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Intelligent Transport Systems (ITS) – latest developments and the use of micro-simulation assessment

S Ball

Transport Research Laboratory

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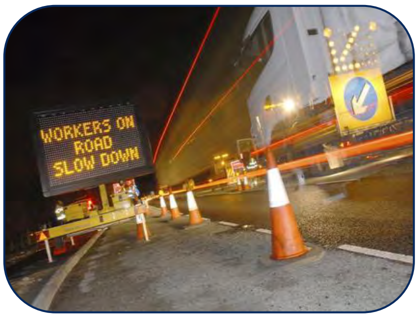


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Intelligent Transport Systems (ITS): latest developments and the use of micro-simulation assessment

Simon Ball

Prepared for: Bill Hewlett, Costain

Quality approved:

Peter Owlett	Jean Hopkin
(Project Manager)	(Technical Referee)

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Contents

Abstract

This report provides an overview of the latest developments in Intelligent Transport Systems (ITS), with a particular focus on applications relevant to micro-simulation, including autonomous/semi-autonomous driving technologies and co-operative systems. Furthermore, there is a review of several examples where micro-simulation has been used to assess the impacts of ITS. Many ITS applications are currently being deployed, or are being sought to be deployed, and some form of verification or testing is required to assess their impact. There are several different approaches for doing this, of which micro-simulation appears to be one of the most powerful methods in some cases. This document is intended to be read in parallel with the accompanying report, which gives a review of the state-of-the-art in micro-simulation. The purpose of these two documents is to provide a baseline understanding of the state-of-the-art in ITS and micro-simulation.

Executive Summary

Intelligent Transport Systems (ITS) is defined as the integration of information and communications technology with transport infrastructure. Different ITS have different purposes, but many have the aim of reducing congestion and/or reducing accidents.

Traffic micro-simulation (or microscopic simulation) is defined as a simulated environment where individual vehicles and their interactions are modelled in detail.

Many ITS applications are currently being deployed, or are being sought to be deployed, and some form of verification or testing is required to assess their impact. This assessment may be required: (a) before development starts; (b) during development to confirm it should continue; (c) to check the effect of systems as they are switched on; (d) to monitor their impact after deployment. In principle (a) and (b) are to check the viability and safety of the concept before investment is made and (c) and (d) are final checks. There are different approaches to running checks at (a), (b), (c) and (d), as discussed in §3.1. In particular, "micro-simulation" appears to be one of the most powerful approaches for assessing the impact of some ITS applications. This paper therefore examines how micro-simulation is being used as a test method for ITS and what needs to be done to make it fully reliable.

This report provides an overview of the latest developments in ITS (§2), with a particular focus on applications relevant to micro-simulation, including car-following, autonomous driving technologies and co-operative systems. Furthermore, there is a review of examples where micro-simulation has been used to assess the impacts of ITS (§3.5).

This document is intended to be read in parallel with the accompanying report (Gibson, 2011), which gives a review of the state-of-the-art in micro-simulation. The purpose of these two documents is to provide a baseline understanding of the state-of-the-art in ITS and micro-simulation.

Several examples of where micro-simulation has been applied to ITS have been reviewed (§3.5). In particular, the following examples have been highlighted as potentially relevant.

Co-operative vehicles and autonomous / semi-autonomous control systems

Many of the examples reviewed involve modelling the ITS application on a short section of motorway and then comparing against a baseline scenario, e.g. as in PRE-DRIVE C2X (§3.5.2). If it is necessary to understand the network-wide effects of these systems, the traditional approach is to model a short section and then scale-up to the whole network by the occurrence of the scenarios, as in CODIA (§3.5.1). However, this approach is limited in that it may not accurately represent the "complexity" at a network level. An alternative approach is as in the recent iTetris project (§3.5.3), which has developed the capability to simulate co-operative systems at a regional city-wide level.

Dynamic route guidance during incidents

Two examples of dynamic route guidance during traffic incidents were reviewed:

- §3.4.1 – The PREDIKT project (Sweden) extended the Mezzo mesoscopic simulation model to provide real-time decision support for incident management. It tested several alternative scenarios, allowing issues to be foreseen. On a city-wide network, the mesoscopic model works approximately 200 times faster than real-time, which is fast-enough to be of use to decision makers.

- §3.5.9 – As part of the TRANSUMO Intelligent Vehicles programme (Netherlands), micro-simulation was used to assess the traffic impacts of traffic information during an incident, both from in-vehicle systems as well as from road-side Variable Message Signs (VMS).

Platooning

The SARTRE project is currently determining platooning strategies and is due to conduct detailed modelling of these strategies in September 2012 (see §2.3 and §3.5.7).

Driverless cars

No examples of micro-simulation applied to driverless cars were found in this review.

Combination of multiple local micro-simulation models to an area-wide model

It was noted that there are multiple micro-simulation models across various cities and it may be beneficial to combine these into one large model for each city.

Pervasive sensors

The novel approach during the MESSAGE project (see §3.7.1) of using pervasive sensors to automatically validate micro-simulation models is of interest.

1 Overview of ITS

1.1 This document

This report provides an overview of the latest developments in Intelligent Transport Systems (ITS), with a particular focus on applications relevant to micro-simulation, including car-following, autonomous driving technologies and co-operative systems. This has been achieved through an extensive review of available materials online and academic library services. This has also involved contacting industry experts for input on the current state of the art.

This document is intended to be read in parallel with the accompanying report (Gibson, 2011), which gives a review of the state-of-the-art in micro-simulation. The purpose of these two documents is to provide a baseline understanding of the state-of-the-art in ITS and micro-simulation.

Section 1 provides an overview of ITS in general. Section 2 covers the latest developments in ITS, with a particular focus on applications relevant to micro-simulation. Section 3 reviews existing examples of how micro-simulation has been used to assess the impacts of ITS. Section 4 gives a summary of the ITS impact studies reviewed in this report.

Appendix A summarises the key relevant points from the recent EC "Future of Transport" White Paper.

1.2 What is ITS?

1.2.1 Definitions of ITS

Intelligent Transport Systems (ITS) means different things to different people, and as such there are a variety of definitions. Some definitions are reproduced here.

[ERTICO-ITS, the network of ITS stakeholders in Europe] (ERTICO, 2011)

> "ITS - Intelligent Transport Systems and Services - is the integration of information and communications technology with transport infrastructure, vehicles and users. By sharing vital information, ITS allows people to get more from transport networks, in greater safety and with less impact on the environment."

[ISO TC 204, the international standardisation body for ITS] (ISO, 2008)

> "ITS is the application of information technology, communications technology, and sensor technology, including the internet (both wired and wireless), to the general challenges and opportunities of surface transportation… ITS holds the promise of improving traffic management and vehicle safety… The major trends are:
>
> - integrating vehicles with roadway networks through the use of on-board wireless communications;
> - conversion of vehicle and infrastructure data to provide timely location based services to drivers and roadway operators;
> - to improve advanced safety applications such as automatic crash notification, secure freight transport and crash avoidance;
> - an improved environment through reduced fuel consumption."

[Bill Gillan, Public Service Review: Transport, Issue 23] (Gillan, 2009)

> "ITS is an umbrella term for a range of information and control systems aimed at optimising the return on transport investment, by improving travel efficiency and reducing the risk of accidents. All ITS include data collection and assessment, strategy processing and feedback of advice and guidance to travellers, both public transport users and drivers. The core technologies employed are sensors, communication links, processing elements, displays and actuators. Communication may rely on optical fibre, wire or wireless links."

For the purposes of this study we focus on the interplay between intelligent control systems and the complex ever evolving real world.

