estimation of the 'share of situations'. Further development of such methodologies and the availability of commonly accepted figures are needed.

[1] EU Energy and transport in figures, Directorate-General for Energy and Transport, statistical pocketbook 2009.
[2] K. Assing, H. Baum, J. Bühne, T. Geißler, S. Grawenhoff, H. Peters, W. H. Schulz, U. Westerkamp. *Socio-economic Impact Assessment of Stand-alone and Co-operative Intelligent Vehicle Safety Systems (IVSS) in Europe - Deliverable D3 Methodological framework and database for socio-economic evaluation of Intelligent Vehicle Safety Systems,* Contract no.: 027421 eIMPACT (2006).
[3] Infras/IWW, External Costs of Transport, Update Study, Final report, Zurich/Karlsruhe 2004.

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1 Introduction

In the context of mobility needs of people and goods, road transport has increased in significance. But the increased benefits of these actions have also translated in a rise of negative consequences in the area of safety, greenhouse gas (GHG) emissions and energy consumption. Road transport is responsible for 60% of the oil consumption at EU level and generates about one fifth of EU's CO_2 emissions (see Figure 2), with passenger cars accounting for around 12% of these. While at EU25 level GHG emissions were reduced by almost 50% between 1990 and 2005, CO_2 emissions from road transport rose by 26%, despite an average new car CO_2 emission reduction of 12.4% for the same time period. Thus, the already significant progress in vehicle technology has so far not been enough to neutralize the effect of increases in traffic and car size. As such, the environmental effects of these actions present challenges that must be addressed in the interest of long-term sustainability and public welfare.

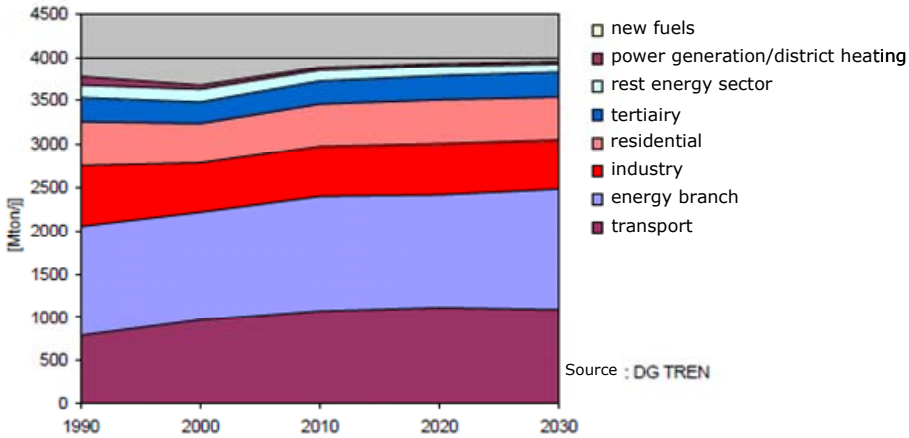

Figure 2: CO_2 emissions per sector in EU25

A valid answer to these problems could be provided by using ICT solutions in support of cleaner and more efficient mobility. One way of achieving this is through applying ICT to a combination of measures that address vehicle and fuel technologies, road infrastructure and vehicle and driver behaviour to achieve the most cost-efficient solutions in regards to energy saving. In order to take such measures, it is important to understand these systems' potential and capabilities in helping to solve the issues related to cleaner and more efficient road transport.

The study, commissioned by the EC, is aimed to support DG INFSO in their positioning and decision making process and will help to define their role in the ICT debate. The project has resulted in state-of-the-art knowledge about the potential of existing and future ICT-based systems/technologies for improving energy efficiency and CO_2 reduction in road transport. This is supported by a survey of existing CO_2 emission models that are able to calculate the effects and by an assessment of aspects relevant to policy making with regard to implementation and deployment of

the most promising ICT based CO_2 reducing systems and services. The application area is EU27.

The European Commission has contracted a consortium to carry out this assessment of the impact of Information and Communication Technologies on Energy Efficiency in Road Transport. The consortium is led by TNO with VTT (Finland) as a partner and Volvo Technology (Sweden) and the Technical University of Crete (Greece) as sub-contractors.

The main elements of the study are:

- Analysis of the benefits of ICT based eco-solutions, Advanced Driver Assistance Systems (ADAS) and traffic management solutions in achieving lower CO_2 emissions through both direct and indirect effects;
- Synthesis of the results, resulting in:
  - a ranking of the most promising systems and solutions examined;
  - a judgment of the usefulness of existing models to estimate the energy efficiency of the systems and solutions examined;
  - an estimation of the ease of implementation of the measures examined.
- Review the state of the art in CO_2 emissions modelling, creating an overview on the state of the art in CO_2 emissions modelling for road transport and conduct an assessment of the underlying models.

For ease of reading, the word “measures” will be used to cover eco-solutions, ADAS and Traffic management solutions in this study. All work will focus on application in the EU-27, while knowledge about world-wide activities such as in Japan and the United States will be incorporated.

The study is directly related to DG INFSO’s main policies, in particular:
- Stimulating the Information Society by rolling out new technologies;
- Exploiting the benefits in the area of Society and Environment;
- It is linked to the i2010 Intelligent Car Initiative, including the following objectives:
  - Provide drivers with real time information about traffic on road networks, thereby avoiding congestion;
  - Find the most efficient routes for any journey.
- Optimize engine performance, thus improving overall energy efficiency.

Reading guide

In chapter 2 the approach of the study is outlined. The selection of promising measures is thereafter explained in chapter 3. The extended assessments of the most promising measures are discussed in chapter 4, with the conclusions drawn in chapter 5. Chapter 6 discusses the assessment of CO_2 models, followed by the overall conclusions and recommendations in chapter 7.

2 Approach

2.1 General methodology

A phase-by-phase approach was used, in which available quantitative and qualitative data from relevant EC studies and relevant other sources were processed for a large number of existing and possible systems. The phases in this approach were:

Phase 1: Initial assessment
The starting point was an initial extensive list of measures. This list was based on experiences from earlier projects, a literature scan and from earlier workshop/expert meetings on policy priorities of ITS measures. Information/data (quantitative and/or qualitative) related to environmental impact of the systems and measures are collected. From earlier studies a considerable amount of data/information was already available.

Phase 2: Selection of most relevant systems
In the second step a selection is made of the most effective or promising systems in terms of CO_2 reduction.

Phase 3: Detailed assessment
The selection of systems is further assessed and completed in the third step. Many sources were available in which the effects of ICT solutions in transport are described. Most did not, however, include detailed analysis of the effects on CO_2 emissions and/or energy efficiency. Many of the ICT solutions were developed to improve throughput or safety. Additional benefits of such systems in the form of e.g. CO_2 reductions are sometimes mentioned but hardly ever elaborated, let alone quantified. In this study, we used, as much as possible, existing evidence of effects, arriving at an estimate of the potential CO_2 reduction in the EU-27 as follows:

- Quantifications of CO_2 reductions in literature are analysed (to what situations do the reductions apply, is information available to scale up results to EU-27 level, etc.).
- If no effects in terms of CO_2 were given, they were derived from the traffic and safety effects given in literature (e.g. changes in average speeds and driving dynamics, such as described in the safety impact assessment in eIMPACT deliverable D4 [1]). From the CO_2 models available, certain relationships between emissions and specific traffic situations or driving patterns can be derived that can be applied to traffic effects found in literature (e.g. changes in average speeds and variation in speed, or travel times). While it wa0s not feasible in this project to do extensive emission modelling based on measurements or output from micro-simulation models (which would give more reliable results), first estimates of the CO_2 emissions were possible that took into account the specific impacts of ICT solutions.

Some ICT solutions may not directly influence CO_2 reductions (through changes in vehicle or driving behaviour). Indirectly, however, many systems still influence CO_2 emissions by reducing congestion (e.g. all eIMPACT systems showed a reduction in accident-related congestion). These effects are also quantified, although with little

information available at the EU-27 level about congestion frequencies, levels and causes.

Phase 4: Assessment of CO_2 models
With respect to CO_2 models, the consortium has made a general inventory of the existing models, and a selection is made of models that are especially suitable for the evaluation of the technologies, systems and measures that are subject of the study. These models are assessed with respect to their abilities in relation to the application area.

Phase 5: Synthesis and ranking
In this step all information collected and results from the expert meetings are processed, reviewed and ordered/ranked to make it suitable for reporting. Additional attention will be given to the synergy between the three different elements (eco-solutions, ADA systems and Traffic Management solutions). Rankings will primarily be based on benefits for CO_2 reduction, but alternative rankings will be studied based on other weigh factors.

[1] I. Wilmink, W. Janssen, et al., *Socio-economic Impact Assessment of Stand-alone and Co-operative Intelligent Vehicle Safety Systems (IVSS) in Europe - Deliverable D4 Impact assessment of Intelligent Vehicle Safety Systems.* Contract no.: 027421 (2008)

2.2 Initial assessment and selection of most relevant measures

The methodology followed in the initial assessment is as follows. Firstly, an extensive literature review was carried out to gather as much information as was available on each of the systems. This information was documented in a template for each of the systems. It included descriptive information about CO_2 impacts, mechanisms for explaining the impacts, ease of implementation, expected penetration rates, etc. Secondly, in order to guide the process of the selection of most promising systems, the information in the templates was translated to an excel sheet, which summarized the information of the templates into estimates on all mechanisms that are relevant for GHG emission or for implementation of the system. This excel sheet was designed to facilitate a multi-criteria analysis. The criteria used were grouped into the following topics:

- CO_2 effects;
- Traffic effects;
- Ease of implementation.

CO_2 effects were estimated based on two criteria: the (direct) CO_2 reduction of the system when it is effective, and the share of situations when it is effective, on the EU network level, measured in percentage of vehicle kilometres. The product of those two gives an estimate of the possible CO_2 reduction of the system on the EU level.

The traffic effects indicate the effects that influence emissions, e.g. reduction in kilometres travelled, speed change (towards optimum speed), homogenization of traffic flow, or more efficient engine use. A high score on traffic effects is associated with a large reduction in CO_2 emissions. The traffic effects can therefore be regarded as second indication on the CO_2 emissions, to be used when no estimate

on CO_2 was available (or only a very uncertain estimate), and also as an extra check on the CO_2 effects reported: a high score on traffic effects should correspond with a high score on CO_2 effect as well. Ideally, the relative scores and ranking based on the CO_2 effects should be comparable with the ranking on traffic effects.

Ease of implementation is a summarizing indicator of all barriers and risks for implementation of the system. This includes measure costs, (incompatible) interests of different stakeholder groups, risks, legal issues etc. This was translated into one of the following categories: very easy, easy, medium or hard. Furthermore, an estimate of the penetration rate was given for the current situation and for 2020.

For each of the other criteria, a classification was made into 2 to 7 classes, with descriptive names on the effect such as “small”, “medium”, “large” etc, and indicated boundaries in percentages. If information was known about the effect in percentages, this was used, otherwise a relative judgement was made. For each criterion, an indication of the certainty of this effect was given. Three levels were identified:

- High (based on empirical data from at least two sources);
- Medium (expert opinion only);
- Low (no information available).

For each of the groups (CO_2 effect, Traffic effect, Ease of implementation, Penetration rate), a score was composed of the ratings on the sub criteria, such that the total score maximum was 100. This was done by giving weights to each of the classes of the sub criteria from 1 to 10 (5 was neutral), and by combining them to an overall score per group:

- CO_2: product of score on CO_2 effect and score on share of situations.
- Traffic: weighted sum of the scores on the sub criteria, which summed to 100, and with a larger weight for the most important criteria with respect to the CO_2 effect:
    - 2 x km travelled;
    - 1 x traffic composition;
    - 1 x average speed;
    - 1 x travel time;
    - 2 x change in amount of congestion;
    - 1 x more efficient engine use;
    - 2 x homogenisation of traffic flow.

N.B. the effect on CO_2 of a change of speed depends on the traffic situation for which the effect will occur: an increase in speed from a congested situation will lead to lower emissions, while an increase in speed in a free flow situation will lead to higher emissions. Therefore, an extra criterion was added to indicate if it has an effect on the speed in congestion or in free flow.

- Implementation: the score of the chosen classification times 10 (to get to 100);
- Penetration rate: average penetration rate of the estimated rates for now and 2020.

Finally, an overall score was produced by combining the scores of the groups CO_2 effect, Traffic effect, Ease of implementation and Penetration rate in a weighted sum.

In the analysis, the weights were varied to study the effect on the rankings and to decide on the best weights. Also, alternative rankings were produced taking into account the (un)certainty, by lowering the scores with a certain weight (1, 0.66 or 0.33 respectively) when the effect is less certain.

The excel document furthermore included an overview table, where the classifications on all criteria can be compared easily for all systems. This was used to judge if the estimations relative to each other were correct, according to our expert judgement.

The multi-criteria excel sheet served as the basis for producing system rankings and multi-criteria analyses. This method was used for all three groups of measures, however, the weights of the multi-criteria ranking differed per group of systems.
In the analysis, some of the original estimates used in the multi-criteria tables were adapted to be more in line with the estimated impacts of the other systems, based on expert judgment and progressing insight.

The final choice of most relevant systems was not per se taken directly from the multi-criteria ranking; there were sometimes other grounds to make another ranking, such as for the safety systems, for which an estimations of the secondary effect on CO_2 reduction was not easily possible beforehand. Reason to include them, was that a good judgement for these systems was only possible by including them in the list of selected systems for further analysis. Also, it should be noted that the estimates in the excel sheet were often very uncertain. Therefore, they should not be considered as reliable source for the expected effect on GHG of the systems, but only as a tool to guide the system selection. The uncertainties and questions that arose in this process are addressed in the next phases.

2.3 Extended assessment of most relevant measures

2.3.1 Emission effects

Emissions of traffic are mainly dependent on the following 3 aspects of traffic:
- Traffic composition: percentage of trucks and distribution over vehicle types with regard to the fuel type (petrol, diesel, electric etc)
- Speed: very low and high speeds are energy inefficient
- Speed variations: generally, emissions are highest during accelerations.

To estimate the effect of these aspects on CO_2 emissions, average CO_2 emission factors (for an average, mixed vehicle fleet) were derived for relatively new cars (euro 4 and euro 5). In Figure 3, the difference in CO_2 emission between trucks and passenger cars and of the speed is shown. The difference between trucks and passenger cars varies with a factor 2.8 to 4.5. The difference between the optimal speed and the CO_2 emission at very low speeds is approximately a factor 3. Figure 4 zooms in on the CO_2 emission of passenger cars and shows the influence of speed variations: constant speed represents a situation where all vehicles drive with perfectly constant speed, while medium interaction is a situation with high speed variations.

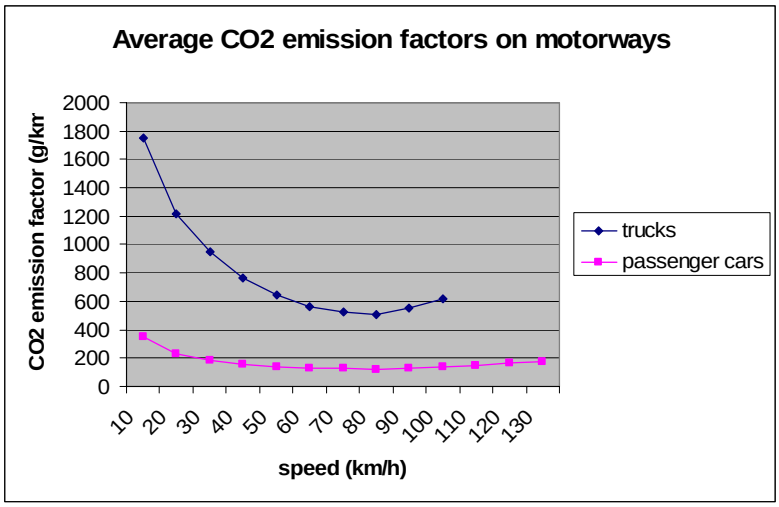

Figure 3: Average CO_2 emission factors on motorways for trucks and passenger vehicles (Euro 4 and 5)

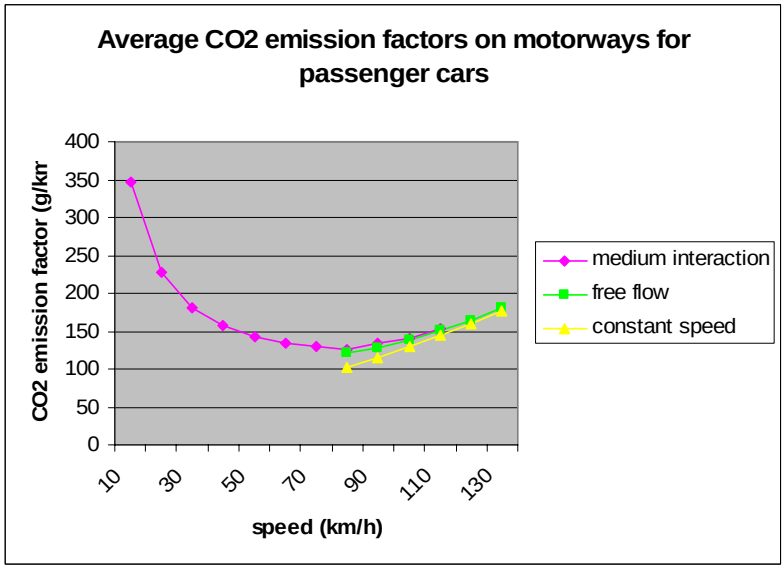

Figure 4: Average CO_2 emission factors on motorways for passenger cars for different interaction levels of the traffic flow

The mentioned aspects which influence CO_2 emission of traffic, were taken into account in the extended assessment.

An important point of attention for studying the effect of Eco-solutions, ADAS and Traffic Management Solutions on CO_2 emissions, especially when used from other reported research, is that the effect is usually studied under specific conditions (e.g. congested traffic on the motorway). This is taken into account by scaling the emission effects to EU level, as elaborated in the next section.

2.3.2 Traffic data for scaling CO_2 effects to EU level

In order to be able to compare the effect on CO_2 reduction of the Eco-solutions, ADAS and Traffic Management Solutions, the emission effects should be scaled to

a comparable level. Since this project focuses on EU27 level, for all promising systems, an estimation is done for the effect on EU27 level, with the help of traffic data from other sources. This effect depends on the road type, e.g. some measures are typically effective on motorways, while others are only applicable to urban areas. Also, the effect is often dependent on the amount of congestion. Therefore,

Our basic source of traffic data was provided by the eIMPACT project [1]. They based their numbers on different sources, e.g. the ProgTrans European Transport Report 2004 and 2006, the International Road Traffic and Accident Database and the Infras/IWW report on external costs of transport [2].
These sources provided an estimation of the distribution of the vehicle mileage over different road types (motorway, rural, urban), as well as over different levels of service [3] for the year 2010 (extrapolations where used to get future estimations). To make these numbers suitable for our purpose, the seven levels of service (A to F) were clustered into three groups: free flow (A), Heavy Traffic (B to E) and congestion (F). This resulted in an estimation of the distribution of the total vehicle mileage as given in Table 3.

Table 3: Estimation of the distribution over road type and amount of congestion of the total vehicle mileage in 2010 in the EU15. Sources: Infras/IWW, External Costs of Transport, Update Study, Final report, Zurich/Karlsruhe 2004, Handbuch für die Bemessung von Straßenverkehrsanlagen (2001) and own calculations

	Free flow	**Heavy traffic**	**Congestion**	**Total**
Motorways	11,9%	8,5%	2,8%	23,2%
Rural roads	48,0%	2,4%	0,6%	51,0%
Urban roads	0%	25,4%	0,4%	25,8%
Total	59,9%	36,3%	3,8%	100,0%

These numbers were estimated for the EU15, however, by the lack of comparable data on EU27 level, we have taken these estimations as best guess for the EU27[1].

Furthermore, the estimated distribution over vehicle types in the EU25 was available, as presented in Table 4. By assuming that most of the vehicle kilometres of goods transport are driven on motorways, followed by rural roads and urban roads respectively, the 17% of vehicle kilometres by goods transport was estimated to be distributed as 25% on motorways, 18% on rural roads and 6% on urban roads (combining these with the distribution over road types of the total vehicle mileage, 23%*25%, 51%*18% and 26%*6%, gives 17% of the total vehicle mileage).

[1] It is expected that the countries that have entered the EU (e.g. Slovenia, Czech Republic, Lithuania) at a later moment on average have a slightly different vehicle mileage distribution. In order to estimate how large the influence of the new member states could be on the distribution of vehicle mileage in the EU, an indicative estimation was done. Since the new EU27 member states (mainly eastern European countries with less extensive motorway networks), we could assume that a larger proportion of the mileage is made on rural roads and less on motorways. Suppose that compared to EU15, half of the proportion is driven on motorways, and the other half is added to rural roads. The distribution over road types for the new EU27 countries would then be 11.5%, 62.5% and 26%. The new EU27 countries account for 21% of the total EU27 population. If we estimate the share of the vehicle kilometres of the new EU27 countries to the total EU27 vehicle kilometres at 20% (a fairly high estimate given that the mileage per person is lower in the new member states), the total EU27 distribution over road types would be 21%, 53% and 26% (instead of 23%, 51% and 26%). The new EU27 countries therefore have a small effect on the final effect estimations in this study.

Table 4: Estimated distribution of vehicle kilometres over vehicle types in the EU25 in 2010 (source: Infras/IWW, External Costs of Transport, Update Study, Final report, Zurich/Karlsruhe 2004)

	2010
Passenger Transport	82%
Goods Transport	17%
Busses	1%

To get an idea of the contribution of each road type and traffic flow situation on CO_2 emissions, average emission factors per road type and speed were used to calculate the distribution in CO_2 emission per road type and amount of congestion, as given in Table 5. What can be seen in this table, in comparison with Table 5, is that the proportion of CO_2 emission on motorways and urban roads increases with regard to the proportion in total vehicle mileage, due to less energy efficiency at low and high speeds and the larger amount of congestion on motorways.

Table 5: Estimation of the distribution over road type and amount of congestion of CO_2 emissions in 2010 in the EU15 (own calculations)

	free flow	**heavy traffic**	**congestion**	**Total**
Motorways	15%	10%	4.4%	29%
Rural roads	37%	2.1%	0.6%	40%
Urban roads	0%	30%	0.7%	31%
Total	52%	42%	6%	100%

Finally, to estimate the potential CO_2 reduction on the EU level of solving congestion, average emission factors in congestion and in free flow per road type where used, where all vehicle kilometres in congestion were replaced with the same amount of vehicle kilometres in free flow, which resulted in the numbers presented in Table 6. The reduction on total share seems low. This is due to the low share of congestion on the total amount of vehicle kilometres.

Table 6: Potential CO_2 reduction for avoiding all congestion on EU15 level in 2010 (own calculations)

	Reduction for avoiding congestion per veh.km	**CO_2 reduction on total share**
Motorways	18%	0.5%
Rural roads	31%	0.2%
Urban roads	37%	0.1%

The figures presented in this section are used in the extended assessment in chapter 4.

[1] K. Assing, H. Baum, J. Bühne, T. Geißler, S. Grawenhoff, H. Peters, W. H. Schulz, U. Westerkamp. *Socio-economic Impact Assessment of Stand-alone and Co-operative Intelligent Vehicle Safety Systems (IVSS) in Europe - Deliverable D3 Methodological framework and database for socio-economic evaluation of Intelligent Vehicle Safety Systems,* Contract no.: 027421 eIMPACT (2006).

[2] Infras/IWW, External Costs of Transport, Update Study, Final report, Zurich/Karlsruhe 2004. Forschungsgesellschaft für Straßen- und Verkehrswesen e.V.
[3] Handbuch für die Bemessung von Straßenverkehrsanlagen, Köln (2001).

2.3.3 Implementation issues

In this section the various topics surrounding implementation of the system are discussed:

- *Current state*: Is the measure operational at this moment? If so, what is the estimated penetration rate or how widely is it applied?
- *Forecasted use*: How widely will the measure be applied in the near future (2020)?
- *Measure costs*: What is the current cost of the measure? How will these costs evolve over time? Is a decline expected with increasing penetration rates?
- *Ease of implementation*: What can be said about the general ease of implementation? Is it a measure that is easy or very complicated to implement?
- *Barriers*: Are there any barriers that stand in the way of implementing the system?
- *Risks*: Are there any significant risks expected?
- *Stakeholders*: Which stakeholders are playing a role in implementing the measure?

2.3.4 Assumptions and uncertainties

The extended assessment had to deal with many uncertainties regarding the effect estimation on CO_2 reduction, mainly because little information was available about CO_2 emissions and share of situations for most of the systems. For a good judgement of the results, it is important to take into account the assumptions and uncertainties which were needed for the effect estimation. Therefore, the most important assumptions and uncertainties for each system are listed in chapter 4.

2.3.5 Energy efficiency of (hybrid) electric vehicles

Given the developments in electrification of the vehicle fleet, a question that arises, is: what are the impacts of the measure when looking at electric vehicles? Is it expected that they will benefit in the same way combustion engine driven vehicles do?

Despite the extra weight of the additional electric system, hybrid electric vehicles have a better energy efficiency than the analogue vehicle with solely a combustion engine. This better energy efficiency can be attributed to a regenerative braking system and the fact that the combustion engine always runs in the optimal working point. The surplus energy produced by the combustion engine which is not required for the propulsion will be converted into electricity. A comparison of the CO_2 emission between conventional combustion engine vehicles, hybrid electric vehicles and full electric vehicles, dependent on the speed, is shown in Figure 5.

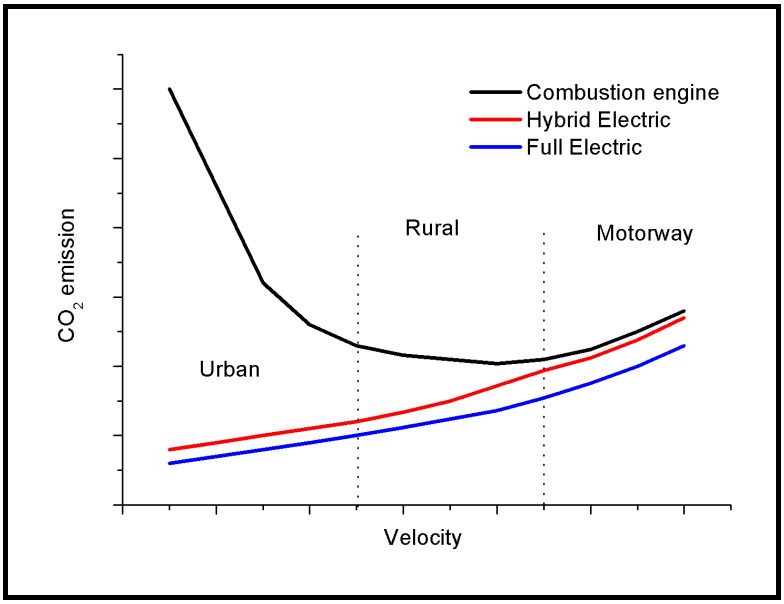

Figure 5: comparison of CO_2 emissions of combustion engine vehicles, hybrid electric vehicles and full electric vehicles, against driven speed

In the figure, it is seen that the full electric vehicle is the most energy efficient for all speeds, and the hybrid electric is more energy efficient than conventional combustion engine vehicles, although the difference is small for high speeds. Electric vehicles (full and hybrid) are especially efficient for low speeds.
In general, the emission of a hybrid electric car scales with the average velocity and only weakly with the driving dynamics, because the electric system of the car is largely responsible for the required extra power to accelerate the vehicle.
The energy consumption of full electric cars, and hence indirectly the CO_2 emission, scales stronger with the driving dynamics than hybrid electric vehicles. The regenerative braking system recovers part of the energy lost during deceleration.

