D3.1: Methodology for classification of ITS

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Gerdien Klunder, TNO

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FP7-ICT-2011-7: Information and Communication Technologies
Low carbon multi-modal mobility and freight transport
This deliverable describes the analysis of impacts ITS exert on transport processes and CO2 emissions. All relevant ITS in the scope of Amitran are identified, described, grouped and qualitatively assessed. The qualitative assessment prepares the development of the Amitran methodology and gives an impression of the relevance of systems for changes in CO2 emissions. The deliverable provides a list and descriptions of ITS, a list and descriptions of factors and parameters influencing or describing traffic demand, driver behaviour and vehicle conditions, as well as long term effects, an estimate of the qualitative impact of ITS on these parameters with a description, an estimate of the relevance of parameters for CO2 emissions, and an assignment of ITS to impact classes.
## Control sheet

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Executive summary

The aim of Amitran is to develop a framework for evaluation of the effects of ICT measures in traffic and transport on energy efficiency and CO₂ emissions. By doing so, Amitran will contribute to the development of ICT solutions that allow more efficient multi-modal transport of goods and passenger mobility.

In order to make Amitran a useful and successful methodology, the relevant intelligent transport systems (ITS) and the transport processes leading to changes in CO₂ emissions have to be identified, described and assessed. These are the objectives of Work Package 3 addressed in this deliverable.

This deliverable describes the methodology and its application for a classification of ITS with respect to their potential impact on CO₂ emissions. In order to provide the basis for the Amitran framework, a detailed approach was followed consisting of several steps:

- identification, classification and description of ITS to be considered by Amitran
- identification, classification and description of transport processes of relevance for CO₂ emissions
- qualitative impact assessment of ITS with reference to transport processes
- qualitative impact assessment of ITS on CO₂ emissions

The assessment of systems and transport processes was conducted by several experts for the different system categories by means of an online survey, direct consultation, and expert discussions. Results from literature review complete the assessment.

The major objective of this qualitative impact assessment of ITS with reference to CO₂ was not to provide just another classification of ITS, but to give insight into how systems affect traffic and CO₂. For this purpose the intermediate step of identifying influencing factors and parameters describing traffic demand, driver behaviour and vehicle conditions was necessary. This list of factors and parameters is an input to the Amitran framework developed in WP 4.

The impact assessment is supported by evidence from the literature and a description of the impact of systems for the most relevant ITS. Based on the qualitative impact assessment all examined ITS are assigned to impact classes. These classes are only an estimate on their potential relevance for influencing CO₂ emissions. The qualitative impact assessment is not a replacement for a detailed assessment conducted with the Amitran methodology.
A detailed system assessment requires a clear definition of the context in which the scrutinised ITS is deployed. This includes a distinct system definition, the description of the setting, in which the system is deployed, and other systems which might interact with the examined ITS. Furthermore, the maturity of systems influences the uncertainty involved in a system assessment. Because the qualitative assessment documented in this deliverable follows a general approach and as such does not limit the context in which systems are deployed nor narrows the definition of systems to a specialised context, not for all systems a concrete impact estimate can be provided.

The list of systems, the impacts these systems have on traffic parameters together with the relevance these parameters have for CO₂ emissions provides a typology of ITS on which the further development of Amitran can be based (WP 4, WP 5).

The major outputs of this deliverable are:

- A comprehensive list of more than 50 ITS for the modes road, rail, and inland waterways, grouped into six categories and further divided into sub-categories for easy reference.
- A list of factors influencing traffic demand, parameters describing traffic demand, driving behaviour and vehicle conditions, which can be influenced by ITS, and long term effects of ITS, supplemented by an estimate of the relevance of these parameters for CO₂ emissions.
- An overview on the most important effect of ITS on the mentioned parameters.
- A classification of ITS into high, medium, and low potential systems with respect to their impact on CO₂ emissions and a qualitative description of these effects.

Systems from the whole range of ITS categories have high potential to influence CO₂ emissions. Not only ITS supported measures like restricted traffic zones, access or road pricing might affect CO₂ emissions significantly, also traveller information (e.g. car-sharing information systems, and real-time traveller information systems) or navigation systems (those for electrical cars more than general ones). Also driver assistance systems (from adaptive cruise control to autonomous driving) promise to have a relevant impact on CO₂. In case of freight, supply chain management systems belong to the high impact class. Finally, multimodal planning support systems (e.g. multimodal tour planning systems) are judged to yield high potential for changes in CO₂ emissions.

It is apparent that systems either affecting the specific emissions caused by vehicles (e.g. driving dynamics), or fostering a modal shift belong to the high impact class. The more directly the system can influence travel or driving behaviour (no impact of acceptance or compliance), the higher the expected impact is.
The impact classification provided in this deliverable is no replacement for a more detailed assessment using the Amitran methodology. Major reasons are that a specific implementation of a system may give different assessment results than found in this study due to the context in which systems are deployed, the connection of systems with each other, the importance of system specification, and the accuracy that can be achieved by an expert survey. A system assessment requires a precise definition of the systems and the potential impacts under scrutiny. Such a definition is provided in this deliverable and will feed into the Amitran framework.

The output of WP 3 documented in this deliverable will feed into the further WPs of Amitran in the following way:

- Factors influencing traffic demand and parameters describing traffic demand, driving behaviour and vehicle conditions will be incorporated in the Amitran framework (WP 4) and, thus, are taken into account in the definition of the model interfaces (WP 5).
- Particular attention will be paid to the processes with high relevance for CO₂ emissions.
- The Amitran framework will consider the identified impact systems have on specific factors and parameters (WP 4).
- Systems with high impact potential for changes in CO₂ emissions will be part of the use cases outlined in WP 2 and detailed in WP 6.
- The ITS typology allows conclusions from assessed systems to systems belonging in the same category and sub-category making Amitran flexible for future application and new systems.
- The list of systems and their description and the ITS typology will be used in the Amitran handbook (WP 7).
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<td>ACC</td>
<td>Adaptive Cruise Control</td>
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<td>BEV</td>
<td>Battery Electric Vehicle</td>
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<td>C2I</td>
<td>Car-To-Infrastructure</td>
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<tr>
<td>CACC</td>
<td>Cooperative Adaptive Cruise Control</td>
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<tr>
<td>CADS</td>
<td>Computer Aided Dispatch and Scheduling</td>
</tr>
<tr>
<td>ERTMS</td>
<td>European Rail Traffic Management System</td>
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<tr>
<td>ETC</td>
<td>Electronic Toll Collection</td>
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<tr>
<td>FMS</td>
<td>Fleet Management System</td>
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<tr>
<td>ITS</td>
<td>Intelligent Transport Systems</td>
</tr>
<tr>
<td>OCS</td>
<td>Operational Control System</td>
</tr>
<tr>
<td>PCC</td>
<td>Predictive Cruise Control</td>
</tr>
<tr>
<td>POI</td>
<td>Point of interests – describes a location that someone likes to go to</td>
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<tr>
<td>RIS</td>
<td>River Information Services</td>
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<td>VMS</td>
<td>Variable Message Sign</td>
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1. Introduction

1.1 Outline

Intelligent Transport Systems (ITS) have an increasing impact on transport and the environment. To guide their development towards the overall aim of a sustainable mobility and a thriving ITS market at the same time, it is crucial to understand their impacts. Hence, within the Amitran project it is the objective of WP3 “Analysis and structuring of ITS impacts” to analyse the impacts ITS have on transport processes and the role these transport processes have for CO₂ emissions. Two objectives are pursued:

- Provision of a qualitative impact assessment of ITS with reference to CO₂, in order to highlight systems of particular relevance for CO₂ emissions.
- Preparation of the Amitran framework development by identifying important effect chains from ITS to CO₂ emissions.

The assessment consists of the following steps:

- Identification, classification and description of ITS to be considered by Amitran (Chapter 2).
- Identification, classification and description of transport processes of relevance for CO₂ emissions (Chapter 3).
- Qualitative impact assessment of ITS with reference to transport processes (Chapter 4).
- Qualitative impact assessment of ITS on CO₂ emissions (Chapter 5).

The qualitative impact assessment of ITS with reference to transport processes serves as input to WP4 and is at the same time the basis for the qualitative impact assessment with reference to CO₂ emissions. These impact assessments rely on literature review and expert opinion and, thus, are qualitative in nature. This assessment is no replacement for a detailed analysis conducted with Amitran, but a guideline to direct the attention to crucial aspects of ITS impacts in relation to CO₂.

For each system the relevant transport processes which can be influenced by the system are identified. With the relevance of the respective processes for CO₂ emissions estimated, the potential impact of all systems on CO₂ emissions can be judged. In the approach systems are assigned to categories. Systems not yet available can also be assigned to one of the categories and the relevant processes can be identified; this means that Amitran is open to new future systems. This typology (systems, categories, transport processes, CO₂ emissions and their relation to each other) paves the way to the Amitran framework definition.
1. Introduction

1.2 Methodology

1.2.1 List of ITS

Amitran takes into account ITS in various fields: systems related to passengers and freight used in road, rail, and inland waterway transport. To make sure that all relevant systems are covered, categories of ITS are taken as a starting point and systems belonging to these categories are identified. The coordination and support action ECOSTAND within the 7th Framework Programme of the European Commission discussed and agreed on such a categorisation on international level even beyond the EU. This categorisation can be found in Deliverable 2.1 of ECOSTAND [ECOSTAND, 2011]. Similar to Amitran ECOSTAND is focused on defining a common methodology (for Europe, Japan and the US) to estimate CO₂ emissions influenced by ITS. Therefore, this categorisation was followed also in Amitran.

The categories were filled with systems mentioned in ECOSTAND, but also additional systems. Standard ITS literature was screened and ITS experts were consulted, to reach a comprehensive list of systems covering all the relevant fields of Amitran. These systems were roughly assessed for their relevance for CO₂ emissions. Systems without any apparent connection to CO₂ have been excluded. A final list was compiled for each category. For better overview, sub-categories were defined, which combine systems with similar function (e.g. the category “navigation and traveller information” was divided into Navigation systems, Traveller information systems, Planning support systems, and Inland waterway information systems).

Two challenges were encountered during the system identification:

- Systems are given different names in different contexts, i.e. systems with comparable functionality are known under several names.
  A glossary was compiled to help finding synonyms or ITS fitting most closely the relevant description (Annex B).
• Systems are grouped and classified depending on context. If the context is very broad, a rough distinction is sufficient and a low number of different systems results. These system definitions, however, comprise more specialised “sub”-systems. If the context is more specialised and a finer distinction of systems is required, more systems have to be defined and the number of systems increases. What is seen as a system or a sub-system, thus, depends on the context. The more distinct definitions become, the more specific an evaluation becomes, but also the more effort is required to realise such an evaluation. Also the viewpoint of the stakeholder changes possible classifications. Amitran used an already internationally recognised categorisation (ECOSTAND) in order to avoid yet another new classification, and follow known paths instead. Amitran furthermore introduces sub-categories to clarify system purpose and character. For some systems, sub-systems are suggested, which could be regarded as separate systems in a more detailed assessment than this deliverable offers.

System categories and systems are described in Chapter 2.

1.2.2 Transport processes and parameters describing them

ITS change CO₂ indirectly by influencing certain transport processes. The factors influencing these transport processes and the parameters describing them have been identified first. By separating the direct and indirect effects of ITS, Amitran follows a new approach as compared to assessments done in the past. This approach offers a better understanding of the mechanisms by which ITS exert their influence, which is required for the development of the Amitran methodology.

The procedure that Amitran has used to better understand how ITS influence CO₂ emissions is illustrated in Error! Reference source not found.
The way ITS exert their influence on transport processes can be distinguished into four groups:

- effect on factors influencing traffic demand and driving behaviour
- effect on traffic demand
- effect on driving behaviour and vehicle conditions
- long term effects of ITS

These effects can be quantified by parameters, which are described in Chapter 3. Factors influencing traffic demand and driving behaviour have an indirect effect on parameters. For example, infrastructure capacity is an influencing factor that can have an impact on speed as a parameter describing driving behaviour. Changes in capacity can also influence the trip generation as a parameter describing traffic demand. Long term effects work in a similar way on the parameters. Some systems might lead to adjustments in public transport scheduling, which will have an impact on traffic demand and finally trip generation and mode choice.
Thus, identifying the influencing factors is important for understanding the effect of ITS and how this effect takes place. The parameters itself are important to quantify the effect. These parameters are the basis for the qualitative impact assessment.

1.2.3 Qualitative impact assessment

This impact assessment of ITS is based on an expert survey with subsequent expert consultations. The expert opinions are supported by evidence from the literature, which is described in Chapter 5. A list of references is provided in the Annex. The results of the expert assessment have been discussed by the consortium. For each system, several experts have been consulted and asked to estimate the impact the system has on the range of different transport processes. This survey was evaluated with respect to the impact itself and to the reliability or precision with which the impact can be predicted in general. While for some systems the affected transport processes are easy to identify, some systems exert an influence on a whole range of processes and the strength of impact depends very much on the context. If no distinct assessment could be provided (e.g. due to dependence on context), the system is listed separately.

The parameters describing traffic demand, driving behaviour and vehicle conditions have different relevance for CO₂ emissions. A change of the route (without a change in destination, time etc.), for instance, has usually less relevance for CO₂ emissions than a change in mode. To take this effect into account, the parameters have been weighted. The weights have been determined by separate judgment and intensive discussions among experts from the consortium. The weights are assigned to three classes of relevance (high, medium, low).

By judging the impact of ITS on CO₂, three dimensions have been considered:

- intensity of impact
- frequency of impact
- number of affected travellers or vehicles

An emergency braking assistant, for instance, has a severe impact on the speed of a vehicle in case it is activated (intensity of impact). However, it will only be applied in very rare circumstances (frequency of impact), and only the vehicle in which the system is installed is affected (number of affected vehicles; following vehicles would have to brake regardless of the system). Overall, no major effect on CO₂ by the change in speed of the vehicle can be expected, because the severe impact on speed is balanced by low frequency of impact (other effects due to avoiding congestion in consequence of avoiding an accident not regarded).
Amitran aims at providing impacts on large scale (e.g. EU level), with focus on accumulated changes in CO₂. The intensity and frequency of impacts are therefore both of relevance. Because the number of affected travellers or vehicles depends on the penetration rate of the systems, the same penetration rate for all systems has to be assumed to avoid bias. The qualitative impact assessment does not consider the likely market penetration and acceptance of systems. The potential impact of systems, thus, remains subject to the penetration rate. The frequency of impact of systems has explicitly been incorporated by scaling the effect on single vehicles to the overall fleet. This applies mainly to vehicle mounted emergency systems.

Due to the fact that the relative importance of transport processes could be assessed differently by different experts (one expert might rate an influence close to zero as “no impact”, another might still rate it as “low impact”), the assessments have been normalised (experts rating systems on average higher have been scaled down and vice versa).

By cumulating the effect of ITS on processes under consideration of the respective weights of the processes, an overall impact of ITS on CO₂ emissions could be estimated. Systems are assigned to three impact classes (high, medium, low impact). The qualitative impact of systems is described in section 5.2.

For some specialised systems no designated experts could be identified in the consortium. These systems are described and assessed briefly, to offer a comprehensive list and ensure the adequate inclusion in the Amitran framework.

The transport processes and their relevance for CO₂ emissions are described in Chapter 3. The results of the system assessment are presented in Chapters 4 and 5; these chapters include the description of ITS effects on processes and model parameters.
2. ITS description and classification

2.1 Introduction

The basis for the work in WP3 is the definition of the systems to be analysed. To structure the work and make the Amitran methodology flexible for later inclusion of new systems, a classification has to be found onto which systems can be mapped. Numerous classifications already exist, which have been developed for different purposes. A major challenge has to be seen in the fact that ITS develop rapidly. And even though systems sometimes follow similar principles, they may have different names in different literature sources.