1.2.2 Policy themes for ITS and example applications

In 2005, the DfT set out the "ITS Policy Framework for the Roads Sector" and identified seven "Themes" for ITS (DfT, 2005):

- Improving road network management
- Improving road safety
- Better travel and traveller information
- Better public transport on the roads
- Supporting the efficiency of the road freight industry
- Reducing negative environmental impacts
- Supporting security, crime reduction and emergency

There is a large number and wide variety of ITS applications, both existing and under development. Some applications serve more than one of the seven policy themes above. Furthermore, ITS applications can use technology that is infrastructure-based, vehicle-based, or both, and may be used in urban, rural or motorway environments. A selection of example ITS applications are discussed below to illustrate these points:

- Vehicle Activated Speeding Signs – infrastructure-based technology; for use in urban and rural environments; for the purpose of improving safety.
- In-vehicle Dynamic Route Guidance – in-vehicle technology; for use in all environments; primarily for the purpose of better traveller information, but may also help reduce congestion.
- Variable Speed Limits – infrastructure-based technology; for use in motorway environments; primarily for the purpose of reducing congestion, but also has safety and environmental benefits.
- Adaptive Traffic Signal Control, e.g. "SCOOT" – infrastructure-based technology; for use in urban environments; primarily for the purpose of reducing congestion and improving bus priority, but also has environmental benefits.
- Co-operative Systems – both in-vehicle and infrastructure-based technology; for use in motorway and urban environments; different purposes depending on the specific application, but may include reducing congestion, improving safety, better traveller information and reducing emissions.

2 Latest developments in ITS

This section gives an overview of the latest developments in ITS. There is a specific focus on any ITS applications that could be modelled using micro-simulation in order to understand their impact on measures such as operational efficiency, safety, the environment, etc. The review includes the latest developments in car-following platoons, autonomous driving technologies and co-operative systems.

The headings in this section are broad categories in ITS; in practice, some ITS applications will sit across more than one of these categories.

2.1 Co-operative Vehicle Highway Systems

The innovative aspect of "Co-operative Vehicle Highway Systems" (CVHS) is that they involve Vehicle-to-Infrastructure (V2I) and/or Vehicle-to-Vehicle (V2V) communications[1]. The following definition for "Co-operative Vehicle Highway Systems" (CVHS) has been proposed (Gelencser et al., 2010):

> "Co-operative vehicle systems communicate and share information dynamically between vehicles or between vehicles and the infrastructure, to give advice or take actions with the objective of improving safety, sustainability, efficiency and comfort…
>
> The scope… ranges from applications which warn the driver, to those which potentially take control from the driver in safety-critical situations…
>
> The scope excludes vehicle-based systems that use non-dynamic information received from the infrastructure e.g. temporary speed limits. The scope also excludes [applications where]… the driver is taken out of the loop under some or all normal driving conditions."

There is on-going research into ITS applications, such as road trains and driverless cars, where the driver is taken out of the loop under normal driving conditions. These applications are discussed later in this chapter in §2.3 and §2.5.

Example applications

There are potentially hundreds of CVHS applications and therefore much of the recent research has focused on interoperability and a common platform for these applications.

The European project, Pre-Drive C2X, defined three different types of CVHS application: safety; traffic efficiency; and infotainment/business/deployment. Selected use cases are re-produced below (Pre-Drive C2X, 2011):

- Selected safety related use cases
  - road works warning
  - stop sign violation
  - traffic jam ahead warning
  - car breakdown warning
  - slow vehicle warning
  - approaching emergency vehicle
- Selected traffic efficiency related use cases
  - in-vehicle signage
  - regulatory and contextual speed limit
  - traffic information and recommended itinerary

[1] The terminology Vehicle-to-X (V2X) or Car-to-X (C2X) is sometimes used; this may involve communications that are Car-to-Car, Car-to-Infrastructure or Car-to-Nomadic Device, etc.

    - limited access warning
    - decentralized floating car data
    - green light optimal speed advisory

- Selected infotainment, business and deployment related use cases
    - vehicle software provisioning and update
    - fleet management
    - local electronic commerce
    - insurance and financial services

Other CVHS applications that are frequently mentioned include:

- Road condition warning
- Obstacle on driving surface
- Weather warning (e.g. ice or fog on road ahead)
- Intelligent on ramp metering
- Intelligent speed adaptation (ISA)
- Eco-driving support
- Non-stop tolling and Pay/earn as you drive

Research projects

Co-operative vehicles have been a research area of great activity over recent years. Table 1 summarises some projects of note. In particular, aspects of the Pre-Drive C2X project are discussed further in §3.5.2.

Table 1 – Summary of various recent CVHS projects

Project	Duration	Location	Specific focus
PRE-DRIVE C2X	2008-2010	Europe	Developed a vehicular communication prototype, to be used in future field operational tests
SAFESPOT	2006-2010	Europe	Safety-related applications
CVIS	2006-2010	Europe	To enable a wide range of potential co-operative services to run on an open application framework
COOPERS	2006-2010	Europe	Infrastructure-based applications for "Co-operative Traffic Management"
SEVECOM	2006-2008	Europe	Security of communications
GEONET	2008-2010	Europe	Geo-networking, i.e. exchange of congestion information with vehicles in a particular geographic area.
E-FRAME	2008-2011	Europe	Extending the European ITS Architecture for co-operative vehicles
COMeSafety European ITS Architecture	2006-2009	Europe	The European ITS Communications Architecture
Advanced Safety Vehicle, Phase 4 (ASV-4)	2005-2010	Japan	Japanese co-operative vehicles; substantially further along than Europe, with more deployed
Vehicle-Infrastructure Integration (VII)	2003-2009	USA	Co-operative vehicles engineering research programme, based on DSRC
IntelliDrive	2009-ongoing	USA	Main American project on co-operative vehicles, based on new technologies; following-on from VII

Potential Issues to investigate with micro-simulation

Examples where micro-simulation has been used to assess the impacts of co-operative vehicles are discussed in the following sections:

- §3.5.1 – CODIA
- §3.5.2 – Pre-Drive C2X
- §3.5.3 – iTetris

2.2 In-vehicle warning and control systems / Advanced Driver Assistance Systems

There are a range of in-vehicle warning and control systems already at different levels of development and deployment. These "semi-autonomous" systems are considered to be a stepping stone to fully autonomous vehicles.

Also referred to as "Advanced Driver Assistance Systems" (ADAS), the DfT states that these fall into three categories (DfT, 2005), namely technologies that:

- "Support drivers by giving warnings and providing information – e.g. dynamic route guidance systems that forewarn of real-time traffic conditions;
- Assist the driver taking over specific elements of vehicle control – e.g. Intelligent Speed Adaptation systems can operate in this way; and
- Over-ride the driver and take control, particularly in emergency situations – e.g. collision avoidance systems that prevent vehicles from driving too closely together."

The DfT recognised that "these systems can improve safety and support vulnerable road users, but can also change driver behaviour and may be distracting". Furthermore, "the overall balance between what is a benefit and what is a distraction is not yet clearly understood and there is no systematic approach being taken to evaluating the impacts (both good and bad)".

ISO TC 204, WG 14

The primary international standardisation body for ITS, ISO TC 204, has a Working Group specifically for in-vehicle warning and control systems (WG 14). Many of the standards in WG 14 define performance requirements and test procedures. Currently there are a range of standards both published and under development for the following applications, including:

- Adaptive Cruise Control
- Full-speed Range Adaptive Cruise Control
- Forward Vehicle Collision Warning
- Traffic Impediment Warning
- Low-speed Following

The working group also has standards relating to other applications that are of reduced utility from a micro-simulation point of view: Lane Change Decision Aid; Lane Departure Warning; Low-speed Manoeuvring; Reverse Manoeuvres.

Adaptive Cruise Control – purely for comfort

Adaptive Cruise Control (ACC) uses headway sensors to continuously measure the distance to other vehicles, automatically adjusting the speed to ensure the vehicle does not get too close to the one in front. The driver activates the cruise control by setting the desired maximum speed and then selecting the time gap to the vehicles in front. ACC then adjusts the vehicle's speed to match that of preceding vehicle as necessary. The system then increases the speed to that previously set when the vehicle in front accelerates or changes lanes.