2.4 Assessment of CO_2 models

In Europe different types of models exist, facilitating the calculation of CO_2 emissions from road transport. The two most important model types are:

- Models following the top-down approach: based on the estimated total fuel consumption, the total CO_2 emissions are calculated. If done on national scale, compensation is applied for international traffic (tourists, gasoline shopping across the border). The resulting information is relatively global, as for instance no distinction can be made by vehicle category or driving behaviour. This approach is normally used to calculate CO_2 emissions for e.g. the Intergovernmental Panel on Climate Change (IPCC).
- Models using the bottom-up approach: CO_2 emissions are calculated based on detailed vehicle categories or even at the single vehicle level, taking into account all characteristics that are relevant for that specific vehicle or vehicle class (like vehicle mass, year of built, type of engine, fuel type, vehicle km travelled). Examples are the VERSIT+ model developed by TNO, that follows a statistical approach and the PHEMS model developed by TU Graz that is based on a so-called engine model.

These models are much more detailed than the first type and most of them are based on experimental (measured) data.

Due to the lack of detail, application of top-down models to calculate the effects of ITS measures is limited. In contrast, the bottom-up models are able to calculate CO_2 emissions per vehicle class. Therefore these models are potential suitable for application to ITS measures. Models for calculation of the potential effect of ITS measures on CO_2 emissions should include:

- Proper modelling for driving dynamics and driving behaviour (e.g. speed, acceleration);
- Vehicle kilometres travelled (to take into account the possible change in kilometres travelled due to an ITS measure).

Approach

The approach as described in section 2.1 is followed. A review of the state of the art emission models for road transport is performed. An initial list with a number of road traffic CO_2 emission models can be found below (Table 7). This initial list will be extended with other models used.

Table 7: Initial list of road traffic CO_2 models to be assessed in this study (source: EC-METI Task Force)

Road traffic CO_2 models	
Model name	**Model type**
COPERT	Aggregated emission factors
MOBILE	Average speed model
TEE	Adjusted average speed model
HBEFA, ARTEMIS	Traffic situation model
VERSIT+	Speed-acceleration based statistical model
UROPOL	'Simple' modal model
MODEM	Instantaneous model – speed based
PHEM	Instantaneous model – power based

The overview of road traffic CO_2 models was focused on, but not limited to, bottom-up models used in Europe. This overview was created using a template such that all relevant information of the different models was available in a consistent manner. In a second step, a list with models with objective requirements and criteria is developed. The models were reviewed and assessed according to the compiled list of requirements, taking into account the:

- Model methodology & uncertainties;
- The suitability and applicability to calculate the potential impact of ITS on CO_2 emissions.

The activities in this WP have resulted in:

1. An overview of state-of-the-art CO_2 emission models;
2. A description of how the models could be used to estimate potential CO_2 emissions;

3. An indication of how the models can be linked to the measures to calculate the potential impact of ITS on CO_2 emissions of road transport.

2.5 Synthesis and ranking

The aim of the synthesis was to review, order and improve comparability of results over all measures and to determine the suitability of the examined CO_2 models to estimate emission reduction of the solutions.

To carry out the synthesis, a two-day expert and synthesis workshop was held. All the consortium partners and sub-contractors have taken part in this workshop. Results of the extended assessment of the measures were discussed, and when possible, the findings were brought a step further. The ease of implementation of the measures was also discussed. Furthermore, some changes in system definitions and combinations of initially reviewed systems were proposed, as well as an addition of the measure Congestion Charging to the list of promising systems, which was originally not selected from the multi-criteria system selection.
The findings of the workshop are taken into account in the descriptions of the extended assessment of the selected systems in chapter 4.

3 Selection of most promising systems

In this section the general approach and uncertainties from the initial assessments are addressed and the most promising systems based on the initial assessment are listed, accompanied with the justifications of choice. First, a short description of all selected systems is given.

3.1 Short system descriptions of selected systems

The system descriptions as given in this section describe the systems which are selected as promising system for the extended assessment. Some system definitions are somewhat different from the systems on the initial list, e.g. some original systems are combined into one system. This was decided in the synthesis workshop. More extensive system descriptions are given in chapter 4.

(Adaptive) Cruise Control
Cruise Control (CC) is a system that automatically controls the speed of the vehicle. Once turned on, it attempts to keep the vehicle's velocity as close as possible to a desired level (set by the vehicle's driver).
The ACC system keeps a driver-set speed (similar to the CC), and on top of this, in case the vehicle in front is slower, a driver-set time (or distance) to this vehicle. It uses a radar system to detect the distance to its predecessor. The system is activated by the driver. The ACC system supports speeds between 30 and 160 km/h, and accelerations between -3 and +3 m/s2. If the speed comes outside these boundaries, the system will be deactivated automatically. Also, if the required deceleration falls outside the deceleration boundary, a warning signal will be given and the system will be deactivated automatically.
The ACC system is mainly a comfort system that takes over the car-following task while the driver remains responsible for steering and collision avoidance.

Lane keeping assistant/emergency braking
These systems are analyzed together, since the mechanism of emission reduction is the same: avoiding congestion by fewer accidents.
Lane Keeping assistance by active steering supports the driver to stay safely within the "borders" of the lane. It determines the vehicle position relative to lane markings and combines this with recognition of driver intention or behaviour to check for unintentional lane departure. The driver is assisted by an active steering wheel trying to intervene in order to keep the vehicle on a correct path within the lane.
An Emergency Braking System warns the driver of an impending collision and mitigates the collision by automatically braking if an accident is considered unavoidable.

Platooning
Platooning is the synchronized movement of two or more vehicles driving one after the other, travelling at the same speed with relatively small inter-vehicle spacing. The engine controls have been modified to allow throttle and braking to take place under programmed computer control. The control algorithm includes input from a laser ranging device mounted on the front of the following vehicle. The control system is able to maintain a fixed separation between the vehicles to within a

tolerance of a few centimetres. As presently configured, the vehicles have only longitudinal controls; lateral position is controlled in the conventional way by driver steering.

Eco-driver Assistance (including Energy-use Indicator and Gear Shift Indicator)

The Eco-driver Assistance aims at assisting and encouraging the driver to use Eco driving. This is done by providing the driver information about the fuel consumption, energy-use efficiency and appropriate gear selection. Information to the driver takes into consideration factors such as engine and transmission efficiency, vehicle speed and rate of acceleration.

Apart from displaying instantaneous and mean fuel consumption on the instrument panel (from the on-board computer), there can be an "Eco Drive Indicator", which lights up when the vehicle is being operated in a fuel-efficient manner with respect to driveline efficiency. The measure also informs the driver when a gear shift is appropriate.

The described measure does not use preview information (e.g. in the form of enhanced map data). Thus, it cannot benefit from advance planning and provide information about fuel-efficient speed profiles during deceleration, e.g. before a red light or stop sign. Neither can it recommend the driver to avoid speeding above speed limits.

Eco-driver Coaching (including Enhanced Map Data)

An Eco driver coaching system that can make use of all features of Eco driving requires preview information to enable optimal advance planning. The preview information, obtained from enhanced map data, should include road slope and curvature and road attributes such as speed limits, stop signs etc.

Compared with "Eco-driver Assistance", some additional features are possible when including enhanced map data. These are recommendation of optimal speed profiles, especially regarding deceleration and avoidance of unnecessary stops, and recommendation against speeding above speed limits.

Fuel-efficient route choice

Fuel-efficient Route Choice is a nomadic device navigation system where optimisation of route choice is based on the lowest total fuel consumption instead of the traditional shortest time or distance. The system is expected to take into account static information like trip length and speed limits. Also road gradients and curvatures can be taken into account, if such information is available. The most advanced version of fuel-efficient route choice navigation would take into account dynamic real-time information about congestion and traffic incidents from probe vehicles running in the street network.

Automatic engine shutdown

A start-stop system automatically shuts down and restarts an automobile's internal combustion engine to reduce the amount of time the engine spends idling, thereby improving fuel economy. The system switches the engine off when the driver shifts into neutral, and releases the clutch after coming to a complete stop. The engine is reignited when the driver selects a gear. This feature is present in hybrid electric vehicles, but has also appeared in vehicles which lack a hybrid power train.

Tyre pressure indicator

A tyre pressure indicator is a system that alerts the driver when the vehicle's tyres are below their ideal pressure. It is generally an electronic system designed to monitor the air pressure inside all the pneumatic tyres on automobiles, aeroplane undercarriages, straddle lift carriers, forklifts and other vehicles. These systems report real time tyre pressure information to the driver of the vehicle - either via a gauge, a pictogram display, or a simple low pressure warning light.
Most pressure-sensor based systems have a two-stage warning approach. The first driver notification is to show that the tyre is a little under-inflated - and so should be pumped up at the next opportunity. The second warning is more important - it is to signify that the tyre is dangerously under-inflated.
For the system also names Tyre pressure monitoring system (TPMS) and Tyre Pressure Indication System (TPIS) are used.

Pay As You Drive
Under Pay as you drive (PAYD) vehicle insurance, also called Distance Based Vehicle Insurance, Mileage Based Insurance, Per Mile Premiums and Insurance Variabilization, a vehicle's insurance premiums are based directly on how much it is driven during the policy term. The more you drive the more you pay and the less you drive the more you save. This can be done by changing the unit of exposure (i.e., how premiums are calculated) from the vehicle year to the vehicle mile, vehicle kilometres or driving time. Also other rating factors such as location, age, vehicle type, and driving record (speeding, close following, etc.) can be incorporated into this price, so higher-risk drivers pay more per mile than lower-risk drivers. Pay as you drive can be optional, so motorists choose the unit of exposure they want, just as consumers now choose different rate structures for telephone and Internet service.
PAYD considered here does not include road charging.

Congestion charging
Congestion charging is a system of surcharging users of a transport network in periods of peak demand to reduce traffic congestion. Examples include some toll-like road pricing fees, and higher peak charges for utilities, public transport and slots in canals and airports. This variable pricing strategy regulates demand, making it possible to manage congestion without increasing supply.
Four general types of congestion charging in cities are in use; a cordon area around a city centre, with charges for passing the cordon line; area wide congestion pricing, which charges for being inside an area; a city centre toll ring, with toll collection surrounding the city; and corridor or single facility congestion pricing, where access to a lane or a facility is priced.

(Dynamic) Traffic signalling optimization
The objective of Dynamic traffic light synchronization based on actual traffic conditions is to optimise journey times and delays in urban, signal controlled, networks by controlling in real-time the green-times, cycle times and offsets (green waves) of the network's junctions. In the simplest case (the "one and a half" generation Urban Traffic Control (UTC) systems, e.g. SIEMENS TASS), the UTC central controller switches between fixed-time plans based on traffic measurements received around the whole network. Also, "local actuation" may imposed, where the aforementioned fixed-time plans are locally and slightly modified based on local traffic measurements (e.g. the green times of specific road segments are slightly reduced or extended based on the presence or absence of vehicles in that particular

segment. The second generation UTC systems such as SCOOT, SCATS, UTOPIA and TUC involve real-time optimisation and/or control techniques in order to optimise the green-times, cycle times and offsets of all network's junctions; the aforementioned quantities are updated on a second-by-second or on an once-every-cycle basis.

Trip departure planning (freight)
To schedule – based on real current and predicted traffic conditions – the trips of fleets of vehicles so that the overall fleet journey time is minimized or significantly reduced. They generally consist of a number of telematic systems which use remote devices on freight vehicles, real-time traffic data and communication links between the vehicles and a control center in order to control and monitor freight operations and present this data in a useable format to freight managers.
In this study, we will concentrate on real-time trip departure planning systems, which use estimations of the actual traffic condition.

Slot management
The objective of Slot Management (typically applied to heavy vehicles; also found as slot allocation and slot reservation) is to improve the use of the existing road capacity and the reduction of congestion. The functioning of the overall system is quite simple: for each of the motorway of highway entrances, a number of "slots" is created; each of these slots corresponds to a particular day and time of the day. The vehicle owners can then book in advance a slot by using an appropriately developed website, where they enter their vehicle data (e.g. plate number). Only heavy vehicles that have booked a slot are allowed to enter the highway or motorway and only at the times they have booked a slot, while when all slots (at a particular time) have been booked no entrance is allowed to other heavy vehicles. In this way, the incoming flow (number of vehicles per time interval) of heavy vehicles is completely controlled.

3.2 Selection of Eco-solutions

Initial list of measures
In the first phase of the project, an initial extensive list of Eco-systems was proposed to be investigated in the project. This list is shown in the table below.

Table 8: Initial list of Eco-systems to be examined in this study

Eco-solutions	
Autonomous driver support systems	**Cooperative systems**
Fuel-consumption/energy use indicators	Fuel-efficient route choice
Feedback and Pay As You Drive (PAYD) systems, including black boxes	Speed advice systems
Gear shift indicator	Controls advice systems
Active gas pedal	Remote diagnostics
Map-enhanced eco-driving	Traffic jam / congestion avoidance
e-Horizon	
Utilities advice systems (e.g. use of airco)	
Automatic engine shutdown (PSA)/hybrid technology	
Tyre pressure indicator	

Compared to the original list of systems, the following changes were made:

- Pay As You Drive (PAYD), moved under Traffic management systems;
- e-horizon, divided into following systems:
  - Map-enhanced Cruise Control, Adaptive Cruise Control and Brake Cruise Control
  - Map-Enhanced Fuel Saving Transmission Functions
  - Map-Enhanced Hybrid-Electric-Vehicle Energy Management
  - Map-Enhanced Auxiliary Control
  - Map-Enhanced After-treatment Control
- Utilities advice systems, regarded as auxiliary control, included;
- Speed advice systems, excluded;
- Controls advice systems, excluded;
- Traffic jam / congestion avoidance, same as RTTI, moved under Traffic management systems;
- Wheel Alignment Diagnosis, included.

The method with the multi-criteria tables, as described in section 2.2, was used to carry out a (multi-criteria) analysis on the Eco-systems.

Sources of uncertainty

The first phase of the project, literature review and screening, faced a high level of uncertainty for the CO_2 emission reduction results as well as for the other information on which the system selection took place. This section presents the types of uncertainty faced for the system selection. The extended system assessment offered the possibility to research these aspects more in-depth.

- Half of the Eco-systems examined in this project do not exist yet on the market. The penetration rate of the already existing ones varies from almost zero to 3%, hence very little (empirical) evidence exists for these systems.
- The level of certainty of 2020 expected penetration rate estimations is low, i.e. almost no information concerning the issue was available.
- As only few of the systems are already on the market, few direct, useful results on CO_2 effects of the Eco-systems were found. In most cases, traffic effects for

the systems were often not detailed enough for the estimation of CO_2 effects. Hence, the translation from qualitative to quantitative estimates of the effects on CO_2 and traffic was a difficult process.

- The different types of Eco-systems are difficult to compare, because the main road type where the systems are effective vary a lot. Some of the systems are effective only in urban areas, some only on motorways and some on all types of roads.
- Use of Eco-systems in different vehicle types can lead to different CO_2 emission effects.
- The share of situations in which the systems are effective in reducing CO_2 emissions could only be estimated roughly.
- As most of the systems inform the driver, e.g. give information on proper gear to use, the effects of the systems depend highly on driver reactions and the variety of reactions between drivers might be large.
- It might be possible that for every system not all the aspects were understood and estimated in the same way, as several partners made estimations. For example the share of situations might have been understood in several ways.
- If the available information was not at the EU level (e.g. only one city, country or road) of from EU (e.g. from USA), the translation of the results to the EU level may not have been reliable and hence comparable.
- In the analyses the homogenization of traffic may be understood in two ways:
  - Homogenization of the whole traffic flow (meaning that the standard deviation of the average speed of whole traffic flow is decreased)
  - Homogenization of one vehicle (speed of one vehicle is harmonized meaning less braking and accelerations even thou the average speed is not affected)
- Most of the Eco-systems have a direct effect on CO_2 reduction through more efficient engine use, but not all. It is possible that more efficient engine use affected the traffic ranking too much and system with and without engine use effects were hence not comparable as e.g. the weights of average speed and traveled km were much lower.

Selection of systems

The rankings coming from the multi-criteria analyses served as the basis on which the systems for the extended assessment were selected. The following Eco-systems showed the most effective and/or most promising results and were assessed further in phase 3 (pluses indicate arguments in favor of the system; minuses indicate possible barriers):

<u>Automatic engine shutdown</u>

+ Estimated over 10% CO_2 reduction
+ Small - medium share of situations and locations when it is effective on CO_2 reduction on EU
+ More efficient engine use
– Uncertain penetration rates in 2020

<u>Energy use indicator</u>

+ Estimated 3–10% CO_2 reduction. If combined with an incentive for driving economically, the effect could probably be larger, up to 20%.
+ Large share of situations and locations when it is effective on CO_2 reduction on EU level
+ Small decrease in amount of congestion
+ Very easy to implement and high penetration expectation for 2020

+ Relatively high level of certainty for all information collected
– Small decrease in average speed and small increase in travel time

Gear shift indicator
+ Appearance in the top 5 in every ranking
+ Estimated 3–10% CO_2 reduction.
+ More efficient engine use and homogenization of traffic flow
+ Very easy to implement and high penetration expectation for 2020
+ Relatively high level of certainty for information.

Energy use indicator and Gear shift indicator focus on the same thing, to give information to the driver that enables or helps him or her to drive more fuel efficiently. Hence it was decided to combine them in the further analysis. Later this will be called Eco-driver Assistance (including Energy-use Indicator and Gear Shift Indicator).

Fuel-efficient Route Choice
+ Appearance in the top 5 in every ranking
+ Estimated 3–10% CO_2 reduction.
+ Greater homogenization of traffic flow
+ Very easy to implement and high penetration expectation for 2020
– Low level of certainty for information

Map Enhanced Eco Driving
+ Estimated 3–10% CO_2 reduction
+ More efficient engine use
+ Easy to implement
+ Relatively high level of certainty for all information collected

Later Map Enhanced Eco Driving is called Eco-driver Coaching (including Enhanced Map Data).

Tyre pressure indicator
+ Medium share of situations and locations when it is effective on CO_2 reduction on EU level. Mainly relevant for heavy trucks, which have a larger number of wheels and larger rolling resistance.
+ Effective on all road types.
+ Easy to implement.
+ The pressure sensor on the vehicle has high and sufficient accuracy.
– The pressure sensor on systems for filling air into the tyres on gas stations have much lower accuracy than the pressure sensor on the vehicle. Thus, even when filling the tyres to the recommended pressure, the actual pressure may be significantly lower.

3.3 Selection of Advanced Driver Assistance Systems

Initial list of measures
In the first phase of the project, an initial extensive list of ADA systems was proposed to investigate in the project. This list is shown in the table below.

Table 9: Initial list of ADAS to be examined in this study

ADA systems	
Autonomous systems	**Cooperative Systems**
Cruise Control (CC)	Cooperative ACC (CACC)
Advanced/Adaptive Cruise Control (ACC)	Intelligent Speed Adaptation (ISA)
Intelligent Speed Information (ISI)/Speed alert	Integrated Full-Range Speed Assistant (IRSA)
Stop-and-go / Full Speed Range Stop-and-Go	Curve speed warning
Lane-departure warning/lane keeping assistant (LDWA)	Cooperative Intersection Collision avoidance
Obstacle collision avoidance	Local hazard warning / Wireless Local Danger Warning
Emergency braking systems (EBS)	Platooning
Electronic Stability Programme/Control (ESP/C)	Autonomous driving
Driver condition warning	In-car traffic info
Pre-Crash Protection of Vulnerable Road Users	In-car data collection
Lane Change Assistant (LCA)	Post crash warning
Night vision	Recommended Speed Profiles

Sources of uncertainty

This section presents the types of uncertainty faced for the system selection of the ADA systems.

- The ADAS examined in this project span those that have been on the market for many years through those that may be introduced after 2010 and are currently in the prototype phase. Little (empirical) evidence exists for many of the systems.
- Given the point above, the ease of implementation of a system is strongly related to its expected penetration rate, which for some systems is unknown. This study made use of the state-of-the-art studies in which future penetration rates were estimated. However, this remains an uncertainty and forecast penetration rates are not available for all systems.
- ADAS were initially developed for comfort and safety reasons, not CO_2 emission reduction. Few direct, useful results on CO_2 effects of the ADAS were found. The translation to quantitative estimates on CO_2 and traffic was therefore a difficult process. This was due to the lack of information on CO_2 effects as well as the range of systems examined. Some systems are on the market, while many are only in the development or prototype stage. Even those on the market have few results reported for CO_2 impacts. As a result, the available results on CO_2 emission reduction for these systems are limited. Most analyses of ADAS did include some traffic impact assessment, for which a logical link to CO_2 emission reduction can be made. However, traffic effects for systems are often not detailed enough for the estimation of CO_2 effects.
- The different types of ADAS are difficult to compare. Some ADAS have a direct effect on CO_2 reduction through for example changes in speed, while other reduce CO_2 indirectly by reducing accident-related congestion.

- Use of ADAS in different vehicle types can lead to different CO_2 emission effects, which has not yet been taken into account in this phase.
- The share of situations in which the systems are effective in reducing CO_2 emissions could only be estimated roughly.
- The compliance rate of drivers for advisory and warning systems plays an important role in determining the CO_2-reduction effectiveness. Advisory and warning systems are relatively easy to implement. This aspect needs to be weighed against the "mandatory" types of systems which are more difficult to implement, but on the other hand are more effective.

Selection of systems

The rankings coming from the multi-criteria analyses served as the basis on which the systems for the extended assessment were selected. The following ADAS showed the most effective and/or most promising results and are assessed further in phase 3 (pluses indicate arguments in favor of the system; minuses indicate possible barriers):

<u>Cruise Control and Adaptive Cruise Control:</u>

Cruise Control

+ Moderate CO_2 effect;
+ High level of certainty for all information collected;
+ Easy to implement;
+ High expected penetration rate.

Adaptive Cruise Control

+ High CO_2 effect;
+ Relatively high level of certainty for all information collected;
+ Relatively easy to implement;
+ Low to moderate penetration rate expected.

<u>Emergency Braking System and Lane Keeping Assistant:</u>

Lane Keeping System

+ Moderate CO_2 effect, although the indirect effect has yet to be taken fully into account. The indirect effect appears to be substantial;
+ Easy to implement;
+ Low to moderate penetration rate expected.

Emergency Braking System

+ Scores highest on reduction in accident-related vehicle congestion among the six safety systems, according to eIMPACT deliverable D4 [1]. There are many more injury accidents than fatal accidents, resulting in an impressive reduction in accident-related vehicle congestion;
+ Scores low on direct CO_2 reduction;
+ Medium level of implementation effort;
– Low penetration rate in 2020, but second highest score behind ESC among the six warning and safety systems.

In phase 3, TNO will carry out a quick-and-dirty analysis of the CO_2-effects of safety systems to determine how valuable these are for reduction in CO_2 emissions, compared to the other systems which have a much larger share of situations where they are effective.

Recommended Speed Profiles

– Recommended speed profiles is not available yet
+ Expected to have a large CO_2 effect
+ Relevant for a large number of vehicle-kilometers, although the indirect effect has yet to be taken fully into account
+ Medium level of implementation difficulty
– Low expected penetration rate in 2020
+ Uses real-time traffic information

Platooning

+ Platooning is a system that scores high on CO_2 reduction.
+ It scored highest on traffic effects and third best on CO_2 (after ACC/CACC) in the multi-criteria analysis. The large CO_2 effect is due to two effects:
  - Reduction of fuel consumption by lowering air resistance, making use of the 'drag' behind the vehicles;
  - Increasing the road capacity by the shorter following distances, and hence reducing congestion.
– Results are uncertain
– A low penetration rate in 2020 is expected
– Implementation is difficult.
+ A simple version for trucks (comparable with ACC, for short distances) is not too hard to implement.

[1] I. Wilmink, W. Janssen, e.a., *Socio-economic Impact Assessment of Stand-alone and Co-operative Intelligent Vehicle Safety Systems (IVSS) in Europe - Deliverable D4 Impact assessment of Intelligent Vehicle Safety Systems.* Contract no.: 027421 (2008)

3.4 Selection of Traffic management solutions

Initial list of measures

In the first phase of the project, an initial extensive list of Traffic Management (TM) Solutions was proposed to be investigated in the project. This list is shown in Table 10 below. To the original list of systems for TM solutions, Pay as you drive (PAYD) was added from Eco-systems. PAYD is a way to manage traffic by making drivers pay for the kilometres driven, and has similarities with some of the other systems in this group (road charging/tolling, demand and access management).

Table 10: Initial list of Traffic Management Solutions to be examined in this study

Traffic management systems	
Autonomous systems	**Cooperative Systems**
Real-time Traffic and Travel Information (RTTI) including multi-modal	Dynamic priority lanes for freight transport
Environmental zone access management	V2I Heavy vehicle and public transport signal priorities
Demand and access management	Variable message signs
Road charging/Tolling	Emergency and bus lane allocation
Slot management	Reversible lanes due to traffic flow
Incident detection/eCall	Dynamic navigation systems
Traffic signalling optimization/ Homogenization	Variable speed limits
Traffic light synchronization/Green waves	Cooperative Multi-modal traffic (information) system
	Trip departure planning (freight)
	Dynamic traffic light synchronization with actual traffic conditions
	Parking availability and guidance

In this section the general approach and uncertainties from the initial assessments are addressed and the most promising systems based on the initial assessment are listed, accompanied with the justifications of choice.

Sources of uncertainty

- For several Traffic Management solutions it was difficult to understand what the penetration rate means. For these systems it was easier to look at the share of situations where it is effective, instead of the penetration rate.
- The share of situations in which the systems would be effective in reducing CO_2 emissions could only be estimated roughly.
- It might be possible that for every system, not all aspects were understood and estimated in the same way, as several partners made estimations. For example, the share of situations might have been understood in several ways.
- Most of the Traffic Management solutions affect decisions on modal choice, route choice, timing of the trip and amount of trips and km's driven. It is extremely difficult to estimate the total EU-level effect, as 1) differences between single persons are large, 2) circumstances differ between areas and nations (e.g. level of public transport, size of the city, quality of the service).
- The different types of TM solutions are difficult to compare, because the main road type where the systems are effective vary. Some of the systems are effective only in urban areas, some only on motorways and some on all types of road.
- Some of the systems were aimed mainly at heavy vehicles, while others are for all vehicles. Use of TM solutions in different vehicle types can lead to different CO_2 emission effects.

- There was empirical data (at least two sources) almost only for traffic signal systems. For other systems the level of certainty was quite low.
- Some of the systems were purely informing, e.g. give information on proper speed or route, and some mandatory (e.g. traffic signals and road tolls). The effects of the informing systems depend highly on driver reactions and the variety of reactions between drivers might be large. The estimations of the effects of the mandatory systems were more precise in that sense.
- If the available information was not at the EU level (e.g. only one city, country or road) or off from the EU (e.g. from USA), the translation of the results in EU level might not be reliable and hence comparable.
- In the analyses the homogenization of traffic might be understood in two ways:
  - Homogenization of the whole traffic flow (meaning that the standard deviation of the average speed of whole traffic flow is decreased);
  - Homogenization of one vehicle (speed of one vehicle is harmonized meaning less braking and accelerations even though the average speed is not affected).