Amitran follows the ECOSTAND classification of systems, but provides a more detailed sub-structure to underline the systems’ functional context. The system structure and the addressed systems are summarised in Table 1 through Table 6 and described in the following sections. Some systems are related to a specific transport mode (e.g. inland waterway information systems, highway systems), others are applicable to several transport modes (e.g. multimodal information systems). From the system names it can be deduced whether the system is unimodal or applicable to several modes.

Some systems require road-side infrastructure, others are usually based on mobile devices or vehicle-mounted. Because the distinction becomes increasingly blurred and some systems can use different technology to fulfil their purpose (e.g. information systems), the following description and assessment are focussed on functionality rather than used devices.

Table 1 Sub-categories and systems in the category “navigation and traveller information”

<table>
<thead>
<tr>
<th>Navigation and traveller information (pp. 21 ff.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Navigation systems</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Traveller information systems</td>
</tr>
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<tr>
<td></td>
</tr>
<tr>
<td>Planning support systems</td>
</tr>
<tr>
<td>Inland waterway information systems</td>
</tr>
</tbody>
</table>
Table 2 Sub-categories and systems in the category “traffic management and control”

<table>
<thead>
<tr>
<th>Traffic management and control (pp. 24 ff.)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal control</td>
<td>Adaptive Signal Control</td>
</tr>
<tr>
<td>Highway systems</td>
<td>Junction Control System</td>
</tr>
<tr>
<td></td>
<td>Road Section Control System</td>
</tr>
<tr>
<td></td>
<td>Collective Re-Routing System</td>
</tr>
<tr>
<td>Railway systems</td>
<td>European Rail Traffic Management System (ERTMS)</td>
</tr>
<tr>
<td>Enforcement systems</td>
<td>Automated Speed Enforcement</td>
</tr>
<tr>
<td></td>
<td>Automated Weight Limit Enforcement by Weigh-In-Motion</td>
</tr>
<tr>
<td>Inland Waterway systems</td>
<td>River Information Services (RIS)</td>
</tr>
<tr>
<td>Parking guidance</td>
<td>Dynamic Parking Guidance System</td>
</tr>
</tbody>
</table>

Table 3 Sub-categories and systems in the category “demand and access management”

<table>
<thead>
<tr>
<th>Demand and access management (pp. 27 ff.)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Electronic Fee Collection</td>
<td>Electronic Toll Collection</td>
</tr>
<tr>
<td></td>
<td>Electronic Ticketing</td>
</tr>
<tr>
<td>ITS Supported Measures</td>
<td>Restricted Traffic Zones</td>
</tr>
<tr>
<td></td>
<td>Access Pricing</td>
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<tr>
<td></td>
<td>Road Pricing</td>
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</tbody>
</table>

Table 4 Sub-categories and systems in the category “driver behaviour change and eco-driving”

<table>
<thead>
<tr>
<th>Driver behaviour change and eco-driving (pp. 29 ff.)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Driving Assistance including</td>
<td>Intelligent Speed Adaptation/Assistance</td>
</tr>
<tr>
<td>cruise control (road traffic)</td>
<td>Green Light Optimised Speed Advisory (GLOSA)</td>
</tr>
<tr>
<td></td>
<td>Adaptive Cruise Control (ACC)</td>
</tr>
<tr>
<td></td>
<td>Predictive Cruise Control (PCC)</td>
</tr>
<tr>
<td></td>
<td>Cooperative Adaptive Cruise Control (CACC)</td>
</tr>
<tr>
<td></td>
<td>Autonomous Driving</td>
</tr>
<tr>
<td></td>
<td>Lane Change Assistance System</td>
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<tr>
<td></td>
<td>Parking Assistance System</td>
</tr>
<tr>
<td>Railway Systems</td>
<td>Driverless Train Operation</td>
</tr>
<tr>
<td></td>
<td>Energy Efficient Train Driving System</td>
</tr>
<tr>
<td>Driving Behaviour (road traffic)</td>
<td>Driving Behaviour Recognition System</td>
</tr>
<tr>
<td></td>
<td>Digital Tachograph</td>
</tr>
</tbody>
</table>
2. **ITS** description and classification

Table 5 Sub-categories and systems in the category “logistics and fleet management”

<table>
<thead>
<tr>
<th>Logistics and fleet management (pp. 31 ff.)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Public Transport Systems</strong></td>
</tr>
<tr>
<td>Computer Aided Dispatch and Scheduling (CADS)</td>
</tr>
<tr>
<td>Operational Control System (OCS)</td>
</tr>
<tr>
<td>Dynamic Schedule Synchronisation</td>
</tr>
<tr>
<td><strong>Freight Transport Systems</strong></td>
</tr>
<tr>
<td>Electronic system for freight transport</td>
</tr>
<tr>
<td>Fleet Management System (FMS)</td>
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<tr>
<td>Intelligent Truck Parking</td>
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<tr>
<td>Supply Chain Management System</td>
</tr>
<tr>
<td>Terminal Management System</td>
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</tbody>
</table>

Table 6 Sub-categories and systems in the category “safety and emergency”

<table>
<thead>
<tr>
<th>Safety and Emergency (pp. 33 ff.)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Augmented awareness</strong></td>
</tr>
<tr>
<td>Collision Warning System</td>
</tr>
<tr>
<td>Cooperative Intersection Collision Avoidance System</td>
</tr>
<tr>
<td>Drowsy Driver Warning System</td>
</tr>
<tr>
<td>Lane Departure Warning System</td>
</tr>
<tr>
<td>Night Vision System</td>
</tr>
<tr>
<td>Vehicle-based Pedestrian Detection System</td>
</tr>
<tr>
<td>Weather Information System</td>
</tr>
<tr>
<td><strong>E-Call</strong></td>
</tr>
<tr>
<td>E-Call</td>
</tr>
<tr>
<td><strong>Inland waterway systems</strong></td>
</tr>
<tr>
<td>River Calamity Abatement Support</td>
</tr>
</tbody>
</table>

If different names for systems are commonly used, these names are given for reference (cf. Annex B).

### 2.2 Navigation and traveller information

#### 2.2.1 Navigation systems

Navigation systems are based on maps to guide the user (driver, cyclist, pedestrian etc.) through the network. If the system integrates up to date traffic information (e.g. RDS TMC information) it is called *dynamic*. Some systems are enhanced by special information (e.g. electric car navigation). Navigation systems can be used for motorised and non-motorised modes. The suggested route can be based on different preferences by the user, including travel time, distance or eco-friendliness.
Static Navigation System

A mobile navigation system (vehicle mounted or as a nomadic device) which relies on static map material only. More advanced versions might provide recommendations based on historic traffic data (e.g. different route during peak-time, based on expected congestion levels).

Dynamic Navigation System

A mobile (vehicle mounted or portable) online navigation system which receives up to date (dynamic) traffic information and displays it on the map and/or considers this information in route suggestions.

Electric Car Navigation System

A vehicle-based navigation system optimized for electric cars calculating the most battery-friendly route and displaying nearby re-charge stations if necessary.

2.2.2 Traveller information systems

Traveller information systems exist in various formats. Systems providing real time information on traffic flow or public transport schedules are called dynamic. Systems limited to the public transport information are referred to as passenger information systems. Systems can either be individual (personalised for the respective user) or collective (i.e. providing the same information to all users). The degree of personalisation can have an impact on the effect on traffic demand and acceptance by the users.

Static Passenger Information

Online or off-line timetables and routing information; the former is updated regularly but not real time, the latter is as “current” as the release date of the software.

Dynamic Passenger Information

Real-time information system about public transport.

- Via Variable Message Signs
  Variable message signs at stops show the upcoming departures or arrivals of public transport services. Other transport options and general information might be presented as well.
• Via Online Schedule/Timetable
  
  Online platform showing real time arrival and departure times, and optionally providing routing, fares, and other information. Can also be accessed via mobile devices.

**Real-Time Traveller Information System**

Services offering real-time traffic information via radio data, traffic message channels or internet. The traveller information system is in this case not combined with maps or routing suggestions. Systems providing public transport information only are covered by Dynamic Passenger Information. Real-time traveller information includes multimodal and intermodal systems. This category, thus, subsumes all traveller information systems not explicitly mentioned elsewhere. Real-time traveller information systems could be further divided according to information scope and content and the media used to distribute the information.

A widespread sub-system uses variable message signs collectively providing traveller information mostly to road users, but not necessarily only on road transport (intermodal information).

The message sign is used for information, not for regulations. The information can comprise incidents, travel times, departure times (public transport), events, etc. For systems displaying regulations (e.g. variable speed limits) refer to Traffic management and control.

**Car-Sharing and Ride-Sharing Information System**

Car-Sharing Information System means an IT supported user service for members of a car-sharing pool operated by service providers or fleet managers. This service informs the members about availability of the pooled cars and their locations. Further reservation of cars is offered.

Ride-Sharing Information Systems are based on a web portal of a provider where users can post trip offers or trip requests, both one-time and on a regularly basis, and find others willing to share a vehicle. The portal can also be operated by a service provider for a dedicated car or bicycle fleet (e.g. electric vehicles).

**2.2.3 Planning support systems**

Planning support systems provide the information used by operators or decision makers to initiate measures or improvements to the transport system. Operators include public transport, traffic management or logistics operators and dispatchers.
2. ITS description and classification

Multimodal Tour Planning System

A system which delivers information on suitable routes and relevant key figures like distance, time, costs or emissions of alternative transport modes to a strategic or tactical transport planner for passenger as well as commercial transport. A number of different types of tour planning tools exist; solutions are based on developer’s specifications. As opposed to a traveller information system, this system is not targeted at travellers, but at traffic managers and transport planners to devise measures to improve the traffic.

2.2.4 Inland waterway information systems

Dynamic information for skippers

Contains geographical, hydrological, administrative data and real time traffic information that are used by skippers and fleet managers to plan, execute and monitor journeys on waterways. Information for skippers is part of the River Information Services (RIS) (p. 26), which are fostered by the European Union. Subsystems of dynamic information for skippers are for example:

- Tactical Traffic Image (TTI) for immediate navigation decisions based on actual traffic situation
- Strategic Traffic Image (STI) for providing an overview of the traffic situation over a relatively large area

2.3 Traffic management and control

2.3.1 Signal control

Adaptive Signal Control

Adaptive Signal Control is traffic signal control based on online actuation. The signal programs and their elements are updated based on traffic information collected by local detectors and/or provided by a central computer. The actuation can aim at different goals (queue length limitation, delay reduction, emission reduction, etc.). Public transport priority can be included as a goal. The term adaptive signal control is used here in a general sense for all kinds of traffic actuated signal control like

- Systems for isolated intersections (local traffic actuation)
- Coordinated systems (”green wave”, network solutions)
- Model based systems (i.e. systems deriving their actuation from real time traffic models, e.g. SCOOT, SCATS, MOTION, BALANCE)
Adaptive signal control requires detectors to monitor the traffic. Currently inductive loops (upstream or downstream), infrared detectors and other stationary detectors are most common, but floating car data can also serve as input to control strategies.

### 2.3.2 Highway systems

Systems used primarily on highways are subsumed in this category. The systems are divided into the network element they affect (junctions, road sections, or flows in the network). These systems commonly use both traffic information and dynamic regulations to influence the traffic flow. Regulations can be speed limits, lane assignments or traffic signals (ramp metering). Because these systems are used on bottlenecks, they are often combined.

#### Junction Control System

These systems influence the traffic flow at the confluence (entry) or diversion (exit) of vehicle flows on highways. Two typical examples are

- **Variable assignment of lanes to travel directions at exits and entries.**
  
  This system can also be used on urban roads (e.g. on the approaches to major venues during events).

- **Ramp Metering**
  
  Traffic signal regulated highway access ramps which split the entering vehicle platoons into single vehicles (or groups of vehicles) and control the amount of entering vehicles.

#### Road Section Control System

Variable message signs allowing flexible speed limits, lane control, and up-to-date warning messages. As opposed to traveller information systems, the variable message signs display road signs instead of free text messages. Road section control systems can be used for lane control, i.e. the assignment, addition or subtraction of lanes on road sections, which includes a dynamic use of the hard shoulder (for lane control at entries and exits, cf. Junction Control System). Subsystems are

- **Dynamic speed limits**
- **Dynamic lane assignments**
- **Warning messages displayed as road signs** (congestion, low visibility, road works, etc.)
- **Dynamic shoulder use** (opening of the hard shoulder during peak times)
Collective Re-Routing System

Dynamic route recommendations by road signs (e.g. Dynamic Route Information Panels, DRIPs) either by replacing the static routing (substitutive re-routing) or by giving additional advice (additive re-routing). The routing advice can be supplemented by additional information on travel times, incidents etc.

2.3.3 Railway systems

European Rail Traffic Management System (ERTMS)

ERTMS is an EU “major European industrial project” to enhance cross-border interoperability and signalling procurement by creating a single Europe-wide standard for railway signalling. The two main parts of ERTMS are the

- European Train Control System, a Europe-wide standardized Automatic Train Protection system
- GSM-R - a European standard for communications in the rail sector using the GSM mobile network.

2.3.4 Enforcement systems

Automated Speed Enforcement

Systems combining speed-detection and vehicle registration in order to fine speeding. Speed detection can be local or on a section based on the average speed (point to point). A Digital Tachograph (p. 31) and Intelligent Speed Adaptation/Assistance (p. 29) have similar effects on driving behaviour (i.e. fostering speed limit compliance), but work differently and are therefore listed as separate systems.

Automated Weight Limit Enforcement by Weigh-In-Motion

System which monitors the weight of vehicles passing on a road combined with enforcement for weight limits similar to speed enforcement.

2.3.5 Inland Waterway systems

River Information Services (RIS)

These services are carried out by waterway administrations aiming for optimal utilization of the infrastructure and assurance of safe navigation on waterways also to foster the traffic by
ship. RIS can include local traffic management as well as lock and bridge management. RIS comprise different subsystems:

- Electronic ship reporting
- Dynamic information for skippers (p. 24)
- Vessel tracking and tracing
- Electronic chart display and information system (ECDIS)

### 2.3.6 Parking guidance

**Dynamic Parking Guidance System**

System which guides drivers to available parking spaces via variable signs or in-car information. The system can potentially address the needs of different users (lorries, electric vehicles). Parking guidance systems can be combined with public transport information (Dynamic Passenger Information, p. 22) at park and ride facilities. Parking information can also be provided in a Dynamic Navigation System (p. 22) or customised to the needs of road freight traffic (Intelligent Truck Parking, p. 32).

### 2.4 Demand and access management

#### 2.4.1 Electronic Fee Collection

**Electronic Toll Collection**

System for collecting road fees by electronic devices instead of conventional toll booths. Vehicles, hence, do not have to stop at the tolling facility. The effect of such systems on CO₂ emissions has to be separated from the effect a toll has in itself (Road Pricing, p. 28).

**Electronic ticketing**

In general electronic ticketing or e-ticketing refers to a paperless ticketing system. Here the focus is on public transport.

There are different kind of applications already in use, the most common one is based on an integrated near field communication chip, either implemented in plastic cards, so called smartcards, or mobile devices. The system enables travellers using public transport without worrying about different kind of tickets and fares as the user will be charged the right fare at any time.
Another application is based on mobile devices (e.g. mobile phone, handheld). The ticket bought by a traveller via internet or short message service will be transferred to the mobile device on which it can be presented on request.

**Other forms of Electronic Fee Collection**

Electronic forms of payment can be used for parking (on-street and off-street). This includes mobile phone parking, where the customer can pay by calling a designated phone number and registering its licence plate number.

Electronic Fee Collection can also be relevant for car-sharing or bike-sharing systems.