Adaptive Cruise Control – "Traffic Assistance System"

ACC is primarily designed as a convenience for drivers. However, there has also been research into ACC that is designed to help smooth traffic flow (Kesting et al., 2008). Such systems determine when the vehicle is travelling through different traffic states and alter the parameters of the ACC. For example, when approaching the downstream front of a shockwave the ACC reduces the gap to the car in front compared to standard ACC; simulation has shown that this can help reduce congestion.

Co-operative Adaptive Cruise Control

Co-operative Adaptive Cruise Control (CACC) is similar to ACC, with the addition that vehicles can exchange information with other vehicles by wireless communication. Although CACC is primarily designed for giving the driver more comfort and convenience, CACC has a potential effect on traffic safety and traffic efficiency. If there are several vehicles equipped with CACC, this is effectively a "platoon". Platoons are discussed further in §2.3.

Potential Issues to investigate with micro-simulation

Examples where micro-simulation has been used to assess the impacts of in-vehicle warning and control systems are discussed in the following sections:

- §3.5.4 – Congestion Assistant
- §3.5.5 – Co-operative Adaptive Cruise Control
- §3.5.6 – Adaptive Cruise Control, "Traffic Assistance System"

Large-scale field operational tests have also been conducted on some of the systems discussed above. These are discussed in §3.2.

2.3 Platoons / car-following technologies / automated road trains

In this context, platoons are groups of automated vehicles following each other, typically with much smaller headways than usual. Benefits of such systems may include better fuel efficiency, increased road user safety, increased traffic throughput, as well as convenience for the driver.

Historic platooning projects

The feasibility of platooning has been analysed in several European projects, including CHAUFFEUR I and CHAUFFEUR II. It has also been considered in the national projects, PATH (USA) and KONVOI (Germany, only Goods Vehicles). These projects focused mainly on the technical feasibility of the concept.

The CHAUFFEUR II project considered three approaches to platooning (van Arem et al., 2006):

- An "electronic tow bar", where vehicle-to-vehicle communication was used to enable the vehicle to automatically follow the manually driven leading vehicle at a short distance between 6 and 12 metres;
- The "Chauffeur assistant", which enabled the equipped truck to follow any other vehicle on a highway with a safe following distance using ACC and a lane-keeping system;
- Electronic coupling of three trucks in a platooning mode with vehicle-to-vehicle communication, whereby the leading vehicle is driven conventionally, and both following trucks follow at a close distance (6 to 12 metres).

It was concluded that the main effects of the CHAUFFEUR II systems were a better usage of road capacity, up to 20% reduction in fuel consumption, and increased traffic safety. However, it was remarked that platooning is mostly feasible at night or on sections with low-traffic volume, because during high-traffic volume the stability of traffic flow decreased. Thus the potential benefits for road capacity do not appear likely to be realised in practice.

Overview of the SARTRE project

SARTRE (SAfe Road TRains for the Environment), is an EC-funded research project to develop strategies and technologies to allow vehicle platoons on public highways (SARTRE, 2011). The project started in September 2009 and is due to end in September 2012. SARTRE is the most advanced platooning project of its type in the world.

The proposed scheme would involve a lead vehicle in a truck or bus with a professional driver, taking responsibility for the platoon. Following vehicles would enter a semi-autonomous control mode with automated longitudinal and lateral control. This would allow the driver of the following vehicle to do other things that would normally be prohibited for reasons of safety; for example, operate a phone, read a book or watch a movie. This concept could lead to a new business model for road use, with the following vehicles being charged to join a platoon.

It is proposed that the platoons would operate on un-modified public highways and interact with other traffic. The consideration of how platoons interact with other non-platoon users is a central part of the project. A large element of the research is looking into this aspect and will provide clear strategies that will be implemented in the prototype system.

Benefits of SARTRE

The estimated benefits of platooning include: environmental benefits (an estimated 20% emissions reduction); safety benefits (reduction of accidents caused by driver action); and a reduction in congestion (smoother traffic flow with potential consequential increase in throughput). There would also be 'convenience' or 'comfort' benefits for the driver. The benefits (Davila, Nombela, 2010) are explored further below.

The estimated **environmental benefits** are based on the outputs of a previous American project, called Partners for Advanced Transit and Highways (PATH) Programme. More specifically, the reduction in fuel consumption depends on the number of vehicles in the platoon, the distance between the vehicles and the aerodynamics of the vehicles. The results of the PATH project suggested that for a platoon travelling at approx 0.2 vehicle lengths apart (i.e. approx 1 metre), there was: a 10% reduction in fuel consumption with 2 vehicles in the platoon; a 20% reduction with 3 or 4 vehicles in the platoon; a 25% reduction with "many" vehicles in the platoon. With vehicles travelling at 1 vehicle length apart (approx 4 metres), this fuel saving is reduced to between 5% and 15%, depending on the number of vehicles in the platoon. The SARTRE project is therefore aiming to have the vehicle headways of "about 1 metre". Also the environmental benefits are greater when there is a smaller vehicle following a larger vehicle. This is the reasoning behind having a lead vehicle in the form of a commercial vehicle, such as a truck or bus.

The **safety benefits** are mainly a reduction in the risk of accidents. The logic behind this is that there would be a trained professional driver, with autonomous control systems for the following vehicles.

In order to understand the proposed potential **traffic flow benefits**, it is necessary to consider four different scenarios.

- "Free traffic" – "SARTRE platooning may not bring improvements for free traffic"
- "Collapsing traffic" – "The point of the collapse is dependent on the required traffic space of each vehicle and the time gap. The smaller the time gap the more the collapse point is shifted towards higher traffic flows."
- "Synchronic inhomogeneous traffic" – [This type of traffic is characterised by] "density waves where vehicles drive in between 30 km/h and 80km/h in a 100-metre distance". "In this case, a significant improvement can be expected as the autonomous guidance helps reduce the dynamics."
- "Stop and go traffic" – "when the platoon leaves the traffic jam, as the acceleration is sufficient enough and controlled, maintaining the space between vehicles thus leading to a faster dissolving of the congestion."

It should be noted that the majority of text from the SARTRE website focuses on the benefits, and there is currently no discussion of the potential disadvantages: e.g. the impact of large platoons on other vehicles when overtaking or merging or diverging.

How the platoons would work – the SARTRE Concept

During the remainder of the project several strategies will be considered on how the platoons would work (Bergenhem et al., 2010).

> "The following vehicles are under automated longitudinal and lateral control… The following vehicle driver must be able to take over control of the vehicle in the event of a controlled or unforeseen dissolving of the platoon. A challenge with such situations is to decide when it is safer to remain in automated control rather than give manual control to the driver.
>
> The platoon can consist of both heavy vehicles, e.g. trucks or buses, and passenger vehicles i.e. cars… It is currently assumed that for safety reasons a car may never travel in a platoon between two heavy vehicles, i.e. trucks/buses…
>
> The project goal of increasing fuel efficiency implies that platoon vehicles must travel with reduced gaps between them. To achieve this goal an appropriate longitudinal and lateral control system must be designed. In vehicles that are currently being produced there are systems such as adaptive cruise control, collision mitigation by braking and lane departure warning. SARTRE plans to use sensors and actuators from state-of-the-art production systems…
>
> Each vehicle must also be equipped with a local control system. To achieve global control over the platoon, a communication system that interconnects the vehicles must be devised… The control strategy for the platoon will be a combination of local control where each vehicle individually senses its environment and global control

where the lead vehicle decides set-points e.g. following distance and speed. Global control may also be required to avoid oscillations in the platoon as these will have a detrimental effect on fuel efficiency, safety and also passenger comfort."