Selection of systems

The rankings of CO_2 and traffic impact coming from the multi-criteria analyses served as the basis on which the systems for the extended assessment were selected. The following TM solutions showed the most effective and/or most promising results and were assessed further in phase 3. Pluses indicate arguments in favor of the system; minuses indicate possible barriers. Even though the Dynamic navigation systems were ranked high, it was not selected for further analyses, because it partly overlaps with some further analyses selected Eco-systems (Fuel efficient route choice and Map enhanced ECO driving).

<u>Dynamic Traffic Light Synchronization</u>
+ Estimated over 10% CO_2 reduction
+ Large share of situations and locations when it is effective on CO_2 reduction on EU level
+ Medium increase in average speed and medium decrease in travel time
+ Small decrease in amount of congestion
+ Homogenization of traffic flow
+ Easy to implement

<u>Pay as you drive</u>
+ Small CO_2 effect
+ Large share of situations and locations when it is effective on CO_2 reduction on EU level
+ Large reduction in kilometers travelled
+ Small decrease in amount of congestion
+ Very easy to implement and expected penetration for 2020 is moderate
– Moderate to low level of certainty for all information collected

<u>Trip Departure planning (freight)</u>
+ Estimated 3–10% CO_2 reduction
+ Medium share of situations and locations when it is effective on CO_2 reduction on EU level
+ Level of certainty is very high
+ Already in use
– Only for heavy duty vehicles

Slot management
+ Estimated 3–10% CO_2 reduction
+ Medium increase in average speed and small decrease in travel time
+ Small decrease in amount of congestion
+ Homogenization of traffic flow
+ Easy to implement
± Small increase in light and medium vehicle kilometers, but decrease in heavy vehicle kilometers

Congestion charging
Added to the list based on discussions in the workshop. Arguments for this were:
+ It is already implemented in some cities and this showed that there is really a rather large effect on vehicle kilometers
+ It is one of the few measures that will not induce extra traffic, when congestion is solved
+ If the potential is considered for all large cities, the effect on EU27 level will probably be relatively high
+ Implementation is quite easy
+ It is not a measure for the far future, but can be implemented in short time

4 Extended assessment of ICT-based solutions

In this chapter the selected systems, as described in chapter 3, are investigated in more detail. Important parts of this inquiry were to address the uncertainties and lacunas from the initial assessment, and especially to estimate the potential effect on CO_2 reduction in more detail and accuracy.

4.1 (Adaptive) Cruise Control

In this section, we describe both the CC and ACC systems, because they are very similar.

4.1.1 System definition

A Cruise Control (CC) is a system that automatically controls the speed of the vehicle. Once turned on, it attempts to keep the vehicle's velocity as close as possible to a desired level (set by the vehicle's driver).
The ACC system keeps a driver-set speed (similar to the CC), and on top of this, in case the vehicle in front is slower, a driver-set time (or distance) to this vehicle. It uses a radar system to detect the distance to its predecessor. The system is activated by the driver. The ACC system supports speeds between 30 and 160 km/h, and accelerations between -3 and +3 m/s2. If the speed comes outside these boundaries, the system will be deactivated automatically. Also, if the required deceleration falls outside the deceleration boundary, a warning signal will be given and the system will be deactivated automatically.
The ACC system is mainly a comfort system that takes over the car-following task while the driver remains responsible for steering and collision avoidance.

4.1.2 Emission effects

The cruise control system reduces CO_2 emissions since the system maintains a constant speed (when used). Furthermore, unnecessary "speed-ups" and abrupt braking are avoided if the driver tries to keep the CC on as long as possible, e.g. by keeping a larger headway or by adjusting the speed setting when necessary.
The ACC system reduces CO_2 emissions by a similar mechanism of reduction of the variability of the speed: it maintains a more constant speed than normal drivers, taking into account the desired headway, and usually accelerates (and decelerates) more smoothly.
Both systems also homogenize the total traffic flow (and can reduce the CO_2 emissions of unequipped vehicles), if the penetration rate is large enough.

For the CC system, effects of 5-10% on CO_2 reduction are reported in the literature. For the ACC system, effects of 0.5-10% are reported, both from simulation studies as from real-world pilots. It should be noted that these effects are perceived in specific situations with the system activated. It is then logical that the CC system has a higher (average) CO_2 reduction, since the speeds will be more constant than with the ACC system (when a predecessor is present), but the CC system can be used less.

The system has no (primary) effect on kilometres travelled. There may be a small effect on the average speed. The speed distribution will become narrower, since the speed will be close to the set speed. The average speed is likely to decrease, since drivers are likely to use the system to overspeed less. However, in a Dutch real-world pilot where 19 vehicles where equipped with ACC and data loggers for 6 months [7], an increase of the average speed when the ACC system was active was found of 5 km/h, but this is assumed to be a consequence of the fact that the system is more used in free flow conditions than in heavy traffic.

Both systems can also affect the road capacity, since the following distances can be different from the average headways of human drivers. In [7], an increase from 1 second to 1.22 seconds was found for driving with an active ACC system in comparison to driving without ACC (same drivers). This causes a capacity reduction, which may cause more congestion as a secondary effect. However, since the system will usually be switched off in heavy traffic, this effect will be counterbalanced somewhat.

Both systems can have an adverse effect, especially in hilly terrain; if the control algorithm is too rigid, the vehicles will keep a too large (energy-inefficient) speed for driving uphill. For the ACC, there is also an adverse effect for driving downhill: while normal vehicles use less energy for driving downhill, the ACC system could counteract this effect to some extent by keeping a constant distance to the predecessor. This effect is larger for trucks, due to the larger weight, which means that the kinetic/potential energy of the truck is much larger. Even a very small inclination may accelerate the truck significantly (so not only in real hilly terrain). Thus, rigid control of the headway to the preceding vehicle may result in lower ability to economize with the energy of the truck. On average, this reduced energy efficiency of ACC can be estimated at ~1% for trucks, and negligible for person cars. Future systems could use a dynamic headway and speed (based on map data) for better energy efficiency.

4.1.3 Effect on EU27 level

The CC and ACC can be used a large part of the driven kilometres.
For CC, the most important requirement is that the vehicle should be able to drive on the desired speed for some time, i.e. that the traffic is in free flowing condition. It will be used mainly on motorways, but can also be used on large part of the rural roads and on some urban arterials. It will be used little on (rural and urban) roads with many sharp curves, since the vehicle has to slow down for every sharp curve (this can be solved by using enhanced map data (road curvature information), BMW may have this feature already for premium class vehicles). In hilly terrain, at least for trucks, the system might have an adverse effect on energy efficiency. However, the drivers may be aware of this and switch the system off in hilly terrain, and the percentage of vehicle kilometres in hilly terrain is assumed negligible (< 1% of total vehicle kilometres driven) for estimation of the effect on EU level. CC is applicable for all vehicle types. Nowadays, almost all trucks are equipped with CC.
An estimation of the percentage of possible kilometres driven with the CC system on EU level, is 42 % (motorway free flow kilometres: 12 % (see chapter 2.3.2), rural free flow, no sharp curves, not hilly: 30%). With an average reported CO_2 emission/fuel consumption reduction of 7.5% when the CC is used, this gives a

potential emission reduction of roughly 3 % on EU level (100 % penetration rate, used all the time when possible).

The ACC system can be used in all situations where the CC system can be used, extended with a part of the vehicle kilometers in heavy traffic, since the system does not need to be switched off in these situations, since it adapts its headway according to the speed of the predecessor. In sharp curves, the ACC system has a problem. An existing ACC system from VW which is used in the Dutch pilot "The Assisted Driver" is used as example. This system works for all speeds above 30 km/h (below this, it will switch off automatically). Also, it switches off for decelerations < -3 m/s2. Although it is applicable for all speeds above 30 km/h, in congestion and heavy traffic, drivers will often turn the system off.
An estimation of the percentage of possible kilometres driven with the ACC system on EU level, is 56 % (motorway free flow and part of heavy traffic kilometres: 16 % (see chapter 2.3.2), rural free flow and part of heavy traffic, no sharp curves, not hilly: 40 %). With an average reported CO_2 emission/fuel consumption reduction of 5 % when the ACC is used, this gives a potential emission reduction of roughly 3 % on EU level as well (100 % penetration rate, used all the time when possible).

4.1.4 Implementation issues

CC and ACC are both easy systems to implement, and are both already on the market. The CC system is already implemented in most modern vehicles, and it is estimated that (almost) all vehicles will be equipped with CC within the next 20 years. ACC is on the market for some years now, especially in the more luxurious cars. The forecasted use is estimated at 3% of the vehicle fleet in 2010, and 8% of the vehicles in 2020 [15].
The CC system is easily retrofittable, while this is not the case for the ACC system.

The CC system is much less expensive than the ACC system; the consumer price for a CC system is around 200 euro, while the ACC system was on the market in 2001 for $1500 - $2000. It is expected that the price will drop for around 750 euro. In the eIMPACT project, deliverable D6 [15], it is estimated that the ACC system will be on the market for 750€ in 2010 and 400€ in 2020.

The CC and ACC systems are not related to important risks. However, since one incident with a CC user occurred in Belgium, the Belgium government has restricted the use of CC on some motorways. In this particular case, it was claimed that the CC system could not be turned off, which caused the accident. Also, the CC might cause an increased safety risk, since the driver's attention may become lower, since his workload reduces by using the system.

Stakeholders for these systems are car manufacturers, garages, aftermarket suppliers (CC only), drivers, and governments in the case of restricted use and safety issues.

4.1.5 Assumptions and uncertainties

We have based our estimations on reported effects of CO_2 reduction, which differ from 0.5 to 10 %. These effects depend much on the specific situation in which it

was investigated, e.g. the amount of traffic and the average speed. It is hard to generalize these different situations.

The effect furthermore depends greatly on the penetration rate and ACC headway setting. Especially for large penetration rates in heavy traffic, the headway setting is of high importance for the effect on traffic flow: if the average used ACC headway setting is larger than the average headway of human drivers, capacity will decrease and more congestion will occur. We did not take this into account in our effect estimation. Since the amount of vehicle kilometers in heavy traffic and congestion on motorways in the EU is (nowadays) about 10%, this effect may be substantial. This effect can be counteracted by instructing the drivers not to use a larger ACC headway setting than they would do without the system. However, from a safety point of view, this is probably not desirable.

Furthermore, the ACC and CC may affect the average speed. As stated before, the average speed is likely to decrease, and the speed distribution will become narrower. This is not taken into account in the effect estimation. A small additional reduction can be expected by this, since for speeds above 90 km/h, a decrease of the speed is favourable for energy efficiency, and there will be less speed variations.

There was very little information available on the mentioned reduced energy efficiency in hilly terrain and in general for the ACC. Some questions which could not be answered accurately, are: How adverse are slopes for energy efficiency for CC and ACC? How steep slopes will cause higher emissions? How many motorways are there with such a slope that using the (A)CC is ineffective? However, we assumed with moderate certainty that this effect is very small compared to the enormous number of vehicle kilometers where the systems are effective.

In the CO_2 effect estimation on EU level, it is assumed that the system is used whenever possible. In practice, drivers will probably use the system less. This is a compliance issue, which will be addressed further in the next paragraph.

4.1.6 Compliance issues

The CC and ACC systems belong to the kind of systems that can be turned on or switched off by the driver. There has been some recent research to this issue, related to the Dutch pilot “The Assisted Driver” ([7], [18], [19], [20]). According to data analysis of this pilot in [19], the system is only used in low-medium traffic densities. Up to a density of 10 vehicles per lane per kilometre (free flow), the ACC system was active over 90 % of the time. Up to a density of 30 vehicles per lane per kilometre (heavy traffic), the ACC system was still active over 60 % of the time. For densities over 40 vehicles per lane (starting congestion), this was less than 30%. Also, it was reported in [7] that the system was used (activated) 50 % of the time in free flow and 35 % of the time in heavy traffic. In total, the system was used 23% of the time (40% of the time on motorways, 22% of the time on rural roads, and 4% of the time on urban roads). Furthermore, Volvo reported that Volvo Long haul trucks in Europe use CC on average 25% of the time.

4.1.7 Implications for electric vehicles

(Hybrid) Electric vehicles will benefit from the system as well, since keeping a more constant speed is beneficial for energy efficiency in general. However, the effects will be smaller.
(Hybrid) Electric vehicles can be equipped with regenerative braking systems which are systems which partially recover the energy which is lost during deceleration.
The effectiveness of CC and ACC systems in full electric vehicles will be lowered dependent on the efficiency of the energy recovery system.
Hybrid electric vehicles, however, are heavier than the comparable conventionally powered vehicles due to the additional electric system present in the vehicle.
The extra weight gives rise to extra CO_2 emission from the hybrid car when driving at a constant speed compared to a car with solely a combustion engine but lower weight.
This extra CO_2 emission and the energy recovery system both will lower the effectiveness of CC and ACC systems in hybrid electric vehicles.

4.1.8 Sources of information

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4.2 Lane keeping assistant/emergency braking

Lane keeping assistance and emergency systems are safety systems that may reduce traffic accidents. The lane keeping and emergency braking system are the most effective systems on avoiding incidents, according to eIMPACT deliverable D4 [3]. They have no direct influence on the energy efficiency of driving itself. However, by reducing incidents, an amount of incident related congestion is avoided, which as such reduces fuel consumption and emissions. Whether this effect would be comparable to the direct effect on the energy efficiency of driving of the other systems, was very unclear at the start of the project. Therefore these systems were included in the extended analysis. Since the emission effect depends on the number of avoided accidents only and hence requires the same type of analysis for both systems, these systems are elaborated together in this chapter.

4.2.1 System definition

Lane Keeping assistance by active steering supports the driver to stay safely within the “borders” of the lane. It determines the vehicle position relative to lane markings and combines this with recognition of driver intention or behaviour to check for unintentional lane departure. The driver is assisted by an active steering wheel trying to intervene in order to keep the vehicle on a correct path within the lane.
An Emergency Braking System warns the driver of an impending collision and mitigates the collision by automatically braking if an accident is considered unavoidable.

4.2.2 Emission effects

Both systems have an indirect effect on CO_2 reduction by avoiding accidents and so avoiding subsequent queue formation (reducing the amount of congestion).
By using the lane keeping system, if the driver obeys the active steering wheel signal, the driver will make fewer unintended lane departures, which reduces the number of accidents.
Using the Emergency Braking system leads to fewer accidents and less severe accidents by warning the driver of an impending collision and mitigating the collision by automatically braking if an accident is considered unavoidable.

The Lane Keeping system is most effective on rural roads, followed by motorways. It is effective for all vehicle types and in every condition; lighting conditions and traffic volume have no special effects on effectiveness. The only requirement is that the road markings need to be present.
The emergency braking system is applicable on all vehicle types and all roads. It is especially effective in high traffic densities and in the dark [3].

The emission effect depends on the number of avoided accidents, and the amount of congestion which is avoided by this. This is very hard to estimate, and depends on many uncertain estimations. No existing study on the effect of avoiding incidents on CO_2 was found. In the eIMPACT project [3], estimations on the number of avoided accidents have been made, which are used to estimate the emission effect of these safety systems on EU level in the next paragraph.

4.2.3 Effect on EU27 level

From the traffic statistics as presented in chapter 2.3.2, the CO_2 emission reduction is estimated which can be saved if all congestion would be solved, by using average emission factors for congestion and free flow traffic, and replacing the emissions of the total vehicle kilometers in congestion by emissions for the same amount of kilometers in free flow, compared with total CO_2 emissions of all vehicle kilometers. This gives an estimated percentage of 0.5% CO_2 reduction for avoiding all congestion on motorways, 0.2% CO_2 reduction for avoiding all congestion on rural roads and 0.1% on urban roads.

Next, an estimation is needed of the part of congestion caused by accidents. On EU27 level, no information in this was available. For the Netherlands, this is estimated to be 12 % in 2007 [5]. Using this as an estimate for the whole EU (however, this percentage could be higher for the whole EU, since The Netherlands have relatively much congestion caused by too low capacity) and for every road type, this gives an estimate of the CO_2 emissions that could be reduced if all accidents could be avoided of 0.06% for motorways, 0.024% for rural roads and 0.012% for urban roads, or 0.1 % in total.
N.B. the part of congestion caused by accidents may differ per road type, but no information was available on this. The presented numbers mainly aim to give an idea of the sense of magnitude.

In eIMPACT [3], it is estimated that Emergency Braking may contribute to 7% reduction of accidents on EU25 level for 100% penetration rate of the system. This gives an estimate of the potential CO_2 reduction on EU level of 7% of 0.1%, which gives 0.007%.

In the same way, the potential CO_2 reduction of the Lane Keeping system can be estimated. According to [3], the lane keeping system contributes to 9% reduction of accidents for 100% penetration rate of the system (EU25 level). The system is only effective on motorways and rural roads. This gives an estimate of the potential CO_2 reduction on EU level of 9% of 0.084%, which is 0.008%.

Comparing the order of magnitude of this potential CO_2 reduction with the estimated effects of the other solutions examined, it is clear that the other solutions have more potential than the safety systems.

4.2.4 Implementation issues

Both systems are relatively easy to implement.
The costs of both systems are low: system costs (including installations costs) for Lane Keeping are about 270 euro for the year 2010 [4], and only 107 euro for the emergency braking system.
The systems are not retrofittable. Both systems are already in production, but the current use is very low. The emergency braking system is under development for heavy-duty vehicles. The forecasted use for Lane Keeping for passenger cars is 6-21% and 6-23% for heavy vehicles. For Emergency Braking, this is 4-11% for passenger cars and 3-7% for heavy vehicles, according to eIMPACT deliverable D6 [4].

Lane Keeping has few barriers or risks. For emergency braking, there is a risk of incorrect activation of the system, which may cause hazardous situations. It furthermore puts a high requirement on reliable environment assessment.
Direct stakeholders are OEMs and suppliers of the systems. Due to the positive safety impacts, possible indirect stakeholders are road operators and governments.

4.2.5 Assumptions and uncertainties

The potential CO_2 reduction calculation is based on many uncertainties and assumptions, such as the number of prevented accidents, share of congestion caused by accidents in the EU, amount of congestion which can be avoided by the system and average speed and dynamics in congestion and free flow, for CO_2 emission factor estimation. However, since the effect is so small compared to the other solutions examined, this will probably still be the case with more exact estimations.

Regarding the estimates for Lane Keeping, there is little empirical data that formed the basis for the safety and traffic estimates provided by the eIMPACT study [3].

For the lane keeping system, a small adverse effect is possible, since some increase in vehicle kilometers is expected because drivers might go out more often under relatively bad conditions.

4.2.6 Compliance issues

The Lane Keeping system is a voluntary system that can be switched on or off by the driver. Since it is a comfort increasing system, and not dependent of road or traffic situation, it can be expected that compliance for this system will be high and will be used most of the time.

The emergency system is stand-by all the time and will get active when necessary. It cannot be switched off. Compliance can therefore be regarded as 100% for this system.

4.2.7 Implications for electric vehicles

The systems do not influence general (longitudinal) driving behaviour, so there are no direct implications for electric vehicles. However, the indirect reduction of CO_2 by avoiding congestion becomes much smaller, since electric vehicles are able to drive more energy efficient in congestion than vehicles with a conventional engine, e.g. braking energy is not lost but used to charge the battery.

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4.3 Platooning

4.3.1 System definition

Platooning is the synchronized movement of two or more vehicles driving one after the other, travelling at the same speed with relatively small inter-vehicle spacing. The engine controls have been modified to allow throttle and braking to take place under programmed computer control. The control algorithm includes input from a laser ranging device mounted on the front of the following vehicle. The control system is able to maintain a fixed separation between the vehicles to within a tolerance of a few centimetres. As presently configured, the vehicles have only

longitudinal controls; lateral position is controlled in the conventional way by driver steering.

4.3.2 Emission effects

The expected effects on emission can be split into direct and indirect effects:

Direct effect:

- It has been observed that vehicle platooning significantly reduces the aerodynamic drag that each vehicle experiences and consequently giving a reduction in fuel consumption and emissions. Platooning furthermore reduces the wake behind the vehicles. This makes that also the first vehicle of a platoon benefits (less drag and higher fuel efficiency).
- Comparable with the cruise control system, platooning gives a much smoother ride with fewer changes in acceleration, which brings down the fuel consumption as well as the emissions.

Indirect effect:

- Vehicle platooning makes it possible for vehicles to travel together closely yet safely. This leads to a reduction in the amount of space used by a number of vehicles on a road up to doubling the capacity according to simulations [1]. Traffic simulations show that platooning can sharply reduce congestion [2]. However, looking at current expansions of road capacity, it shows that a increase of capacity often leads to more road users, which lead to increasing overall emissions.

The system is mainly applicable for use on motorways, although it could also work on rural roads (straight road parts for a longer distance). Transport corridors seem the best location for the system to be realistically applicable and hence effective. The system is mainly applicable in free flow traffic conditions. It is unclear whether from a practical point of view the system is also applicable on roads with many on-ramps, or in heavy traffic situations. More advanced versions could work in urban areas in combination with for instance signal controlling, green waves.
The system can be applied in all lighting conditions. And it can be equipped in all vehicle types, although in the first place the main application thought to be for trucks that travel together for long distances.

4.3.3 Effect on EU27 level

Platooning is mainly suitable for use on motorways in free flow conditions of which the share of total vehicle mileage is estimated at 15%.

Reported reduction of emissions due to direct effect:
There are several studies that give an indication of emission reduction or fuel saving for platooning applications. E.g. in [3] the fuel consumption of two tandem trucks is recorded for truck spacings of 3, 4, 6, 8, and 10 meters. The average fuel consumption saving achieved by tandem operation varied from about 11% at 3-4 meters spacing to about 8% at 8-10 meters spacing. In [4], a reduction of up to 20% in fuel consumption was found for the Chauffeur I system for trucks with very close following distance (6-12m). In [5,6], a study into truck automation and exclusive

truck lanes, for a spacing of 4 meters, CO_2 reductions of 11.3% and 17.7% were found respectively for the front and rear truck, and 8.1% and 15.5% for a spacing of 10 meters. According to this source, the savings due to the aerodynamic drag reduction do not diminish rapidly when increasing the gap.

- Based on the above sources, for cars it is estimated that for all vehicles in the platoon, dependent on the gap (3-6 metres) and length of the platoon (2-4 vehicles), give an average CO_2 reduction of **7%** [5,6]. This is the reduction because of the reduction in drag and the constant speed (less variation).
- For trucks it is estimated that for all vehicles in the platoon, dependent on the gap (3-10 metres) and length of the platoon (2-3 trucks), give an average CO_2 reduction of **11%**. This is the reduction because of the reduction in drag and the constant speed (less variation).

Reported reduction of emissions due to <u>indirect effect</u>:

- No estimations exist on this effect except in simulations. If we would assume though that all congestion could be avoided using the system, assuming 100% penetration rate, then an additional **0.5%** of the total CO_2 emissions can be saved (see section 2.3.1). This excludes extra emissions due to increased traffic volumes.

To estimate the overall effect on emission reduction, we need to look at the share of situations in which the system can be applied. Again we look separately at cars and trucks:

- For cars it is estimated in section 2.3.2 that of the total vehicle mileage of all vehicles the share of cars driving on motorways is 17.4%. For rural roads this share equals 41.8%.
- For trucks these shares for motorways and rural roads are respectively 5.8% and 9.2% (see section 2.3.2).

The total reduction of emissions per vehicle type are as follows:

- For cars when looking at the reduction on motorways, we get 17.4% of 7% is 1.2%. And for rural roads this number equals 41.8% of 7% is 2.9%. Combined this gives **4.1%.**
- For trucks the same calculation gives for motorways 0.6%, for rural roads 1% and combined **1.6%.**

Thus the total reduction of emissions, assuming the system is applied on both motorways and rural roads and has 100% penetration, equals to **6.2%**.

4.3.4 Implementation issues

Current state: Not yet operational; systems on trucks and cars have been tested/piloted.
Forecasted use: No information available. This also holds for the subject of retrofit.
Measure costs:

- Depends on costs of the required advanced sensors, actuators, and communication to other computers
- More expensive than ACC (system needs: ACC + communication)

Ease of implementation: Easy to medium; vehicles need to be equipped with sensors and the platooning following system.
Barriers:

  - Safety, legal and liability issues

- High penetration rate required (for significant effects)
- Advanced control algorithms required for longitudinal control and weaving/merging

Risks: Failing sensors: high accident risk at close following distances.
Stakeholders: Vehicle owners, vehicle manufacturers, producers of radar device to measure distance to previous vehicle, road authorities

4.3.5 Assumptions and uncertainties

Some uncertainties regarding the effect of the system are:

- The (few) results from the reports referred to are uncertain and there is a large variation in the expected CO_2 reduction;
- The emission effects depend on the headway distance between vehicles although [6] showed that the effect because of drag reduction does not diminish rapidly with increasing gaps;
- Penetration rate: It will take a long time for the penetration rate to be high enough to give significant overall CO_2 reduction numbers;
- It is uncertain to under what conditions and consequently in which share platooning can be used on rural roads.

4.3.6 Compliance issues

Platooning needs several vehicles to function. The effect also depends on how easy it is for vehicles to connect to each other when driving on the road.

4.3.7 Implications for electric vehicles

The emission reduction because of the platooning system is assumed to be comparable for electric vehicles to the emission reduction for vehicles with only combustion engines, since the same drag reduction and capacity increase is achieved.

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4.4 Eco-driver Assistance (including Energy-use Indicator and Gear Shift Indicator)

4.4.1 System definition

The Eco-driver Assistance aims at assisting and encouraging the driver to use Eco driving. This is done by providing the driver information about the fuel consumption, energy-use efficiency and appropriate gear selection. Information to the driver takes into consideration factors such as engine and transmission efficiency, vehicle speed and rate of acceleration.

Eco driving involves the following measures to optimize fuel consumption:

1. At start, change to gear 2 as soon as possible and further to higher gears at 1/3-1/2 throttle.
2. On each gear, accelerate only to engine speed where engine torque is as high as possible (normally 3000 rpm), avoid higher engine speeds.
3. Cruise as much as possible (suitable engine speed is 1500 rpm), use highest gear if possible.
4. Skip gears if possible.
5. Avoid idling.
6. If the car has a strong engine and a high maximum torque, avoid downshifting, e.g. in uphill driving, give more throttle instead.
7. Drive with advance planning, i.e. coast to traffic lights or intersection to avoid unnecessary braking and the timing is such that a complete stop can be avoided.
8. Drive with the traffic rhythm, do not overtake.

With Eco-driver Assistance, measures 1 to 6 from above are supported, excluding the recommendation on uphill driving of measure 6.

Apart from displaying instantaneous and mean fuel consumption on the instrument panel (from the on-board computer [2]), there can be an "Eco Drive Indicator", which lights up when the vehicle is being operated in a fuel-efficient manner with respect to driveline efficiency. The measure also informs the driver when a gear shift is appropriate, by means of a gear shift indicator, see example in Figure 6. The gear shift indicator uses information about the rotational speed of the engine in combination with the speed, and advises to change to a higher or lower gear at the moment that this is most appropriate for the best fuel efficiency.

Figure 6: Example of a gear shift indicator on a vehicle instrument panel

When cruising at an unfavourably high speed, resulting in high air resistance, the indicator may also turn red, since high speeds have significant negative effect on fuel economy.

The described measure does not use preview information (e.g. in the form of enhanced map data). Thus, it cannot benefit from advance planning and provide information about fuel-efficient speed profiles during deceleration, e.g. before a red light or stop sign. Neither can it recommend the driver to avoid speeding above speed limits.