**2.4.2 ITS supported measures**

This category lists measures which are often realised by means of ITS, which is the reason for including them in Amitran. They are also part of the ECOSTAND approach.

**Restricted traffic zones**

Entry restrictions to a given area. Criteria can be vehicle type, vehicle registration plate, credits, etc. They are also known as „low-emission zones“, „low-noise zones“, „environmental zones“, „green zones“ and „clear zones“.

**Access Pricing**

Charging for access to a transport system (road, rail) where the price depends on real time information regarding e.g. air pollution, capacity utilisation.

**Road Pricing**

Charging for the use of a road or other road facility (e.g. tunnel, bridge, parking lot), possibly during certain time slots (for example peak hour). Examples are:

- Object/Route fees – fees charged for use of a particular object (tunnel, bridge) or a sector of road (mountain pass)
- Network fees – fees charged for use of a particular road network (highways)
- Area fees – fees charged for use of a car in an area (a city, a city centre)
- Parking fees
2.5 Driver behaviour change and eco-driving

2.5.1 Driver assistance and cruise control (road traffic)

Driver assistance and cruise control support the driver in controlling the speed of the vehicle or realising manoeuvres. The different systems can be distinguished by their purpose, the extent to which they intervene in the driving, and the communication with the infrastructure or other vehicles.

**Intelligent Speed Adaptation/Assistance**

A technology which assists the driver in keeping the speed limit. There are advisory systems that warn the driver that he is driving faster than allowed on the given road and systems which directly intervene to make speeding harder or impossible. As opposed to cruise control, the system does not impact the speed if it is lower than the speed limit and does only react to speed limits.

**Green light optimised speed advisory (GLOSA)**

This system receives information from traffic lights to advise the driver on a speed which avoids unnecessary stops.

**Adaptive Cruise Control (ACC)**

Adapts the vehicle's speed to the vehicle in front. A distance measuring system attached to the front of the vehicle is used to detect whether slower moving vehicles are in the ACC vehicle's path. If a slower moving vehicle is detected, the ACC system will slow the vehicle down and control the distance, or time gap, between the ACC vehicle and the leading vehicle.

**Predictive Cruise Control (PCC)**

Cruise control system which uses vehicle, infrastructure and topographic data to anticipate a fuel saving driving style. Currently systems focus on the topography. Changes in the road environment such as a change in gradient ahead of the vehicle are predicted and the speed is adapted for optimal fuel economy.

**Cooperative Adaptive Cruise Control (CACC)**

It is an enhancement to adaptive cruise control systems that can optimize vehicle’s speed profile by adding communication with other vehicles and/or infrastructure.
Autonomous Driving

Road vehicle systems which enable vehicles to be driven automatically without human control. For similar systems in trains see Driverless Train Operation (p. 30).

Lane Change Assistance System

Monitors the vehicle’s adjacent lanes; if a lane change manoeuvre is initiated, and the system detects a potential conflict with a vehicle in the adjacent lane, the system will alert the driver.

Parking Assistance System

Systems which assist drivers in the parking process which is automated to varying degrees depending on the system, ranging from collision warning sounds to full automation.

2.5.2 Railway systems

Energy Efficient Train Driving System

Based on information about the maximum speed limit of the track ahead and the next scheduled stop, the system provides the train driver with a recommendation for a train speed and indicates if the current kinetic energy is sufficient to reach the next stop or required speed change without providing engine support.

Driverless Train Operation

A train or people mover is driven automatically. A human operator might be on board for door closure and operation in case of emergencies.

2.5.3 Driving behaviour (road traffic)

Driving behaviour recognition system

Driving behaviour recognition systems analyse the pattern of how a vehicle is driven. The system takes all kind of energy consuming devices in the vehicle into account. The condition of the driver is not analysed. Depending on the system the driver is directly informed about inefficient driving behaviour. Also data transmission to an analysing tool is possible. This can incur a back office process to provide feedback including learning and teaching procedures. This system might be used by fleet operators to monitor performance of their drivers.
Digital Tachograph

The Digital Tachograph is a regulatory instrument to enforce the regulations in road transport especially with the view to increase road safety. It records the working and the resting times of drivers as well as the vehicle speed over time with the aim to ensure that appropriate rest periods are taken by drivers and that a maximum allowed speed is not exceeded.

2.6 Logistics and fleet management (commercial and public transport fleets)

2.6.1 Public transport systems

Computer Aided Dispatch and Scheduling (CADS)

System used for demand responsive public transport that incorporates transit routes, schedules, any trip orders, and vehicle assignments to allow dispatchers to know where the transit vehicles are located. This enables dispatchers to more efficiently dispatch trip requests or to better maintain service and respond to disruptions.

Operational Control System (OCS)

These systems serve the purpose of optimising operational control for more efficiency and punctuality in public transport. They utilise dynamic operational data to assure punctuality and precise connection times and improve the allocation, rotation and maintenance of vehicles online. Such a system is operated in a public transport control centre and can include several subsystems like communication to the drivers and passenger information provision. OCS can also be the basis for an improvement of public transport provision, similar to a Multimodal Tour Planning System (p. 24). Dynamic Schedule Synchronisation (p. 31) can be a subsystem of an OCS, but is treated here as a separate system due to its specific functionality.

Dynamic Schedule Synchronisation

The departure times of public transport services are dynamically synchronised at interchanges to ensure a smooth transfer of passengers.

2.6.2 Freight transport systems

Electronic system for freight transport (e-Freight)

The term e-Freight enfolds paperless, electronic flow of information for a simple and harmonised procedure to support the physical flow of goods. Included are functions for
tracking cargo from door-to-door irrespective of the combination of modes and for tracing its movements if needed. E-Freight mechanisms are required to be technology independent to secure a wide application range. For e-Freight implementation the entire communications process between all stakeholders (see Figure 2) in the supply chain must be set on an electronic basis. All interfaces and intermediate stages must comply with set standards. Electronic systems for freight transport can also incorporate information on permissive load and unload times in different areas of a city.

Figure 2 Stakeholders and their tasks and connections in the e-Freight framework

**Fleet Management System (FMS)**

FMS encompass all operations from vehicle acquisition to disposal to satellite positioning and data communication to back office applications.

**Intelligent Truck Parking**

ITS applications designed to solve the problem of too many trucks for not enough parking slots which leads to illegal parking and extremely congested and chaotic parking areas, which in turn pose a safety risk. Intelligent truck parking is similar in function to a Dynamic Parking Guidance System (p. 27), but addresses the particular needs of trucks and can also be an individual (as opposed to a collective) system. Intelligent truck parking can be further specified:
2. ITS description and classification

• Truck Parking Online Information System
  Online service for truck drivers/companies to find available truck parking lots and the number of available spaces in them.

• Intelligent Compact Parking
  Information on or control of prospective departure times for lanes in parking areas so trucks with the same planned departure time can park in one lane and do not block each other.

• Secure Truck Parking
  Secured parking sites for high value cargo

Supply Chain Management System

It offers integration of short-, mid- and long-term planning to provide an efficient supply network in adjusted capacities. Supply Chain Management systems include specialised modules devoted to demand forecasting, production, transportation, delivery and distribution.

Terminal Management System

Packages to support loading processes at freight terminals in transport chains. The system is mainly dependent on a software solution expediting internal order processes.

2.7 Safety and emergency systems

2.7.1 Augmented awareness

Augmented awareness systems provide information to the driver on processes occurring in the surrounding environment of the car or in the car itself which pose a potential danger. Advanced systems can even take action by, for instance, perform an emergency braking.

Collision Warning System

In-vehicle electronic system monitors the road in front of the vehicle and warns the driver when a collision risk is detected. Subsystems are for example:

• Vehicle detection systems
• Animal Detection System

For pedestrian protection systems refer to → Vehicle-based pedestrian detection system below.
### Cooperative Intersection Collision Avoidance System

These systems are both vehicle and infrastructure-based and use vehicle-to-infrastructure (V2I) communication. Drivers are warned about likely violations of traffic control devices and/or potentially inform drivers about the existence of pedestrians within an intersection.

### Drowsy Driver Warning System

A system that constantly monitors driver interactions and/or vehicle movement to detect signs of driver drowsiness in which case a suitable warning is given.

### Lane Departure Warning System

In-vehicle electronic system that monitors the position of the vehicle within the lane and warns the driver if the vehicle crosses lane markings without using the turn indicator.

### Night Vision System

On-board system which increases a driver’s visibility range in darkness or poor weather beyond the reach of the vehicle’s headlights. Images of the road ahead are projected on a dashboard screen or onto the windshield.

### Vehicle-based pedestrian detection system

System is an on-board system which uses cameras or other sensors to detect pedestrians in front of the vehicle and automatically brakes or warns the driver.

### Weather Information System

Systems that provide weather information tailored to particular agency requirements, including current and forecast road, surface, or travel conditions (e.g. flooding, heat advisories, wind advisories, visibility, icing conditions).

#### 2.7.2 E-Call

A call to an emergency centre is initiated automatically in the event of an accident. A voice call connection is established and the location is transmitted to the emergency dispatcher.
2.7.3 Inland waterway systems

River calamity abatement support

Registers vessels and their transport data at the beginning of a journey and updates the data during the trip. In the event of an accident, the authorities are then able to provide data immediately to the rescue and emergency teams. The Electronic Navigational Charts and the Tactical Traffic Image provide the basis for the coordination of rescue forces and nautical measures. This can be a subsystem of River Information Services (RIS) (p. 26).
3. Transport processes and impacts on CO₂ emissions

3.1 Introduction

ITS exert their influence on CO₂ emissions indirectly by influencing traffic demand, vehicle conditions, driver behaviour, and thus also traffic flow. To get a clearer picture of how this influence works, traffic demand, vehicle conditions, driver behaviour, and traffic flow are separated into “processes”. These processes are described by factors and parameters (section 3.2). Changes in the transport processes result in changes in CO₂ emissions. This impact can be quantified by parameters relevant for CO₂ emissions like vehicle kilometres travelled (section 3.2.3). How strongly the transport processes are connected to the CO₂ impacts has to be subject to measurements or modelling. As a preparatory stage in Amitran, this connection was judged by experts to be able to assess the impact of ITS on CO₂ emissions (section 3.3).

Former projects and working groups (e.g. ICTEE¹ or ICT for Clean & Efficient Mobility²) estimated the impact of ICT in transport on CO₂ directly without the intermediate step of looking at the effect chains. This two-step approach in Amitran helps to pave the way to an assessment framework which takes the intermediate steps into account. Furthermore, it helps to make the effects of ITS more transparent.

3.2 Factors and parameters influenced by ITS

3.2.1 Overview

Traffic can be analysed by looking at different transport processes. These processes can be described by factors and parameters. The processes and consequently the factors and parameters describing them can be influenced by ITS. These factors and parameters can be distinguished into four groups.

- Factors influencing traffic demand and driving behaviour (section 3.2.2, p. 37)
- Parameters describing traffic demand (section 3.2.3, p. 38)

¹ Impact of Information and Communication Technologies on Energy Efficiency in Road Transport
² Working Group on ICT for Clean and Efficient Mobility
3. Transport processes and impacts on CO2 emissions

- Parameters describing driving behaviour and vehicle conditions (section 3.2.4, p. 40)
- Long term effects of ITS (section 3.2.5, p. 41)

The different factors and parameters are illustrated in Figure 3. They are explained in detail in the subsequent sections, divided into the four mentioned groups. Rebound effects are not explicitly depicted in the figure to simplify the illustration. Long term effects often are caused by rebound effects. These effects are important for a sound assessment of ITS and will be considered in the Amitran methodology.

**Figure 3 Overview of factors and parameters influenced by ITS**

### 3.2.2 Factors influencing traffic demand

**Infrastructure capacity**

Infrastructure capacity describes the maximum amount of traffic which can pass an infrastructure element (road section, junction, block on railway track etc.) in a given time interval, usually expressed in vehicles per time period. The capacity usually has a static and a stochastic element, both of which can be influenced. The static capacity is influenced by providing, for instance, an additional lane (shoulder use on motorways, HOV lane etc.) or by
increasing the frequency of public transport services. The stochastic element originates from the traffic flow and its variation itself. The less homogenous the traffic flow is, the more volatile the capacity gets (breakdown probability). The homogeneity of traffic flow can be influenced, for instance, by speed limits.

**Transport cost**

Financial incentives (positive or negative) can make certain modes of travel or times of travel more or less attractive for freight as well as passenger transport. Examples: pay as you drive, avoidance of rush hour, tolling, discount tickets for public transport, etc.

**Availability of transport mode and means (vehicle/train/vessel)**

- In freight transport and logistics: decision on the procurement and availability of vehicles (transport means) of a certain company or organisation, including the time and location of the availability
- In private passenger transport: vehicles available in a household (cars, bicycles etc.); can be own vehicles (car ownership) or shared vehicles.
- In public transport: vehicles (buses, trains, trams, etc.) availability.

Availability applies also to the availability perceived by the user (information on availability). If a vehicle is physically available, but this fact is not known to the potential user, from the user’s perspective it is the same as if the vehicle is not available.

**Connection with other transport modes**

Connection with other modes is the alignment of times, for example by making use of arrival time estimation (busses waiting for train arrival). This factor is relevant for public transport and freight only.

**Location choice**

- In freight/logistics: location of company, location of distribution centres etc.
- In passenger transport: location of where people live.

**3.2.3 Parameters describing traffic demand**

Parameters describing traffic demand have an effect either pre-trip or on-trip. Pre-trip the effect can either be a short term effect right before a trip, or it can be a long term effect, for instance in case of strategic route planning of freight shippers or public transport operators. The long term planning is conducted by the traffic actors with a perceived average situation in
mind. The short term planning is based on the perceived imminent pre-trip situation (e.g. short term traffic forecast). Not for all processes the distinction between pre-trip and on-trip planning/choice appears to be relevant, even though the decisions take place at different times. Only for route and mode choice the distinction is made in the assessment.

**Trip generation**

Trip generation is expressed by the number of trips made from a certain location. An example is the choice between working from home or going to the office. While the ITS influence the trip generation on a microscopic level (individual decisions to make a trip or not), this also affects the trip generation on the macroscopic level (e.g. rate of trips per person/company and hour). Trips are generated for both passenger transport and freight transport (e.g. if separate trips with delivery vans are replaced by one trip with a lorry, not only the vehicle type/transport means is changed, but also the trip generation).

**Destination choice**

The destination choice defines the destination of a trip. An example is the choice between going to the small supermarket close by or to the large supermarket further away. In logistics the destination choice is an important decision, for instance, for milk runs, if the destinations for the tour are determined flexibly depending on the capacity of the vehicle and the demand. The destination choice has a major impact on distances driven.

**Long term (strategic) route planning (pre-trip)**

Routes chosen strategically in long term planning. This route choice does not have to be related to a specific trip. It is based on the perceived average situation. Examples: default route from home to work, corridor for demand responsive public transport, default delivery tour.

**Long term (strategic) mode planning (pre-trip)**

Modes chosen strategically in long term planning. This mode choice does not have to be related to a specific trip. It is based on the perceived average situation. Examples: default mode for trip from home to work, mode chosen for regular freight service.

**Short term route planning (pre-trip)**

Route chosen before the trip has started. The route might be changed on-trip (see On-trip route choice). Short term route planning is related to a specific trip.
Short term mode planning (pre-trip)

Choice of modality for a certain (part of the) trip, before the trip has started, similar to short term route planning.

Choice of transport means (vehicle/train/vessel)

Characteristics of transport means are the type of vehicle/train/vessel within a chosen mode and its specifics such as fuel, engine type, etc.; as specific as possible. For a passenger, for example, if he has more than one car to choose from, for freight for example the type of truck.