Use Cases have been defined for operations within the platoon:

- Platoon Use Cases
  - Create platoon
  - Join platoon
  - Maintain platoon
  - Leave platoon
  - Dissolve platoon
- Back-office Use Cases
  - Register
  - Handle platoon status
  - Charge platoon
  - Guide to platoon

Potential Issues to investigate with micro-simulation

There are certainly several major issues regarding the potential impact that platoons (as defined in SARTRE) may have on traffic flow, in particular the effect on congestion, overtaking and merging at junctions. Work Package 5 of the SARTRE project is "Assessment" and is due to be completed in 2012, but initial results have already been presented.

- §3.5.7 – The sub-microscopic simulation tool, PELOPS, is being used to assess the traffic impacts of platoons, as part of the SARTRE project.

2.4 Intelligent Speed Adaptation

Intelligent Speed Adaptation (ISA) is a driver assistance system that applies information on the current road to advise or control the vehicle speed. ISA can take three forms:

- Advisory/Informative– this simply displays information to the driver on the speed limit on the current road; this is envisaged as useful particularly when driving through foreign countries and also road works;
- Optional/Voluntary – this limits the vehicle speed to comply with the fixed speed limit on the current road, as well as any speed limits that change with road geometry; however, this can be over-ruled by the driver at anytime;
- Mandatory – this limits the vehicle speed to comply with the speed limit on the current road and cannot be over-ruled; a potential application of this may be to HGVs, which already have mandatory controls to limit them to 56mph on motorways.

There have been several pilots and field trials of ISA, notably in Sweden, where several thousand vehicles were equipped between 1999 and 2002 (wiki.fot-net.eu, 2011). There have also been ISA trials in Belgium, Spain and the Netherlands. The DfT has conducted four ISA field trials in Leeds as well, with 20 vehicles equipped (DfT, 2007).

A non-regulatory example was the InnovITS-funded project, Sentience, which involved a hybrid petrol-electric vehicle equipped with ISA (www.sentience.info, 2011). The Sentience vehicle used information on the road conditions ahead to change the balance between the electric and petrol engine; for example, if there was a hill ahead, it knew it would be able to save energy by using the regenerative braking more. Project partners included Ricardo, TRL, Orange, innovITS and Ordnance Survey.

Potential Issues to investigate with micro-simulation

One potential impact of ISA is that journey times would be longer, because many human drivers usually travel faster than the speed limit. As a result of slower speeds, there would be more cars on the road and potentially more congestion.

Examples where micro-simulation has been used to assess the impacts of ISA are discussed in the following sections:

- §3.5.8 – Leeds University study on the impacts of ISA

2.5 Driverless cars and other autonomous technologies

Historic projects

"The Automated Highway" was an American demonstration project, whereby cars were able to drive themselves on the motorway, not necessarily in a platoon. The proposed system was to work through a combination of: magnets spaced every metre in a dedicated lane; a traffic management centre; in-vehicle devices; and other field equipment (Banasiak, 1996). The system was able to keep equipped vehicles in-lane, properly spaced, and guided toward their destination while sensing and avoiding obstacles. The system was demonstrated on an 8-mile trial segment of motorway near San Diego in August 1997. However, after the demonstration the idea was dropped, due to liability issues (Cheon, 2000).

PROMETHEUS was a large European project with multiple partners running from 1987-1995, which investigated the concept of driverless cars. The technology involved is now somewhat out-of-date and so has not been covered in detail in this review.

Current projects – military

Recently, there has been interest again in driverless cars, particularly in the military sector, with several demonstrations. The benefit of driverless cars in the military is that they could be deployed in war zones with reduced numbers of service personnel at risk from road-side bombs.

The "Darpa Grand Challenge" is a competition funded by the American military, where autonomous cars attempt to complete a challenging course through the desert (www.darpa.org, 2011). Groups compete against each other to win the $2 million prize. The contestants are not allowed to control or send signals to the robots once the race starts.

Similarly, the "Darpa Urban Challenge" was an autonomous ground vehicle race held at an airbase in California in 2007 (www.torctech.com, 2011). In order to complete the course, fully autonomous vehicles had to traverse 60 miles of urban and off-road environments in under 6 hours. Vehicles had to achieve speeds of up to 30 mph while negotiating live traffic from both human test drivers as well as the other robotic competitors. Each autonomous vehicle had to complete a series of simulated military supply missions requiring merging into moving traffic, navigating traffic circles, negotiating busy intersections, parking in marked lots, handling roadblocks, and avoiding obstacles.

In 2007, BAE Systems demonstrated its first, fully autonomous ground vehicle: a converted Bowler 'Wildcat' off-roader (www.baesystems.com, 2007). It took six months, to transform a commercially available 4x4 vehicle and equip it with the ability to drive and think for itself. The Bowler Wildcat was able to follow planned routes at speeds of up to 40 mph, as well as avoid obstacles in its path, all without the need of a driver.

Current projects – road-cars

Various vehicle manufacturers and research organisations have recently developed demonstration driverless vehicles. These vehicles work using a combination of lasers, video detection, radar, and wheel sensors. Such examples include:

- Google Car
- GM Driverless car
- Stanford "Junior"
- Volkswagen Golf Gti Automatic

Potential Issues to investigate with micro-simulation

As will be discussed in §3.1, 'sub-microscopic simulation' explicitly models three parts of the system: the driver, the vehicle and the road environment. Driverless cars effectively simplify this problem, replacing the human driver with autonomous control.

No examples of micro-simulation applied to driverless cars were found as part of this literature review.

If there was large-scale roll-out of driverless cars, there may be similar issues to ISA, in that equipped vehicles would travel exactly at the speed limit, tending to reduce overall traffic speed.

2.6 Other ITS applications of interest

This review has concentrated on predominantly in-vehicle motorway applications, such as car-following platoons, autonomous and semi-autonomous driving technologies and co-operative systems. As discussed in §1.2.2, the scope of ITS is much wider than this and can include infrastructure-based applications (e.g. Variable Speed Limits), applications in the urban environment (e.g. Adaptive Traffic Signal Control) and traveller information applications (e.g. Dynamic Route Guidance, both road-side and in-vehicle). These applications are not explained here, but some are considered in the next section on assessing the impacts of ITS.

Potential Issues to investigate with micro-simulation

Examples where micro-simulation has been used to assess the impacts of the following ITS applications are discussed in:

- §3.4.1 – Dynamic Route Guidance (mesoscopic simulation)
- §3.5.9 – Dynamic Route Guidance (micro-simulation)
- §3.5.10 – Variable Speed Limits
- §3.5.11 – Adaptive Traffic Signal Control, e.g. SCOOT

3 Case studies in ITS and simulation

3.1 "Measures of impact" for different types of ITS

As discussed in §1.2.2, ITS applications exist to serve a variety of policy themes. The impact (and hopefully success) of a particular ITS application may be determined through assessing a combination of "measures" in relation to these policy themes. For example, the impact of a safety-related ITS application could be measured through assessing the number of accidents in a 'Before' and 'After' study, or alternatively in the occurrence of heavy braking and failed lane changes in a model simulation. These "measures" are discussed further in §3.5.12.

These impact assessments may be done through a variety of methods, such as: field operational tests (FOTs); macroscopic simulation; mesoscopic simulation; microscopic simulation (commonly referred to as micro-simulation); sub-microscopic simulation.

Simulation is commonly used to assess impacts of ITS in desk-based research studies. However, simulation can also be used in real-time to aid traffic managers in making decisions on how to use the ITS; for example, what traffic information to display during an incident (e.g. see §3.4.1).