4.4.2 Emission effects

The effects on emission are direct, since the purpose of the measure is to improve engine and transmission efficiency. The fuel-consumption/energy-use indicator gives the driver direct feedback on the effect of his or her driving behaviour on fuel consumption. This teaches the driver which behaviour has which effect on fuel efficiency. [2]
The gear shift indicator also helps the driver to improve engine efficiency. A lower shifting speed results in a deeper throttle position to compensate for the lower engine power available at the lower engine speed. A deeper throttle position implies higher engine efficiency. It is also fuel efficient to shorten the acceleration periods and skip gears during the acceleration (see description of Eco-driving in Section 4.5.1)

Emission effects (qualitative/ quantitative):
For the fuel-consumption/energy-use indicator, it has been stated that the fuel savings average is about 5% [2].

For the gear shift indicator, the potential of the gear shift indicator has been analysed using standard and real-world driving cycles. For instance, the fuel consumption reduction over the standard legislative driving cycle, MVEG-B, has been measured to be 3-5% [4]. The MVEG-B driving cycle is a standard legislative driving cycle. The largest portion of the reduction from the gear shift indicator was obtained during the urban part of the driving cycle (UDC, Urban Driving cycle). This is because over the EUDC part (Extra Urban Driving Cycle) there is not much room for optimizing the shifting points. In the EUDC cycle, all steady speeds are already in the 5th gear, with exception of the steady speed of 50km/h. Most manufacturers preferred to drive this part in the standard 4th gear, even in the adapted GSI situation [4].

Only a small optimization can therefore be gained over the MVEG-B, based on the advice of a gear-shift indicator, but for real-world driving the difference between normal gear shifting and optimized gear shifting is larger, which allows for more optimization, such as in the CADC.
Over the real world driving cycles, CADC Urban and Rural, the fuel saving potential of the gear shift indicator for petrol cars is higher, with 7% over the Urban part of the CADC, and 11% over the Rural part. The higher reduction for the rural part is caused by the difference in driving between the urban and rural situation. Under rural driving conditions (in the real world cycle) more situations occur in which a benefit can be obtained by cruising in a higher gear than the one prescribed. Under urban driving circumstances the obtainable benefit is less, because adapted shifting can in most cases only be achieved by shifting up earlier during accelerations; only a small share of the time is spend cruising [4].
For the diesel cars, the effects over the cycle parts Urban and Rural of the CADC, respectively, are 4% and 6%. The effect for diesel cars is lower than for petrol cars since CADC diesel drivers already shift at substantially lower engine speeds [4].

The Eco-driver Assistance measure may influence average speed. If excessive cruising speeds are avoided, average speed is expected to decrease. However, at least to some extent, this is counteracted by shorter acceleration periods, which may lead to somewhat increased average speed,

4.4.3 Effect on EU27 level

Under which conditions is the measure applicable:
Eco-driver Assistance is applicable for both light-duty and heavy-duty vehicles. It is applicable both in free flowing and congested traffic, and on all road types and under all road and lighting conditions. It is also applicable for all speeds, but the gear shift indicator has highest potential for driving conditions ranging from 0-80 km/h (which may be the case in rural areas).

EU27 effect: The total effect of Eco Driver Assistance on EU27 level, assuming 100% penetration and 100% driver compliance, including effect of recommendation against driving at excessive speed, is estimated to be 5-15% reduction in road traffic CO_2.

4.4.4 Implementation issues

Implementation of Eco-driver Assistance is easy. Forecasted use is expected to increase, since implementation is straightforward and there is, and will be, much focus on fuel consumption. There are no main barriers or risks associated with the measure.

The current implementation state is that Fuel-consumption indicator is standard or optional in new vehicles, both light and heavy duty. Gear shift indicator is available in some cars: BMW 1 Series, 3 Series and 5 Series models, with a six-speed manual transmission. It is standard in, for instance, Ford Fiesta and Mondeo ECOnetic, plus Focus ECOnetic (from early 2009 on 109PS model). It is also standard in Ford Transit and Transit Connect TDCi models.

A gear-shift retro-fit for BMW exists, ”Mini”. However, this appears to be an indicator which can be customized by setting the gear change engine speed, without concern of optimization of fuel efficiency.

From some examples (found on different internet sources), the costumer price for a gear shift indicator is estimated to vary from 100 to 210 euro.

The measure is applicable within all EU. Stakeholders are OEMs, suppliers, retro-fit suppliers, carrier owners, drivers.

4.4.5 Assumptions and uncertainties

Driver compliance is the main uncertainty regarding the effect of this measure. This cannot be estimated at this stage.

Several sources report that education in Eco driving reduces the fuel consumption by 5-10% [5]. Thus, the order of magnitude on the CO_2 effect is relatively certain, even though the exact number for the described measure is not known.

4.4.6 Compliance issues

Driver compliance is difficult to estimate. However, hopefully, the measure teaches the driver in how to employ Eco driving. Thus, warning or indication of inefficient energy use or inappropriate gear may be shown less and less often. This effect may reduce the problem of the driver getting tired of the system and switching it off, and will help to maintain a longer lasting effect of the (educated) eco-driving style.

4.4.7 Implications for electric vehicles

The measure can be used for electric vehicles. There is no fuel consumption meter on an electric vehicle, however, an energy-use indicator can be used. This could take into account the efficiency of the electric motor as well as factors influencing the efficiency and lifetime of the energy-storage device.

Possibly, the most fuel-efficient manner to conduct the vehicle will be somewhat different, since the efficiency curve of an electric motor differs from that of an internal combustion engine. However, it will always be of value to economize with the kinetic/potential energy of the vehicle, regardless of type of driveline. This may even be more crucial for an electric vehicle due to the limited reach of the battery.

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4.5 Eco-driver Coaching (including Enhanced Map Data)

4.5.1 System definition

To make use of all measures of eco-driving (see description below), preview information is required to enable optimal advance planning. Therefore, the "Eco-driver Assistance" system can be improved with the inclusion of preview information obtained from enhanced map data. The Eco-driver Coaching system is thus defined as the Eco-driver Assistance system, extended with enhanced map-data. The preview information should include road slope and curvature and road attributes such as speed limits, stop signs etc. Compared with "Eco-driver Assistance", described in Section 4.4.1, comprising recommendations regarding acceleration, gear shifting and avoidance of excessive cruising speeds, some additional features are possible with enhanced map data. These are recommendation of optimal speed profiles, especially regarding deceleration and avoidance of unnecessary stops, and recommendation against speeding above speed limits. The information to the driver can be in the form of a recommended speed or gear or in

the form of a recommended action, e.g. “release gas pedal” or “decelerate” etc. The use of preview information can be illustrated with the following two examples:
A) Preview information shows that 200 m in front of the car (which cannot yet be seen by the driver) there is an intersection that requires a stop or low speed. By slowing down by engine braking (and fuel cut), the vehicle can be brought to a low speed just before the intersection and thus optimal use can be made of the vehicle kinetic energy. This could be done by a message saying “slow down to speed X”

B) The vehicle is approaching a downhill slope that will accelerate the vehicle. By use of preview information, the driver can be advised to slow down before the crest of the hill. The speed can be regained in the downhill slope, such that the use of brakes can be avoided.

Eco driving involves the following measures to optimize fuel consumption:

1. At start, change to gear 2 as soon as possible and further to higher gears at 1/3-1/2 throttle.
2. On each gear, accelerate only to engine speed where engine torque is as high as possible (normally 3000 rpm), avoid higher engine speeds.
3. Cruise as much as possible (suitable engine speed is 1500 rpm), use highest gear if possible.
4. Skip gears if possible.
5. Avoid idling.
6. If the car has a strong engine and a high maximum torque, avoid downshifting, e.g. in uphill driving, give more throttle instead.
7. Drive with advance planning, i.e. coast to traffic lights or intersection to avoid unnecessary braking and the timing is such that a complete stop can be avoided.
8. Drive with the traffic rhythm, do not overtake.

All of the above measures can be supported by the Eco-driver coaching system. In addition to Eco-driver Coaching, the system especially supports measure 7, to drive with advance planning, using enhanced map data.

One should note that by including real-time traffic information in the preview information, the fuel economy could be further improved by enabling the driver to avoid e.g. congested routes. Information about green and red light could also be included to plan speed before traffic lights for best fuel economy. However, this type of dynamic information was not included in the description of this measure. (This is covered, to some extent, in the measure “Fuel-efficient Route Choice”.)

4.5.2 Emission effects

Mechanism of emission effects:
The emission reduction effect of Eco-driver Coaching is direct, since the measure aims at improving the engine and transmission efficiency and using the vehicle kinetic/potential energy in the most efficient way. This is done by increased coasting, i.e. increased use of engine braking with fuel cut, reduced foundation braking and avoidance of unnecessary stops (which consumes excessive fuel when starting from stand still).

Moreover, the measure aims at increasing driving at highest gear (which results in higher engine efficiency). Avoidance of cruising above speed limits may also be

effected, which reduces fuel consumption thanks to lower air resistance at lower speed.

Emission effects (qualitative/ quantitative):
The potential for Eco driving is significant, since driver behaviour influences both engine efficiency, aerodynamic drag, rolling resistance and braking. Generally, it has been found that between 5-10% fuel can be saved by educating drivers in Eco driving, both for light duty and heavy duty.

Education in Eco driving, however, suffers from the problem that drivers may exhibit varying ability to assimilate the Eco driving knowledge and they also tend to forget or loose motivation with time. Thus, for a driver coaching system, the potential could be higher, provided that the driver motivation to comply with the system can be kept high over time.

The coaching system may also be more efficient in the way that the preview information can be obtained more in advance, i.e. before it can be obtained by eye sight. By including recommendations against cruising above speed limits, the potential may also be larger than the 5-10% stated above.

The Eco-driver coaching measure may result in decreased average speed, due to avoidance of cruising speeds above speed limits. On the other hand, this is counteracted, at least to some extent, by shorter acceleration periods, which may lead to somewhat increased average speed.

Some effect estimates were obtained from previous studies: For light-duty vehicles, a study with 86 drivers was carried out in Sweden 1998. Of these 86 drivers, 45 had been educated in Eco driving, whereas the other 41 had no such education. The result was that the Eco drivers had 7% lower fuel consumption than the conventional drivers. Previous studies have reported around 10% less fuel consumption for Eco drivers.

Schenker AB in Gothenburg performed a test with 10 distribution-truck drivers in Stockholm in 2001. After education in Eco driving, the fuel consumption decreased by 17 % on average. Average speed increased by 2.4 km/h. The potential for distribution vehicles is higher than for long haul, since they experience a larger number of accelerations and decelerations. Normally, around 5-6 % fuel can be saved by Eco driving education for long haul with automated gearbox, according to the vehicle responsible person at Schenker AB.

4.5.3 Effect on EU27 level

Eco-driver coaching is applicable for both light-duty and heavy-duty vehicles. It is applicable both in free flowing and congested traffic, and on all road types and under all road and lighting conditions.

It is also applicable for all speeds, however, gear shifting assistance is most relevant for speed variations ranging from 0-80 km/h, which is mainly the case in urban and rural areas.

EU27 effect: The effect on CO_2 reduction of Eco-driver Coaching with preview information is potentially higher than that of Eco-driver Assistance without preview information. The total effect of Eco Driver Coaching on EU27 level, assuming 100% penetration and 100% driver compliance, including effect of recommendation against speeding above speed limits, is estimated to be a 10-20% reduction in road traffic CO_2 emissions.

4.5.4 Implementation issues

Implementation of Eco-driver Coaching is relatively easy, the main obstacle is that implementation requires availability of preview information, in the form of enhanced map data. Presently, the measure is not implemented. The forecasted use is likely to increase, since the potential is large, implementation is relatively easy and enhanced map data will become available for a larger share of roads (it will be available for the four best road classes in EU within 2013).

The measure cost is relatively low to medium. The cost for map data can be shared with other applications requiring preview information. Stakeholders are OEMs, suppliers, map data suppliers, carrier owners and drivers. There are no major risks associated with the measure and it is applicable within all EU.

4.5.5 Assumptions and uncertainties

Driver compliance is the main uncertainty regarding the effect of this measure. This cannot be estimated at this stage.
Several sources report that education of drivers in Eco-driving reduces the fuel consumption between 5-10%. The effect of avoiding speeding above speed limits is a fuel saving of up to 10% [3]. Thus, the estimation of 10-20% fuel-reduction for the Eco-driver coaching seems relatively well founded.

4.5.6 Compliance issues

Driver compliance can be improved by use of remote diagnostics or incentives for driving fuel efficiently. The possibility to compare with peer drivers could also increase driver motivation.

4.5.7 Implications for electric vehicles

The measure can be used for electric vehicles. Possibly, the most fuel-efficient manner to conduct the vehicle will be somewhat different, since the efficiency curve of an electric motor differs from that of an internal combustion engine. However, it will always be of value to economize with the kinetic/potential energy of the vehicle, regardless of type of driveline. This may even be more crucial for an electric vehicle due to the limited reach of the battery.

4.5.8 Sources of information

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4.6 Fuel-efficient route choice

4.6.1 System definition

Fuel-efficient Route Choice is a nomadic device navigation system where optimisation of route choice is based on the lowest total fuel consumption instead of the traditional shortest time or distance. The system is expected to take into account static information like trip length and speed limits. Also road gradients and curvatures can be taken into account, if such information is available. The most advanced version of fuel-efficient route choice navigation would take into account dynamic real-time information about congestion and traffic incidents from probe vehicles running in the street network.

Note that this measure could be implemented together with Map enhanced eco-driving measures ('eco-driver Coaching'), since both require map data, however, dynamic fuel efficient route choice also requires information about traffic flow.

4.6.2 Emission effects

In Sweden the potential for reducing fuel consumption and the emission of CO_2 with fuel-efficient route-choice was estimated. The analysis was based on a large database of real traffic driving patterns connected to the street network in the city of Lund. It was found that in 46% of all trips the driver's spontaneous choice of route was not the most fuel-efficient. These trips could save, on average, 8.2% of fuel by using a fuel-optimised navigation system. This corresponds to a 4% fuel reduction for all journeys in Lund [1].

According to [1] the 50 journeys that would have been assigned an alternative more fuel-saving route by the system would, on average, have saved 8.5% in time. A navigation system optimized at lowest fuel consumption would thus save fuel and time in most cases.

Concerning the potential for real-time information from probe vehicles, the study showed that, on average 2.7% of all journeys in Lund with duration longer than 5 minutes include at least one segment that is disturbed, i.e. has a stop time exceeding 80 s. For 76% of "disturbed" journeys a more fuel-efficient route existed. The average reduction in fuel consumption if these vehicles were rerouted would be 7.6%. The probability that a disturbance event would be broadcasted by at least one of the probe vehicles in Lund was, according to the study, 26%. Thus, despite being

limited, this study indicates that the fuel consumption of journeys involving a disturbed segment could be reduced by approximately, 7.6% * 76% = 5.8%, using a navigation system that takes into account real-time information concerning the traffic situation. However, the critical issues of estimating the general benefit of such a system are: the frequency of disturbance events and the degree to which the events could be revealed in real-time. [1]

In the case of Lund, disturbance events are rare which in itself means a small potential for fuel-saving. Furthermore, the degree to which the probe vehicles were able to cover the street network was rather low, only 26% of the events would have been revealed. Thus, regarding journeys in Lund, the total fuel reduction potential reported to real-time information from probe vehicles was negligible, 0.04%. However, the results indicate that for cities with more serious traffic flow problems a navigation system using real-time traffic information could be beneficial if enough real-time information could be provided to the system. It was also found that the vehicles that would have been rerouted due to traffic disturbance in order to save fuel would also have saved time; according to this study 15%. It should, however, be noted that these calculations were based on rather small numbers of disturbances and must be interpreted with caution. [1]

If the system uses real-time information, it is expected to decrease congestion slightly as drivers are guided to alternative routes. If driving in congestion is reduced, also stop-and-go driving and idling are avoided and hence less emissions are produced. It is estimated that the total kilometres travelled can increase slightly as detours taken to avoid congestion can be longer than congested routes. If congestion can be avoided, a slight increase of average speed and decrease of travel time is expected.

4.6.3 Effect on EU27 level

The system is applicable in all conditions and environments, wherever a digital map is available and alternative routes are available.

Real-time traffic information has potential for fuel-saving in congested areas if a sufficiently large proportion of the network disruptions can be identified and reported in real-time.

Effect on EU27 level is calculated for two cases (route choice and congestion), assuming CO_2 will be decreased by the same percentage as the fuel consumption.

Route choice:

- 26% of vehicle kilometres are driven in urban roads and the effect in urban areas is 4% (estimated from figures from [1]). This gives a total reduction of 1%.
- 74% of vehicle kilometres are driven in motorways and rural roads, and the effect on these roads is estimated to be 1%. This gives a total reduction of 0.7%.
  - Total reduction 1.7%

Congestion:

- Percentage of vehicle mileage that can be affected is calculated separately for motorways, rural roads and urban roads (congested mileage% * alternative route%, with alternative route % an expert estimate).:
  Motorways: 2.8% * 50% = 1.4%
  Rural roads: 0.6% * 25% = 0.15%
  Urban roads: 0.4% * 80% = 0.32%
  Total: 1.9%
- The proportion of congested mileage is based on information from the eIMPACT project. The proportion of alternative routes is our expert estimation.
- Effect of congestion information is estimated to be 20% for all road types. Total reduction: 1.9% * 20% = 0.4%

Based on this, the system would decrease CO_2 emissions altogether (route choice and congestion) on EU27 level by 2.1%.

4.6.4 Implementation issues

The costs of the system include the price of the navigation device, maps and service fee for the real-time information. One barrier to implementation is the availability of maps and correct traffic flow information. It is estimated that the map data will become available within a few years. One safety risk concerning all nomadic devices is the possible unsafe installation of the device, e.g. to get released and becoming a projectile during a crash.

Inquiries show that it would be possible to include a fuel efficient route choice option in the navigational systems of tomorrow, but further research would be needed in cooperation with vehicle navigation companies. A fuel efficient route choice based on static map data is relatively easy to develop and implement. In 2020 the penetration rate of the system is estimated to be 25%. Involved stakeholders include OEMs, suppliers, service providers, cities and map providers.

4.6.5 Assumptions and uncertainties

As the examined system does not yet exist on the market, it was hard to find any evidence or estimates on the effects of the system. Also the level of certainty of the expected penetration rate estimation for 2020 is low, i.e. almost no information concerning the issue was available. The share of situations in which the system is effective in reducing CO_2 emissions could only be estimated roughly.
Furthermore, there can be an adverse effect when many vehicles will choose the most fuel efficient route, since as a consequence, congestion might occur on this route.

4.6.6 Compliance issues

The system has a positive effect only if the drivers react correctly on the information given by the system, i.e. if they follow the fuel efficient route as given by the system. No information was available on this.

4.6.7 Implications for electric vehicles

The measure can be used for electric vehicles. Possibly, the most fuel-efficient manner to conduct the vehicle will be somewhat different, since the efficiency curve of an electric motor differs from that of an internal combustion engine.

It is assumed that the best choice for an electric vehicle could be another route than for a conventional vehicle. This depends however, how detailed the route calculation is and whether the engine efficiency etc. are taken into account. An electric vehicle may be more energy-efficient when travelling in congested traffic than a conventional vehicle. Hence for an electric vehicle congestion avoidance is less important as, for example no energy is consumed when the vehicle is standing still.

It is assumed that the best choice for an electric vehicle will, in most cases,
be the shortest route, whereas for a conventional vehicle, it is important to avoid very low speeds (like in congestion), since this is not fuel efficient. This is due to the possibility to regenerate braking energy in an electric vehicle and to that the electric motor has high efficiency also at low load.

4.6.8 Sources of information

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4.7 Automatic engine shutdown

4.7.1 System definition

A start-stop system automatically shuts down and restarts an automobile's internal combustion engine to reduce the amount of time the engine spends idling, thereby improving fuel economy. The system switches the engine off when the driver shifts into neutral, and releases the clutch after coming to a complete stop. The engine is reignited when the driver selects a gear. This is most advantageous for vehicles which spend significant amounts of time waiting at stop lights or frequently come to a stop in traffic jams. This feature is present in hybrid electric vehicles, but has also appeared in vehicles which do not have a hybrid power train.

4.7.2 Emission effects

The start-stop system shuts down the engine during the idle period. Therefore the emissions are reduced emissions during this period in comparison to the case the engine was running idle. However, the engine needs to be turned off for at least 3 seconds before the system is actually effective [8]. The restart of the engine should be compensated for in these first three seconds.

The system is applicable is applicable on all road types, in traffic situations where the engine is idling (e.g. traffic jams, rail road crossings, traffic lights, bridges over waterways that are open). It can be used in all lighting conditions. All vehicle types can be equipped with the system.

4.7.3 Effect on EU27 level

We assume the system is applicable in/on

- Urban areas, in stand-still situations because of traffic lights, (un)loading, waterways etc. These are the areas where the system will have the most significant effect on reduction of emissions.
- Rural areas, again in stand-still situations because of traffic lights, (un)loading, waterways etc. However these situations occur less often than in urban areas.
- Motorways in situations with congestion, specifically during stand-still congestion situations.

Estimations of the CO_2 emission reduction by TNO

For an estimation of the reduction of emissions we will need the percentage of time that vehicles stand still on the various road types for the system to be effective. From TNO figures this percentage for urban areas is estimated to be 14% for cars (Versit+ database, measurements of real-world driving cycles, v < 5.0 km/u en a < 0.5 m/s^2) and 25 % for trucks (recent pilot in The Netherlands, stop time > 1 minute). The figure for cars consists of every moment the vehicle needs to stand still, thus taking into account traffic lights, waterways bridges etc. The percentage mentioned for the trucks only takes into account the situations where the truck stands still for at least 1 minute. It is assumed that the start-stop system is not activated for trucks for short seconds stand still situations such as traffic lights. Therefore we assume that trucks will not activate the system on roads other than in urban areas in loading and unloading situations. For rural areas the idle times for cars are estimated at 3.7% and 2.6% for rural roads and motorways respectively.

Furthermore, TNO has gathered data on the emissions of traffic during the driving in the various driving environments as well as during idling time. For cars, it is found that they produce 155 grams CO_2 per kilometre when driving in an urban area, 125 grams in rural areas and 317 grams on motorways. Furthermore it is known that cars produce 1471 grams of CO_2 per hour idling. The same figures for trucks equal 770 grams CO_2 per kilometre, and 6904 grams of CO_2 per hour idling.

Now we can separately calculate the reduction of the emissions for cars and trucks on the various road types:

- *Cars*:

Urban areas: Assuming the average speed of a vehicle, while driving, in an urban areas is 40 km/h, the distance that on average cars travel in an urban city is calculated: (100%-14%)*40 = 34.4 kilometres. Driving those kilometres an emission amount of 5332 grams (155*34.4) is produced. During the 14% per hour that a car is idling 205.94 (14%*1471) grams of CO_2 is produced. Therefore, assuming the system shuts down the engine during all idling times, there will be a reduction of 3.7%.

Rural areas: Following the same procedure as above: we assume an average speed of a vehicle in a rural area to be 75 km/h. The distance that cars on average travel in rural areas is: (100%-3.7%)*75 = 72.2 kilometres. During these kilometres an emission amount of 9028 grams (125*72.2) is produced. During the 3.7% per hour that a car is idling 54.4 (3.7%*1471) grams of CO_2 is produced. This leads to a reduction of 0.6%.

Motorways: The same calculation is done for motorways assuming an average speed of 100 km/h. This leads to a reduction of 0.3%.

However, restarting an engine also produces emissions. It is estimated that a restart of the (warm) engine is equivalent in its fuel consumption to three seconds of idling. Therefore this last result needs to be rectified by looking only at the times where the vehicle is standing still longer than 3 seconds for the system to come to the overall net effect on emissions.

Overall: Using the outcomes of above, the emission reduction for all road types combined can be calculated. For this the share of time in which a vehicle drives on a certain road type is needed. In section 2.3.2 it was shown that for cars these shares were estimated to be 39%, 34.3% and 12.5% for urban roads, rural roads and motorways respectively. With these numbers the overall reduction on CO_2 emission due to the start-stop system in cars can be calculated: 39%*3.7%+34.3%*0.6%+12.5%*0.3% = **1.7%**.

- *Trucks*:

Urban areas: Here the same procedure as above the same calculations is followed, but now with the emission data for trucks and the idling time share for trucks in urban areas. This eventually gives a reduction of 7%.

Overall: The share of time that a vehicle of the type truck is driving in an urban area is equal to 2.5%. The overall estimated reduction is then equal to: 2.5%*7% = **0.2%**.

- *Overall*:

The sum of the previous results for the trucks and cars gives the overall estimation on the reduction of CO_2 emissions because of the start-stop system: **1.9%**.

Estimations of literature

In the literature various numbers were found on the potential reduction of the start-system. These estimations are all coming from the OEMS of the start-stop system. Among them are Volvo, Fiat, Bosch and Valeo. The estimated effects were in the range of 4-6% for all road types and traffic conditions combined. More specifically, it was estimated that in urban areas the reduction would be in the range of 8-15%. In highly congested areas the start-stop system would help to reduced as much as 15-25% percent of the CO_2 emissions.

4.7.4 Implementation issues

Current state*:* The system is currently installed in hybrid vehicles. Here are some updates on how far several manufacturers/car companies are with their implementation:

- Valeo, a manufacturer of the start-stop system, expects over 4 millions equipped vehicles in Europe in 2010 [4].
- Bosch, also a manufacturer, has installed the start-stop system in already half a millions BMW's and Mini's [10].
- The joint company PSA (Peugeot, Citroen) aims to produce a million vehicles per year with the system starting in 2010 [7].
- Mercedes aims to get all his engines compatible with their start-stop system in 2011 [12].

Forecasted use*:* Bosch estimates that by 2015 20% of all new vehicles will be equipped with a start-stop system [11]. With respect to the possibility of retrofitting it into cars already on the market, there are some sites that mention this possibility but there is no evidence that the system is (officially) available on the market for retrofit.

Measure costs*:* No numbers were found on this in the literature except for one mentioning it's "cost premium is minimal" [9].

Ease of implementation*:* Can be regarded as easy.

Barriers*:* No real barriers are foreseen.

Risks*:* No risks are foreseen.

Stakeholders*:* Manufactures of the system (car companies, other system manufactures).

4.7.5 Assumptions and uncertainties

It is unclear which percentage of total idling time of vehicles are actually periods that they stand still longer than 3 seconds.

4.7.6 Compliance issues

The system, as it is used in cars running on only a combustion engine, is activated when a driver releases the throttle, and holds the brake pedal. Thus for the system to be effective, the driver needs comply with these actions.

4.7.7 Implications for electric vehicles

The start-stop system is already present in hybrid electric vehicles.

4.7.8 Sources of information

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4.8 Tyre pressure indicator

4.8.1 System definition

A tyre pressure indicator is a system that alerts the driver when the vehicle's tyres are below their ideal pressure. It is generally an electronic system designed to monitor the air pressure inside all the pneumatic tyres on automobiles, aeroplane undercarriages, straddle lift carriers, forklifts and other vehicles. These systems report real time tyre pressure information to the driver of the vehicle - either via a gauge, a pictogram display, or a simple low pressure warning light. [13]

Most pressure-sensor based systems have a two-stage warning approach. The first driver notification is to show that the tyre is a little under-inflated - and so should be pumped up at the next opportunity. The second warning is more important - it is to signify that the tyre is dangerously under-inflated. [3]

For the system also names Tyre pressure monitoring system (TPMS) and Tyre Pressure Indication System (TPIS) are used. [13]

4.8.2 Emission effects

A well-inflated tyre offers least rolling resistance and thereby increases fuel efficiency. CO_2 will be decreased by the same percentage as the fuel consumption. According to [4], driving on tyres with air pressure at 50kPA (0.5kg/cm²) below the recommended pressure decreases fuel efficiency by 2 per cent and 4 per cent in urban and suburban areas respectively. Several studies support that finding (Figure 7).