Load factor and occupancy

In freight transport, the load factor refers to the amount of freight (in $m^3$, kg, etc.), relative to the capacity of the vehicle/train/vessel used. Occupancy applies to the number of passengers in a vehicle in passenger transport relative to the vehicle’s capacity. It can be strategically planned, but also decided upon flexibly shortly before or even during the trip.

Departure time planning and choice

Departure time choice is the choice of time when a trip starts (from home, from work, from distribution centre, etc.). This can also be the scheduled time in long term planning (departure time planning).

On-trip route choice

On-trip route choice is the adjustment of the route during a trip. It is based on the perceived current situation (e.g. because of the real time traffic situation or weather conditions).

On-trip mode choice

On-trip mode choice is the change of mode during a trip. It is based on the perceived current situation (e.g. switching from car to train when there is a traffic jam).

3.2.4 Parameters describing driving behaviour and vehicle conditions

Lane choice

Lane choice is the choice of a lane during a trip (for road transport only). Lane choice can be influenced by either different speeds on the lanes or by routing decisions. If the speed is different on different lanes, this is reflected by the separate parameter speed.
3. Transport processes and impacts on CO2 emissions

Speed

Speed describes the speed (for all modes), be it the desired speed (speed choice) or the driven speed profile.

Headway

Headway is the distance to the predecessor of a vehicle/train/vessel.

Driving dynamics

Driving dynamics refer to the control of a vehicle/train/vessel (e.g. braking, steering, accelerating, gear selection).

Use of auxiliary systems and vehicle performance

Auxiliary systems (e.g. air-conditioning, windows, heater, radio, lights) can be optionally switched on or off during the trip. Other parameters of relevance can be parameters on vehicle condition: tyre pressure, aerodynamics, excessive weight, open windows, etc.

3.2.5 Long term effects of ITS

Traffic demand induced on the long term

The number of people that want to travel changes not only on a short term basis, but travel behaviour follows long term adjustment processes leading to induced traffic (e.g. by providing more capacity a route becomes more attractive, thus attracts new traffic). Short term traffic demand is described by the “trip generation”.

Changes of the infrastructure network

The infrastructure (roads, railways, waterways etc.) is adjusted to the traffic demand. While for short term decisions the infrastructure has to be seen as fixed, it might change on the long run.

Changes in public transport and freight transport scheduling

Public transport schedules are adjusted to the traffic demand. While for short term decisions the timetables of public transport have to be seen as fixed, they might change on the long run.
3.3 Relevance of parameters for CO₂ emissions

ITS exert their influence on transport processes, which in time relate to changes in CO₂ emissions. In order to derive the relevance of ITS for CO₂ emissions, it is important to give the factors and parameters describing the transport processes an adequate weight reflecting their relevance for changes in CO₂ emissions. The lane chosen by a car, for instance, has no direct consequences for the CO₂ emitted by this car, whereas the speed it travels at is of high relevance. If an ITS influences only the lane choice, it has less relevance for CO₂ emissions than a system influencing the speed of a vehicle.

The factors and parameters described in section 3.2 have been assigned a relevance for CO₂ emissions by experts in the consortium and supported by evidence from the literature. After this the assignment was discussed and agreed upon. The relevance of parameters describing traffic demand and parameters describing driver behaviour and vehicle conditions are shown in Table 7 and Table 8. Factors influencing traffic demand have been excluded to avoid a double weighting of their influence. If a system affects, for instance, transport cost, this will have an indirect impact on trip generation, route choice, mode choice, and others. The relevant process for the system assessment is the change in trip generation, route choice, mode choice etc. The relevance was used as a weight for aggregating the effect of systems on CO₂ emissions (cf. Chapter 4). Due to the nature of the decision on weights (qualitative, expert judgement) the relevance is not expressed as a number, but three categories (high, medium and low) are used.

Table 7 Relevance of parameters describing traffic demand

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<tr>
<th>Parameter</th>
<th>Relevance</th>
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<tr>
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<td>Pre-trip route choice</td>
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<td>Pre-trip mode choice</td>
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<td>Choice of transport means</td>
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<td>Load factor and occupancy</td>
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Table 8 Relevance of parameters describing driving behaviour and vehicle conditions

<table>
<thead>
<tr>
<th>Parameter</th>
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<td>Lane</td>
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<td>Speed</td>
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<td>Headway</td>
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<td>Driving dynamics</td>
<td>high</td>
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<tr>
<td>Use of auxiliary systems and vehicle performance</td>
<td>medium</td>
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</table>

The highest relevance for CO₂ emissions is expected from the parameters:

- trip generation,
- destination choice,
- mode planning/choice,
- choice of transport means,
- speed, and
- driving dynamics.

Trip generation determines how many trips are made, which is crucial for the CO₂ emissions. The transport mode and means (vehicle type) have a crucial role in the emissions per kilometre driven, similar to speed and driving dynamics. The destination choice has a significant impact on the distances driven. As compared to these parameters, route choice, occupancy, auxiliary systems and vehicle performance are of lesser importance for the CO₂ emissions, even though their effect must not be neglected. Occupancy/load factor is mainly relevant for the CO₂ emissions related to ton kilometres/passenger kilometres or total emissions (as opposed to emissions related to vehicle kilometres). All long term effects and the choice of lane are expected to have a low relevance for CO₂ emissions. It has to be noted, though, that the induced demand, which is a long term effect, can from a long term perspective lead to significant changes in CO₂ emissions. However, this change will be difficult to attribute to a single system. A careful consideration of this potential effect cannot be replaced by modelling as is the basis of Amitran.

The following indicators are identified to be relevant to describe the impact of transport processes on CO₂ emissions. This is a preliminary list which will be expanded in WP4. The mentioned indicators guided the experts in their judgement of the relevance of transport processes for CO₂ emissions. The indicators are also referred to in the qualitative description of the effects of ITS.

- speed of a vehicle/train/vessel
- acceleration
Transport processes and impacts on CO2 emissions

- kilometres travelled by a vehicle/train/vessel
- travel time (as a substitute for kilometres travelled that also incorporates idling time)
- weight of a vehicle/train/vessel or the specific energy consumption (e.g. per gross-ton-kilometres or per passenger-kilometres)
- type (size) of a vehicle/train/vessel with consequences to the energy consumption and emissions per vehicle-kilometres
4. Expected impact of ITS on transport processes

4.1 Introduction

This chapter describes the results of an assessment of ITS with respect to transport processes. The assessment is based on a Delphi method [Turoff H. et al., 2002] that forecasts the impact based on the input of a panel of experts realised by a comprehensive expert survey covering all systems introduced in Chapter 2. The expert survey was amended by a literature review. The outcome of this assessment forms the basis for the evaluation of the relevance of systems for CO₂ emission changes. It is, thus, input to WP4 and WP5 and the development of the Amitran framework and model interfaces. The tables reflect the opinion of the experts. Because no clear line can be drawn between “high impact” and “low impact”, ticks give only an impression of the parameters identified as being particularly important by the participating experts. In the framework and interface development (WP 4 and WP 5), the consideration of parameters is not limited to the ones highlighted in the following sections, but particular attention is paid to them.

The core objective of this chapter is to describe the qualitative impact of the ITS in relation to transport processes (cf. section 3.2). It considers the impact on the different modes as well as the impact on the behaviour of travellers, drivers, skippers and planners that finally determine the traffic demand. While this assessment also serves a broad classification of systems to classes with regards to CO₂ impact, the major objective was an identification of factors and parameters influenced by systems. These influences have to be taken into account in the development of the Amitran framework (WP 4), in the development of the model interfaces (WP 5).

All experts addressed by the online survey were first filtered for their expertise in the different ITS categories. Experts in a category subsequently assessed the systems they are familiar with within this category. For each transport process the influence had to be rated as “no impact”, “low impact”, or “high impact”. The experts, thus, rated the intensity of impact of a system. As has been explained before (cf. section 1.2.3, p. 17), the penetration rate of systems is not addressed by this assessment. In case of individual systems (e.g. safety and emergency systems), the frequency of impact is also not part of the assessment, since a single system was regarded by the experts, not the overall effect on the transport system. These aspects are included subsequently in the evaluation of the relevance of systems for CO₂ emissions (Chapter 5).

The rating of the experts was averaged to identify the transport processes affected most by the respective system. For each system in the respective sub-category, the transport processes
4. Expected impact of ITS on transport processes

rated by the experts as having greatest significance are indicated with an X. The next sections present the result of this assessment structured by system categories.
### 4.2 Navigation and traveller information

| System                                      | Infrastructure capacity | Availability of transport mode | Connection with other modes | Location choice | Trip generation | Destination choice | Strategic route planning | Strategic mode planning | Pre-trip route choice | Pre-trip mode choice | Vehicle (train/vessel) choice | Load factor and occupancy | Departure time choice | On-trip route choice | On-trip mode choice | Lane choice | Speed | Headway | Driving dynamics | Use of auxiliary systems | Transport demand | Network design | Public transport scheduling |
|---------------------------------------------|-------------------------|--------------------------------|-----------------------------|------------------|----------------|-------------------|------------------------|------------------------|-----------------------|----------------------|-----------------------------|--------------------------|---------------------|------------------------|-------------------|---------|-------|-------------|----------------------|-----------------------|----------------------|----------------------|
| Static Navigation System                   |                         |                                |                             |                  |                |                   |                        |                        |                       |                     |                            |                          |                     |                        |                   |         |       |             |                       |                       |                      |                      |
| Dynamic Navigation System                  |                         |                                |                             |                  |                |                   |                        |                        |                       |                     |                            |                          |                     |                        |                   |         |       |             |                       |                       |                      |                      |
| Electric Car Navigation System             | X                       |                                |                             |                  |                |                   | X                      | X                      |                       |                     |                            |                          |                     |                        |                   |         |       |             |                       |                       |                      |                      |
| Static Passenger Information               |                         |                                |                             |                  |                |                   |                        |                        |                       |                     |                            |                          | X                   |                        |                   |         |       |             |                       |                       |                      |                      |
| Dynamic Passenger Information              | X                       |                                |                             |                  |                |                   | X                      | X                      | X                     | X                   |                            |                          |                     |                        |                   |         |       |             |                       |                       |                      |                      |
| Real-Time Traveller Information System     |                         |                                |                             |                  |                |                   |                        |                        |                       |                     |                            |                          | X                   |                        |                   |         |       |             |                       |                       |                      |                      |
| Car-Sharing and Ride-Sharing Information System | X       |                                |                             |                  |                |                   | X                      | X                      | X                     | X                   |                            |                          |                     |                        |                   |         |       |             |                       |                       |                      |                      |
| Multimodal Tour Planning System            |                         |                                |                             |                  |                |                   | X                      | X                      | X                     | X                   |                            |                          | X                   |                        |                   |         |       |             |                       |                       |                      |                      |
| Dynamic information for skippers           | X                       |                                |                             |                  |                |                   |                        |                        |                       |                     |                            |                          |                     |                        |                   |         |       |             |                       |                       |                      |                      |
4.3 Traffic management and control

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<th>Infrastructure capacity</th>
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### 4.4 Demand and access management

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4.5 Driver behaviour change and eco-driving

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3.1: Methodology for classification of ITS (version 11, 2013-06-12)
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### 4.6 Logistics and fleet management

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5. Relevance of ITS for CO₂ emissions

5.1 Introduction

Chapter 2 introduced the ITS which are in the scope of Amitran. These ITS have an influence on traffic and, thus, also on CO₂ emissions. The influence on traffic can be described by looking at factors influencing traffic demand and parameters describing traffic demand, driver behaviour and vehicle conditions. These factors and parameters have been described and their relevance for CO₂ emissions is underlined in Chapter 3. The impact of systems on the mentioned factors and parameters has been estimated by experts as documented in Chapter 4.

In this chapter the results from the subsequent chapters is combined to provide an estimate of the impact ITS have on CO₂ emissions. This evaluation provides an identification of the systems of primary relevance for reducing CO₂ emissions. It has to be stressed that the primary goal of the applied methodology is the understanding of the ways ITS exert their influence on traffic. The impact classification of ITS serves as an orientation only and does not replace a detailed assessment using the Amitran methodology.

As is also described in D4.1, long term effects and rebound effects are not taken into account in Amitran, since very little is known about these effects and there are no tools to model them. Long term effects are mentioned to make the user aware of them. Only in some very specific cases induced demand can be taken into account, depending on the models that are used. This is explained further in D4.1.

Methodology

The qualitative impact assessment of ITS is based on an expert survey as described in section 1.2.3 (pp. 17 ff.). The experts rated the influence of systems on parameters, which in turn are weighted for their relevance for CO₂ emissions (cf. section 3.3). In order to avoid a double influence of factors, only parameters describing traffic demand and driver behaviour/vehicle conditions are taken into account in the assessment. A system influencing location choice on the long term, for instance, will also influence destination choice. Experts will therefore point out both influences separately. If the influence on location choice would be included in the overall rating of the effect of the system on CO₂ emissions, the effect would be overrated.
Due to the broad scope of Amitran, diverse systems and parameters have been assessed by experts from various fields. To get a more representative result, the assessments of the experts have been normalised. Experts being more restrictive in their assignment of high impact estimates to parameters received more weight than experts rating all possible influences and, thus, distributing more points to parameters per system. This procedure ensures a more differentiated view on the impact of ITS.

The impact a system has on certain parameters occurs with different frequencies. Systems for which the intensity of impact is high, but the frequency of this impact is low, have been rated down by a factor to account for this low frequency. This factor has been determined by the experts from the consortium involved in the impact assessment. Factors have been chosen from broad categories (“triggered by very rare events” to “not triggered”). They do not represent an exact frequency, but reflect the order of magnitude. The frequency is primarily relevant for safety and emergency systems, which have a high impact on driver behaviour when they issue a warning. Since this only happens in rare emergencies, this high impact results in an impact on traffic flow and CO₂ only in rare situations.

As the final result of the qualitative assessment all systems have been assigned to one of three impact classes:

- high potential impact systems
- medium potential impact systems
- low potential impact systems

This assignment takes intensity of impact, frequency of impact, and the relevance of parameters for CO₂ emissions into account (cf. explanations in the chapters before). All these different factors are combined to an overall assessment. Systems receiving an overall rating of at least 70 % of the top rating are assigned to the “high potential impact” category. Systems receiving an overall rating less than 30 % of the top rating are assigned to the “low potential impact” category. This classification offers an estimate of the potential the listed ITS have to influence CO₂ emissions. High potential impact systems belong to the top 30 % concerning the overall impact rating. Low potential impact systems belong to the bottom 30 %. Systems for which the impact estimate is based on the opinion of one or two experts only, or for which the impact depends very much on circumstances and, thus, no definite impact potential can be assigned, are separated from the other systems. They are at the bottom of each list under the title of “low reliability”. No exact ratings in numbers are given on purpose to underline the qualitative nature of the assessment.
Uncertainties in the assessment

The conducted qualitative impact assessment is subject to some uncertainties. The assessment is aimed at giving an overview on the potential importance of ITS for influencing CO₂ emissions. The systems cover all areas of transport from road to rail and shipping for both passengers and freight. Accordingly the description of parameters is very general, and the context of system deployment is deliberately not defined. This leaves room for interpretation by the experts. These uncertainties can and have to be addressed by a more detailed assessment using the Amitran methodology. Some issues are highlighted in the following paragraphs.

Context sensitivity

The impact of systems can depend significantly on the context of their deployment. Consequently, an impact assessment has to be based on a careful description of the setting and a detailed system definition. The context also has to take the combination of systems into account, whose effects can influence each other. Systems where context plays a major role are in particular traveller information systems and traffic management systems.

The effect traveller information systems have on the users depends very much on the type of information provided and the quality of that information. The statement that a route is congested has a different effect than information on travel times, route and mode alternatives. In this deliverable a distinction is made between dedicated passenger systems and more general information systems (including multi- and intermodal systems) and between static and dynamic (real time) systems. Still it is important to take into account dependence of effects of information systems on information content and the connection with other systems.