The difference between macroscopic and mesoscopic and microscopic can be defined as (Burghout, 2004):

> "The levels of detail in simulation models range from macroscopic via mesoscopic to microscopic. Macroscopic models describe the traffic at a high level of aggregation as flow (the number of vehicles per hour that pass a certain point), without considering its constituent parts (the vehicles), whereas microscopic models describe the behaviour of the entities making up the traffic stream (the vehicles) as well as their interactions in detail. Mesoscopic models are at an intermediate level of detail, for instance describing the individual vehicles, but not their interactions."

These different methods have their own advantages and disadvantages:

- Field operational tests – assessing the impacts in a real-world environment, comparing the 'Before' and 'After', using real data over a statistically significant period of time. FOTs are predominantly for near-to-market applications that are almost ready for deployment.
- Macroscopic simulation – modelling the impact in a simulated environment at a high level of aggregation with flows on links, rather than individual vehicles. This is useful for estimating the impact on measures such as modal shift over large networks.
- Mesoscopic simulation – simulation where vehicles are modelled individually, but their interactions are captured in an aggregate manner. These have an important performance advantage over micro-simulation models. Commonly used to model behaviours such as route choice of individual vehicles in relation to traffic information.
- Microscopic simulation – modelling the impact in a simulated environment, where it is necessary to take account of individual drivers and their interactions in detail. However, some measures such as the occurrence of flow breakdown on motorways and other complex and emergent behaviour are difficult to re-create, regardless of assessing particular ITS applications.
- Sub-microscopic – simulation with individual vehicles as in micro-simulation, but breaks this down one step further by representing the three parts of the system: the driver, the vehicle and the road environment.

These are discussed further below, with particular emphasis on how micro-simulation has been used.

3.2 Use of field operational tests to assess the impacts of ITS

Field Operational Tests (FOTs) are defined as (www.fot-net.eu, 2011):

> "Large-scale testing programmes aiming at a comprehensive assessment of the efficiency, quality, robustness and acceptance of ICT solutions used for smarter, safer and cleaner and more comfortable transport solutions, such as navigation and traffic information, advanced driver assistance and co-operative systems."

FOTs involve equipping large numbers of vehicles with ITS applications and collecting data over a statistically significant period of time in real-world traffic conditions.

Large scale field operational tests give information not only about technological issues, but also deployment-related concerns, such as what the impacts are on safety, efficiency, and on the environment. FOTs help to understand several key questions: How does the driver use the system? What are the short and long term effects? How can the system performance be further improved?

The results of FOTs help business leaders to make informed decisions about the market introduction or improvements in the systems. They also enable policy makers to establish the right policy framework for deployment of these systems, such as via a market-driven approach, incentives or mandatory fitting of certain types of systems.

3.2.1 EuroFOT

EuroFOT (www.eurofot-ip.eu, 2011) was an EC-funded field operational test that involved equipping more than 1000 vehicles and trucks with ITS applications. A large amount of data was collected across Europe in real-world traffic conditions with ordinary drivers. Data was collected through a wide range of sensors and devices monitoring individual driver behaviour, as well as questionnaires.

The project aimed to address the following research issues:

- What is the performance and capability of the systems?
- How does the driver interact with and react to the systems?
- What are the impacts on safety, efficiency, and on the environment?

The project ran from 2009 to 2010 and was a collaboration of 28 organisations, including vehicle manufacturers, automotive suppliers, universities and research centres. Eight different ITS applications were tested, predominantly 'semi-autonomous' in-vehicle warning and control driver assistance systems (see §2.2):

- Assisting the driver in forward/rear safety - longitudinal control functions:
  - Adaptive Cruise Control
  - Forward Collision Warning
  - Speed Control System
- Assisting the driver to detect hazards at the sides - lateral control functions:
  - Blind Spot Information System
  - Lane departure warning / Lane assist / Impairment warning
- Advanced applications:
  - Curve Speed Warning
  - Fuel Efficiency Adviser
  - Safe Human/Machine Interface

The project used the standard methodology for FOTs, which was developed in 2008 in the EC-funded FESTA project.

3.3 Use of macroscopic models to assess the impacts of ITS

Macroscopic modelling only has flows on links, rather than representations of individual vehicles as in micro-simulation. There are different types of macroscopic models, with different terminology, such as "strategic models" and "traffic assignment models". The most well-used macroscopic model is VISUM. The common themes include:

- Network – the physical road network links, programmed with characteristics, such as number of lanes and speed limits, as well as the public transport network. Many macroscopic models have networks that are city-wide or regional-wide, with thousands of links.
- Origin-Destination Matrix – this details the number of trips starting and ending in zones. Often the matrix is created from a combination of the "Trip Generation" and the "Trip Distribution".
- Mode Choice – whether each trip is undertaken by car or different types of public transport.
- Route Assignment – assigning the trips to a particular route between the origin and destination.

Some ITS applications are discussed below, where this type of transport model has been applied to understand the impacts of ITS.

Road pricing schemes

It is possible to use macroscopic models to assess the impact of road pricing schemes, both time-distance-place schemes and area-based schemes. One such study (Cheng Lu et al., 2008) proposed a simulation-based approach to capture the users' path choices in response to time-varying toll charges.

Other approaches (e.g. Olszewski, Xie, 2005) don't use traffic models, but instead use real congestion data and mathematical models to assess the impact of different pricing strategies.

Improvements in public transport

It is possible to use traffic models to assess the impact of certain public transport ITS schemes. For example, smartcards have been shown to reduce bus boarding times, and estimates of the reduction in bus journey times can be included in the model. The model can then be run with and without the reduction in bus journey times to assess the impact of the scheme in terms of predicted bus utilisation and modal shift to public transport.

SatNav with dynamic route guidance

In-vehicle dynamic route guidance is an ITS application of particular interest, because the impact it has on route choice is not fully understood. If all equipped drivers take the alternative route to avoid congestion ahead and the penetration rate is very high, there is the potential scenario of violent oscillations between two route choices. This is a major risk as more and more people get 'intelligent SatNavs'.

3.4 Use of mesoscopic models to assess the impacts of ITS

In mesoscopic simulation, vehicles are modelled individually, but their interactions are captured in an aggregate manner. Examples of mesoscopic models include:

- DynaMIT [Massachusetts Institute of Technology]
- DYNASMART [University of Texas, Austin]
- Mezzo (open-source) [Royal Institute of Technology, Sweden]
- CONTRAM [TRL / Mott MacDonald]

One of these is discussed below.

3.4.1 (Traffic Info): Assessing the impact of traffic information in incident management for real-time decision support

Centre for Traffic Research, Royal Institute of Tech. (Sweden); 2009

Modelling package used: Mezzo

This journal paper discussed the PREDIKT Project and Mezzo simulation tool (Burghout, Andreasson, 2009).

Outputs of the PREDIKT project

The PREDIKT project extended the Mezzo mesoscopic simulation to model drivers' responses to incidents and various scenarios with different traffic information. The model was able to "provide decision support for incident management, by means of state-estimation based on the latest sensor data and faster than real-time prediction of outcomes of various candidate management scenarios". It was a four-year project and funded by the Swedish National Road Administration.

The authors stated that simulation-based real-time prediction consists of three main aspects:

- Off-line calibration of the model in 'average conditions'.
- On-line state estimation – This entails the on-line calibration of the model to the current traffic conditions from the latest sensor readings (traffic flows, speeds, and travel times). This also involved the re-estimation of the Origin-Destination matrix to reflect the real-time current demand.
- On-line prediction – The next step is to predict the short-term (15-45 min) effects of a number of possible response scenarios.

While step 1 is not time-critical, steps 2 and 3 need to be performed much faster than real-time, if the operator is to successfully implement the most promising response scenario.

The model developed within the PREDIKT Project was "able to run a full Stockholm network at 200x real-time (6000+ links) and the case study network (Stockholm Södermalm + Södra länken, 1000 links) at 1500x real-time, which is more than fast enough for use in online state estimation and prediction".