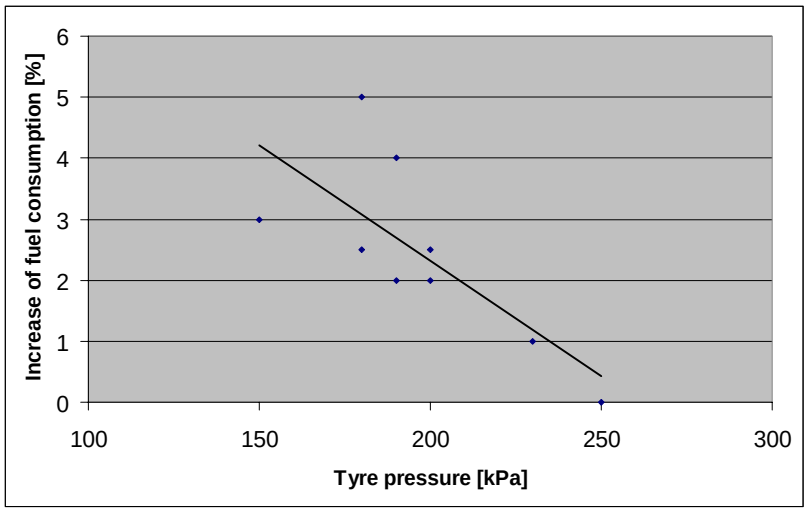

Figure 7: *Effect of too low tyre pressure on increase of fuel consumption (Ecodrive.org 2009, Schrader electronics 2009, North Lanarkshire Council 2009, ViaMichelin 2006, TyreSafe 2008, ATS Euromaster 2009)*

The use of the system has no effect on traffic – neither for the kilometres travelled, nor for traffic composition. It can also be assumed that it has no effect on used speeds as, in practise, for example for a 45-series tyre, a 25 per cent pressure drop from 2 Bar (29 psi) to 1.5 Bar (21.75 psi) results in a decrease in rolling radius of only about 0.8mm, so the lower pressure does not effect on the speedometer significantly and hence does not influence the selected speed [3].

A tire pressure indicator might also have positive secondary effects. Too low tire pressure has unfavorable effects on vehicle handling and braking distance which can be improved by the system. Also accidents due to too low tire pressure are reduced and thus accident related congestion and emissions are reduced to some extent as well.

However, it should be noticed that the system has a positive effect only if the drivers react correctly on the information given by the system.

4.8.3 Effect on EU27 level

The system is applicable in all conditions and environments.

Because the air temperature within a tyre can vary over a very wide range, most tyre pressure sensors also measure air temperature in order that they can compensate their electronics for temperature-induced drift. The normal operating temperature range of the tyre pressure monitoring sensors fitted to the BMW X5 is from -40 degrees to 120 degrees C. The sensors can also cope with a peak temperature of 170 degrees C without being damaged. [3]

The system is especially relevant for heavy trucks, which have a larger number of wheels and larger rolling resistance.
The pressure sensor has high and sufficient accuracy. The sensor can accurately indicate a difference of about 0.1 bar. For example, the nominal pressure of a heavy

truck should be 8.5 bar and a pressure that is 10% (0.85 bar) under that, is easily noticed by the sensor and will have a notable effect on fuel consumption.

In Michelin's tyre pressure campaign during 2003–2008, tyre pressures have been measured in 36 countries (mostly EU countries). Based on collected data the air pressure appeared to be dangerously too low (the pressure in at least one tyre is 0.5 bar below the recommended) in average 38% of the measured passenger vehicles. The lowest shares were in Austria, in Germany and in Italy (15–17%) and the highest shares in Baltic countries and in Greece (62–67%). The differences between countries have been explained by regular inspections and winter tyres: e.g. in Finland the quite low share (19%) compared to other countries have been explained by the annual "tyre check" campaigns and the mandatory winter tyres which make drivers check the pressure of tyres twice a year after changing them. In most of the EU countries the winter tyres are not compulsory, so drivers do not need to check the pressure even twice a year. ([3],[5],[6],[7])

In a North American study from 2002, over 6000 heavy vehicles (involving 35,000 tyres), were surveyed. It was reported that approximately 19% of tyres in fleets of less than 50 trucks were under-inflated by 20 psi (138 kPa) or more, 1 out of 5 trucks inspected had at least one tyre that was under-inflated by 20 psi (138 kPa) or more, 3% of all trucks inspected had 4 tyres or more under-inflated by 20 psi (138 kPa) or more, and twin tyres were a particular problem: 20% of twin tyres on drive axles varied by more than 20 psi (138 kPa); 25% of twin tyres on trailer axles varied by more than 20 psi (138 kPa). Similar variances to the US findings have been confirmed in a local, random vehicle check in the north of Scotland on a timber haulage fleet. [8]

Based on the following assumptions, the system would decrease CO_2 emissions in EU27 by 1.2%.

- Air pressure is too low in about 20% of the heavy vehicles and 38% of the passenger vehicles.
- Share of kilometres: heavy 20%, light 80%.
- CO_2 will be decreased by the same percentage as the fuel consumption.
- The system decreases fuel consumption by 2 percent in urban roads
- 26% of vehicle km's are driven in urban roads.
- The system decreases fuel consumption by 4 per cent in suburban areas (motorway and rural).
- 74% of vehicle km's are driven on motorways and rural roads.

4.8.4 Implementation issues

It has been estimated the tyre pressure monitoring systems will become much more common in the next few years. It is expected that at a minimum, makers will fit pressure monitoring systems using wheel speed indication (the cost for the implementation of this is nominal as most of the components already exist in most cars), while the better system is the direct monitoring of tyre pressure and temperature by means of radio sensors. By using the wheel speed sensors to detect tyre-to-tyre differences in straight-line wheel speeds, an under-inflated wheel can be

identified. This is because the rolling radius of the wheel will decrease with a drop in pressure, and so relative to the other wheels, it will rotate more quickly. [3]

In the EU, a proposal for a new regulation concerning type-approval requirements for the general safety of motor vehicles was published recently, addressing Low Rolling Resistance Tyres and Tyre Pressure Monitoring Systems in order to reduce CO_2 emissions from cars. eSafety Forum has also recommended the EU to make tyre pressure monitoring systems a (mandatory) option for all new cars. [4]

There are some accuracy issues which have to be taken into account when implementing the system. The pressure sensor on systems for filling air into the tyres at gas stations have much lower accuracy than the pressure sensor on the vehicle. Thus, even when filling the tyres to the recommended pressure, the actual pressure may be significantly lower.

Another error source is estimation of the temperature of the gas inside the tyre, since the measured pressure must be corrected for changes in temperature (ideal gas law: pV=nRT). The temperature is dependent on whether the vehicle is moving or standing still, whether brakes have recently been used, outdoor temperature and sunshine on the tyres. The temperature can be more accurately estimated when including more in-vehicle data to the diagnosis, for example from sun sensor, brake usage sensor or pressure data from all individual tyres which is then compared and analysed (i.e. if pressure is higher on one side, the sun is probably shining on this side). This error source can be addressed and solved, however, it requires a more complex diagnosis, using more in-data, which makes implementation a bit less simple.

4.8.5 Assumptions and uncertainties

In the literature no evidence was found on the share of vehicles having too low pressure of -0.1... -0.5 bar. This was not taken into account in the estimations, such that our calculation could be an underestimation.

4.8.6 Compliance issues

The system has a positive effect only if the drivers react correctly on the information given by the system. The emission estimates are based on the potential effect when everybody reacts to the system immediately and correctly. In practice, for lower compliance there will be a smaller effect.

In goods transport, remote diagnostics can be used to inform a back-office and can ensure that the drivers respond to warnings about reduced tyre pressure.

4.8.7 Implications for electric vehicles

The power source of the vehicle does not affect the possibility to install a tyre pressure indicator to vehicle. It does not affect the CO_2 emission either. Maintaining

an appropriate tyre pressure is beneficial for the energy efficiency in general, thus also for electric vehicles.

4.8.8 Sources of information

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4.9 Pay As You Drive

4.9.1 System definition

The PAYD measure that was selected for detailed analysis was Pay As You Drive Insurance system. Under Pay as you drive (PAYD) vehicle insurance, also called Distance Based Vehicle Insurance, Mileage Based Insurance, Per Mile Premiums and Insurance Variabilization, a vehicle's insurance premiums are based directly on how much it is driven during the policy term. The more you drive the more you pay and the less you drive the more you save. This can be done by changing the unit of exposure (i.e., how premiums are calculated) from the vehicle year to the vehicle mile, vehicle kilometres or driving time. Also other rating factors such as location, age, vehicle type, and driving record (speeding, close following, etc.) can be incorporated into this price, so higher-risk drivers pay more per mile than lower-risk drivers. Pay as you drive can be optional, so motorists choose the unit of exposure they want, just as consumers now choose different rate structures for telephone and Internet service. [5]
PAYD ensures that low-mileage drivers stop subsidizing the accident costs of high mileage drivers. By allowing people to save money by driving less, PAYD creates incentives for reducing the various costs that driving imposes on society.

PAYD systems that complement or compensate other charges placed on drivers, e.g. fuel tax, were not included. In addition, yearly vehicle taxes could be based on PAYD systems and are very similar to PAYD insurance systems but simpler as they do not include the safety component. Neither mileage based road charging nor congestion charging are considered here as they were analyzed as an independent measure. Some remarks on other means of PAYD incentives not in the frame of insurance are given at the end of section 4.9.4.

4.9.2 Emission effects

With insurance costs that vary with miles driven, people are able to save money by reducing their driving. The net social benefits consist mostly from reduced accidents and congestion, as well as from reduced local pollution, carbon emissions, and oil dependence, by reducing the driven vehicle kilometres. It is estimated that insurance premiums would decline for almost two-thirds of drivers, since a minority of high-mileage drivers are responsible for the majority of miles driven. [2]

If all motorists paid for accident insurance per mile rather than in a lump sum, they would have an extra incentive to drive less. In USA it has been estimated that driven kilometres would decline by 8 percent nationwide. This would reduce fuel consumption and CO_2 emissions by about 8%. There is significant variation from state to state. States with more accidents and higher premiums would see larger reductions. It is estimated that PAYD will decrease especially "pleasure driving" and journeys with feasible travel mode alternatives. [2]

According to [5] a comprehensive traffic modelling exercise done by [10] indicated that, for example, a 2¢ per mile vehicle fee applied to all vehicle travel in the US would reduce vehicle mileages and trips about 4%, a 6¢ per mile vehicle fee 10%

and a 10¢ per mile vehicle fee 15%. A 2¢ per mile vehicle fee would reduce congestion delay by 10%. This suggests that PAYD vehicle insurance applied to all vehicles in an urban region could reduce congestion delays by 10–25%.

According to [5] based on estimation done by [10] PAYD pricing could reduce affected vehicles' annual mileage by 8–10%, with larger reductions by higher-risk motorists, since they pay higher per mile-premiums. Optional odometer-based PAYD would probably attract 20–40% of total policies, representing a significant portion of motorists who expect to drive less than 80% of average annual mileage in their rate class, representing 10–20% of total mileage, and GPS-based pricing would probably attract 24% of motorists, representing 12% of total mileage, due to its significantly higher financial costs and privacy concerns. These portions should increase over time as fixed rate premiums increase, since they will lose the cross subsidy from lower annual mileage motorists, eventually causing the market to shift to PAYD pricing, although this would probably take about decade.

[1] has used insurance premium data to calculate the average per-mile insurance premium in each state in US. He inserted per-mile premium estimates into a driving and accident model to predict driving reduction and accident savings state by state. Using data from the late 1990s, he estimated driving would decrease by about 10% nationally.

Based on a Dutch study, PAYD would reduce annual mileage of drivers by 2.8% in short term and 3.9% in long term [6].

PAYD might have effect on traffic composition by decreasing kilometres of light vehicles (e.g. increased ridesharing and teleworking). In consequence to this, it probably increases use of public transport as well as walking and cycling. PAYD is estimated to have minimal effect on annual mileage of commercial traffic. [5]

PAYD might also have secondary effects. If the driving is declined in total, this also decreases the number of accidents as the exposure is decreased. This leads to reduced congestion costs due to decreased accident related congestion. Vehicle crashes should decline even more than mileage (a 10% mileage reduction is predicted to reduce crashes by 12–15%) if the higher-risk motorists (who currently pay high premiums per vehicle-year) would pay higher per-mile fees, and would therefore have the greatest incentive to reduce their driving. [5]

However, PAYD might slightly increase mileage and speeds of those drivers who do not have PAYD as consequence of the less traffic due to those drivers who have decreased driving because of having PAYD.

4.9.3 Effect on EU27 level

The system is applicable on all conditions and environments.

PAYD will reduce fuel consumption by the same proportion that it reduces driving. Based on results from different sources it was estimated that PAYD would decline driving in USA by 8% nationwide. This driving reduction would reduce carbon dioxide emissions by 8 percent. There might be significant variation from country

to country, from urban to rural, etc. Variation might depend on level of public transport and personal attitudes and values. It was estimated that in EU the effects are bigger because of the better public transportation systems and possibilities for walking and cycling and the US value could be multiplied by 1.2–1.5.

Based on this is calculated that the effect on CO_2 in EU level would be 10.8% (8% * 1.35[2]).

4.9.4 Implementation issues

PAYD seems to be a win-win situation for consumers, insurance companies and society, but the question remains how to allocate the costs and benefits in a balanced way.

Some established companies are already using monitoring technology to offer mileage discounts on insurance premiums. For example in June 2008, Progressive (USA) announced a national rollout of its MyRate insurance program. Under MyRate, cars driven less often, in less-risky ways, and at less-risky times of day can receive a lower premium. Also General Motors Acceptance Corporation (GMAC) Insurance has offered mileage-based discounts since 2004 to OnStar subscribers located in certain states; drivers in thirty-four states are currently eligible. The system reports the odometer reading at the beginning and end of the policy term, and the customer receives discounts on a sliding scale for driving less than fifteen thousand miles: 1–2,500 miles (40 percent discount), 2,501–5,000 (33 percent), 5,001–7,500 (28 percent), 7,501–10,000 (20 percent), 10,001–12,500 (11 percent), and 12,501–15,000 (5 percent). [5]

Besides USA, PAYD is being implemented in a number of other countries. In Israel, 15 percent of all vehicles (two hundred thousand of them) run with PAYD insurance offered by Aryeh Insurance. Miles are recorded by small wireless transmitters in vehicles and received at fuel pumps. Polis Direct in the Netherlands offered its Kilometre Policy since 2004, but ceased this policy in 2007. Recently, a new Dutch insurance company, DeKilometerverzekering.nl, has started offering insurances based on PAYD. Today the PAYD system is used also at least in France, Austria, Russia, Spain and South Africa. Other countries with at least limited PAYD pilot programs include Canada (where Aviva Canada offers it in Ontario), Japan (offered by Aioi), Ireland (AXA Insurance) and Italy (Lloyd Adriatic).It is estimated that the use of PAYD will increase in future due to driver attitudes towards climate change. ([5],[7])

In the Netherlands, reason for Polis Direct ceasing the PAYD policy was that the lower premiums did not compensate the higher administrative costs and manual check-up costs of the mileage. Also, the effect on kilometres driven was temporarily, because clients had a cost reduction mainly the first year. After PolisDirect, two comparable initiatives were launched: one for lease drivers and one aimed at young drivers. In this last one, not only the amount of kilometres, but also the speed is monitored. Also Norwich Union in the United Kingdom had a PAYD pilot program, but according to a BBC report, Norwich Union suspended its

[2] Average of 1.2–1.5

mileage-based insurance scheme less than two years after it was launched. One reason they said that lead to this was that the scheme only attracted around 10% of the insurer's target of 100,000 subscribers. There however, can be other reasons too: Firstly, the offer was based purely on price, not on service. In the price-sensitive insurance market, this left Norwich Union open to undercutting by competitors. Secondly, while the hardware was complex ("expensive"), and included navigation, it did not include a crash sensor. Thus, although navigation was offered, a driver assistance service was not. ([4],[6])

Several methods can be used to calculate and collect premiums. One is to have motorists prepay for the miles they expect to drive during the term of coverage (typically a year), either in a lump sum or in several payments. For example, some motorists might pay for 12,000 miles at the start of the term, while others might pay for just 5,000 miles at first and make additional payments as needed. The total premium is calculated at the end of the term based on recorded mileage. Vehicle owners are credited for unused miles or pay any outstanding balance. Other insurance companies charge for insurance as they do now, but provide a rebate if, at the end of the policy term, a vehicle's mileage is below certain limits. Another approach is for insurance companies to bill motorists based on their monthly or bimonthly vehicle mileage, similar to other utilities. This requires more frequent mileage data collection, but will probably have a larger effect on the driver behaviour, since they get more frequent and more direct feedback. [5]

The costs of PAYD system depend highly on the way the information about vehicle mileage is collected. In the simplest version, there are no extra costs for the vehicle owner: brokers or vehicle owners report odometer readings, by email or mail, with random verification spot checks. More sophisticated systems use electronic devices which automatically send mileage data, or even track when, where and how a vehicle is driven. The cost of automated data collection is declining since most new cars have odometer data recorded in the engine computer, and many have wireless communication systems or GPS transponders [5]. Currently the implementation cost of this type of system is estimated to be 300 euro per vehicle. Some companies use mileage data that is automatically transferred each time a vehicle is refuelled. Another approach is to require odometer audits. This could provide data as accurate as other metered goods (such as electricity) at little extra cost. Packaging the PAYD with other in-vehicle services will decrease the costs.

PAYD pricing is implemented by individual insurance companies, although legal or administrative changes may be needed to remove regulatory barriers. Governments can implement incentives or regulations to encourage insurers to offer PAYD pricing, and public-private projects can help pilot and promote this pricing option. [5]

In USA, in order to overcome barriers and facilitate the spread of PAYD, a three-part strategy has been suggested. First, states should pass legislation permitting mileage-based insurance premiums. Second, the federal government should increase the funding available to PAYD pilot programs to $15 million over five years. Finally, the federal government should offer a $100 tax credit for each new mileage-based policy that an insurance company writes, to be phased out once 5 million vehicles nationwide are covered by PAYD policies.

Despite the large social benefits from PAYD, there are currently several barriers to its widespread adoption. The main market and regulatory failures that prevent PAYD from emerging on its own are monitoring costs and state insurance regulations. Also the insurance industry has generally opposed PAYD pricing because it requires changes in their practices and may reduce long-term profits by reducing total premiums. PAYD insurance requires changes in the way fees are calculated, and a network of odometer auditors, and so it is difficult for an individual insurance company to implement. Higher-mileage motorists tend to oppose PAYD insurance because it would increase their costs. Most consumers are unfamiliar with the full benefits of PAYD insurance, and many are sceptical of change. Also the tracking technology has only recently become affordable; insurers are anxious about drivers' privacy concerns; and there is a substantial risk for whichever company was first to offer PAYD on a large scale. ([3],[5])

The European Parliament has approved the introduction of an EU-wide pay-as-you-drive scheme for lorries. The charges will be lower for more environmentally friendly lorries. However, because of a disagreement over rates, it is not yet clear if and when the new scheme will be introduced. It is intended to replace the current fixed charge for lorries. The main dispute is about a proposed surcharge for driving during the morning and evening rush hours. The surcharge could be as high as 65 cents per kilometre. The EU's transport ministers will discuss the scheme later this year, and will then take a decision on the rates issue. [8]

There are other conceivable examples of charging drivers per driven kilometre. A well-known example is an extra charge to the fuel prices. In this way, drivers pay more when they drive more, and drivers that drive less fuel efficient or drive in less fuel efficient cars, pay relatively more than fuel efficient drivers. Furthermore, with additional ITS measures, it would be possible to vary the amount to be paid according to the time of day and the location, e.g. charge more during peak hours and on heavily used motorways. A reliable and fraud proof device for logging the time and position of the driver is needed for this. Also, differentiation with respect to CO_2 emissions is possible. The implementation of such systems is complex, as many stakeholders are involved.
No examples have been found of implemented systems where drivers pay for every driven kilometre at the scale of a whole country and every road type. The Dutch government has been preparing a road pricing concept for the Netherlands. In this concept all drivers are charged for their driven kilometres differentiated to place and time. This system has not yet been implemented and thus no evaluations are yet available In Germany, the MAUT is an existing charging system, but only for heavy goods vehicles on certain motorways.

4.9.5 Assumptions and uncertainties

In the literature found there was hardly any evidence or estimates on the effects of PAYD system on the European drivers. The basic problem is that it is difficult to generate real-world evidence about the effects of PAYD because, even in the few cases in which a program similar to PAYD has been offered, there is usually no reliable information about a driver's vehicle mileage prior to entering the program. Also the real-world experiences found from the literature is based on small sample sizes.

4.9.6 Compliance issues

There are no compliance issues as the driver does not need react on the system in any way.

4.9.7 Implications for electric vehicles

The measure can be used for electric vehicles. However, the effects might be different than for conventional vehicles because of the possible differences in insurance policies and fees.

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4.10 Congestion charging

4.10.1 System definition

Wikipedia [1] explains congestion charging as follows:
Congestion pricing or congestion charges is a system of surcharging users of a transport network in periods of peak demand to reduce traffic congestion. Examples include some toll-like road pricing fees, and higher peak charges for utilities, public transport and slots in canals and airports. This variable pricing strategy regulates demand, making it possible to manage congestion without increasing supply. Market economics theory, which encompasses the congestion pricing concept, postulates that users will be forced to pay for the negative externalities they create, making them conscious of the costs they impose upon each other when consuming during the peak demand, and more aware of their impact on the environment.

Road charging on urban road networks is limited to a small number of cities, including London, Stockholm, Singapore, and Milan [1].

Four general types of congestion charging in cities are in use; a cordon area around a city centre, with charges for passing the cordon line; area wide congestion pricing, which charges for being inside an area; a city centre toll ring, with toll collection surrounding the city; and corridor or single facility congestion pricing, where access to a lane or a facility is priced. [1]
Charges can be per kilometre, per time interval or per entrance. The charges can be differentiated per vehicle type or for all vehicles ([2],[3]).

The objective of the charge is to reduce congestion by encouraging traffic to use less congested alternative routes and hours. Also, the use of other modes of (public) transport is encouraged. Other objectives include the improvement of journey time reliability for car users, the improvement of air quality, and to make the distribution of goods and services more efficient.

London congestion charging scheme [4]
In London, the main objective was to reduce congestion in Central London. In February 2002 the final form of the scheme was announced, and the charge was introduced in February 2003. In February 2007 the charging zone was extended Westwards. Vehicles which drive within a clearly defined zone of central London between the hours of 07:00 and 18:00, Monday to Friday, have to pay an £8 daily Congestion Charge. Payment of the charge allows you to enter, drive within, and exit the Charging Zone as many times as you wish on that day.

The charge aims to reduce traffic congestion and improve journey times by encouraging people to choose other forms of transport if possible. Some individuals and vehicles are exempt from payment, or can claim a discount on the charge. All monies raised from Congestion Charging are spent on London's transport facilities.

Stockholm congestion charge ([1],[2])

The primary objectives of the trials were to reduce congestion, increase accessibility and improve the environment. The purpose of the (full-scale) trials was to test whether the efficiency of the traffic system can be enhanced by congestion charges.

Secondary objectives of the trials were:

- Reduce traffic volumes on the busiest roads by 10-15%
- Improve the flow of traffic on streets and roads
- Reduce emissions of pollutants harmful to human health and of carbon dioxide
- Improve the urban environment as perceived by Stockholm residents
- Provide more resources for public transport

All costs were paid by the national government. The budget for the trials was SEK 3,8 billion.
Public transport was extended with 197 new buses and 16 new bus lines. This provided an effective and fast alternative for travelling at peak hours from the municipalities surrounding Stockholm into the inner city. Where possible existing bus-, underground- and commuter train lines were reinforced with additional departures. To facilitate travelling a large number of new park-and-ride facilities were built in the region. The present park-and-ride facilities were made more attractive.

Milan [7][8]
In January 2008 Milan began a one-year trial program called Ecopass, charging low emission standard vehicles and exempting alternative fuel vehicles and vehicles using conventional fuels but compliant with the Euro IV emission standard.

4.10.2 Emission effects

Effect estimates are based on effects studies for London, Stockholm and Milan.

Emissions are changed through several mechanisms. Primary effects or congestion charging include (in the charged area) a reduction of vehicle kilometres in charged area, a congestion reduction that leads to a reduction of the driving dynamics, and an increase of the average speed. This is one of the few measures that improve throughput without inducing extra traffic. Secondary effects possibly include an increase of vehicle kilometres travelled outside the charged area ([2],[3]).
Also, there may be a shift towards less polluting vehicles that are often exempt from the fees or have to pay less.

In Stockholm, the trial reduced traffic crossing the congestion-charge cordon by 22%. Planners expected a 10-15% reduction. The total number of vehicle kilometres travelled (VKT) was reduced with 14%. Congestion decreased, which improved reliability of travel times. CO_2 emissions were reduced by 14% in the inner city and 2-3% overall in Stockholm County.
NOx, and other noxious pollutants were also reduced. Public transport use increased by about 6% (but about 1.5% of that is credited to higher fuel prices during this period). The specific charges for specific vehicle types have changed the traffic composition (e.g. hybrid vehicles have become more popular ([2],[3]).

First results are also available for Milan, from the website of the Ecopass system and a report with the results from the first 12 months ([8],[9]). The first results indicate that 5 million vehicles less drive in the center of Milan per year (-14%). The share of less polluting vehicles has risen. Speed has increased by 4% and there is less congestion. Also, there are fewer accidents. CO_2 emissions have decreased by 9%.

Table 11 shows the influences of congestion charging on emissions in London (to mode B in the Centre Charge Zone). More information about the congestion charging in London can be found on the TRL website [6].

Table 11: Emission effects for London congestion charge

Emission	Charging Zone			Inner Ring Road		
Change	Nox	PM10	CO2	Nox	PM10	CO2
Traffic volume change	-1,4	-0,8	-8,4	7,4	9,7	3,8
Speed change	-6,5	-5,5	-7,3	-7,7	-6,9	-8,5
Vehicle stock change	-5,5	-9,2	-0,7	-6,7	-9,6	-0,7
Overall traffic emissions change						
2003 vs 2002	-13,4	-15,5	-16,4	-6,9	-6,8	-5,4
2004 vs 2003	-5,2	-6,9	-0,9	-5,6	-6,3	-0,8

Figure 8 and Table 12 show an example of the reduction in vehicle kilometers for London.