Also the effect of traffic management systems depends on the type of information that is provided and the quality of that information. If, for instance, an alternative route is advised (by a dynamic re-routing system) without giving reasons (e.g. travel time estimates), the effect is different from a system providing both (i.e. dynamic re-routing with travel time information).

In case of parking guidance systems, there could be a difference between a system advertising park and ride without public transport information and one with a dynamic passenger information system connected. The combination of the systems makes, thus, a big difference.

User experience and system maturity

Generally, a user trusts (and, thus, follows) a system more, if he looks back to positive experiences. The impact of systems can, therefore, also depend on the maturity of systems.
System development, furthermore, introduces some uncertainty in case of new systems. Systems for driver and behaviour change and eco-driving in particular undergo a rapid development. For some systems the potential effect can already be judged or even measured; for other systems (e.g. autonomous driving), the development stage still leaves some uncertainty.

The effects of driver behaviour change and eco-driving systems depend also on the connection with other systems or transport modes. With smart integration of navigation and traveller information systems, even a mode shift can be caused on the long run. But this effect is difficult to judge as a general assessment.

The effect of such systems, moreover, depends on the way the information is presented (visual, haptic, acoustic).

**Qualitative impact description**

In order to allow a more detailed understanding of the impact ITS have on traffic and CO₂ emissions, the effects of the most relevant systems (high or medium potential impact) are briefly described in sections 5.3 to 5.7. Where possible, major results from past research and field operational tests are highlighted. This description offers some background information to better understand the ways how systems influence traffic. The Annex provides a list of resources for most systems. Both descriptions and resources do not provide a comprehensive account of available evidence for all systems, but are meant as a starting point for potential Amitran users and as a documentation of the background on which the expert assessment is based.

**Chapter outline**

Section 5.2 provides an overview on the impact potential of all systems that have been assessed. The systems are sorted according to the above mentioned impact classes. Systems with lower reliability of the assessment are listed separately.

Sections 5.3 to 5.7 provide qualitative descriptions of the effects of the systems, structured in the same way as in Chapter 2. The descriptions make reference to the transport processes and the indicators affected by them mentioned in section 3.3 (p. 42 f.). These descriptions are provided only for systems with a high or medium potential impact.
5.2 Overview on impact potential

5.2.1 High potential impact systems

Table 9 Systems with high potential impact on CO₂

<table>
<thead>
<tr>
<th>Category</th>
<th>Sub-category</th>
<th>System</th>
</tr>
</thead>
<tbody>
<tr>
<td>Navigation and traveller information</td>
<td>Traveller information systems</td>
<td>Car-Sharing and Ride-Sharing Information System</td>
</tr>
<tr>
<td></td>
<td>Planning support systems</td>
<td>Multimodal Tour Planning System</td>
</tr>
<tr>
<td>Demand and Access Management</td>
<td>ITS supported measures</td>
<td>Restricted traffic zones</td>
</tr>
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<td></td>
<td></td>
<td>Access Pricing</td>
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<tr>
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<td></td>
<td>Road Pricing</td>
</tr>
<tr>
<td>Driver behaviour change and eco-driving</td>
<td>Driving assistance and cruise control (road traffic)</td>
<td>Autonomous Driving</td>
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<tr>
<td></td>
<td></td>
<td>Adaptive Cruise Control (ACC)</td>
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<tr>
<td></td>
<td></td>
<td>Cooperative Adaptive Cruise Control (CACC)</td>
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<tr>
<td></td>
<td></td>
<td>Predictive Cruise Control (PCC)</td>
</tr>
<tr>
<td>Logistics and fleet management (commercial and public transport fleets)</td>
<td>Freight transport systems</td>
<td>Supply Chain Management System</td>
</tr>
<tr>
<td>Low reliability of assessment</td>
<td>Navigation and traveller information</td>
<td>Electric Car Navigation System</td>
</tr>
<tr>
<td></td>
<td>Traveller information systems</td>
<td>Real-Time Traveller Information System</td>
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</tbody>
</table>

5.2.2 Medium potential impact systems

Table 10 Systems with medium potential impact on CO₂

<table>
<thead>
<tr>
<th>Category</th>
<th>Sub-category</th>
<th>System</th>
</tr>
</thead>
<tbody>
<tr>
<td>Navigation and Travel Information</td>
<td>Navigation systems</td>
<td>Static Navigation System</td>
</tr>
<tr>
<td></td>
<td>Traveller information systems</td>
<td>Dynamic Passenger Information System</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Static Passenger Information</td>
</tr>
<tr>
<td>Traffic Management and Control Systems</td>
<td>Signal control</td>
<td>Adaptive Signal Control</td>
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<tr>
<td></td>
<td>Highway systems</td>
<td>Road Section Control System</td>
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<td></td>
<td></td>
<td>Collective Re-Routing System</td>
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</tbody>
</table>
5. **Relevance of ITS for CO2 emissions**

### Table 11 Systems with low potential impact on CO2

<table>
<thead>
<tr>
<th>Category</th>
<th>Sub-category</th>
<th>System</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traffic Management and Control Systems</td>
<td>Inland Waterway systems</td>
<td>River Information Services (RIS)</td>
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<tr>
<td></td>
<td>Railway systems</td>
<td>European Rail Traffic Management System (ERTMS)</td>
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<tr>
<td>Driver behaviour change and eco-driving</td>
<td>Driving assistance and cruise control (road traffic)</td>
<td>Lane Change Assistance System</td>
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<tr>
<td></td>
<td>Railway systems</td>
<td>Parking Assistance System</td>
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<td></td>
<td></td>
<td>Energy Efficient Train Driving</td>
</tr>
</tbody>
</table>

### Low potential impact systems

- Demand and Access Management Systems
  - Electronic Fee Collection
  - Electronic Ticketing

- Driver behaviour change and eco-driving
  - Driving behaviour (road traffic)
  - Driving behaviour recognition system

- Logistics and fleet management
  - Public transport systems
  - Computer Aided Dispatch and Scheduling (CADS)
  - Dynamic Schedule Synchronisation
  - Operational Control System (OCS)

- Freight transport systems
  - Fleet Management System (FMS)
  - Intelligent Truck Parking

### Low reliability of assessment

- Navigation and Travel Information
  - Navigation systems
  - Dynamic Navigation System

- Traffic Management and Control Systems
  - Enforcement systems
  - Automated Weight Limit Enforcement by Weigh-In-Motion

- Demand and Access Management Systems
  - Electronic Fee Collection
  - Electronic Toll Collection

- Driver behaviour change and eco-driving
  - Railway systems
  - Driverless Train Operation
  - Intelligent Speed Adaptation/Assistance

- Logistics and fleet management
  - Freight transport systems
  - Electronic system for freight transport

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3.1: Methodology for classification of ITS (version 11, 2013-06-12)
5. Relevance of ITS for CO2 emissions

<table>
<thead>
<tr>
<th>System</th>
<th>Safety and Emergency Systems</th>
<th>Augmented awareness</th>
<th>Collision Warning System</th>
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<tbody>
<tr>
<td></td>
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<td>Cooperative Intersection</td>
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<td>Collision Avoidance System</td>
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<td>Drowsy Driver Warning System</td>
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<td>Lane Departure Warning System</td>
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<td>Vehicle-based Pedestrian Detection System</td>
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</tbody>
</table>

Low reliability of assessment

<table>
<thead>
<tr>
<th>Navigation and Travel Information</th>
<th>Inland waterway information systems</th>
<th>Dynamic information for skippers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Logistics and fleet management</td>
<td>Freight transport systems</td>
<td>Terminal Management System</td>
</tr>
<tr>
<td>Driver behaviour change and eco-driving</td>
<td>Driving assistance and cruise control (road traffic)</td>
<td>Green Light Optimised Speed Advisory (GLOSA)</td>
</tr>
<tr>
<td></td>
<td>Driving behaviour (road traffic)</td>
<td>Digital Tachograph</td>
</tr>
<tr>
<td>Safety and Emergency Systems</td>
<td>Augmented awareness</td>
<td>Night Vision System</td>
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<td>Weather Information System</td>
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<td>E-Call</td>
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<td>E-Call</td>
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<tr>
<td>Inland waterway systems</td>
<td></td>
<td>River Calamity Abatement Support</td>
</tr>
</tbody>
</table>

5.3 Navigation and traveller information

5.3.1 Navigation systems

**Static Navigation System**

- The route choice pre- and on-trip is influenced due to information the navigation system is giving the driver of a vehicle. This will influence the vehicle-kilometres (16 % less kilometres) [Vonk et al., 2007].
- It has a favourable effect on driving performance and a small positive (but not significant) effect on the number of incidents, crashes and near-crashes [Perez et al., 1996]. That contributes to a decrease in congestion and influences travel time.
- Vehicles with a navigation system opt more frequently for less congested routes [Perez et al., 1996].
- It influences the exceedance of the permitted speed limit (+5 %), though no significant change in average speed [Vonk et al., 2007]
Further it could have impact on a fuel efficient route choice (for static navigation systems that offer this service); 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 [Hanna Larsson, 2009], [Klunder, 2009].

### Dynamic Navigation System

A Dynamic Navigation System has influence on

- Route choice (pre-trip and on-trip) since the system can advise an alternative route that reduces the expected travel time. In most cases this influences the number of vehicle-kilometres.
- Mode choice (pre-trip and on-trip) since the system can indicate that the traveller might not reach his destination in time (due to congestion) and this could cause a shift to another mode. This reduces car or truck vehicle-kilometres.
- Departure time choice since the driver might decide to leave earlier or later due to the expected travel time calculated by the system. A dynamic navigation system can in some situations lead to significant travel time reduction in comparison to static navigation systems and manual navigation, if they are designed correctly. [Uang, 2003, p.437]
- Destination choice, since a driver might decide to choose another destination (or go back home) when – due to congestion – the expected travel times on all possible routes are too high. This influences vehicle-kilometres.
- Trip generation, since a traveller might decide not to leave his current location due to the traffic situation and expected travel times. This influences vehicle-kilometres.

On societal level, the dynamic navigation system has the following effects:

---

3 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.
5. Relevance of ITS for CO2 emissions

- Reduction in traffic congestion on main route as users leave congested roads and an increase in traffic, accident risk and pollution along secondary roads [Helling, 2006, p.36]. A study in Toronto showed that dynamic navigation systems reduce travel time and improve throughput. However, it also showed an increased number of accidents in the network when such systems were used [Look, 2001, p.50-51]. Dynamic navigation systems for drivers lead to a reduction of travel time for those who use them and as an externality for those who do not use them. [Levinson, 2003, p. 81-82]

- In combination with a planning system, the efficiency for vehicle use e.g. in freight transport and for taxi/shared taxi could be influenced. Due to available real time data about expected arrival times and alternative routes the vehicle could be rerouted to get the maximum of capacity utilization and to reduce vehicle-kilometres. If short requests of customers could be transmitted into the vehicle and the dynamic navigation system informs the driver how the best trip to immediate stops could be realized. Further idling time as well as empty vehicle-kilometres could be minimized and the number of passengers per time period or the freight volume could be increased.

- Influencing driver behaviour and affecting average speed. A study notes effects on the user of such a system: (i) notable travel time savings if alternative routes are available (ii) stress reduction due to traffic jam avoidance (iii) informational benefits - users know how long a trip including traffic delays will take. Flip side effects are: (iv) more stress and an increased accident risk due to use of unfamiliar roads on alternative routes and (v) an increase in travel time if traffic conditions on the alternative route are not represented accurately in the system. [Helling, 2006, p.34-35].

- Real-time on-trip information reduces travel time for those who utilize them significantly as well as to a lesser degree for those who do not. The advantage is greatest when a small number of people has access to such technology and is reduced with higher levels of penetration. It however remains beneficial even at those high levels. It stabilises traffic flow and this is called the most relevant gain from information in road traffic. [Emmerink, 1995, p.49-50]
  This holds (only) for current implementations. Further developed systems could include such a feedback loop (e.g. by improved traffic prediction).

- A better distribution of vehicles over different routes in a network (optimum is equilibrium of capacity usage). The benefits increase in direct relation to the density of the area’s road network and the accuracy of the dynamic traffic information used by the system. [Helling, 2006, p.37-38] Travel time reductions for all users are greatest if the road network is used to a level near its maximum capacity and if there are singular incidents. [Levinson, 2003, p.85-86]
Electric Car Navigation System

An Electric Car Navigation System has influence on

- Mode choice (on all levels as well) and choice of transport means, since the driver might choose to drive more with his electric car, since he is less afraid of having an empty battery. This influences energy consumption and the emissions per kilometre.
- Route choice (on all levels: strategic, pre-trip and on-trip), since the navigation system will advise the most battery-friendly route and give information on charging points along the route. The route the driver takes might then differ from the route the driver would normally take.
- Location choice as a more strategic (long term) aspect, since this could be influenced by charging infrastructure near the location.
- Destination choice, since this choice could depend on information on the charging status of the electric car and the calculation of the expected energy consumption for a trip by the system. The driver could decide (pre-trip or on-trip) if a trip with the electric car is possible and which destinations could be reached with/without recharging underway.
- Departure time choice, since this could be influenced by the possible need to recharge underway, which means a longer travel time.
- Through these different influences there could be an effect on the vehicle-kilometres. What can also influence the vehicle-kilometres is the fact that the driver can avoid a long search for recharging devices.
- Last, the navigation system can influence the driver behaviour (speed and acceleration) since the system compares energy usage and calculates the distance the batteries can supply and indicate whether there is a problem in reaching the destination. The driver could be (or feel) encouraged to drive more sportively or smoothly.

5.3.2 Traveller information systems

Static and Dynamic Passenger Information / Real-Time Traveller Information System

These systems are influencing the following parameters to some extent identically:

- Mode choice, since public transport can become more (or less) attractive for travellers. On the other hand pre-trip mode choice will be influenced. 35% of travellers answered in a survey that they would not shift in case of disturbances in public transport service the transport mode, but 26% would shift to car, or 15% would use park & ride [Roider, 2011]. A long-term case study on Chicago public transport found that real-time information increases bus ridership though such increases might be quite modest. [Tang, 2012, p. 157-158]
• Trip generation, because people might decide to travel more based on the easy access to static or dynamic travelling information. Both these influences result in a change in kilometres driven per mode; for CO₂ calculation only the shift to kilometres driven on the road are of importance (individuals may travel less kilometres in public transport, but the trains, buses, etc. still drive the same amount of vehicle-kilometres, subject to long term effects and induced changes in public transport services).

Other issues which are expected to be influenced by a Dynamic Passenger Information System or Real-Time Traveller Information Systems are:

• Route choice, as several routes might be available for a trip made with public transport. With the system’s better (real-time) information other choices might be made on the route. A study in Portland showed that many users will at least make one decision about their trip due to on-route real-time information e.g. they choose an alternative route and the profit with shorter travel times and more efficient travelling. [Dziekan, 2007, p. 493]

• Departure time choice. Because of real-time public transport information being available, travellers might choose another departure time. Surveys on a case study indicate 78% of users looking at departure displays on a bus stop on trips, 94% of users using online information service feel they can spend more time at home or work because of it [FTA, 2006, p.46]. Study hypothesizes reduced waiting time but is not certain of how much time it actually is. [FTA, 2006, p.41].

• the travel time of passengers. A case study of morning rush hour in a public transport corridor in Boston, with a methodology focusing on which route the user selects finds that real-time information yields very modest reductions in travel time. Departure information alone is found to be insignificant to total travel time even though users will adjust their route on-trip based on the information. [Hickman, 1995, p.222-225].

On a longer term, all systems can possibly influence:

• the traffic demand, because of changes in modes chosen and trip generation, traffic demand might evolve.