Simulation tool used – Mezzo

Mezzo is an open source, event-based, mesoscopic simulation model. Similar to other mesoscopic models, vehicles are modelled individually, but their interactions are captured in an aggregate manner. Specifically:

- On links, empirically calibrated speed-density relationships are used to calculate travel times;
- At nodes, turning-specific "queue-servers" are used to model the effect of capacity constraints.

The model is event-based, which means that only changes in the traffic system state are calculated, such as vehicles entering or exiting links, traffic signals changing state etc. The alternative to event-based is time-stepped (or clock-based), as in micro-simulation models, where the state of all vehicles is evaluated at regular intervals. Event-based models have an important performance advantage over time-stepped models, saving much wasted computation time.

In addition to the speed-density functions and queue-servers at nodes, the model represents explicitly the backward propagating shockwave of queued vehicles starting to accelerate, providing correct representation of the propagation of congestion.

The model has been developed with the ability to interface in a hybrid way with micro-simulation models.

Further info on Mezzo -> www.ctr.kth.se/publications/ctr2004_04.pdf (Burghout, 2004)

3.5 Use of microscopic models to assess the impacts of ITS

This section considers some examples where micro-simulation has been used to assess the impacts of ITS. This is a selection of projects covering some of the applications discussed in §2.

3.5.1 (CVHS): Co-Operative systems Deployment Impact Assessment (CODIA)

TRL, VTT; 2008

Modelling package used: SISTM

TRL conducted a traffic and emissions impact assessment for the deployment of various co-operative systems. This was part of a wider cost-benefit analysis undertaken by the Finnish company VTT. This was an 8-month EC-funded project (Kulmala et al., 2008).

Methodology

The traffic and emissions impacts of eight different co-operative vehicles applications were assessed. The applications included speed reduction warnings due to conditions on the roads ahead for poor weather, congestion and accidents. The SISTM model was adapted to represent each application; some key aspects of the modelling were:

- Data was obtained on estimates of penetration rates for future years: 2010, 2020, and 2030. A lower-bound and higher-bound penetration rate simulation run was conducted for each application for each future year. The 0% and 100% penetration rates were also conducted.
- Both "Motorway" (multiple lanes) and "Rural" (single lane) scenarios were modelled.
- A number of runs were conducted for each scenario with different random number seeds.
- Scenarios were conducted for different flow rates: "Level of Service B, D, F".
- The stretch of road that was simulated was of the order of approximately 1000 metres. This short section was then scaled-up to EU-wide, using total vehicle km

by road type and flow, as well as the extent to which each system would be in use.

- The acceleration and deceleration rates were put into an in-house emissions and noise model, which estimated the environmental impact.

Results

The most substantial traffic impact was due to the congestion warning application, where drivers were warned to slow down if there was congestion ahead. In this scenario there was a (Europe-wide) increase of 73.3 million vehicle hours in the 100% penetration scenario compared to the baseline 0% penetration. The direct emission effects were very small for all systems, and the noise impacts were negligible.

3.5.2 (CVHS): Pre-Drive C2X

European project with multiple partners; 2008-2010

Modelling packages used: VISSIM+VCOM; ITS Modeller; PreScan+OPNET; Combined tool; VISSIM+NS-2; SUMO+communication; VSimRTI; VSimRTI with OPNET; VISSIM+VCOM/NS-2+PHEM;

Pre-Drive C2X was a European project (2008 to 2010) that prepared a large scale field trial for vehicular communication technology. The project developed a detailed specification for such a system and a functionally verified prototype, based on the European COMeSafety architecture for a "Vehicle-to-X" communication system. The prototype is robust enough to be used in future field operational tests.

The "Integrated Simulation Tool Set"

As part of the project an integrated simulation model for co-operative systems was developed. This enables a holistic approach for estimating the expected benefits in terms of safety, efficiency and environment. The "Integrated Simulation Tool Set" is defined as the combination of four models:

- Traffic model – Vehicles and their movements
- Communication model – Messages and their flow
- Environment model – Vehicles and their emissions
- Application model – Information and its effects

The tool set includes all tools and methods necessary for functional verification and testing of co-operative systems in a laboratory environment and on real roads in the framework of a field operational test. It can be used for: assessing global benefits of C2X applications; developing C2X technology; planning FOTs.

The Integrated Tool Set is a collection of different micro-simulation models and combinations of models. A key achievement of the project was to recommend which models/bundles are appropriate for assessing the different applications, as detailed in Table 2. See the companion report (Gibson, 2011) for further information on some of these models.

Table 2 – Pre-Drive C2X: Co-operative systems use cases and recommended modelling bundles (reproduced from Benz, 2010)

Use Case / Application	Bundle
Traffic jam ahead warning	VISSIM + VCOM; ITS Modeller; PreScan+ OPNET; Combined tool
Decentralized Floating Car Data (FCD)	VISSIM + NS-2; VISSIM + VCOM; SUMO + communication
Traffic information and recommended itinerary *[i.e. Dynamic Route Guidance]*	SUMO + communication; VSimRTI
Green light optimized speed advisory	VSimRTI with OPNET; VISSIM + VCOM / NS-2 + PHEM
Warning for car breakdown / road works / slow moving vehicle	Combined tool
Regulatory and contextual speed limit	VSimRTI

One of the use cases modelled was a dynamic route guidance application, where equipped vehicles reported their travel times, and based on this information receiving vehicles chose the fastest route. The results showed travel time benefits of at least 20% for equipped vehicles at most penetration rates. There were also reduced emissions for equipped vehicles at penetration rates below 35%; at higher penetration rates it was predominantly non-equipped vehicles who benefited from lower emissions.

Two key observations of the gaps in existing models were to:

- "create, adapt and improve interfaces"
- "accommodate C2X applications methodologically".

Figure 1 shows an example architecture used in the project with interfaces between the main modelling package, VISSIM, and various other modules.

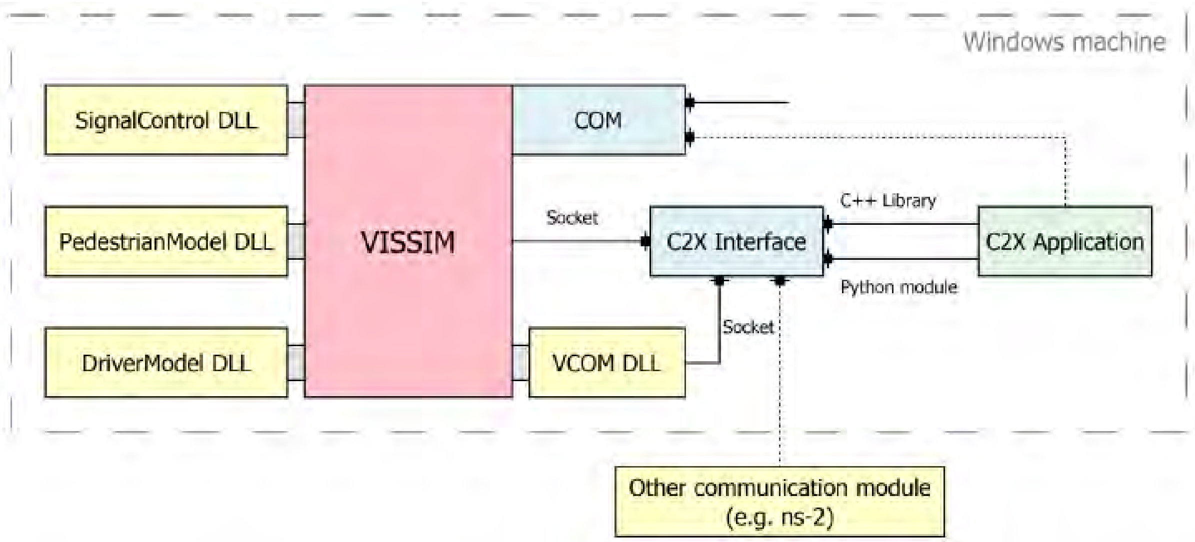

Figure 1 – "Additional and improved interfaces" (reproduced from Benz, 2010)