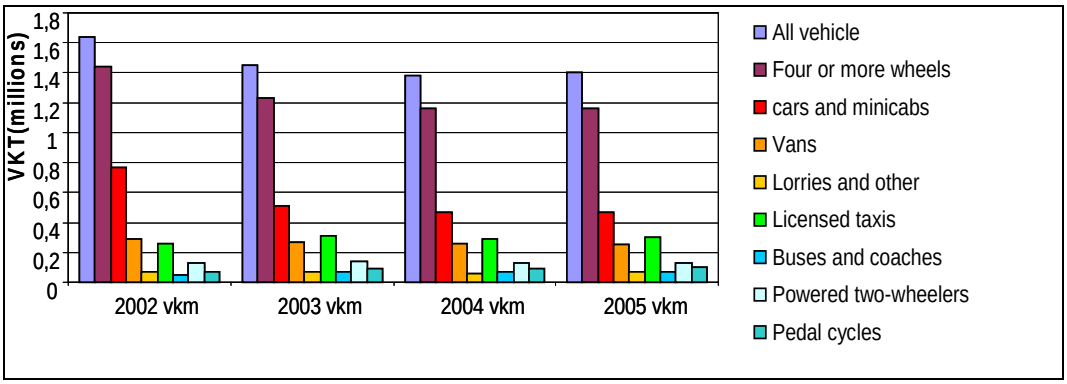

Figure 8: Vehicle kilometres travelled per vehicle type – changes over time

Table 12: Vehicle kilometres travelled per vehicle type – changes over time

Vehicle Type	2002 vkm		2003 vkm		2004 vkm		2005 vkm		2003 versus 2002
All vehicle	1,64	100%	1,45	100%	1,38	100%	1,4	100%	88%
Four or more wheels	1,44	88%	1,23	85%	1,16	84%	1,16	83%	85%
Potentially chargeable	1,13	69%	0,85	59%	0,8	58%	0,79	56%	75%
cars and minicabs	0,77	47%	0,51	35%	0,47	34%	0,47	34%	66%
Vans	0,29	18%	0,27	19%	0,26	19%	0,25	18%	93%
Lorries and other	0,07	4%	0,07	5%	0,06	4%	0,07	5%	100%
Non Chargeable	0,51	31%	0,6	41%	0,58	42%	0,61	44%	118%
Licensed taxis	0,26	16%	0,31	21%	0,29	21%	0,3	21%	119%
Buses and coaches	0,05	3%	0,07	5%	0,07	5%	0,07	5%	140%
Powered two-wheelers	0,13	8%	0,14	10%	0,13	9%	0,13	9%	108%
Pedal cycles	0,07	4%	0,09	6%	0,09	7%	0,1	7%	129%

4.10.3 Effect on EU27 level

Congestion charging will mainly be useful for very large cities. These cities (>500,000 inhabitants) represent about 10% of the EU population. We can assume that the number of vehicle kilometres in these cities is more than 10% of the total vehicle kilometres in urban areas, since in the urban areas of such large cities, the inhabitants will drive relatively more on urban roads than in less populated areas. Therefore we estimated that about 20% of all vehicle kilometres in urban areas is driven in these cities. In urban areas, about 26% of the total number of vehicle kilometres is driven. The effect in the city centres is about 10% reduction on CO_2 emission, as illustrated before. This gives a total CO_2 reduction on EU27 level of roughly 10% *20%*26% = 0.5%.

N.B. It should be noted that the amount of vehicle kilometres outside these areas is expected to increase a little, which is not taken into account in the above calculation. The effect can therefore be overestimated.

4.10.4 Implementation issues

Road charging has been implemented in several European cities (London, Stockholm, Milan).

Congestion charging is applicable in cities of a certain size. A likely size is estimated to be around 500.000 inhabitants or more. The number of European cities with this minimum number of inhabitants is approximately 50, with a total population of approximately 57 million. [10]
[3]. 57 million represents about 10% of the EU population.

Forecasted use:
No forecasts are available with respect to expected implementation in ten or twenty years time.

Many perceive road charging schemes to be difficult to implement. Critics maintain that congestion pricing is not equitable, places an economic burden on neighbouring communities, has a negative effect on retail businesses and on economic activity in general, and is just another tax [1].
The main implementation issues are non-technical (since several road charging systems are operational – from technologically innovative to relatively simple ones with little ICT). Many stakeholders are involved (e.g. municipal policy makers, road authorities, politicians) to get the system implemented, and citizens often have strong opinions about the charge.
Implementation costs are quite high, but the system generates revenues with which transport facilities can be improved for all modes of transport.

The road charging has been shown to work in several cities. With growing concerns over pollution and climate changes, politicians may be more inclined to initiate and vote for congestion or road charging schemes. Furthermore, at the start of the trial, 55% of Stockholmers thought the trial was a "bad decision." That number fell to 41% after just a few months ([1],[2]).

4.10.5 Assumptions and uncertainties

The effects of congestion charging have been documented quite well, although it has only been implemented in a few cities.

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[3] With the exception of UK towns, the City Mayors survey provides population figures for cities with legally defined boundaries, with recognised urban status and with their own local government. The figures do not take into account suburban settlements or other heavily populated areas outside city boundaries. Some of the population figures for towns in the United Kingdom include neighbouring rural areas if they and the towns share local government.

4.10.6 Compliance issues

None reported.

4.10.7 Implications for electric vehicles

Congestion charging, when exempting electric vehicles as vehicles with low emissions, can accelerate the introduction and use of electric vehicles.

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4.11 (Dynamic) Traffic signalling optimization

4.11.1 System definition

The objective of Dynamic traffic light synchronization based on actual traffic conditions is to optimise journey times and delays in urban, signal controlled, networks by controlling in real-time the green-times, cycle times and offsets (green waves) of the network's junctions. In the simplest case (the "one and a half" generation UTC systems, e.g. SIEMENS TASS), the UTC central controller switches between fixed-time plans based on traffic measurements received around the whole network. Also, "local actuation" may imposed, where the aforementioned fixed-time plans are locally and slightly modified based on local traffic measurements (e.g. the green times of specific road segments are slightly reduced or extended based on the presence or absence of vehicles in that particular segment.

The second generation UTC systems such as SCOOT, SCATS, UTOPIA and TUC involve real-time optimisation and/or control techniques in order to optimise the green-times, cycle times and offsets of all network's junctions; the aforementioned quantities are updated on a second-by-second or on an once-every-cycle basis.

4.11.2 Emission effects

Mechanism of emission effects (Primary, Secondary)
Primary effect:
The goal of Dynamic traffic light synchronization with actual traffic conditions is to optimise traffic network mean speed and delays – in real-time and based on actual traffic measurements – by optimally handling traffic lights signal settings, reducing thus – to the minimum possible – "stop and go" situations and keeping vehicle speeds – to the maximum possible – constant.

Secondary effect: None.

Emission effects (qualitative/ quantitative):
The table below provides with comparative evaluation data between dynamic traffic light synchronization systems (2nd generation UTC systems) and optimised fixed-time (non-dynamic) UTC systems [1]-[8]. For each system the improvement of the mean speed is mentioned, as well as the estimated effect on CO_2 emissions. It is assumed that the reduction of CO_2 emissions equals half of the speed improvement percentages because of fewer stops and shorter acceleration periods.

Table 13: Evaluation data between traffic light synchronization and optimised fixed time systems

Traffic Network	Dynamic UTC System	Improvements in traffic network's mean speed)	Improvements in CO_2 emissions
Glasgow, U.K.	SCOOT	~5%	~2.5%
Coventry, U.K.	SCOOT	~5%	~2.5%
Worcester, U.K.	SCOOT	~8%	~4%
Southampton, U.K.	SCOOT	~20%	~10%
London, U.K.	SCOOT	8%	4%
Toronto, Canada	SCOOT	8%	4%
Sao Paolo, Brazil	SCOOT	>20%	>10%
Beijing, China	SCOOT	~10%	10%
Nijmegen, The Netherlands	SCOOT	No improvement	No improvement
Anaheim, USA	SCOOT	No improvement	No improvement
Chania, Greece	TUC	>25%	>12.5%
Turin, Italy	UTOPIA	20%	10%

Notes:

- In order to assess the improvements in CO_2 emissions, the model of [9] was employed which relates CO_2 emissions to average network speed; the estimates provided in the table above correspond to the most conservative one resulted by employing the model of [9] assuming a mean network speed in the range 10-15 km/h.
- SCOOT implementation in Southampton, U.K. was compared against fixed-time UTC system with local vehicle-actuation.
- TUC implementation in Chania, Greece was compared against optimised "one-and-half" generation UTC systems.
- Comparative evaluation of SCOOT and TUC that took place in Southampton, U.K. (by alternating weekly the two systems) has shown that the two systems have the same effect in terms of emissions efficiency.
- An intensive, time-consuming fine-tuning is required in all different types of 2nd generation UTC systems. Such a fine-tuning, which is typically taking place manually, is quite "expensive" as it requires the involvement of many traffic engineers; in cases where such a fine-tuning has not taken place, or it took place but not properly, the UTC system performance may be very poor. Moreover, the fine-tuning procedure should take place continuously in order to take care of changes in traffic demand patterns; otherwise, the system performance deteriorates over time [10].

Km travelled: A significant improvement of traffic conditions due to the use of an efficient dynamic traffic light synchronization system can be a motive for "newcomers" to use the network and, as a result, such an improvement may lead to increase of the traffic demand. For this reason many authorities take additional measures, in parallel to operating their dynamic traffic light synchronization system: gating at significant network entrances, tolling, etc. In any case, the effect of the improvement (of traffic conditions due to the use of efficient dynamic traffic light synchronization systems) to the traffic demand is difficult to estimate; moreover, it is not clear – and difficult to estimate – whether the "newcomers" due to the aforementioned improvement were using alternative – less efficient – routes or they were using different modes (e.g. public transport).

Traffic composition: No significant effect expected.

Average speed/travel time/road capacity: See table above.

Homogenization of traffic flow: Efficient dynamic traffic light synchronization systems have a significant effect on traffic homogenization mostly due to their capability of avoiding, delaying or reducing congestion.

More efficient engine use: due to minimization of "stop-and-go" conditions (while in congestion)

Driving dynamics: Shorter acceleration periods and smoother driving style can be expected, more precisely more narrow acceleration distributions, more narrow speed distributions etc. Also fewer stops are expected.

Under which conditions is the measure applicable:

Traffic: Applicable both in free flowing and congested traffic.

Speed: Applicable for all speeds.

Road conditions: Applicable on signalized urban streets and under all road conditions.

Lighting: Applicable under all lighting conditions.

Vehicles: Applicable for all vehicle types.

4.11.3 Effect on EU27 level

EU27 effect: The total effect on EU27 level for all cities employing modern (real-time) UTC systems (e.g. around 10% of medium- and large-cities in Europe) is estimated to be 5-15% reduction in road traffic CO_2.
UTC systems can potentially improve the traffic throughput in all urban areas. These are not only the cities where UTC is present now, but also were it can be introduced successfully. (N.B. Even when it is already present today, better calibration of the system will have a large effect as well). We can assume that, potentially, all vehicle kilometres in urban areas can benefit from the system. In urban areas, about 26% of the total number of vehicle kilometres is driven. This gives a total CO_2 reduction on EU27 level of roughly 8% (average CO_2 reduction in urban areas) *26% (vehicle kilometres in urban areas) = 2%

4.11.4 Implementation issues

Current state: Implemented in thousands of urban networks around the world.

Forecasted use: No information available.

Measure costs: The installation cost of such systems varies from 10KEuro to 50KEuro per junction. The operational cost varies from 1KEeuro to 25KEuro per junction/per year. Significant maintenance (fine-tuning) due to the necessity of continuously updating the signal settings and other UTC system control parameters to compensate for medium- and long-term changes in traffic demand patterns. However, since existing systems also need considerable maintenance costs, the costs for more advanced systems do not need to be higher. On the contrary, lower maintenance costs are possible with self-calibrating systems.

Ease of impl.: Upgrading non-real time UTC systems into real-time ones is, in general, cumbersome requiring a lot of road works mainly for installing the system detectors (sensors) underneath the pavement and for connecting the local junction controllers to the central UTC. However there are also systems known that are easier to implement and therefore cheaper such as infrared sensors mounted close to the actual signalling device.
Still, a quite cumbersome procedure is required for the initial fine-tuning of the system.

Barriers: The main problem with those systems is their degradation due to changes in traffic demand patterns which results in requiring a continuous time- and effort-consuming human-based calibration procedure.

Risk: No risk.

EU-27 level: Applicable within all EU.

Stakeholders: Cities and road administrations

4.11.5 Assumptions and uncertainties

The estimates of improvements provided in paragraph EU27 are based on the assumption that the dynamic traffic light synchronization systems to be deployed will be constantly and efficiently fine-tuned. Alternatively, they can incorporate automated fine-tuning tools such the one in [10] that can replace the – costly and risky – manual fine-tuning operations.
It is uncertain whether it may be assumed that by increasing the mean speed in urban areas because of fewer stops and shorter acceleration periods, the CO_2 emissions reduce as much as half of that increase (in percentage).

4.11.6 Compliance issues

N/A

4.11.7 Implications for electric vehicles

No implications.

4.11.8 Sources of information

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4.12 Trip departure planning (freight)

4.12.1 System definition

The Trip departure planning system schedules – based on real current and predicted traffic conditions – the trips of fleets of vehicles so that the overall fleet journey time is minimized or significantly reduced. They generally consist of a number of telematic systems which use remote devices on freight vehicles, real-time traffic data and communication links between the vehicles and a control center in order to control and monitor freight operations and present this data in a useable format to freight managers; the effective use of these systems can lead to improvements in fleet efficiency and productivity via reductions in fleet mileage and/or journey times, operational costs and fuel consumption.

Based on the way they incorporate information regarding traffic conditions, trip departure planning systems can be classified into three types:
1. "Static" systems where the estimates of journey times along a specific route are based on either static average data (e.g. distance divided by an average speed) or on historical traffic data that may change at different days and different times of the day.
2. Real-time systems that employ short-term estimation of the journey times: the journey time along a specific route is calculated by assuming that the current traffic conditions along all links of the route will remain unchanged until the journey is completed.
3. Real-time systems that employ model-predictive estimation of the journey times: based on current traffic conditions, these systems predict the journey times by using appropriate traffic models.

In this work, we will concentrate on real-time trip departure planning systems. Please note that these systems are also referred as (dynamic) fleet management systems (although, in many cases, fleet management systems are also referred to systems that employ different or a more general class of functions than trip departure planning).

Another classification of trip departure systems is based on the types of vehicles they are applied to:

C1. Typical freight or other delivery-type vehicles, where the vehicles have to travel at a number of customer locations in order to pick and/or deliver goods. In such systems, the minimization of journey times involves not only the traffic conditions along alternative routes but also the assignment of vehicles to locations (which vehicle goes to which customer) as well as capacity constraints (the vehicle should have enough "space" when they arrive at a particular customer in order to be able to load all the goods the customer wants to deliver).

C2. Fleets of taxis as well as private cars where the trip departure planning system assists the drivers to pick the "shortest-in-time" route to their destination (by taking into account real-time traffic conditions).

C3. Busses and other public transport vehicles: in these cases the trip departure planning system goal is, typically, not the selection among alternative routes as the

vehicles travel along pre-specified, fixed routes. The goal here is to schedule the frequency the vehicles arrive at passenger stops (time distance between consecutive vehicles serving the same route). By keeping the aforementioned frequency (or time-distance) as constant as possible, the overall journey times of the vehicles are minimized: if the time-distance is not constant we may have situations where at some stops the passengers wait too long while at other stops the vehicles arrive very frequently; such a situation can be avoided by delaying some vehicles at the stops by having them waiting at the stops more time than they need to pick the passengers.

4.12.2 Emission effects

Mechanism of emission effects (Primary, Secondary)
Primary effect:
Through minimization or reduction of total fleet journey times.
Secondary effect: None.

Emission effects (qualitative/ quantitative): [1]-[10]

The vendors of such systems claim a 30% improvement in terms of journey times and fuel consumption. However, real-life evaluations of such systems have shown that the improvements are lower, but still significant. Below we present some examples on the improvements produced by deploying such systems (as compared to the situation before the system was deployed).

Table 14: Improvements of trip departure planning systems

Company	System	Fleet Size	Km traveled	Fuel Consumption
Marks and Spencer	ISOTRAK	>240	15% reduction	8%
Sainsburys	ISOTRAK	12 vans	info not available	15%
Riggot & Co Ltd	Minor Planet	12 vans	info not available	15%
Taxi companies in Taiwan	-	16 vehicles	Info not available	16%

Km travelled: reduced by 5%-15% for categories C1 and C2; no effect for category C3.

Traffic composition: No effect.

Average speed/travel time/road capacity: Around 5-15% improvements in mean speeds and travel times.

Homogenization of traffic flow: No significant effect.

More efficient engine use: avoidance of congested routes.
Driving dynamics: Shorter acceleration periods and smoother driving style can be expected.

4.12.3 Effect on EU27 level

Under which conditions is the measure applicable:
Traffic: Applicable both in free flowing and congested traffic.
Speed: Applicable for all speeds.
Road conditions: Applicable on all road types and under all road conditions.
Lighting: Applicable under all lighting conditions.
Vehicles: Applicable for all vehicle types.

EU27 effect: The total effect of dynamic trip departure planning on EU27 level, is estimated to be 5-15% reduction in road traffic CO2 for around 10% of all commercial vehicles in Europe at 2012.
Potentially, when applied to all goods transport vehicles and busses, which is estimated at 17.5% of the total vehicle fleet in 2010 (Infras/IWW, External Costs of Transport [12]), there can be a CO2 reduction of 0.9-2.6% (1.8% on average).

4.12.4 Implementation issues

Current state and Forecasted use [11]: 27.4 million commercial vehicles are owned by enterprises in Europe, with another 1.4 million vehicles being owned by public entities. About 20 percent of the light commercial vehicles and 5 percent of the medium and heavy trucks are in private ownership, which include vehicles owned by private persons but used for business purposes. Altogether enterprises and public entities own approximately about 19.9 million light commercial vehicles, 6.8 million trucks and 0.7 million buses and coaches in Europe. Furthermore, according to [11], there are about 2.5 million heavy trailers or semi-trailers, 2.0 million construction equipment units and 3.0 million agriculture equipment units. Between 2007 and 2012, the forecasts provided in [11] estimate that that the penetration rate for fleet management in Europe will increase from 2.8 percent to 11.3 percent at the end of the period.

Measure costs: The costs of introduction of road freight fleet management systems will differ depending upon what features the system has and the size of the haulier's fleet to be 'wired up' [1]. Figures taken from U.K.'s Department of Transport suggest that a sophisticated application made up of several pieces of on-board hardware, networked software and integration with third party software would typically cost between 2KEuro and 4KEuro per vehicle, with straightforward vehicle tracking systems costing around about 1.5 KEuro. Such systems can also be bought on finance for between 50 and 100 Euros per month. The above mentioned costs do not include costs related to real-time traffic data (over the whole traffic network where the fleet is deployed) that are typically provided by the owners of the resident traffic control system (e.g. traffic authorities); the cost of receiving real-time traffic data varies a lot and depends on many factors (e.g. size and type of the fleet) but in any case it is significantly lower than the savings from operating a real-time trip departure planning system.

Ease of impl.: Easy.

Barriers: Drivers' compliance and the fact that the prediction of future traffic conditions is inaccurate (based on existing traffic model prediction tools).

Risk: Drivers' compliance.

Retrofit: Straightforward to any existing vehicle

EU-27 level: Applicable within all EU.

Stakeholders: OEMs, suppliers, retro-fit suppliers, carrier owners, drivers.

4.12.5 Assumptions and uncertainties

Driver compliance is the one of the uncertainties regarding the effect of this measure. However, past experience using these systems has shown that, in general, drivers' compliance is high; this is mostly due to the fact that these systems allow the operators (managers) to check whether the drivers' have complied to the system recommendations or not.

Finally, it was assumed that the improvements in CO_2 emissions are approximately equal to the improvements in fuel consumption and/or speed.

4.12.6 Compliance issues

See above.

4.12.7 Implications for electric vehicles

The measure can be used for electric vehicles.

4.12.8 Sources of information

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4.13 Slot management

4.13.1 System definition

The objective of Slot Management (typically applied to heavy vehicles; also found as slot allocation and slot reservation) is to improve the use of the existing road capacity and the reduction of congestion. The functioning of the overall system is quite simple: for each of the motorway of highway entrances, a number of "slots" is created; each of these slots corresponds to a particular day and time of the day. The vehicle owners can then book in advance a slot by using an appropriately developed site, where they enter their vehicle data (e.g. plate number). Only heavy vehicles that have booked a slot are allowed to enter the highway or motorway and only at the times they have booked a slot, while when all slots (at a particular time) have been booked no entrance is allowed to other heavy vehicles. In this way, the incoming flow (number of vehicles per time interval) of heavy vehicles is completely controlled.

An example of a successful slot management application (and one of the few applications of slot management worldwide) is the Gotthard motorway, the main Swiss Alpine link; the particular slot management system ensures that, per hour, a maximum of 60 to 150 trucks, or per day, a maximum of 2000 to 5000 trucks, in both directions, use the Gotthard tunnel [1]-[3].

4.13.2 Emission effects

Mechanism of emission effects (Primary, Secondary)

Primary effect: Controls (in a 100% mode) the flow of incoming heavy vehicles (and thus the traffic composition). In this way the "disturbance" created by heavy vehicles to the overall traffic is minimized, leading to more homogenous traffic conditions (by "transferring" some of the heavy vehicle demand from peak hours to off-peak periods). As reported in [4]-[9], the effect of traffic composition to motorway speed, as well as to CO_2 and other emissions can be quite significant when traffic composition control measures manage to operate the motorway in under-critical conditions; this is mainly due to fact that – given that the total demand (passenger plus heavy vehicles) is fixed and assuming that this demand is under-critical in case the traffic composition of heavy vehicles is zero– traffic flow dynamics theory and experimental data indicate that there exists a certain threshold for traffic composition of heavy vehicles, above which motorway becomes congested (capacity degrades as traffic composition of heavy vehicles increases). On the other hand, the effect of traffic composition of heavy vehicles in case of under-critical conditions to emissions is negligible. As a result, the effect of slot management can be – under the most conservative estimates – a reduction in CO_2 emissions in the order of 10% (which corresponds to the capacity drop when motorway conditions become congested), provided that slot management achieves to operate motorway in under-critical conditions. In other words: if slot management achieves to control traffic composition of heavy vehicles so that congestion is avoided during peak hours, by inevitably increasing traffic composition of heavy vehicles during off-peak hours, a reduction in CO_2 emissions in the order of 10% should be expected; the increase of traffic composition of heavy vehicles during off-peak will have a negligible effect as compared to the effect during peak hours.
Secondary effect: None.

Emission effects (qualitative/ quantitative): Quantitative data are not available ; however, by employing the models (theoretical and experimental) of [4]-[9], a reduction of CO_2 emissions of at least 10% should be expected, provided that slot management achieves to control traffic composition so that congestion is avoided during peak hours.

Km travelled: A potential effect of slot management is that some heavy vehicles may take alternative routes in order to reach their destination faster than they would do if they have entered the motorway according to their slot reservation spots. Apparently, this effect will be negligible in case where the alternative routes are either non-existent (e.g. in case of tunnel motorways like the Gotthard motorway example) or they are very "hard to access". As a matter of fact, in most motorways equipped with tolls' infrastructure, the motorway authorities have already taken measures to make the alternative routes "hard to access" (in order to "enforce" vehicles to pay tolls); as a result, it is expected that the number of heavy vehicles taking alternative routes will be negligible, if slot management is imposed to any of the existing motorways with tolls infrastructure.

Traffic composition: Significant impact; see description above.

Average speed/travel time/road capacity: Significant impact; see description above.

Homogenization of traffic flow: Significant impact; see description above.

More efficient engine use: Significant impact, mostly due to homogenization of traffic and congestion avoidance.

Driving dynamics: Significant impact, mostly due to homogenization of traffic and congestion avoidance.

4.13.3 Effect on EU27 level

Under which conditions is the measure applicable:
Traffic: Applicable both in free flowing and congested traffic.
Speed: Applicable for all speeds.
Road conditions: Applicable on motorways equipped with controlled toll entrances and under all road conditions.
Lighting: Applicable under all lighting conditions.
Vehicles: Applicable to heavy vehicles.

EU27 effect: The total effect of slot management on EU27 level, is estimated to be at least 10% reduction in road traffic CO_2 for the motorways that impose slot management and provided they manage to control traffic composition so that congestion is avoided during peak hours. This effect includes emission reduction by avoiding congestion, and is therefore applicable to the total traffic flow (not only goods vehicles). Applicable to any motorway with tolls infrastructure.
The actual number of vehicle kilometres on existing tolls infrastructure in the EU27 was not available, but we estimated that potentially, 10% of the total vehicle kilometres on motorways can be driven on toll motorways (existing toll motorways, extended with motorways which are suitable for tolling). The potential effect on CO_2 reduction of slot management, when applied to all motorways suitable for tolling, can therefore be estimated at 10% of the total CO_2 reduction for avoiding all congestion on motorways, which is estimated at 0.5% in section 2.3.2. This gives a potential reduction of 0.05%. When applied to all motorways (which is practically infeasible), the potential reduction is about 0.5%.

4.13.4 Implementation issues

Current state:
- Only few motorways world-wide impose slot management.

Forecasted use: No information available.

Measure costs: According to [1]-[3], the cost of implementing and operating the slot management system on the Gotthard motorway (25 Km long) is as follows (approximate figures):
- Investment costs:

- Software: 1.5 MEuro
- Booking terminals: 1.5-3 MEuro
- Infrastructure for heavy vehicles service centres (cost unknown).

➢ Operating costs: 0.75 to 1.5 MEuro.

Ease of impl.: Installing and operating slot management systems on motorway already equipped with tolls' infrastructure is technically and operationally feasible [1]-[3]. An operational management system (website, booking system, administration, enforcement) have been already developed and operating in an efficient manner in Gotthard motorway with no significant barriers. It has also to be emphasized that similar systems have been operational (with success) in port terminals for many years.

Barriers: Low acceptance for carrier owners.

Risk: Enforcement; however, according to [1]-[3], employing enforcement measures is easy.
Retrofit: Straightforward for all motorways already equipped with tolls' infrastructure.

EU-27 level: Applicable within all EU (all motorways equipped with tolls' infrastructure).

Stakeholders: carrier owners, motorway operators.

4.13.5 Assumptions and uncertainties

The main assumption is that the system is capable of operating motorway in under-critical conditions (by "transferring" some of the heavy vehicles demand from peak hours to off-peak periods). The measure will have no effect in cases where the demand of passengers' vehicles is already higher than the capacity of the motorway.

4.13.6 Compliance issues

No significant compliance issues, as slot management can be enforced by a number of different measures already applied for enforcing tolls.

4.13.7 Implications for electric vehicles

Slot management can accelerate the introduction and use of electric vehicles when exempting or lowering fees of electric vehicles for slot management.

4.13.8 Sources of information

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5 Results and analysis of extended assessment

5.1 Overview of potential CO_2 effects, implementation and compliance issues

The assessment of most promising systems has resulted in an estimation of the potential CO_2 reduction on EU27 level, as well as an estimation of the ease of implementation of these measures. The potential CO_2 reduction is based on the maximum possible use of the system, i.e. a 100% penetration rate of an in-vehicle system, or application on all suitable roads and areas, e.g. for dynamic traffic light optimization, application in all urban areas. An overview of the estimated potential CO_2 reductions per measure is shown in Figure 9, ranked on the percentage reduction. This reduction is given as a percentage of the total CO_2 emission by road transport in the EU27.