• the location choice because people might choose other places to live, or transport/logistics companies might change their locations, because the systems changes travel patterns, or makes certain trips easier/faster. This influences travel time and vehicle-kilometres of the traveller.

• public transport scheduling due to new travel patterns, changes in mode choice, trip generation and departure time choice. Public transport companies might on the long term change their scheduling or the characteristics (such as size) of the vehicles.
the efficiency of vehicle use (occupancy). These systems help to offer existing and in some cases also residual capacities (e.g. for commuter trains, busses) in connection with tariff information. This information is used in few cases for marketing or to influence the capacity utilisation of vehicles/trains. E.g. the efficiency of vehicle/train use is influenced in some cases by special tariffs (one day-ticket is cheaper after 09.00 a.m. because the morning rush hour is over, weekend ticket. trains with high residual capacity) based on long term data about capacity use. These tariff information as part of information systems should support to enhance the capacity utilisation.

**Car-Sharing and Ride-Sharing Information System**

Car-Sharing Information System influences:

- the vehicle availability will increase and the type or size of vehicles changes. Travellers do not need an own car, or for some trips only a smaller one, if car sharing could be easily accessed based on information concerning the availability of cars with different sizes. This is a relevant factor for the transport process because the car ownership has a high influence to traveller's travel behaviour.
- the strategic mode planning because a membership in a car sharer pool or at least the registration with it is a pre-condition. The decision is influenced by the costs of membership and the costs for transport (costs per time, kilometre or per use). Furthermore, Car-Sharing Information system influences the strategic mode planning because certain modes might become more or less attractive if the user could efficiently and fast compare alternative modes and routes.
- the destination choice due to the availability of a car. Traveller’s decision of an activity especially in the spare time could be influenced, e.g., the public transport does not offer alternative services, and finally the vehicle-kilometres driven will increase.
- the pre-trip mode choice. The decision of a traveller to use car sharing services is influenced by access, availability and costs for car use, e.g., on short request in case of “car-to-go” service, and the online information about the status of available cars. That means, the transport mode, the transport costs and the departure time planning/choice are parameters that are influenced. In case public transport does not offer alternative services to the user the vehicle-kilometres change (similar to destination choice, see below).
- the pre-trip mode choice when being integrated into (long-distance) public transport information systems since the car sharing option could fill the gap of lacking public feeder service. Thus the whole trip could be switched from private car to car sharing/long-distance public transport with reduced vehicle-kilometres
- the vehicle choice on long term to some extent due to user preferences and the information about the suitable type of vehicles in the neighbourhood.
Ride-Sharing Information Systems lead to

- the reduction of the numbers of trips with own vehicles. A study of online carpool service in New Zealand pointed out that among registrants the percentage of those sharing rides increased from 12.4% to 27.9% while the number of registrants who drove alone to work was reduced from 36.6% to 29.9%. Share of registrants who used public transport for commuting purposes declined from 43.5% to 32.2%. [Abrahamse, 2012, p.48-49]

In a mid-1990s study comparing a web-based rideshare program with a traditional rideshare program found that the online service did not surpass the traditional program in numbers of users, but attracted a different client base with little overlap. Conclusion: a web-based service attracts a new potential user base to ride-sharing. [Dailey, 1999, p.23-25] However, this could change with the more widespread use (and experience) with web-based services over time.

- the reduction of costs and travel times. A simulation study of dynamic ride-sharing in Atlanta showed that such a system could be successful in a large metropolitan area as large enough pools of participants would develop to make the system sustainable. This could have benefits such as reduced travel costs and travel times through use of High Occupied Vehicles (HOV) lanes as well as reduced congestion. [Agatz, 2011, p.549]

For both systems the following effects have to be considered:

- Pre-trip and on-trip route choice is influenced, because the driver might drive another route to pick up the passenger (at a defined parking space or at another place such as the house of the passenger) to start and end the trip and to give the car back. This could cause additional vehicle-kilometres in case there is a distance between the last stop (e.g. at traveller’s home to carry some things into a house or to distribute fellow travellers) and the defined place to give back the car to the service provider or to be used by others. The systems could help to reduce these additional vehicle-kilometres by stating the nearest point to hand back the car or to find the best suitable fellow travellers. A study of carpooling club in Lisbon, Portugal concluded that carpooling’s appeal is limited to certain groups who have more open attitudes and highly value even small economic benefits. A trust problem remains but a club does achieve level of trust similar to that amongst co-workers. Carpooling’s potential to reduce urban congestion, however, is limited. The club model cannot overcome trust and flexibility issues. [Correia, 2011, p.89]

- The public transport scheduling (on long term and only as a secondary effect) could be influenced due to public transport services and car- or ride-sharing are often two complementary components for the users and could help to optimise the service based on users data or user requests. That could help to find efficient solutions to organise transport in an urban area. Finally, this will influence the train-kilometres and the vehicle-kilometres in an urban area.
5.3.3 Planning support systems

Multimodal Tour Planning System

- This ex-ante system forces to check alternative opportunities to get to a point of interest (person transport) or to the point of delivery (freight transport). In both cases, people decide based on experiences or patterns and additional information of alternatives are not easy to get or not reliable. Better information about departure time (e.g. of bus or train) or the estimated time of arrival will enhance the traffic demand on long term for public transport services and promote the use of less energy demanding transport modes in freight and passenger transport. A study on a system in the Chicago region outlined that a system did not attract mostly suburban users who are more likely to drive, but rather regular transit users. Large majority of users were already planning to use transit before using the web service. System was reported to have made public transport use more likely amongst those who were unsure of what mode to use before browsing to the website. 40% of all users said the system caused them to make one public transport trip they otherwise wouldn’t have made. [Biernbaum, 2010, p.40-41]
- the connection with other transport modes in case the system gives all information to users (passengers, shippers) to plan the transport chain. That influences the used modes and vehicle/train/vessels-kilometres.
- The pre-trip mode choice and the means of transport chain will be influenced as described above. The transport costs are one essential criterion for shippers or passengers to decide for multimodal transport. Hence this information should be part of a system. It has to be added that costs are not for everybody or in every case the significant criterion but also safety and security, reliability, transport time have often more relevance for the decision.
- the departure time choice because the average speed is influenced by waiting times and operation time to change the transport mode.
- the traffic demand due to information the shippers or persons have about the opportunity to transport/travel that will influence the transport volumes or number of passengers per mode.
- the vehicle/train/vessel choice because the use of capacity of the vehicles/trains/vessels that provides service along the transport chain (e.g. timetables offer the service). That will influence the transport service e.g. by use of size-optimized vehicles or to adjust service on long term. That influences the vehicle/train/vessel-kilometres per mode.
choice of the vehicle/train/vessel to transport a loading unit in freight transport is often a pre-condition to use intermodal transport services. It is essential to know which loading units, transportation safety devices, and outer packing for a product is necessary to transport in inter- or multimodal transport chains for which costs. Based on this information given by a multimodal tour planning system a shipper would be able to decide which transport unit (e.g. pallet, big-bag, container, tank truck) is suitable for a selected transport chain and this determines distances of the used modes in vehicle/train/vessels-kilometres. In freight transport the best offer of a service provider will be accepted (e.g. by costs, transport time and quality).

5.4 Traffic management and control

5.4.1 Signal control

Adaptive Signal Control

The system influences:

- infrastructure capacity because it regulates the bottlenecks of infrastructure (e.g. cross-ways, one line traffic due to reconstruction of roads, regulated access to roads). A study which modelled traffic at a stretch of the Pacific Coast Highway in Lomita, CA and compared various different traffic signal strategies found that the RHODES adaptive signal control strategy works better than pre-timed or fixed-time strategies and other adaptive strategies “in terms of both the overall system and the arterial only traffic performance”. The model tested for travel times, average speed and number of stops. [Skabardonis, 2010, p.42-48] Field test of RHODES adaptive signal control system in Tempe, Arizona showed that it did not improve on the performance of the well-functioning existing non-adaptive system. Researchers however pin that outcome on a number of factors: the existing system was finely tuned over years to existing conditions whereas RHODES was not and unlike the current system RHODES was run on only one set of parameters. Researchers and stakeholders alike believe RHODES “shows promise” and may offer improvement if it was fully implemented. [Mirchandani, 2001, p.64-66]

- the route choice pre- and on-trip due to the length of the periods of red and green phases for the different directions (pre- and on-trip) and the length of the waiting queue to pass the traffic light (on-trip). Thus the vehicle-kilometres are influenced based on the experiences of the drivers concerning different routes and the expected travelling time in dependency with the number of traffic lights and the expected waiting times due to red light periods, if knowledge or perception of the difference is available/assumed
5. Relevance of ITS for CO2 emissions

- infrastructure capacity utilization and mode choice by the priority given to trams and buses to reduce the transport time in public transport (e.g. in combination with temporary special lanes for busses in case of crowded streets or with traffic light controlling that gives priority to busses or trams). That helps to enhance the reliability for these high occupied vehicles in peak hours and therefore attracts more passengers. The priority influences the travel time in comparison with cars and brings more people in a predictable time period to their destination (e.g. downtown area, sports event stadium). This could contribute to a mode shift from car to public transport due to reduced time to get from origin to destination (e.g. for trips to a sport stadium).
- According to a report assembled for the U.S. Department of Transportation (DoT), adaptive traffic control systems show a number of benefits. The authors analysed various case studies and based on that data they report a 10% to 41% reduction in stops due to such systems, a reduction in reported delays between 14% and 44% and a reduction in fuel consumption between 2% and 13%. It also reports that the impact on vehicle emissions “appears to be positive” based on a few studies. Seven of eight studies reported a reduction in travel time as well, one study however showed an increase of 6% in travel time. [Proper, 2001, p.10-12]

5.4.2 Highway systems

Junction Control System

The system influences:
- the infrastructure capacity by adjusting Signal Phase and Timing to increase the throughput of the intersection avoiding congestion. In case of a ramp metering system it decreases the flow onto the motorway. This increases the average speed of vehicles in the overall network and harmonises the flow on the main carriageway (i.e. stop-and-go traffic) at the specific location.
- the lane choice if the number of lanes could be adapted in dense traffic flow (e.g. opening of the shoulder lane in case of high traffic flows, see figures).
5. Relevance of ITS for CO2 emissions

Road Section Control System

This system encourages drivers to keep speed moderate and drive smoothly and includes dynamic speed limits, dynamic lane assignment, dynamic shoulder use (opening of the hard shoulder during peak times). Road section control systems are influencing:

- speed, headway, and driving dynamics: less braking and acceleration of vehicles is necessary as all drivers run smoothly and at a more homogeneous speed. A field trial of variable speed limits in Stockholm showed that variable speed limits reduce the average speed of drivers. [Vägverket, 2006, p.1-2]
5. Relevance of ITS for CO2 emissions

- the increase of traffic flow and capacity (hence less traffic congestion). That decreases travel times for all users. A study comparing sections of a motorway in Germany with and without road section control systems found no significant improvement on road capacity and no performance improvement but it did find a notable improvement in traffic flow stability. Near full saturation levels the section with the road section control system avoided a collapse of traffic flow and maintained flow longer than the section without such a system. [Schick, 2003, p.213-217] An investigation of the impact of variable speed limits on accident risks found that reducing speed limits based on adverse conditions like weather does significantly lower the risk of a crash and while increasing the travel time system-wide only slightly. [Lee, 2004, p.12-14]

Further a road section control with warning messages (congestion, low visibility, road works, etc.) helps

- to avoid incidents that could cause congestion and increase of travel time. In a study of variable speed limits on German motorways, it was found that they lead to only a slight increase in road capacity, however there is much less variance in capacity on roads with variable speed limits suggesting a stabilising influence on traffic flow which leads to reduced breakdowns of traffic. [Geistefeldt, 2011, p. 55]
- to encourage the drivers to adjust the speed or headways and avoid strong braking manoeuvre (safety reasons). Non-mandatory and merely advisory variable speed limits in Stockholm, Sweden were found to have no notable impacts on traffic conditions. [Nissan, 2011, p. 108]

Collective Re-Routing System

- on-trip route choice due to the fact that a driver could individually decide to detour with additional vehicle-kilometres but by reduced travelling time in comparison with another route that is congested.
- better utilization of infrastructure because it helps to avoid traffic on congested routes and bypasses bottlenecks by using capacity (vehicles per time period) of alternative routes.
- better traffic flow with less driving dynamics (acceleration and braking) of vehicles.
- minimisation of time losses for the entire collective of the traffic participants.
5.4.3 Railway systems

**European Train Control System (ERTMS)**

ERTMS is a Europe-wide standardized automatic signalling, control and train protection system. It consists of standards for communication between train operators / trains and infrastructure managers / infrastructure e.g. by GSM-Rail (communication of train drivers and railway control centres sector using an own GSM mobile network.) and the European Train Control System (ETCS), that realises a secure train operation. It improves

- the capacity planning and the pre-trip route choice because interoperability on long train haulage becomes reality and the locomotives and the staff could use the networks of different infrastructure managers without any immediate stops (primary effect). This fosters the realisation of a Trans-European Transport Network TEN-T network with free rail-freight traffic flows without barriers in long term and reduces travelling times of trains (secondary effect).
- on-trip route choice in case of unexpected events the trains can be re-routed due to the improved localisation and communication.
- the capacity utilization because inefficient train control systems could be replaced, in many cases the capacity (trains per time period) of the infrastructure will be increased, and the management and maintenance becomes faster and cheaper because of pre-defined European technical standards.
- the (maximum or recommended) driving speed of the trains due to signalisation is transmitted to the drivers desk at the locomotive and this enables a driving behaviour with an improved anticipation on the speed and behaviour of trains ahead. In case of using the technology of ETCS level 3 the moving block system indicates to the driver a maximum (recommended) speed taking into account the speed of the train ahead. This makes the driving behaviour smoother and reduces energy consumption due to driving dynamics (braking and acceleration) of the train.

5.4.4 Enforcement systems

**Automated Speed Enforcement**

The system influences:

- the average speed of vehicles because in most cases speeding fines are expected.
the driving dynamics will be reduced because the difference of speeds between vehicles is less. Depending on the speed limit and how strict enforcement is this increases or decreases the infrastructure capacity (expressed in the number of vehicles per time period). A decrease in capacity was observed on Dutch motorways with very strictly enforced 80 km/h speed limits. After increasing the speed limit in peak hours to 100 km/h, this effect disappeared [Stoelhorst et al., 2011][Burgmeijer et al., 2010].

• route planning / route choice because some drivers may avoid roads with a strictly enforced speed limit, especially if this is a relatively low speed limit. A British study concludes such speed management leads to reduced mean speeds and accident rates, it also says there is some evidence suggesting that it affects route choice. [Mountain, 2005, p.12]

• the infrastructure capacity, if the system leads to a more homogenous or inhomogeneous speed distribution of all vehicles.

Automated Weight Limit Enforcement by Weigh-In-Motion

• In case overloaded trucks are in use the systems would lead to an increase in trip generation and driven vehicle-kilometres as more trucks are needed to carry the same transport weight.

• Route choice as drivers of overloaded trucks might avoid roads with this system in use. This would lead to an increase in vehicle-kilometres.

5.4.5 Parking guidance system

Parking guidance system influences the time that a driver needs to find a parking place. This can be for drivers of commercial vehicles, e.g. for the regulated breaks and rest periods (working time regulations for drivers of commercial vehicles above 7.5 tonnes gross weight and bus drivers), but also for drivers of private vehicles. The driver might use a different parking space than originally planned (destination choice) and even switch the mode of transport, e.g. if park-and-ride facilities are advertised.

• This reduces vehicle-kilometres to search for a parking place and avoid additional kilometres due to leaving the direct route and re-route on-trip.

• This improves the capacity usage of available parking space. Every driver can follow the given advice in a city or on a motorway to find a parking place on shortest way and in shortest time. If the vehicle has special needs (lorry, electric vehicle etc.), it could be guided to a parking space fulfilling these needs.