Communication Models

When assessing any co-operative vehicles application, the communication module is a key part of the model. One area of work within Pre-Drive C2X was to recommend the appropriate level of detail in the type of communication, depending on the application. This level of detail, or "scalability" ranged from "Information Level" to "Packet Level" to "Bit Level". An overview of the work in communication models included the following points (Hartenstein et al., 2010):

- "Starting point: various isolated communication models for certain aspects were available
- Recommended appropriate communication models for use cases and application scenarios
- Created interfaces between communication, traffic, and environmental models and tools for the integrated tool set
- Created new communication models that are highly accurate but fast to execute
- Validated communication models (cross validation between tools, partners and different communication layers)
- Predicted communication and corresponding application performance"

Emission Models

Three different types of emission models were considered (in order of complexity):

- Average speed models (e.g. COPERT) – These were not recommended for assessing most C2X applications, because "change in driving has to be depictured".
- Velocity and Acceleration (e.g. VERSIT+) – These were recommended as suitable for most C2X applications, except for scenarios where the engine has to work harder, e.g. "if change in gear shift behaviour has to be expected, if a road gradient exists or if effects of vehicle designs or loadings shall be simulated".
- Engine power (P_e) and Engine speed (rpm) (e.g. PHEM) - These were recommended as suitable for all C2X applications.

The two latter models are "emission map-based models", i.e. each type of vehicle has a 3-D graph, so for an instantaneous pair of velocity and acceleration, the emissions (grams/sec) can be read off from the graph.

The project also used information from the Handbook Emission Factors for Road Transport (HBEFA), which provides emission factors for all current vehicle categories for a wide variety of traffic situations.

Further info on Pre-Drive C2X -> http://www.pre-drive-c2x.eu/.../publications

3.5.3 (CVHS): iTetris – "The Integrated Platform for Large Scale Simulation of Co-operative ITS Strategies"

European project with multiple partners; 2008 - Jan 2011

Modelling packages used: SUMO; NS-3

The iTETRIS project developed an open, ETSI-compliant, and flexible simulation platform to conduct large-scale simulations of co-operative systems (ict-itetris.eu, 2011). This has enabled road authorities to gain clear evidence at city-level on the benefits and impact of co-operative ITS solutions, before they are widely deployed and evaluated in FOTs. In particular, the city-wide impacts on road traffic efficiency, operational strategy, and communications interoperability can be assessed.

The European-funded project was completed in January 2011. The work packages were as follows:

- Traffic Management Scenarios
- Traffic Management Policies and Protocols
- Traffic Modelling
- Wireless Communications Simulation Modelling
- Integration of Traffic and Wireless Simulation Platforms
- Routing and Data Distribution Strategies
- Integration of V2V and V2I Communication Capabilities
- Dissemination & Exploitation

Simulation packages used – SUMO and NS-3

iTETRIS integrated a traffic simulation platform with a wireless communications platform. Both platforms are well-known and widely used open-source simulation tools:

- SUMO is a microscopic traffic platform developed by the German DLR laboratories (http://sumo.sourceforge.net);
- NS-3 is a wireless communications simulation platform and is able to perform large-scale simulations (http://www.nsnam.org).

The iTETRIS simulation platform follows a three-block modular approach. The two open source simulation platforms, which were not altered by the iTetris project were not directly connected to each other. Instead, they were connected via a central module called the "iTETRIS Control System (iCS)". In order to consider simulation efficiency for large scale simulation, all three components ran on the same computer.

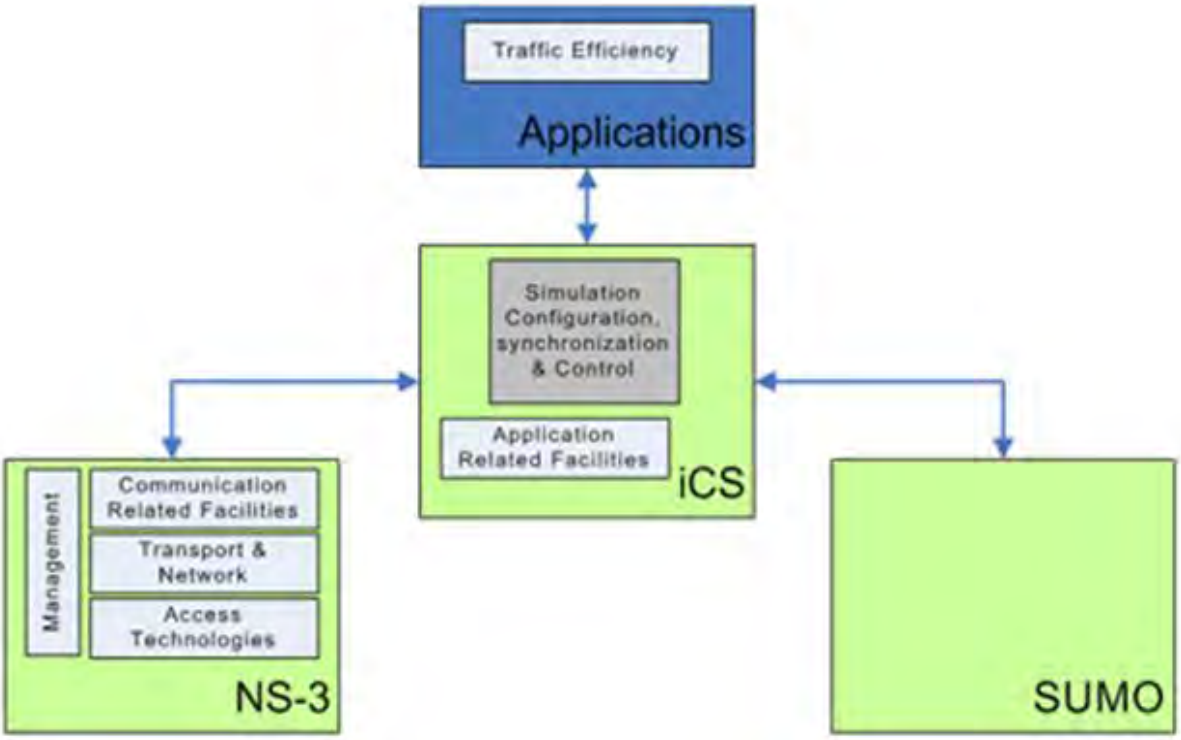

Figure 2 - The iTETRIS simulation platform (reproduced from ict-itetris.eu, 2011)

Future uses of the iTETRIS platform

The following uses of iTetris have been proposed (Wetterwald, 2010):

- "Performance evaluations of communication protocols
- Evaluation of the effect of traffic management applications
- Simple integration of novel applications and scenarios
- Help future FOTs for planning in their preliminary phase
- Extend the SUMO or ns-3 simulator to cover new emerging use cases and scenarios, or even replace either of them with another simulator, as interoperability is a key objective of the development of the iCS."

Further info on iTetris -> http://ict-itetris.eu/

3.5.4 (ADAS): Adaptive Cruise Control "Congestion Assistant"

Rapp Trans AG, Delft University (Netherlands); 2010

Modelling package used: ITS Modeller (and Paramics as a front-end)

This journal paper presented the results of a micro-simulation study to assess the effect of a Congestion Assistant on the traffic flow in terms of traffic efficiency and traffic safety (Van Driel, Van Arem, 2010).