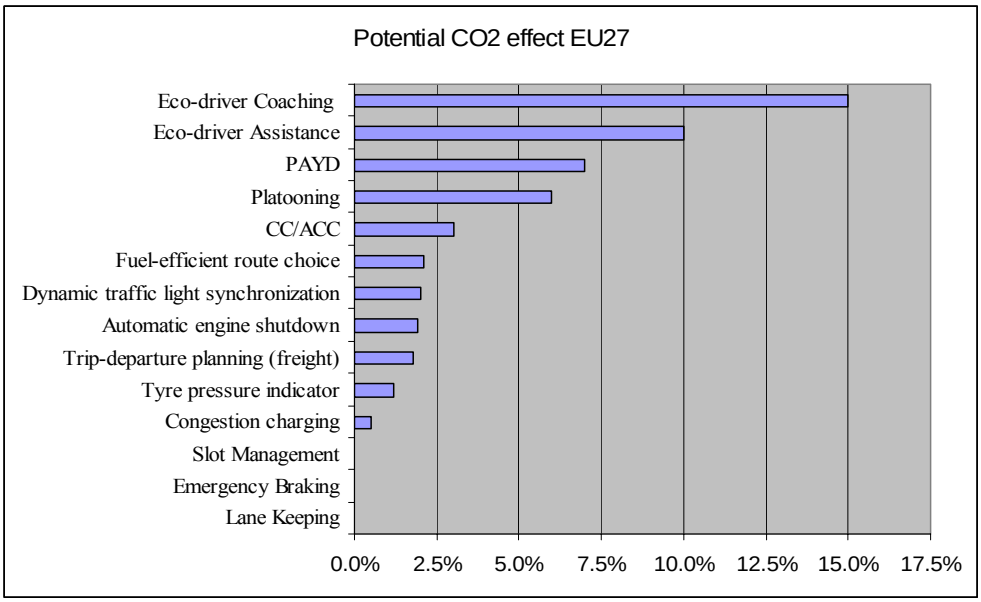

Figure 9: ranking of promising measures on potential CO_2 effect

However, since these numbers indicate what the maximum effect can be, for some measures it will be easier to reach this potential effect than for others. This may depend on all kinds of implementation issues, such as costs, safety issues, technical complexity, legal aspects, different stakeholders, etc., as well as on the expected driver compliance of the measure. For instance, the driver may be less prone to follow a fuel efficient route (which may not be the fastest one), or to adopt an economic driving style (eco-driving), than to use a comfort system such as ACC. For some measures, compliance is not an issue, such as for dynamic traffic light synchronization, since all drivers simply have to obey the traffic light status (and they will even be more willing to do this with better synchronization). This, as well as ease of implementation and expected future use, is summarized in Table 15.

Table 15: Overview of potential CO_2 effects, ease of implementation, compliance and expected future use for promising measures

System	Potential CO_2 effect EU27	Ease of implementation	Compliance issue	Expected future use
Eco-driver Coaching	15%	Medium	Medium	Large
Eco-driver Assistance	10%	Easy	Medium/hard	Large
PAYD	7%	Medium	Medium	Medium
Platooning	6%	Very hard	Hard	Small
CC/ACC	3%	Easy	Easy	Large
Fuel-efficient route choice	2%	Medium/hard	Medium	Medium
Dynamic traffic light synchronization	2%	Medium	No issue	Large
Automatic engine shutdown	2%	Easy	Easy	Large
Trip-departure planning (freight)	2%	Medium	Medium	Large
Tyre pressure indicator	1%	Easy	Medium	Large
Congestion charging	0.5%	Medium	No issue	Medium
Slot Management	0.05%	Hard	No issue	Small
Lane Keeping	0.008%	Easy	Easy	Large
Emergency Braking	0.007%	Easy	No issue	Large

The diagram below offers more insight into the results with respect to the potential CO_2 effects versus the ease of implementation. On the horizontal axis, an indicative estimation of the ease of implementation is plotted against the CO_2 reduction on the vertical axis. As can be seen, systems that have a large contribution to CO_2 reduction are not necessarily hard to implement. The Eco-driver systems and PAYD again score well with regard to both criteria.

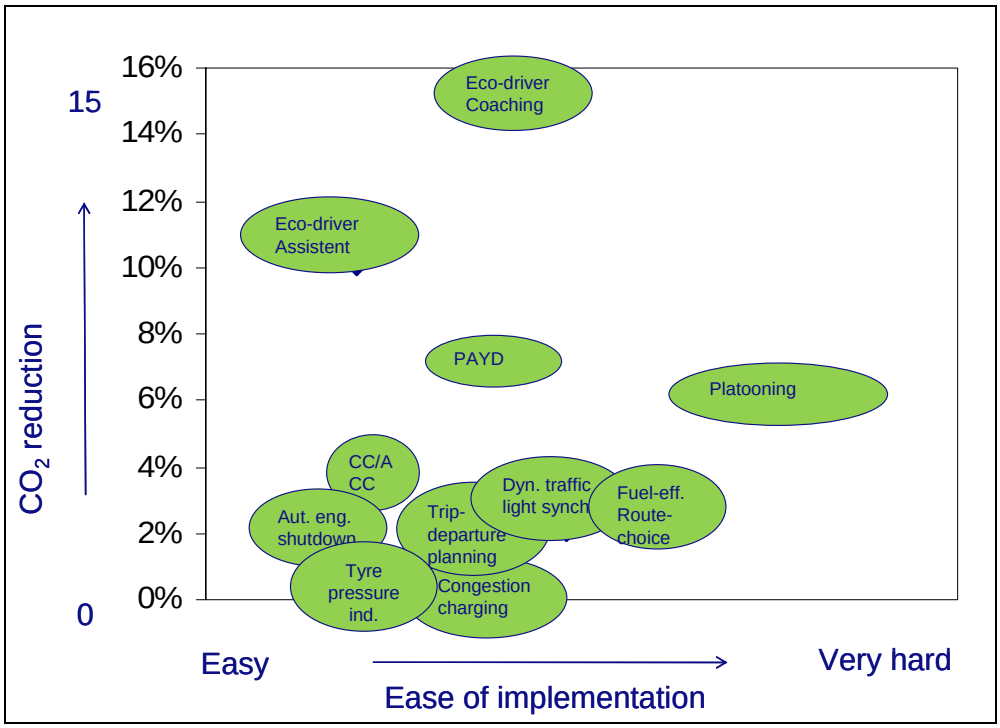

Figure 10: Overview of potential CO_2 effects versus the ease of implementation

Based on these results, the measures can be divided in groups, to their potential CO_2 effects. For each group, a short explanation and important issues will be given in the following sections.

5.2 Measures with a very large CO_2 reduction on EU27 level

The following two systems have the largest potential CO_2 reduction on EU27 level of 10-15%:

- Eco-driver Coaching
- Eco-driver Assistance

The large effect is expected because the system enables driving in a more energy efficient manner (thanks to the support by a number of tools such as gear-shift indicator, speed profile recommendations, using enhanced map data) in all circumstances and on all road types. Implementation of the Eco-driver Coaching system is less straightforward since it requires the use of enhanced map data. For both systems, the effect is highly dependent on the willingness and attitude of the driver to comply with the most energy efficient driving style. These measures aid the driver in this by providing tools such as a gear-shift indicator and energy-use indicator, and will therefore have a larger effect than just educating the eco-driver driving style to (new) drivers.

5.3 Measures with a large CO_2 reduction on EU27 level

The following two systems have a large potential CO_2 reduction on EU27 level of 6-7%:

- Pay As You Drive
- Platooning

The substantial effect of PAYD is due to the fact that the amount of vehicle kilometres driven will decrease significantly. As considered here, the financial incentive is provided in a reduction on insurance costs. This measure seems promising, however, existing examples in e.g. the Netherlands, U.S. and U.K., have shown that implementation is not very easy, mainly because it is hard for insurers to get a profitable business case for this type of insurance, since administrative costs and costs for mileage checking are high. Also, only a part of the total insurance cost can be variabilized. A comparable measure where the driver pays for his amount of driven kilometres such as road charging issued by the (national) government, offers furthermore possibilities for differentiation to vehicle type, e.g. charge more for more polluting cars or subsidize electric vehicles.
The CO_2 reduction of platooning is mostly due to drag reduction. Also, a small part is due to capacity increase from the short following distances, which will result in less congestion. Technically, platooning seems feasible, but the large effect will only be reached for high penetration rates, and implementation could require also infrastructural changes at e.g. on-ramps and weaving sections, which complicates the implementation. Furthermore, there is also a safety problem with travelling with very short following distances between vehicles. Therefore we expect this measure only to be applicable in a more distant future (more than 10 years), and the penetration rate is expected to be limited.

5.4 Measures with a medium CO_2 reduction on EU27 level

This group consists of various measures, both adaptive driver assistance systems, ‘technical’ vehicle systems as well as traffic management systems, with an estimated CO_2 effect of 1-3%:

- (Adaptive) Cruise Control
- Dynamic traffic light synchronization
- Fuel-efficient route choice
- Automatic engine shutdown
- Trip-departure planning (freight)
- Tyre pressure indicator

(Adaptive) Cruise Control has a relatively large effect on CO_2 reduction, since it is applicable on a large part of all vehicle kilometres driven, and homogenizes the traffic flow by driving with a more constant speed. The effect is reached by homogenization of the traffic flow. Even if only a part of the vehicles is using these systems, from a certain penetration rate, the non-equipped vehicles will be forced to drive with more constant speeds as well. The effect for both is estimated to be almost equal. Adaptive Cruise Control is applicable in more traffic situations such as heavy traffic, but can have a

small adverse effect in some situations. Both CC and ACC are easy implementable and are already on the market. However, it should be noted that the effect of ACC also depends on the used headways; if these are smaller than average (which turned out to be the case in a recent pilot), capacity decreases, which leads to more congestion. It should also be noted that a more fuel-efficient variant of both CC and ACC can be obtained by including preview information in the control of these applications, and thereby optimize vehicle speed with regard to fuel efficiency. This can be regarded as an autonomous variant of Eco-driver Coaching.

Dynamic traffic synchronization can achieve a large effect on throughput and emissions in urban areas, by optimization and better calibration to the actual traffic conditions around the traffic signals, and can potentially be introduced in all urban areas. The effects are due to less stops for red light, such that there are less accelerations and higher average speeds in the overall network. There are few barriers for implementation, however, introduction and maintenance are rather costly.

Fuel-efficient route choice achieves a positive effect on CO_2 emission by recommending routes with the lowest energy consumption over the total route, e.g. based on (actual) speeds and length. Technically, this measure is feasible, but depends on the availability of actual traffic information. Furthermore, if no incentive is coupled to following the recommended route, compliance could be low, since the fuel-efficient route is not necessarily the fastest route.

Automatic engine shutdown reduces vehicle emissions and energy consumption during idling. The potential CO_2 reduction could be estimated with a relatively high accuracy, since many measurements on idling emissions and idling times were available. Implementation is easy and the system is already on the market. There is (almost) no compliance issue, since the system works automatically (for most existing systems, the driver only needs to put the gear in neutral) and does not give discomfort to the driver. For electric vehicles, the system will have no benefit, since energy consumption for idling electric vehicles is already zero.

Trip-departure planning can offer large benefits in terms of kilometres driven and avoiding congestion and thereby to CO_2 reduction, mainly for freight operators and logistical companies. It is expected that almost all freight operators are going to use a comparable system.

A tyre pressure indicator will reduce the number of vehicles driving with underinflated tyres, which will be beneficial for energy consumption and reduce CO_2 emissions. It is estimated that at present, possibly up to around 40% of the vehicles have underinflated tyres. There are no significant barriers for implementation. Tyre pressure monitoring systems will become much more common in the next few years.

5.5 Measures with a moderate CO_2 reduction on EU27 level

These measures have less CO_2 reduction on EU27 level than the measures presented in the previous sections, because they are applicable in fewer situations.

- Congestion charging
- Slot Management

Congestion charging as considered in this study is only applicable to large cities. It has already been implemented in London, Stockholm and Milan, and has shown that, locally, a substantial effect on throughput and emissions can be achieved. Therefore, although no high overall effect in the EU is achieved, it is very useful for these cities.

The same holds for slot management; especially on important corridors where it is important that the traffic can be controlled (e.g. tunnels), the measure can be useful. Large-scale implementation does not seem to be feasible and will still not give a significant CO_2 reduction, compared with e.g. eco-driving assistance.

5.6 Measures with a very small CO_2 reduction on EU27 level

Regarding safety systems that only have an indirect effect on CO_2 emissions by avoiding incidents and subsequent queue formation: Our effect estimation has shown that these systems have a much lower potential regarding CO_2 reduction. Of course, it can still be worthwhile to stimulate the use of these systems for improving traffic safety.

5.7 Final remarks regarding the extended assessment

A side remark concerning the presented CO_2 effects, is that the estimations are based on the vehicles of today. When the measures are applied in future years, the effect in absolute terms will become smaller, since future vehicles will become cleaner and more energy efficient already by fuel efficiency improvements (engine, rolling resistance, drag etc). This is added on top of the presented estimates, and will change the potential and ranking. In the case of massive electrification/hybridization of the fleet, there might be less impact of the measures on reduced CO_2 on the EU27 level (in absolute terms), but they will still be equally important for the fossil fleet.

Furthermore, these numbers present the potential for 100% penetration rate. For new in-vehicle systems, this is achievable only after a minimum time of about 15 years, if all new vehicles are equipped with the system.

Finally, it can be noted that for most of the presented promising measures, the effect on CO_2 emission does not interfere with the effect of the other measures, such that the total effect, when used in combination, is the summation of the separate effects. This is the case for e.g. Dynamic traffic light synchronization, Tyre pressure indicator and Congestion Charging, in combination with any other measure. However, some measures have overlapping functionality or effects, such that their combined effect is smaller than the sum of the separate effects. This is the case mainly for the eco-driver coaching and eco-driver assistance systems.

To give an indication of the total potential effect of a combination of measures, two examples of combinations are presented below. The first combination consists of all systems with the highest potential combined, excluding overlapping systems, and the second only comprises systems which are deemed easy to implement.

Combined potential of all measures considered to be independent: 37%

- Measures include: Lane Keeping, Emergency Braking, Slot Management, Tyre pressure indicator, Trip-departure planning (freight), Automatic engine shutdown, Dynamic traffic light synchronization, Fuel-efficient route choice, Platooning, PAYD, Eco-driver Coaching

Since some of the measures listed above may be hard to implement, we have also looked at the combined potential of independent measures that are already on the market and relatively easy to implement. This effect is approximately 16%.

- Measures include: Eco-driver Assistance, CC/ACC, Automatic engine shutdown, Tyre pressure indicator, Emergency Braking, Lane Keeping

The above effects are for 100% penetration rate. It is not clear when this percentage will be reached, as this depends on many things (e.g. vehicle renewal rates, acceptance, policy incentives).

There are no specific barriers for stimulating the deployment of a combination of the promising systems and measures.

[1] EU Energy and transport in figures, Directorate-General for Energy and Transport, statistical pocketbook 2009.

6 Review of the state of the art in CO_2 emissions modelling

6.1 Introduction

This chapter focuses on available CO_2 models to calculate the effects of measures on the CO_2 emissions from road transport. First, model requirements for this type of calculations are explained. Then an overview of currently available CO_2 emission models for road-transport is given. Subsequently the chapter focuses on models that are suitable to evaluate the effects of the three classes of measures considered in this study:

- Eco-solutions
- Traffic Management
- ADAS measures

This includes a description of how the models could be used to estimate potential CO_2 emissions and also shows the available gaps in the current modelling methods.

To accurately simulate the road transport CO_2 emissions, the following chain of models or information is needed:

- A representation of the infrastructure on which the traffic measure will be implemented.
- A representation of the traffic measure.
- A traffic model for the driver behaviour in response to the infrastructure and the traffic measure.
- A CO_2 emission model which can be used to evaluate the effect of the specific measure.
- A model to translate the CO_2 emission reduction from single vehicle or on the local infrastructure to the CO_2 reduction on national or European level.

In this chapter the focus has been on the CO_2 emission models. However, it has to be noted that more questions need to be addressed for a full understanding of the problem:

- Are the existing traffic simulation models sufficiently accurate to model the effects of the traffic measures on the emissions?
- Can all envisaged traffic measures be modelled?
- Do we posses a good enough database of vehicle mixes for the measures we want to simulate?
- Are validated vehicle engine behaviour models available to evaluate the Eco-solutions?

More detailed information about traffic simulation models can be found in Methodologies for the impact assessment of ICT for transport on CO_2 emissions: EC-Meti task force.

6.2 Model requirements

The evaluation of the effects of Traffic management measures, ADAS measures and Eco-solutions on the CO_2 traffic emission all set different requirements to the CO_2 emission models needed to evaluate the measure.

The type of emission model which is needed for evaluation of the different measures, depends on the mechanism of the measure and how it affects the individual vehicle behaviour and the traffic flow: if single vehicle dynamics and engine efficiency are influenced, a very detailed model which simulates the engine power demand of the vehicle or an instantaneous emission model, is needed. When the measure only affects the composition of the traffic flow, the total vehicle kilometres travelled or the congestion, a more aggregated model can be used, such as traffic situation or vehicle fleet models. This is summarized in Figure 11.

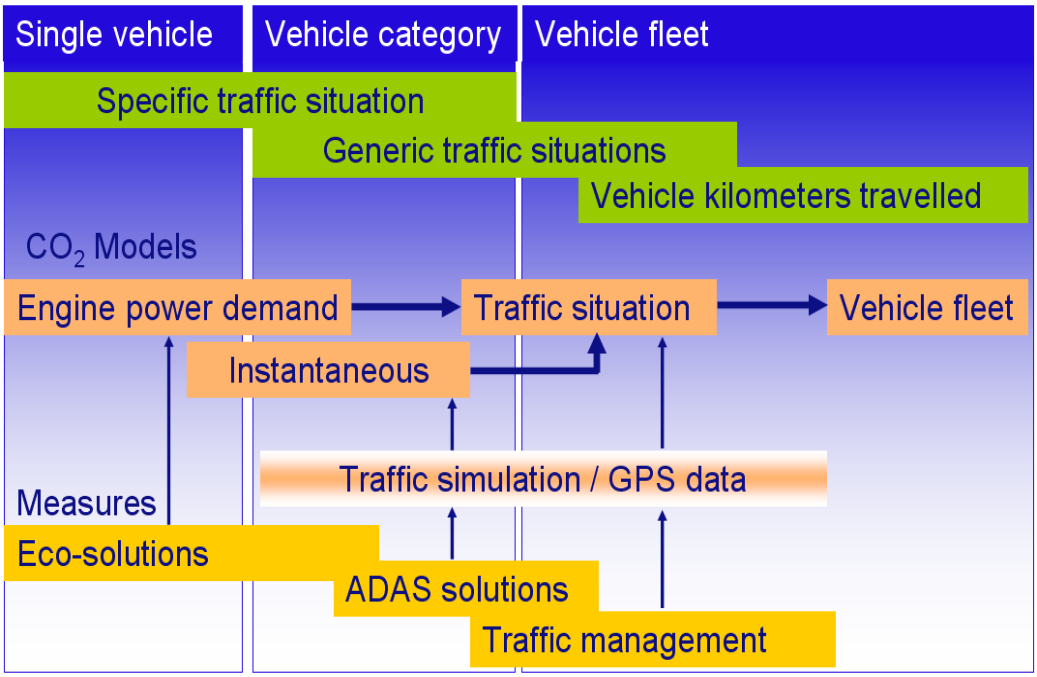

Figure 11: Flow chart indicating the necessary steps to evaluate the effect of the measures on the country wide contribution of the traffic CO_2 emission for the three types of measures. For all CO_2 models the calculated reduction need to be scaled from single vehicle or vehicle category to vehicle fleet

In general, emission models based on traffic situations can be used to describe traffic management measures, instantaneous emission models can be used to describe ADAS measures and engine power demand models for ECO solutions. Instantaneous emission models in combination with microscopic traffic simulations are also suitable to evaluate traffic management measures. This is explained below.

Model requirements for Traffic Management Measures

Traffic management measures primarily affect the traffic intensity and the amount of congestion. Therefore these measures can be evaluated using the more generic CO_2 emission models based on traffic situations. A traffic situation describes the traffic flow

on a road which is characterized by only a few parameters e.g. the average speed and flow.

An example of a model based on traffic situations is the ARTEMIS model. It contains four traffic load levels: free flow, heavy traffic, saturated traffic and stop and go, all characterized by the average speed. A more detailed description of these traffic situations can be found in the description of the ARTEMIS model. However, the ARTEMIS model alone is not sufficient to evaluate the effect of a traffic management measure. The effect of the traffic management measure on the average speed and vehicle flow before and after the traffic management measure is in effect can be evaluated with a separate traffic simulation model or can be derived from real world loop measurements.

Model requirements for ADAS

In general, CO_2 emission models based on traffic situations are not suitable to evaluate the effect of ADAS or Eco-solutions, because these measures influence the driving dynamics on the single vehicle level. Therefore more detailed emission models are needed to quantify the effects of ADAS and Eco-solutions. In particular the instantaneous emission models are applicable. These models require input data in the form of time speed cycles of individual vehicles (e.g. second by second). These time speed transients need to be provided by traffic simulation models or from real world driving data (GPS).

Traffic micro-simulation models such as AIMSUN, ARCHISIM, PARAMICS and VISSIM are designed to simulate traffic flows at the individual vehicle level, in order to evaluate traffic throughput in the network. Emission models are very sensitive to the exact velocities and dynamics, which can be difficult to predict with these traffic simulation models.

Examples of instantaneous emission models which are able to calculate emissions from input data from traffic models, are DIVEM, CMEM, VeTESS, VETO and VERSIT+(^{micro}). However, the combined use of the traffic model and the emission model will give the emission reduction only for the specific local situation.

The effect of ADAS measures can be limited to only a group of vehicles, for example only vehicles which have Adaptive Cruise Control (ACC) will be affected by it.

Therefore, the relative amount of travelled kilometres (VKTs) of this group of vehicles needs to be evaluated. Moreover can this group of vehicles affect the driving dynamics of the other traffic.

ADAS measures influence the drive dynamics and can effectively be evaluated with instantaneous emission models. Instantaneous emission models are based on datasets of emission fields from single vehicles, which relate the actual vehicle velocity and acceleration to the emission at that instance of time. A dataset of emission maps (for instance as a function of velocity and acceleration) needs to be available for sufficient vehicles from the vehicle category to obtain a representative emission (reduction) for that vehicle category.

Model requirements for Eco-solutions

Eco-solutions that directly interfere with the power train of vehicles have to be modelled with more detailed engine power demand models and vehicle design models, like PHEM, ADVISOR, VeTESS and ADVANCE. For example, to calculate the effects

of a gear-shift indicator, the model needs to have gear-shifting as (possible) input, and use it in its emission calculations. Notice that instantaneous emission models and the detailed vehicle emission models need input data in terms of time-speed transients of single vehicles. These time- speed transients can be obtained by microscopic traffic simulation programs, or from real-world measurements.
Models which have separate emission fields for idling vehicles, like VERSIT+^{micro}, can describe the effect of e.g. start-stop systems (Eco-solution). Hence for this case, a more detailed model such as PHEM is not necessary.

6.3 Models examined

In this paragraph a list of CO_2 emission models is presented which are suitable for the evaluation of the effect of Traffic management, ADAS and Eco-solutions on the CO_2 emissions. This overview of models has been created via a quick scan (literature search). Starting point was the information available from the EC-METI Task force[4] and information provided by Volvo Technology and TNO. In this quick scan the models are categorised according to the main specifications:

- the generic model type according to the level of detail
- the type of input data required

Table 16 shows an overview of the models found in the quick scan. The list consists mainly of models developed in Europe. However, also a few models from outside Europe (US and Australia) have been included in the quick scan and are indicated as such. The models are categorized with respect to their generic types:

- Regional models, the emissions are calculated by the product of the emission per vehicle, the vehicle fleet composition and the mileage per vehicle group on the various road types, urban rural and highway.
- Instantaneous models, the emissions are calculated using time speed transients of single vehicles.
- Policy assessment models, calculates the change in composition of the vehicle fleet due to political and economical measures.
- Models based on traffic situations e.g. free flow, medium congestion, strong congestion
- Macroscopic Traffic flow models yielding mainly traffic volumes
- Engine power demand models

The models listed below which are written in bold are selected as being potentially suitable and are described in more detail in section 6.4. Appendix 1 gives a short description of each model, including the reason why it was decided not to include the model for further evaluation in this study.

[4] The EC-METI Task force is developing an expert report contributing to the development of international, standardized assessment methodology of impact if ITS on energy efficiency and CO_2 reduction in road transport. TNO is member of this Task force.

Table 16: Overview of CO2 emission models evaluated in the quick scan.

Model name	Type	Type of input data
ADVANCE	Engine power demand	Time speed cycles
ADVISOR (US)	Engine power demand	Test cycle, technology
AMESim	Engine power demand	
ARTEMIS	Traffic situation	Road type, speed limit and congestion level
ATESAME	Combined traffic flow model emission model	Traffic flow model
BURDEN (US)	Regional model	Speed bin distribution
CAR II	Traffic situation	Road type and congestion level
CMEM (US)	Instantaneous model	Time speed cycles
COPERT	Regional model	Road type and average speed
DGV	Instantaneous model	Time speed cycles
DIVEM	Instantaneous model	Time speed cycles
DRIVE	Engine power demand	
DMRB	Regional model	Road type and average speed
DYMOLA	Engine power demand	Vehicle parameters
EMFAC (US)	Regional model	Speed bin distribution
EMV	Regional model	Road type and average speed
GLOBEMI	Policy assessment model	Total fuel consumption
HBEFA	Traffic situation	Road type, speed limit based congestion
IEM	Instantaneous model	Time speed cycles
LIISA	Regional model	Road types
MEEM (US)	Engine power demand	
MIMOSA	Traffic situation	Road type
MOBILE 6 (US)	Regional model	Road type and average speed
MODEM	Instantaneous model	Time speed cycles
MOVES (US)	Regional model	Energy consumption based
MVEI	Instantaneous model	Time speed cycles
NAEI	Regional model	Speed bin distribution
PdP (Australia)	Instantaneous model	Time speed cycles
PHEM	Engine power demand	Time speed cycles
QGEPA (US)	Regional model	Road type and average speed
SAVE	Engine power demand	Time speed cycles
SMARTWAY	Engine power demand	Truckfleet, FC and fuel reduction measures such as efficient tyre systems
TEE	Regional model	Road type, average speed, cong. Level
TEMAT	Policy assessment model	Road type
TEMPO	Policy assessment model	
TREMOD	Regional model	
TREMOVE	Policy assessment model	Road types

Model name	Type	Type of input data
UROPOL	Instantaneous model	Time speed cycles
VERSIT+	Instantaneous model	Road type and time speed cycle
VeTESS	Engine power demand	Time speed cycles
VETO	Instantaneous model	Engine maps and vehicle parameters

6.4 Selected models

Using the requirements described in section 6.2, a first selection of models has been made. This selection was based on the model type, how up-to-date the model is and whether enough information was available on the model. Only the most recently developed models have been considered. The selected models are listed in Table 17.

Table 17: Selected models from the quick scan, categorized

Traffic Management	ADAS	Eco-solutions
ARTEMIS	CMEM	ADVANCE
Enviver (VERSIT+^{micro})	DIVEM	ADVISOR
HBEFA	VERSIT+^{micro}	PHEM
		VeTESS

Templates have been developed to get consistent information for the most important models. For various models shown in table 3 this template has been filled in. In addition, a brief description of several of the selected models can be found below.

ARTEMIS (EU) [ARTEMIS]
ARTEMIS stands for Assessment and Reliability of Transport Emission Models and Inventory Systems and is based on traffic situations. The original ARTEMIS model has been developed within a European project and is provided as a runtime version of an MS-ACCESS Database containing the following elements:

- a database containing emission factors from emission measurements performed within the ARTEMIS project but also from other, mainly national sources,
- a fleet model, allowing the user to setup the necessary fleet compositions for a particular country and for one or several years,
- an emission factor module which calculates weighted emission factors for particular traffic situations,
- an emission model which calculates the overall emissions either on an aggregate basis for a particular country or region or city, or for a specific network i.e. on likewise basis.
- PHEM, which will be discussed below, is used to calculate the heavy duty emission factors in this model.