• This also reduces additional braking and acceleration (driving dynamics) of vehicles and can lead to more homogenous speed due to the shortening of the searching process.
5. Relevance of ITS for CO2 emissions

- Parking guidance systems can also increase the attractiveness of road traffic, if (perceived or real) parking problems are tackled and, thus, induce additional trips on the road.
- If the information is provided pre-trip (e.g. on the internet), such systems can also influence the departure time choice. If a trip is shifted to a less or more congested time, this leads to changes in travel time, speed and driving dynamics.
- Parking guidance systems increase the attractiveness of the area they are applied to, which can influence the location choice of companies for their offices and the attraction of leisure and shopping trips.

The effect of parking guidance systems is influenced by numerous other factors, including road and parking pricing, availability of parking space, accuracy of given information, and road layout. The effect can be greater if they are combined with other traveller information or navigation systems.

5.5 Demand and access management

5.5.1 Electronic Fee Collection

Electronic Toll Collection

- It helps to manage the traffic on toll stations in an efficient manner. That reduces traffic jams and improves the acceptance of the users to pass road sections with a toll. Hence, the travel time is nearly equal to a road section without any toll and shorter than with a conventional toll booth.
- Electronic toll collection lanes can be used without stopping the vehicle, thus increasing the average speed. If compared to free flow, though, the speed is lower, depending on the system used. A study of an Electronic Toll Collection (ETC) system in Orlando, Florida, which utilizes Automatic Vehicle Location technology, found that in the dedicated electronic toll collection lane throughput increased by 154%, average delay has decreased by 1 minute and total queuing delays were reduced by 8.5 vehicle hours per peak hour. Mixed lanes with electronic no-stop collection and collection by hand or machine did not show such benefits, but because traffic shifted towards the electronic toll collection lane delays were reduced there, too. Overall operation of the toll plaza was thus improved. [Al-Deek, 1996, p.221-222]
- By passing the toll facility without stop, electronic toll collection helps to reduce braking and acceleration (driving dynamics) of vehicles at the toll station. A study based on a modelling of the benefits of electronic payment systems indicates significant time and gasoline savings and minor emissions reductions through the application of no-stop toll payment lanes. [Chaudhary, R.H., 2003, p.58-59]
5. Relevance of ITS for CO2 emissions

- By improving the traffic flow quality at the toll facility, electronic toll collection can influence departure time choice (longer queues during peak hours are not as relevant), route choice (less avoidance of toll facility due to travel time), and even traffic demand due to higher attractiveness of the road section. A report about an electronic payment system in Baltimore, Maryland, USA indicated that the effective capacity of electronic payment lanes is more than double that of manual payment lanes. It also estimated that there would be significant emissions reductions. [Saka, 2000, p.10-11]

The effect of electronic toll collection is superimposed by the effect of the toll itself and the alternatives of the electronic toll collection lane (number of lanes and service time of non-electronic toll collection lanes) and route.

**Electronic ticketing**

- The system will have an influence on all kind of mode choice (strategic, pre-trip, on-trip) because fewer barriers for using public transport may occur (ticket choice, payment process).
- There is also an influence on departure time choice as there is no additional time for purchasing a ticket necessary.

**Other forms of electronic fee collection**

Electronic fee collection can apply to parking fees, where it might reduce the impediment to use a non-free parking space.

**5.5.2 ITS supported measures**

**Restricted traffic zones**

- Restricted traffic zones reduce the number of trips (at least in the zone) which leads to less vehicle-kilometres travelled in the defined zone, a lesser and/or better utilization of the infrastructure capacity, and less vehicle-kilometres from polluting vehicles [Klunder, 2009].
- In Stockholm, the trial reduced traffic crossing the congestion-charge cordon by 22%. The total number of vehicle kilometres travelled (VKT) was reduced by 14%. Congestion decreased, which improved reliability of travel times. CO2 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).
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. The first results indicate that 5 million vehicles less drive in the centre 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. CO₂ emissions have decreased by 9%.

Emission effects for London congestion charge were: (i) speed change: 7.4%, (ii) traffic volume change: -8.3%, total CO₂ reduction (2003 vs. 2002): 16.4%.

Furthermore, the vehicles in the restricted traffic zone will reach a higher average speed with a smoother driving style due to the reduced number of vehicles in the zone.

It changes pre-trip and on-trip route choice and destination for drivers of vehicles that are not allowed to enter the restricted traffic zones. That may causes detours with more vehicle-kilometres and more congestion on the other routes. On the other hand, it might also be that another destination closer by is chosen, which will lead to fewer vehicle-kilometres.

It influences the pre-trip mode choice in case the point of interest is inside the restricted traffic zone such that travellers will decide to public transport and cycle traffic for the whole way or for a part of it. That leads also to less vehicle-kilometres on the road and increases trip generation (more trips) for public transport.

The choice of the ownership of the transport means (private car) could also be influenced. If travellers have to enter the restricted traffic zone frequently, they would decide to buy e.g. a zero emission vehicle if this restriction demands to use only zero emission vehicles or will not take the car but a bicycle or a two-wheeler. That all influences the vehicle-kilometres per mode.

Otherwise it could increase parking search traffic outside these zones due to drivers who want to change the transportation type which can lead to traffic obstructions at boundary areas.

### Access Pricing

- It could influence the pre-trip mode choice (considering alternatives such as public transport or bicycling) due to a change in the relative price between the modes.
- It could influence the pre- and on-trip route choice in case of dynamic pricing that depends on time of day, location and traffic situation (e.g. congestion, level of measured emissions). This will influence the vehicle-kilometres, for example when drivers make a detour to avoid additional costs. Note that the costs of congestion are relatively high which implicates that in case this is included in the dynamic access pricing, a change of routes could imply that the external costs of the other cost components (including CO₂) could also become higher.
5. Relevance of ITS for CO2 emissions

- It could also influence the occupancy if more persons share one vehicle due to an increased price so the (additional) costs will split between more people.

Road Pricing

When Road Pricing is introduced, the attractiveness of road transport (transport costs) changes. This has an influence on:

- Mode choice; travellers might decide to use other transport modes, for example public transport instead of the car.
- Trip generation; because of a change in road transport costs, travellers might decide to make more or less trips.
- Destination choice; travellers might choose other destinations because of the costs of road transport (for example a supermarket more close to home).
- Departure time choice; when Road Pricing is differentiated over time (for example driving during peak hours is more expensive) travellers might choose other departure times.
- Route choice (possibly); when Road Pricing is differentiated over road types/areas. Detours will increase vehicle-kilometres.
- All in all, these influences result in a change in kilometres driven per mode; for CO2 calculation only the change in vehicle-kilometres driven on the road are of importance (individuals may travel less kilometres in public transport, but the trains, buses, etc. still drive the same amount of kilometres). Another result could be less congestion and increase of average speed because the number of vehicles on the road decreases.

On a longer term, there are other possible influences:

- Traffic demand; because of changes in modes chosen and trip generation, traffic demand might evolve.
- Location choice; people might choose other places to live, or transport/logistics companies might change their locations.
- Public transport scheduling; due to new travel patterns, changes in mode choice, trip generation and departure time choice, public transport companies might on the long term change their scheduling or the characteristics (such as size) of the vehicles. (With the same argument, the infrastructure might change on the long term).
5.6 Driver behaviour change and eco-driving

5.6.1 Driving assistance and cruise control (road traffic)

Intelligent Speed Adaptation/Assistance

An Intelligent Speed Adaptation (ISA) system is a system that assists the driver in not exceeding the speed limit. The system can have different forms; it can be an advisory system warning the driver (with an auditory or visual signal) or an intervening system, physically making speeding harder or impossible, for example with a haptic gas pedal.

ISA has an influence on

- The speed of the vehicle since it prevents the driver from speeding. Whether the average speed increases or decreases cannot be predicted, since some drivers use ISA to drive faster and closer to the speed limit (they are less afraid of exceeding the speed limit).
- The driving dynamics since some ISA systems intervene by braking automatically, or they induce the driver to brake.
- The capacity of the road, since the ISA system can influence the standard deviation of the speed, and the differences between the speeds of different vehicles. In this way traffic can be more homogeneous.

Adaptive Cruise Control (ACC)

- the (long-term) capacity utilization of the infrastructure because of a high safety level that reduces accidents and causes less traffic jams (automatically regulated headways lead to smoother traffic flow). A simulation-based study found that in traffic where all vehicles have Adaptive Cruise Control, traffic congestion is significantly reduced. The results are mixed when Adaptive Cruise Control and non-Adaptive Cruise Control vehicles both use a road. In a single lane simulation, concentrations of Adaptive Cruise Control vehicles of upward of 20% would prevent traffic disruptions, however in multiple lanes even an ACC concentration of 50% would lead to only small improvements over traffic with all manually driven vehicles. It points out a possible problem in lane merging as the "optimal" headway between two Adaptive Cruise Control vehicles might be too small for a manually driven vehicle to safely merge into. [Davis, 2004, p.066110-7]
• the number of braking and acceleration processes because the Adaptive Cruise Control could probably not provide the same foresighted driving behaviour like a driver – normally, a driver not only considers the next vehicle in front but also preceding vehicles ahead he is able to perceive. This effect of a reduced environment perception compared to a human driver could counteract the generally smoother dynamics (less acceleration/deceleration) by an automatic control. The side effect from the system’s reduced perception of the environment could, and probably will, be avoided by the driver by switching off the Adaptive Cruise Control. A study came to the conclusion that it is implied that the Adaptive Cruise Control has no impact on maximum road capacity. The same study did report less variation in acceleration patterns which could lead to reduced fuel consumption. It also reported that a lot of drivers turn off the Adaptive Cruise Control in particularly congested traffic situations and that there are no signs of improved traffic efficiency in peak conditions due to Adaptive Cruise Control. [Marsden, 2001, p. 48-49]

• A study of the effects of adaptive cruise control on driver behaviour found that drivers generally drive faster, accept smaller headways and perform lane changing manoeuvres more efficiently. [Hoedemaeker, 1998, p. 101-105]

**Predictive Cruise Control (PCC)**

• The system influences speed, headway and driving dynamics. A study which included a field experiment with a predictive cruise control system for heavy trucks designed to incorporate the geometry of the road ahead into the cruise control mechanism found significant fuel savings. Over a 120 km long trip a fuel consumption reduction of 3.5% without an increase in travel time was found. [Hellström, 2007, p.8]

Research involving a cruise control system designed to optimize a truck’s performance in economic terms through predictive incorporation of road slope shows significant fuel savings with only minimal time lost. [Passenberg, 2009, p.5-6]

A study investigating the fuel saving potential of predictive driving strategies in urban situations taking information about the vehicle’s environment into account such as traffic lights, found significant fuel savings in an experimental test of an equipped vehicle. [Raubitschek, 2011, p.6-7]

**Cooperative Adaptive Cruise Control (CACC)**

• As an enhanced version of Adaptive cruise control the system similarly influences speed, headway and driving dynamics, but due to the communication with other vehicles or infrastructure it takes more parameters into account for a better optimized operational profile. This will lead to a further reduction of fuel consumption.
5. Relevance of ITS for CO2 emissions

- CACC can help maintain a safe distance, and it can prevent some rear-end accidents from happening. It can help make driving smoother (better “anticipation” for disturbances in the traffic flow ahead).
- The system can influence the infrastructure capacity by minimizing the headway and aligning the speed. In a study investigating the effects of CACC used by trucks, it was shown that when sufficiently widely deployed the capacity of the road section can be increased by 6%. The average speed of car traffic meanwhile increases by 6.4%. [Müller, 2012, p.100]
  It was found in a simulation study that if CACC is deployed widely (+60% penetration) it can significantly improve throughput and traffic flow stability. With a penetration rate of less than 20% CACC has no positive impact on the capacity. [van Arem, 2006, p.434-435]
  Another study found that a market penetration of above 40% CACC would lead to significant improvement in traffic dynamics. It would greatly increase the capacity of a highway by improving traffic flow and increasing average speed. [Arnaout, 2011, p.714-715]

Autonomous Driving

Assumption is that only special infrastructure sections are enabling autonomous driving (e.g. motorways). Autonomous Driving influences:

- speed as it automatically adjust the speed depending on the traffic flow, speed limits and pre-sets given by the driver.
- headway, based on the driven speed.
- Driving dynamics as the system can adjust speed and headway in a more smooth way than a driver by avoiding acceleration and braking where possible. This will decrease fuel consumption and CO2 emissions.
- the infrastructure capacity because of a more homogenous speed and minimized headway. In addition it reduces accidents and induced traffic jams as a primary effect.
- The control of such a system can be optimized for energy consumption. This can relate to optimized driving dynamics as well as to driving in closely spaced platoons reducing air drag. Both effects can considerably reduce energy demand.
- to a lesser extent to pre-trip and on-trip route choice. If a driver prefers going by car in a modus of autonomous driving and only special infrastructure sections are enabling it (e.g. motorways), this could lead to an increase in driven vehicle-kilometres.
5. Relevance of ITS for CO2 emissions

- Since autonomous vehicles and automated highways have not been implemented yet outside experimental tests there is as of now no empirical evidence of realised benefits in a real transport network. However, there have been computational simulations which in one instance found: “Compared to today’s manually driven highways, such an AHS (Automatic Highway System) can carry twice the number of vehicles at highway speed with a substantial improvement in safety.” [Godbole, 2000, p.23].

5.6.2 Railway systems

Driverless Train Operation

- The system influences the parameters driving dynamics and speed as the system will operate the train on an optimal speed level with respect to factors like signalling ahead, topography, punctuality of the train, etc. In this way it will lead to a better energy efficiency of railway operation.

5.6.3 Driving behaviour (road traffic)

Driving behaviour recognition system

- The system gives feedback to a driver on how efficient the vehicle is driven. This can influence the driver’s behaviour regarding speed, headway and driving dynamics. For example, an extended headway reduces the need for braking and acceleration. This would reduce the average fuel consumption. The overall fuel savings depend on the driver’s behaviour and on the situation (e.g. urban, motorway or mixed).
- The use of auxiliary systems can be influenced by the system too, as it can show how much fuel is needed for auxiliary system like air condition. Again, the fuel savings depend on the drivers.

5.7 Logistics and fleet management (commercial and public transport fleets)

5.7.1 Public transport systems

Computer Aided Dispatch and Scheduling (CADS)

With IT-based technologies the finding of an optimal deployment of trucks according to the orders and their proximity is supported. In principle this technology application is similarly deployed in train operations.
A study from 2004 stated, that around 23% of the firms are using that kind of ITS [Léonardi and Baumgartner 2004, pp. 454]. An impact of this system on companies introducing the system is given in [Léonardi and Baumgartner, 2004, pp. 461]:

- The total load increases by 14% (due to more vehicles used).
- The total distance increases by 3% as the system influences strategic route planning and pre-trip route choice.
- The total fuel consumption increases by 2% (due to increased distance).
- the mean fuel use (l/100km) per vehicle decreases by 1%.

A survey with associations and firms of different branches evaluated the effect of ITS on transportation. Following impacts of dispatching and transport planning could be found [Bernsmann et al., 2006 pp. 84]:

- a reduction of empty driven kilometres of 10 %.
- a reduction of driven kilometres of 7 %.
- On load factor, the increase of the usage of the vehicles capacity by 17 %.

**Operational Control System (OCS)**

- The system influences the availability of transport modes and the connection with other modes as it ensures a greater punctuality and assures connections to other lines within the public transport network.
- With a higher reliability and shorter travel times due to reliable transfer connections travel behaviour and therefore traffic demand might be influenced on a long term perspective, thus will lead to a change in public transport scheduling as well (e.g. an increase in headway to meet a higher demand).
- By increasing punctuality and, thus, ensuring homogeneous headways between public transport vehicles (reducing bus bunching/platooning) the system will lead to a more homogenous occupancy of the vehicles.