The ARTEMIS model deals implicitly with congestion effects. Congestion effects are contained in four discrete, so called traffic activity scenarios:

1. free flow traffic, characterized by constant high speeds, 90 -120 km/h on the highway

and 45 – 60 km/h in urban situations.

2. heavy traffic, characterized by velocities slightly below the speed limit, 70 – 90 km/h
   on the highway and 30 – 45 km/h in urban situations.
3. saturated traffic, characterized by significantly lower velocities, 30 – 70 km/h on the highway and 15 – 30 km/h in urban situations.
4. stop and go, characterized by an average velocity of 5 - 30 km/h on the highway and between 5 – 15 km/h in urban situations.

These scenarios are combined with 69 different road categories (town/rural, different velocity limits and status of the roads) resulting in a total of 276 different traffic situations. In the current version of the model, 2009, no custom developed traffic scenarios can be imported. The resolution between the default traffic activity scenarios is not sufficient to describe traffic management measures.

VERSIT+ (NL)
The recently updated emission model VERSIT+ is an instantaneous emission model with a solid statistical basis (1400 vehicles). Calculation of the emissions is done using the time speed profiles of the vehicles. The time speed profiles can be provided by microscopic simulations but also by real world GPS data. The newest model-version 3.0 (2009) has default emission maps as a function of the velocity and the driving dynamics for a number of different vehicle categories: light duty, heavy duty (heavy duty and middle heavy duty) and busses, both in an urban situation and on the motorway (road types). The vehicle fleet composition is based on fuel type and Euro class. By default the vehicle fleet composition is developed from the vehicle kilometers travelled kilometers for the different vehicle categories, fuel types and Euro classes for the Netherlands.

VERSIT+ has been used to evaluate the emission effects of:

- Adaptive Cruise Control (ACC) using time speed transient data obtained via GPS
- Emission effects of static speed limits on motorways

VERSIT+ has a solid vehicle database; however, the vehicle fleet composition is based on the Dutch situation. The vehicle fleet composition of other European countries is under development.

EnViVer (NL)
EnViVer is a coupling between a micro traffic simulation model (VISSIM) and an emission model based on VERSIT+^{micro}. VERSIT+^{micro} is an instantaneous emission model based on VERSIT+, however with vehicle data on a more aggregated level. Based on the simulated time-speed profiles, the emissions are calculated using VERSIT+^{micro}. EnViVer has been used to simulate the emission reductions of:

- Replacement of an intersection with traffic light by a roundabout.
- Adjusting the “green” time of traffic lights on the basis of the amount of traffic in the corresponding direction in real time. (Dynamic traffic light adjustment)
- Static green waves

HBEFA (Germany,Austria and Swiss (DACH)) [HBEFA]
HBEFA stands for Handbook Emission Factors**.** The HBEFA model is provided as a runtime version of an MS-ACCESS Database containing the following elements:

- a database containing emission factors from emission measurements performed within the DACH-NL-S-group as well as within the ARTEMIS project,
- a fleet model, allowing the user to setup the necessary fleet compositions for a particular country and for one or several years,
- an emission factor module which calculates weighted emission factors for particular traffic situations.

HBEFA contains less traffic situations then ARTEMIS. However, mid 2009 a new version (3.1) will become available including an expert version in which customized traffic situation can be added. This expert version will not be publicly available.

- PHEM, which will be discussed below, is used to calculate the heavy duty emission factors in this model.

Currently the resolution between the default traffic situations is not sufficient to describe traffic management measures, however, a new version of the emission model is under development which might be suitable.

CMEM (US), Comprehensive Model Emission Model [CMEM]
CMEM was developed to evaluate the effects of ADAS (ITS) on the emission of vehicles. CMEM is a power demand model in which the needed engine power is calculated from time speed profiles (second by second). CMEM is based on 315 vehicles (US) dynamometer tests. The emissions of different vehicle classes can be aggregated. Currently the newest version 3.0 (developed in 2005) includes 28 Light Duty classes and 3 Heavy Duty classes; moreover it contains the emission classes ULEV, SULEV and PZEV, which include plug-inn hybrid vehicles and dedicated CNG vehicles. The database solely contains American vehicles.
The database solely contains American vehicles, which makes CMEM unsuitable for European situations.

DIVEM(D), [DIVEM]
DIVEM, the Dynamic Instantaneous Emission Model is under development by EMPA and will become available at the earliest at the end of 2010.
The emission fields are obtained through a non linear parameterization of the emissions measured
on the dynamometer. Currently the database consists of 20 euro 4 petrol driven cars and 10 euro 4 diesel driven cars.
The limited vehicle database makes DIVEM currently unsuitable to evaluate the effects of ADAS measures, however, plans exists to extend the vehicle database before the end of 2010.

ADVANCE (NL) [ADVANCE]
Advance is a vehicle design model built in MATLAB/Simulink. The model is based on an instantaneous power demand model based on time –speed transients like MVEG-B which have to be provided as input by the user. The model contains adaptable generic models of various parts of a vehicle like the vehicle body, wheels with suspension kinematics, engine, clutch, gearbox and differential. The emission is calculated on the basis of torque losses of each part of the power train and ultimately calculated based on static engine emission maps. The current library of engine maps is not up to date and the newest vehicles are five years old.
The limited vehicle database makes ADVANCE currently less suitable to evaluate ECO solutions. However, plans exist to update the vehicle database.

ADVISOR (US) [ADVISOR]

Advisor is a Matlab-based program for rapid analysis of design changes for Light Duty and Heavy Duty vehicles including hybridization and fuel cell technology. Moreover, the effect on the NO_x emission on the size and type of catalysts likes SCR and NAC can be evaluated. The effect of engine downsizing on the CO_2 emission is included. The database only contains American vehicles, which limits the use of the model in Europe.

PHEM (Austria) [PHEM]
Vehicle based model used to simulate emissions of Heavy Duty vehicles and busses. Engine maps provide emissions based on the euro classes 0 to 5, weight of the truck, rated engine power, roll resistance, air resistance, engine speed (rpm), gearbox type, gearshift behaviour.
The emissions are based on static motor measurements, i.e. the engine is stabilized at a specific engine speed and specific load. A gearshift model is used to describe the dynamical effects which yield emissions which are in reasonably good agreement with real world emissions.
The database needs to be updated when new types of engines become available. The engine map and the time speed transients, typical for the considered class of vehicles, will provide the emissions of CO_2, NO_x and PM_{10}. PHEM can calculate the possible emission reduction of ECO solutions on Heavy Duty Vehicles.

VeTESS (EU) [VeTESS]
VeTESS was the main deliverable from the EC 5th framework project DECADE which was cooperation between MIRA, IDIADA (CLE) and VITO.
VeTESS is an engine power demand model like PHEM based on vehicle mass, rolling resistance, aerodynamic resistance and steady state engine emission maps.
Dynamical emission effects are incorporated by adding a jump fraction, a transient emission fraction (overshoot) and a non equilibrium fraction following changes in torque.
The results of the model were compared with real world emission of the VW Polo 1.4 16V, Skoda Octavia 1.9 TDI and the Citroen Jumper 2.5D for light duty and the van Hool city bus for heavy duty.
The engine map database consists only of these few vehicles, which limits the applicability of the model. The emissions considered are CO_2, CO, THC, NO_x en PM.
The very limited vehicle database makes VeTESS not very suitable to evaluate ECO solutions. However, plans exist to extend the vehicle database.

6.5 Practical examples

A number of models mentioned in this study, have already been used to evaluate the effect on road traffic CO_2 emissions from ICT based measures. For each category of measures, an example will be described briefly in the following section:

Traffic management

The Stockholm congestion charge project has been evaluated regarding CO_2 emissions using the traffic situation emission model ARTEMIS (described in chapter 6.4). Traffic metering and data from the National Vehicle Register were used for a statistical calculation of the total traffic work and the vehicle fleet composition. The calculations were compared with data calculated from a traffic model: Emme/2. The reduction in CO_2 emission inside the charging zone was calculated to be 14 % (24 hrs average). Outside the charging zone the CO_2 emission was reduced by only 1 % [ARTEMIS].

Advanced driver assistance systems

In the TRANSUMO IV (TRANsition to SUstainable MObility) project, the effect of Adaptive Cruise Control (ACC) on the fuel consumption has been evaluated using the VERSIT+^{micro} model (TNO).
The real world time speed transients of the cars employing ACC were recorded using GPS data and compared against a group of vehicles not equipped with ACC.
A considerable reduction (approximately 5%) in the fuel consumption was observed for the group of vehicles equipped with ACC. However, the impact of the technique on the CO_2 emission on a country and EU wide scale needs to be evaluated with additional models.

In Lund, Sweden, a fuel-optimized navigation system was evaluated using the VETO and VeTESS models, see the sections 6.3 and 6.4. The vehicle fleet was approximated with three cars: a small and a large petrol car and a diesel car. The actual time-speed transients are derived from digitalized routes from the navigation system. These routes were extracted from a large database of real traffic driving patterns connected to the street network. The conclusion was that the navigation tool could save about 8 % of fuel [VETO].

Eco-solutions

In August 2002, TNO Automotive converted a yellow Volkswagen New Beetle into a series hybrid vehicle. A reduction in fuel consumption with respect to the conventionally fuelled vehicle was found to be approximately 25 %. The power train of the vehicle was optimized using the vehicle design model ADVANCE.

6.6 Discussion & conclusions

A quick scan has been made to evaluate existing CO_2 emission models for their applicability to the proposed ICT based measures.

Three categories of measures are considered:

- Traffic management measures,
- ADAS measures and
- ECO solutions.

A wide variety of models was found ranging from generic models like traffic situation models, to the very detailed engine power demand models or even vehicle design models. In Figure 12 an overview is provided of the model chain with the most relevant models discussed above positioned at the appropriate level.

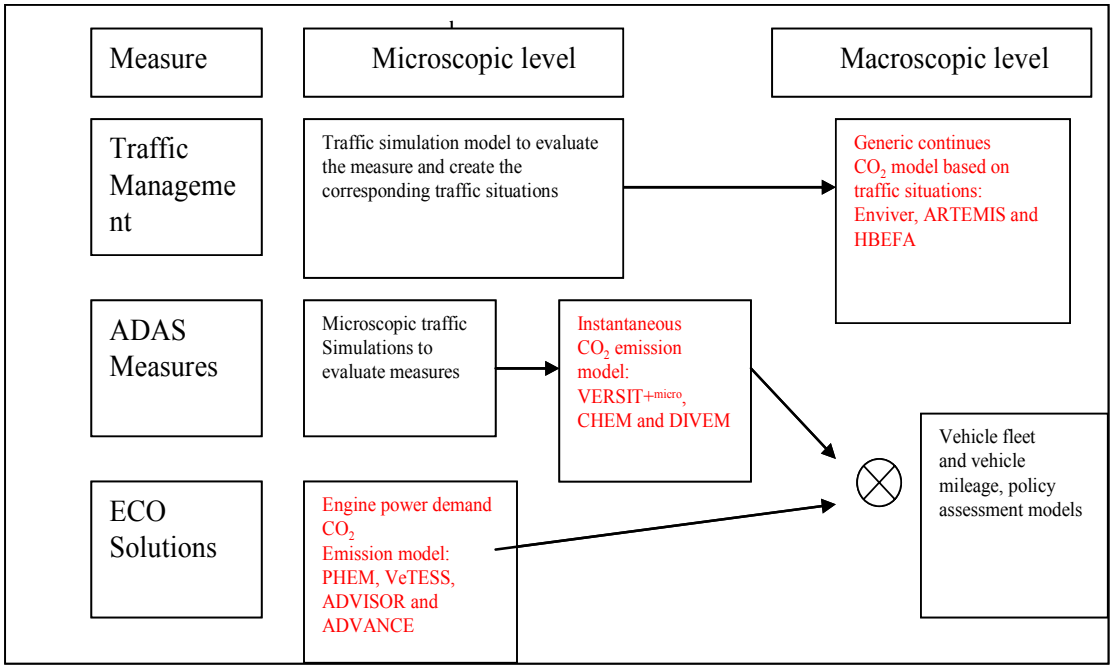

Figure 12: Flow chart indicating the necessary steps to evaluate the effect of the measures on the country wide contribution of the traffic CO_2 emission exemplified with some models.

It can be concluded that, although numerous CO_2 models exist which generally are methodologically sound, only a few models are up-to-date and are based on a reasonably large emission dataset. Experimental data on both real-world traffic emissions and driver behaviour will be very valuable for further development and validation of these models.
Both on the input-side as on the output-side of the CO_2 models, more development is needed. Regarding the input, this contains the generation of realistic driving patterns from traffic micro-simulations models or real-world measurements. Regarding the output, this concerns extrapolating the results to a national or regional scale.

Each category of measures sets its own requirements to the models. In addition, the CO_2 effects of each measure cannot be directly calculated by a stand-alone CO_2 emission model. Often, output from for instance a traffic simulation model is needed to calculate the effect of the measure on the traffic parameters like the average speed, the amount of congestion and the traffic volumes.

Traffic management

Traffic management measures influences the traffic intensity and the amount of congestion. These measures can be evaluated using CO_2 emission models which are based on traffic situations. For to ensure a good resolution, such models should contain a large variety of traffic situations. The models currently available do not include a sufficiently large set of traffic situations for a proper validation. In the future, models like HBEFA will be extended and might provide the possibility to import traffic situations. An alternative option is to carry out microscopic traffic simulations on the network, with and without the specific traffic management measure. The obtained time speed transients used in instantaneous emission models, listed in table 3 under the caption ADAS. However, care should be taken as most microscopic traffic models were not developed with the objective to obtain time-speed profiles accurate enough for emission modelling, which is especially difficult in cases where measures have impact on driver behaviour.

Advanced driver assistance

ADAS measures affect the driving pattern, and therefore can best be evaluated using microscopic traffic simulations, with and without the application of the ADAS measure. Also empirical GPS data can serve as input for the emission models. Emissions can be calculated using instantaneous emission models like VERSIT+^{micro} or DIVEM. However when using this approach it has to be checked that the emission model used contains a sufficiently large emission database. which is currently only the case for VERSIT+, in the Dutch situation. In addition, (microscopic) traffic simulations do not automatically deliver realistic output in terms of time-speed profiles that can serve as input for the instantaneous emission models.

Eco solutions

The ECO solution measures affect the drive-train characteristics and / or the driving behaviour. Therefore an (virtual) evaluation can be performed with an engine power demand model or a vehicle design model. In general it can be stated that vehicle design models are too detailed and a more generic engine power demand model like PHEM or VeTESS are preferred. However, most power demand models only contain very limited emission data. This results in the risk that the models are too much tuned towards some specific vehicles and do not provide results that are representative for a certain vehicle category.

It should be noted that this was a theoretical study based on review of literature and direct communication with model developers; most models were not evaluated in practice.

In this study the focus has been on the CO_2 emission models only. However, especially for the evaluation of future measures, a chain of models is needed, including the earlier mentioned (microscopic) traffic simulation models and extrapolation models to extrapolate the results from the emission models to a national or regional scale. Although outside the scope of this study, it has to be noted these models also have to be considered for a full understanding of the problem. Relevant considerations here are:

- In case traffic simulation models are used, these models should generate realistic speed-time profiles to ensure accurate input for the emission models.

- Can all envisaged traffic measures be modelled?
- Extrapolation of the CO_2 model results towards national, regional or European scale is needed. This is an important part of the study, which can significantly influence the results. Currently, as in this study, this is often done via an estimation of the 'share of situations'. Further development of such methodologies and the availability of commonly accepted figures are needed, including detailed information about vehicle fleet compositions.
- As these impact studies are performed for future systems and future situations, it is necessary to also take new technology like hybrid vehicles or even future technology like full electric vehicles into account in the models.

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7 Conclusions and Recommendations

This project has resulted in a list and ranking of 12 systems that are promising for CO_2 reduction, with an estimated potential effect on EU27 level, an estimation of the ease of implementation of these measures and a judgment of the usefulness of existing CO_2 emission models to estimate the energy efficiency of the systems and solutions examined.

Based on the estimation of the potential CO_2 reduction on EU27 level, the measures are divided in groups relative to their potential CO_2 effects, as follows:

Largest CO_2 reduction on EU27 level:
- Eco-driver Coaching
- Eco-driver Assistance

Large CO_2 reduction on EU27 level:
- Pay As You Drive
- Platooning

Medium CO_2 reduction on EU27 level:
- (Adaptive) Cruise Control
- Dynamic traffic light synchronization
- Fuel-efficient route choice
- Automatic engine shutdown
- Trip-departure planning (freight)
- Tyre pressure indicator

Moderate CO_2 reduction on EU27 level:
- Congestion charging
- Slot Management

The most important factor for the CO_2 reduction on EU level appears to be the share of situations where it is effective. That explains the high potential of the eco-driving systems and PAYD. Another important factor is the influence of the measure on the amount of vehicle kilometres travelled, and the ability to reduce the dynamics of the traffic flow (speed variations and accelerations) at a large scale. Congestion charging and Slot Management have less potential CO_2 reduction on EU27 level, because they are applicable in fewer situations, but they can still have a substantial local effect.

For some measures it will be easier to reach the potential effects than for others. This may depend on all kinds of implementation issues, as well as on the expected compliance of the driver for the measure. Systems that are both promising in terms of CO_2 reduction and ease of implementation are Eco-driver Assistance, Cruise Control and Adaptive Cruise Control, Automatic engine shutdown and the Tyre pressure indicator.

Regarding safety systems that only have an indirect effect on CO_2 emissions by avoiding incidents and subsequent queue formation, our effect estimations have shown that these systems have a much lower potential regarding CO_2 reduction. Of course, it can still be worthwhile to stimulate the use of these systems for improving traffic safety.

The extended assessment faced many uncertainties regarding the effect estimation on CO_2 reduction, mainly because little information was available about CO_2 emissions and share of situations for most of the systems.

The estimations of the presented CO_2 effects are based on the vehicles of today. When the measures are applied in future years, the effect in absolute terms will become smaller, since the vehicles will become cleaner and more energy efficient already by 'normal' technological developments.

For each of the selected systems, implications for electric vehicles have been addressed. In general, measures that are effective on the energy efficiency of conventional engine vehicles are also beneficial for electric vehicles; however, the effect may be smaller, since electric vehicles are already capable of more energy efficient driving, especially for low speeds.

Finally, it can be noted that most of the presented promising measures are independent of each other, such that the total effect, when used together, is the summation of the separate effects. It can therefore be recommended to stimulate the deployment of a combination of the promising systems and measures.

Apart from the ranking of ICT measures, a quick scan has been carried out related to the existing CO_2 emission models and their suitability to assess the impact of proposed ICT based measures. A wide variety of models was found ranging from generic models like traffic situation models, to the very detailed vehicle design models. Each category of measures sets its own requirements to the models.

Traffic management measures influence the traffic intensity and the amount of congestion. These measures can be evaluated using CO_2 emission models which are based on traffic situations. To ensure a good resolution of the estimations, such models should contain a large variety of traffic situations. The models currently available do not include a sufficiently large set of traffic situations for a proper validation. In the future, models like HBEFA will be extended and might provide the possibility to import traffic situations. An alternative option is to make microscopic traffic simulations on the network, with and without the specific traffic management measure in combination with an instantaneous emission model.

Advanced driver assistance systems affect the driving behaviour, and therefore can best be evaluated using microscopic traffic simulations, with and without the application of the ADAS measure. However, also empirical GPS data can serve as input for the emission models. Emissions can be calculated using instantaneous emission models like VERSIT+ or DIVEM. However when using this approach, it has to be noted that the emission model used does contain a sufficiently large emission database. In addition, (microscopic) traffic simulations do not automatically deliver realistic output in terms of speed-time profiles that can serve as input for the instantaneous emission models.

Eco solutions affect the drive-train characteristics and / or driving behaviour. Therefore an (virtual) evaluation can be performed with an engine power demand model or a vehicle design model. In general it can be stated that vehicle design models are too detailed and a more generic engine power demand model like PHEM or VeTESS are preferred. However, most power demand models do only contain very limited emission

data, with the risk that the models do not provide results that are representative for a certain vehicle category.

In general it can be stated that, although numerous CO_2 models exist which generally are methodologically sound, only a few of them are based on a reasonably large emission dataset. Models based on data of only a few vehicles might provide results that are not necessarily representative for a certain vehicle category. Therefore, the availability of experimental data on both realworld traffic emissions and driver behaviour is valuable for the further development and validation of these models.

In addition the CO_2 emission model alone is not able to evaluate the effects of each measure directly. Often these models are used in a chain of models, as for instance a traffic simulation model is needed to calculate the effect of the measure on the traffic parameters like average speed, amount congestion and the traffic intensity. For an reliable and accurate result the complete chain should provide accurate results. Therefore it is noted that:

- In case traffic simulation models are used, these models should generate realistic speed-time profiles to ensure accurate input for the emission models.
- Extrapolation of the CO_2 model results towards the national, regional or European scale is needed. This is an important part of a study aiming to provide effects at a higher level, which can significantly influence the results. In this project, this was done by an estimation of the 'share of situations'. Further development of this method and availability of commonly accepted figures are needed.

Finally, we would like to point out that more accurate effect estimations and identification of technical, organizational and policy barriers would be possible by creating and analyzing Field Operational Tests (FOTs) concerning energy efficiency of ITS measures. Also the running FOTs can contribute to a better assessment of ITS in relation to Energy Efficiency, e.g. data collected in FOTs can help in improving our knowledge on driver behaviour in combination with ITS measures, and for improving the traffic and emission models. We would recommend to investigate to what extent the running FOTs are already used for research to energy efficiency of ITS, and to extend them to include this subject if this is not sufficiently covered yet.

Appendix 1: Brief description CO_2 emission models

AMESim [AMESim]
AMESim is a Computational Fluid Dynamics based vehicle design model used i.e. by G.M., Renault, Bosch, Peugeot, Citroen, Fiat, Hyundai and was developed by LMS Imagine Labs.

ATESAME (Be)
ATESAME is a combined traffic flow and emission model developed by the University of Liege, Belgium. The emission factors are based on the vehicle type and the average speed of the vehicle.
The emissions are the product of the emission factor and the travelled distance.

CARII (NL)
CARII is an air quality model used in the Netherlands. The model is based on the traffic situations Urban with the subdivision free flow, medium congested, congested and rural and highway. Based on the traffic intensities it calculates the concentrations of several pollutants in the air. The CO_2 emissions are not included in the model.

COPERT IV [COPERT-IV]
COPERT IV is a commonly used regional emission model based on emission factors per vehicle class multiplied with the corresponding vehicle mileage. Therefore it is an ideal tool to estimate the effect on emissions of changes in the vehicle fleet; however, no effects of congestion can be simulated.
COPERT IV is not suitable to calculate effects of traffic management, ADAS measures or ECO solutions. However, COPERT is extensively used in Europe and a detailed description can be found in the annex.

DGV (A)
The Digitalized Graz Method

DRIVE [DRIVE]
Drive can dynamically simulate car engines, gearboxes and transmissions and was developed by
Systems & Advanced Technologies Engineering (sate, Italy).

DRMB (UK) [DRMB]
The DRMB model is a design manual for Roads and Bridges Screening which is based on average emission factors. The model is developed by the Highways Agency from the UK.

DYMOLA [DYMOLA]
Dymola can manipulate symbolic differential and algebraic equations and was developed by Dynasim in Sweden.

EMV
EMV was used to assess emissions from traffic in Sweden. It is a Swedish regional model and has recently been replaced by ARTEMIS.

GLOBEMI [GLOBEMI]
Globemi is a global CO_2 emission model based on the vehicle stock, vehicle kilometres on major roads. The emission model is used by the Austrian Energy Agency.

IEM
IEM, Instantaneous Emission Model is currently under development by TRL, no detail information is available at this moment.

LIISA [LIISA]
LIISA 2007 is a global emission model developed by the Technical Research Centre of Finland VTT.

MEEM [MEEM]
The vehicle Design Model, MEEM, Modal Energy and Emission Model is a power demand model based on a parameterized analytical representation of e.g. losses in the gearbox. The last publication was in 2001 and no contact could be made to one of the authors.

MIMOSA (Be) [MIMOSA]
Mimosa was developed by AMINAL/VMM and VITO, Belgium.
The emission factors are based on Copert.

MODEM [MODEM]**,** [MOBILE6, UROPOL, MODEM]
Modem is an instantaneous emission model and was originally developed by INRETS France in 1990 and later updated by TRL in the UK. However, due to the limited number of euro classes available in the database and the absence of heavy duty vehicles it has been abandoned.

Mobile, MVEI, Burden, EMFAC and QGEPA (US) [MOBILE6], [EMFAC, BURDEN], [MOBILE6, UROPOL, MODEM]
The US models Mobile and MVEI are applicable to emission inventories of large regional areas; however, these models are not suitable to calculate effects which are microscopic in nature such as ADS measures. QGEPA is an extension of Mobile 6 which includes diesel powered vehicles. Both Burden and EMFAC are included in the MVEI modelling suite.

MOVES2009 (US) [MOVES]
MOVES, MotorVehicle Emission Simulator, serves as a replacement for Mobile 6. This program estimates the regional emissions of road traffic based on emission factors differentiated to vehicle types, e.g. passenger cars, heavy duty and fuel type over different road types e.g. urban, rural and off road.

NAEI (UK) [NAEI]
NAEI stands for National Atmospheric Emission Inventory.

PdP [PdP]
PdP is an instantaneous emission model under development by the institute Pacific AIR & Environment in Australia.

SAVE [SAVE]
SAVE, Sustainable Action on Vehicle Energy is an instantaneous emission model which is currently under development at the University of Warwick in the UK and is expected to be ready at the beginning of 2012. Currently no detailed information about the model is available.

SMARTWAY [SMARTWAY]
Smartway is based on MOBILE 6 and the emissions are estimated on the basis of standard drive cycles. Average emission values for fuel saving techniques are used which makes the model not suitable for the evaluation of ADAS and ECO solutions. Moreover is the focus of smartway on heavy duty vehicles.

TEE (IT) [TEE]
The TEE model, the reconstructed speed-time profile emission model was developed by ENEA (Italy). The emission model calculates based on hour by hour traffic flow measurements and on network data like the number of lanes and the number of intersections the fuel consumption.
The last publication was in 1996.

TEMAT (Be)
TEMAT is a macroscopic emission model developed by VITO, Belgium.
The emission factors of TEMAT are based on Copert. The emissions per vehicle type are calculated by the product of the emission factor per velocity bin multiplied with the travelled distance.
No congestion effects can be simulated.

TREMOD [TREMOD]
TREMOD is based on average traffic parameters with insufficient resolution and therefore not suitable to model effects which influence the driving dynamics.
The emission factors are based on HBEFA.

TREMOVE [TREMOVE]]
TREMOVE is a policy assessment model which predicts the development of the vehicle fleet in the future. To evaluate emissions, emission models like COPERT IV need to be used. However, TREMOVE can be suitable to predict the impact on the vehicle fleet of the technology needed for the eco solutions or ADAS measures.

UROPOL [MOBILE6,UROPOL,MODEM]
UROPOL is a simple modal mass model relating the actual velocity and acceleration to the instantaneous emission. The model seems to be obsolete no recent information could be found.

VETO [VETO]
VETO is a mechanistic simulation model which is used to describe fuel use and emissions, fuel use and tire wear for one vehicle at a time. It was developed in 1987 by VTI (Swedish National Road and Transport Research Institute). The program uses vehicle parameters. Parameters for a vehicle can be imported to the model. The advantage is that one can assess environmental effects on a detailed level, but the disadvantage is that data for the vehicle need to be imported to the model if you choose to study a modern car model. Data are available for older car models.