**Dynamic Schedule Synchronisation**

- In case of a delayed vehicle (e. g. train) the system can influence the departure time choice by forwarding the expected arrival time and advice a later departure time for other vehicles (e. g. a bus will wait for passengers transferring from a delayed train). This will influence the connection with other modes as well.
- Based on reliable transfer connections the system influences the departure time choice of travellers, as there is no need for additional buffer time for missed transfers necessary anymore and therefore they might start a trip later.
5. Relevance of ITS for CO2 emissions

- The system will influence strategic route planning as travellers might choose routes with a transfer instead of a direct bus because travel time is less and they can rely on the transfer connections.
- With a higher reliability and shorter travel times due to reliable transfer connections travel behaviour and therefore traffic demand might be influenced on a long term perspective, this will lead to a change in public transport scheduling as well (e.g. an decrease in headway to meet a higher demand).

5.7.2 Freight transport systems

Electronic system for freight transport

E-freight influences:

- the flow of data and information that could reduce waiting times and could accordingly reduce transport times to load and unload freight.
- the data quality; based on an electronic system for freight transport system and the related standardisation of data and data formats, it is possible to set and control quality standards for data; as a consequence waiting times due to incomplete or lacking documentation can be reduced or avoided.
- mistakes that occur in loading and enabling announcements to all partners in a supply chain to be prepared for providing the confirmed service. That reduces vehicle-kilometres as a secondary effect.

Fleet Management System (FMS)

A Fleet Management System has influence on

- Vehicle availability, since fleet management includes the selection and acquisition of vehicles this determines the vehicles/vessels/trains that are owned by a logistics company. Fleet management systems also keep track of which vehicles will be in maintenance at which moment.
5. **Relevance** of ITS for CO2 emissions

- Route choice (pre-trip and on-trip), since some vehicles are not able to use several routes. For example there are height or weight restrictions for certain parts of the road or waterway. Therefore the vehicle choice does influence the set of possible routes to choose from. By using a fleet management system, the location of the vehicles is known through GPS. In case of for example a traffic jam, this makes it easier to change the route on-trip. A study conducted by Motorola in 2008 by survey of a large number of enterprises found that use of GPS fleet tracking solutions led to significant time savings (54 minutes a day on average) and fuel savings by reducing the distance travelled by the fleet. This was achieved through optimized route organization.

- Transport means choice, since the fleet management system determines which vehicles are owned by the logistics company. The initial investments and the operational costs of the vehicles also have an impact on choices made. Also the fleet management system can show the location of vessels, trucks and trains, which gives an indication of when they will be available again.

- Load factor / occupancy, each transportation means has different capacity characteristics. Fleet management systems can help to optimize the load factor of the available vehicles by selecting the vehicles in correspondence with the expected operational requirements. A study detailing a real-time fleet management system and evaluating it in a trial showed that a truck equipped with the system was able to reach more customers and provide more satisfactory performance than trucks without it in the event of unexpected delays in an urban road network [Zeimpekis, 2008, p. 6-7, 9].

On societal level, the Fleet Management System has the following effects:

- The mix of vehicles that are used is influenced by fleet management systems and therefore the resulting external costs of the vehicles as well.

**Intelligent Truck Parking influences:**

- Strategic route planning as well as pre-trip and on-trip route choice because a route with such a system might be chosen instead of a more direct route to avoid illegal truck parking and search for parking spaces, with a consequence in increasing driven vehicle-kilometres.

- Departure time choice as a better journey planning for dispatchers is possible.

- Infrastructure capacity, due to a better utilisation of existing truck parking spaces [Anner, 2009, p.33].

- Traffic safety through reduction of illegal truck parking.
Supply Chain Management System

The coordination of (all) actors and their logistical activities in a value added chain is the aim of SCM. This includes the common planning of flows of commodities, information and finance. The effects of the system are [Bernsmann et al. 2006, pp. 135]:

- shortening of the order-to-delivery-time because of a controlled and transparent material and information flow and has therefore a long term impact on the traffic demand (new production concepts, variation of products, new marketing opportunities [see Gilaninia et al. 2011]).
- impact on the departure time planning by the coordination of the interactions. An integrated dynamic scheduling system for meat product fabrication at Swift & Company led to an improvement in on-time delivery of 8% on average and up to 22% at peak times [Bixby, 2006, p.80].
- on one hand side a reduction of trips and vehicle-kilometres by avoiding wrong deliveries and in time detection of meanderings. On the other hand side an increase of the number of trips is possible because of just-in-time (JIT) deployment with probably more vehicle-kilometres [Sanchez-Rodrigues 2006, pp. 19 ff. and 29 ff.].
- optimisation of transport capacities promoted by in-time information flows. That enhances the use of capacities and reduces vehicle-kilometres.
- reduction of stocks (warehouses) by enabling just-in-time and just-in-sequence interaction. At Kwangyang Works of POSCO, a steelworks, the introduction of a real-time production and scheduling system, led to an improvement in on-time delivery [Tang, 2001, p. 7].
6. Summary

This deliverable describes the methodology and its application for a classification of ITS with respect to their potential impact on CO₂ emissions. In order to provide the basis for the Amitran framework, a detailed approach was followed consisting of four steps:

1. Identification, classification and description of ITS to be considered by Amitran
2. Identification, classification and description of transport processes of relevance for CO₂ emissions
3. Qualitative impact assessment of ITS with reference to transport processes
4. Qualitative impact assessment of ITS on CO₂ emissions

The major objective of this qualitative impact assessment of ITS with reference to CO₂ was not to provide just another classification of ITS, but to give insight into how systems affect traffic and CO₂. For this purpose the intermediate step of identifying influencing factors and parameters describing traffic demand, driver behaviour and vehicle conditions was necessary. This list of factors and parameters is an input to the Amitran framework developed in WP 4.

The assessment of systems and transport processes was conducted by several experts for the different system categories by means of an online survey, direct consultation, and expert discussions. Results from literature review complete the assessment.

The impact assessment is supported by evidence from the literature and a description of the impact of systems for the most relevant ITS. Based on the qualitative impact assessment all examined ITS have been assigned to impact classes. These classes are an estimate on their potential relevance for influencing CO₂ emissions.

It has been underlined that a detailed system assessment requires a clear definition of the context in which the scrutinised ITS is deployed. This includes a distinct system definition, the description of the setting in which the system is deployed and other systems which might interact with the examined ITS.

Furthermore, the maturity of systems influences the uncertainty involved in a system assessment. Because the qualitative assessment documented in this deliverable follows a general approach and as such does not limit the context in which systems are deployed nor narrows the definition of systems to a very specialised context, not for all systems a distinct impact estimate could be provided.
The list of systems, the impact these systems have on transport processes and consequently the factors and parameters describing them together with the relevance these parameters have for CO₂ emissions provides a typology of ITS on which the further development of Amitran can be based (WP 4, WP 5).

The major outputs of this deliverable are:

- A comprehensive list of more than 50 ITS for the modes road, rail, and inland waterways, grouped into six categories and further divided into sub-categories for easy reference (Chapter 2).
- A list of factors influencing traffic demand, parameters describing traffic demand, driving behaviour and vehicle conditions, which can be influenced by ITS, and long term effects of ITS, supplemented by an estimate of the relevance of these parameters for CO₂ emissions (Chapter 3).
- An overview on the most important effect of ITS on the mentioned parameters (Chapter 4).
- A classification of ITS into high, medium, and low potential systems with respect to their impact on CO₂ emissions and a qualitative description of these effects (Chapter 5).

The qualitative impact assessment highlights that systems from the whole range of ITS categories have high potential to influence CO₂ emissions. Not only ITS supported measures like restricted traffic zones, access or road pricing might affect CO₂ emissions significantly, also traveller information (e.g. car-sharing information systems, and real-time traveller information systems) or navigation systems (those for electrical cars more than general ones). Also driver assistance systems from adaptive cruise control to autonomous driving promise a relevant impact on CO₂. In case of freight, supply chain management systems belong to the high impact class. Finally, multimodal planning support systems (e.g. multimodal tour planning systems) are judged to yield high potential for changes in CO₂ emissions.

It is apparent that systems either affecting the specific emissions caused by vehicles (e.g. driving dynamics), or fostering a modal shift belong to the high impact class. The more directly the system can influence travel or driving behaviour (no impact of acceptance or compliance), the higher the expected impact is.

The impact classification provided in this deliverable is no replacement for a more detailed assessment using the Amitran methodology. Major reasons are that a specific implementation of a system may give different assessment results than found in this assessment and in literature due to the context in which systems are deployed, the interactions between systems, the importance of system specification, and the accuracy that can be achieved by an expert survey. A system assessment requires a precise definition of the systems and the potential
impacts under scrutiny. Such a definition is provided in this deliverable and will feed into the Amitran framework.

The output of WP 3 documented in this deliverable will feed into the further WPs of Amitran in the following way:

- Factors influencing traffic demand and parameters describing traffic demand, driving behaviour and vehicle conditions will be incorporated in the Amitran framework (WP4) and, thus, are taken into account in the definition of the model interfaces (WP5).
- Particular attention will be paid to the processes with high relevance for CO₂ emissions.
- The Amitran framework will consider the identified impact systems have on specific factors and parameters (WP4).
- Systems with high impact potential for changes in CO₂ emissions will be part of the use cases outlined in WP2 and detailed in WP6.
- The ITS typology allows conclusions from assessed systems to systems belonging in the same category and sub-category making Amitran flexible for future application and new systems.
- When useful the list of systems with their description and the ITS typology will be included in the Amitran handbook (WP7).
Annex A References for system assessment

A.1 Navigation and Travel Information

A.1.1 Navigation systems

A.1.1.1 Static Navigation System


A.1.1.2 Dynamic Navigation System


A.1.2 Traveller information systems

A.1.2.1 Car-Sharing and Ride-Sharing Information System


### A.1.2.2 Dynamic Passenger Information


### A.1.2.3 Real-Time Traveller Information System


A.1.3 Planning support systems
A.1.3.1 Multi-Modal Tour Planning System


A.1.4 Inland waterway information systems
A.1.4.1 Dynamic information for skippers


A.2 Traffic Management and Control
A.2.1 Signal Control
A.2.1.1 Adaptive Signal Control


### A.2.2 Highway systems

#### A.2.2.1 Collective Re-Routing System


#### A.2.2.2 Road Section Control System


A.2.3 Railway systems

A.2.3.1 European Rail Traffic Management System (ERTMS)


A.2.4 Enforcement systems

A.2.4.1 Automated Speed Enforcement


A.2.5 Parking guidance
A.2.5.1 Dynamic Parking Guidance System


A.3 Demand and Access Management
A.3.1 Electronic Fee Collection
A.3.1.1 Electronic Toll Collection


A.3.2 ITS supported measure
A.3.2.1 Restricted Traffic Zones


A.4 Driver Behavior Change and Eco-Driving
A.4.1 Driving assistance and cruise control (road traffic)
A.4.1.1 Intelligent Speed Adaptation/Assistance

Annex A References for system assessment


A.4.1.2 Adaptive Cruise Control (ACC)


A.4.1.3 Predictive Cruise Control (PCC)


A.4.1.4 Cooperative Adaptive Cruise Control (CACC)


A.4.1.5 Autonomous Driving


Annex A References for system assessment


A.5 Logistics and Fleet Management

Carbon Footprint of Freight Transport (COFRET) (2012). D 2.3 Future technologies and innovations relating to freight transport which are relevant for carbon footprint calculation.

A.5.1 Public transport systems

A.5.1.1 Computer Aided Dispatch and Scheduling (CADS)


A.5.2 Freight transport systems

A.5.2.1 Electronic system for freight transport

e-freight project. General project description.

A.5.2.2 Fleet Management System


A.5.2.3 Intelligent Truck Parking


A.5.2.4 Supply Chain Management System


A.6 Safety and Emergency Systems

A.6.1 Augmented awareness

A.6.1.1 Drowsy Driver Warning System

A.6.1.2 Lane Departure Warning System


A.6.1.3 Collision Warning System

### Annex B  Glossary

<table>
<thead>
<tr>
<th>System</th>
<th>Descriptor in Amitran</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adaptive Traffic Control at Intersections</td>
<td>Adaptive Signal Control</td>
<td></td>
</tr>
<tr>
<td>Automatic fare collection</td>
<td>Electronic ticketing</td>
<td></td>
</tr>
<tr>
<td>Collision avoidance</td>
<td>Collision Warning System</td>
<td></td>
</tr>
<tr>
<td>Driver impairment</td>
<td>Drowsy Driver Warning System</td>
<td></td>
</tr>
<tr>
<td>Dynamic Lane Management</td>
<td>Road Section Control System</td>
<td>For road sections</td>
</tr>
<tr>
<td>Dynamic Lane Management</td>
<td>Junction Control System</td>
<td>For junctions</td>
</tr>
<tr>
<td>E-ticket</td>
<td>Electronic ticketing</td>
<td></td>
</tr>
<tr>
<td>Environmental zone</td>
<td>Restricted traffic zones</td>
<td></td>
</tr>
<tr>
<td>Intelligent Compact Parking</td>
<td>Intelligent Truck Parking</td>
<td></td>
</tr>
<tr>
<td>Lane keeping</td>
<td>Lane Departure Warning System</td>
<td></td>
</tr>
<tr>
<td>Low-emission zone</td>
<td>Restricted traffic zones</td>
<td></td>
</tr>
<tr>
<td>Low-noise zone</td>
<td>Restricted traffic zones</td>
<td></td>
</tr>
<tr>
<td>Platooning</td>
<td>Autonomous Driving</td>
<td></td>
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<tr>
<td>Predictive Powertrain Control</td>
<td>Predictive Cruise Control</td>
<td></td>
</tr>
<tr>
<td>Ramp metering</td>
<td>Junction Control System</td>
<td></td>
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<tr>
<td>Collective Traveller Information by Variable Message Signs</td>
<td>Real-Time Traveller</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Information System</td>
<td></td>
</tr>
</tbody>
</table>
Annex C  Expert skills

This annex summarises the skills of the experts involved in the system assessment (cf. section 1.2.3). A list of the experts with their respective background is provided in a separate confidential annex (System Assessment Background).

25 experts were involved in the system assessment. Experts were assigned to systems according to their expertise in the system category. An overview on how many experts were involved in the assessment of the respective system categories is shown in Table 12.

Table 12 Number of experts involved in WP 3 assessment for respective system categories

<table>
<thead>
<tr>
<th>Category</th>
<th>Number of experts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Navigation and Travel Information</td>
<td>10</td>
</tr>
<tr>
<td>Traffic Management and Control Systems</td>
<td>11</td>
</tr>
<tr>
<td>Demand and Access Management Systems</td>
<td>7</td>
</tr>
<tr>
<td>Driver Behaviour Change and Eco-driving</td>
<td>12</td>
</tr>
<tr>
<td>Logistics and fleet management</td>
<td>11</td>
</tr>
<tr>
<td>Safety and Emergency Systems</td>
<td>6</td>
</tr>
</tbody>
</table>

Most experts have more than ten years of professional experience in the transport field including senior researchers with over 20 years’ experience. Professional background ranges from mathematics, operations research, physics, psychology and cognitive sciences, geography, urban planning to economics, and different fields of engineering (transport engineering, civil engineering, mechanical engineering, computer engineering). Many experts have worked on emissions and air quality issues and have long experience in the field of ITS.

Many experts have been involved in numerous European projects, also related to impact assessments and ITS analysis. The experts work at one of the consortium’s organisations (TNO, PTV, DLR, Tecnalia, Ecorys, Ertico).
Annex D Bibliography


3.1: Methodology for classification of ITS (version 11, 2013-06-12) 102


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