Methodology

The "Congestion Assistant" was a combination of two driver-support Adaptive Cruise Control systems: an active pedal when approaching a traffic jam and a stop-and-go pedal when driving in a traffic jam. Key aspects of the methodology included:

- There were six variants of the system, each modelled for penetration rates of 0% (i.e. the reference), 10% (feasible in 2015-2020) and 50% (future years).
- The simulated road was approximately 6km and consisted of a four-lane motorway segment with a left lane drop that caused congestion.
- The duration of each scenario was 2.5 hours with the first and last 15 minutes not taken into account. There were 10 replications of each scenario with different random number seeds.
- The reference situation was calibrated and validated with data measured on the Dutch A12 motorway and showed a satisfactory resemblance with respect to the congestion build-up.

Micro-simulation requirements and ITS Modeller

In order to assess the effect of the Congestion Assistant on highway traffic, the authors required the modelling approach to be able to do the following:

- "Simulate the traffic flow by distinguishing individual driver–vehicle combinations that represent the interactions between vehicles and between driver and vehicle;
- Simulate changes in driving behaviour induced by the Congestion Assistant to describe the behaviour of vehicles equipped with or without this system;
- Simulate highway environments, including bottlenecks, such as on-ramps and lane drops that can cause congestion; and
- Realistically represent traffic flow dynamics, particularly with respect to the congested regime and the transitions between free flow and congestion."

The authors stated that commercially available models, such as VISSIM, AIMSUN, and Paramics "do not satisfy these requirements because they offer too few possibilities to use detailed models for driver and vehicle behaviour and the behaviour of systems such as the Congestion Assistant". Instead, the "ITS Modeller" package was used, which was specifically developed (by TNO) to comply with these requirements.

ITS Modeller is a modelling environment developed in Java in which intelligent co-operative vehicle-infrastructure systems can be modelled, tested, and evaluated for their effect on traffic efficiency, traffic safety and the environment. It is a structured set of driver and vehicle behaviour models, including the operation of in-car systems. The driver model in ITS Modeller is based on a previous model, MIXIC, which was validated and applied for a variety of conditions.

In this study, Paramics was used as the front-end, but ITS Modeller calculated the vehicle positions and fully replaced the driver models of Paramics.

Results

All variants of the Congestion Assistant resulted in less congestion in comparison with the reference situation. The active pedal smoothed the traffic flow when approaching a traffic jam by prompting better anticipation behaviour of the driver compared with unsupported drivers. This resulted in slightly less congestion and a safer approach to the jam. Vehicles equipped with the stop-and-go system followed other vehicles more efficiently than non-equipped vehicles when driving in and leaving a jam, by adapting smaller headways and eliminating driver reaction time. This reduced the amount of congestion and significantly cut the average travel time and delay. For the scenario with 10% of the vehicles equipped, a reduction of 30% in travel delay was estimated.

3.5.5 (ADAS/CVHS/platooning): Co-operative Adaptive Cruise Control

IEEE; 2006

Modelling package used: MIXIC

The authors of the "Congestion Assistant" paper also used micro-simulation to assess the impact of "Co-operative Adaptive Cruise Control" (CACC) (van Arem et al., 2006).

Methodology

CACC is similar to ACC, with the addition that vehicles can exchange information with other vehicles by wireless communication. Although CACC is primarily designed for giving the driver more comfort and convenience, this study aimed to investigate what the potential positive and negative impacts may be on both traffic safety and traffic efficiency.

The microscopic-traffic simulation model MIXIC was used to examine the impact of CACC. MIXIC simulations were conducted on a four-lane Dutch highway, approximately 5km in length, with a bottleneck due to a lane drop.

Results

The simulations showed that CACC has the ability to improve traffic-flow performance, particularly in conditions with high-traffic volume and when high fractions of the vehicle fleet are CACC equipped. In this case, more vehicles are able to participate in a CACC platoon, resulting in reduced time gaps and improved string stability.

As communication was restricted to longitudinal control and no restrictions to the length and compactness of CACC platoons was given, the system had a negative effect on traffic safety in the merging process. CACC platoons prevented other vehicles from cutting in, resulting in an increasing number of removed vehicles due to conflicts, as more vehicles were CACC-equipped. It was recommended that possible solutions for dealing with this negative effect of CACC on the merging process should be studied.

3.5.6 (ADAS/CVHS): Adaptive Cruise Control, "Traffic Assistance System"

Technische Universitaet Dresden, Collegium Budapest; 2008

Modelling package used: IDM and MOBIL

This journal paper presented the results of a micro-simulation study to assess the effect of adaptive cruise control, which had the purpose of reducing congestion (Kesting et al., 2008).

Application Tested

The ACC "Traffic Assistance System" proposed in this paper was similar to those discussed in §3.5.4 and §3.5.5, but it was novel in that it determined which out of five traffic states the vehicle was travelling in and then modified the ACC parameters accordingly. Specifically:

- Free traffic – unmodified ACC.
- Approaching the "upstream front" of congestion – modified ACC to brake earlier for a safety benefit.
- Congested traffic– unmodified ACC.
- Passing a bottleneck – modified ACC to have increased acceleration and therefore shorter headway to the car in-front.
- Approaching the "downstream front" of congestion – modified ACC to have shorter headway to the car in-front and therefore the capability to brake harder if needed.

The most common states are free traffic and congested traffic, and so the ACC parameters are modified only for a small minority of the driving time. Therefore, the driver is not in-convenienced too much by heavy braking etc.

'Bottlenecks', such as lane closures and increased gradients, are fixed locations, and it was therefore proposed that these sites would be identified by GPS and a digital map database. For the other traffic states, it was possible to determine which of the states the vehicle was travelling in with a simple algorithm. However, the accuracy of this could be improved through vehicle-to-vehicle communication.

Methodology

The authors give several reasons why the Intelligent Driver Model (IDM) is an appropriate car-following model to simulate ACC. The modifications to the ACC accelerating, braking and headway parameters described above were included in the IDM, by applying multiplication factors to the relevant IDM parameters.

The authors also discussed the complications in modelling human driving behaviour compared to ACC:

1. "The finite reaction time of humans results in a delayed response to the traffic situation.
2. Imperfect estimation capabilities result in perception errors and limited attention spans.
3. Human drivers scan the traffic situation several vehicles ahead while ACC sensors are restricted to the vehicle immediately in front.
4. Furthermore, human drivers anticipate the future traffic situations by making use of further clues (such as brake lights) and by forming plausible hypotheses such as assuming constant accelerations of all neighbouring vehicles in the next few seconds."

"…For realistic human reaction times of the order of the time gaps, the destabilizing influences of points (1) and (2) above would lead to traffic instabilities and accidents. However, points (3) and (4), i.e., the spatial and temporal anticipation, compensate for that. This has been shown using the recently proposed human driver model (HDM) (Treiber et al., 2006), which extends car-following models like the IDM to the points mentioned above."

The authors state that when implementing the proposed system, these differences would need to be taken into account. However, this paper was only intended to be a 'proof of concept' to investigate the influence of ACC on macroscopic traffic flow properties. Therefore, they justified using the simpler IDM instead of the HDM to simulate human driving behaviour.

In addition to the IDM for longitudinal behaviour, the MOBIL model was used to simulate lane-changing behaviour.

Results

Micro-simulation runs were conducted of a 13km section of 3-lane motorway near Munich. Penetration rates of 0%, 5%, 15% and 25% of the proposed system were tested. In the 0% base scenario, the majority of the motorway section was congested due to an on-ramp bottleneck. In the 25% penetration rate scenario, the congestion was entirely removed. There were also substantial reductions in the congestion even in the 5% scenario.

Further info on ACC Traffic Assistance System -> (Kesting et al., 2008) Further info on HDM -> www.vwi.tu-dresden.de/…/HDM.pdf (Treiber et al., 2006)

3.5.7 (Platooning): SARTRE

European project with multiple partners; 2010-2012
Modelling package used: PELOPs

Work Package 5 of the SARTRE project (see §2.3) is "Assessment" and is due to be undertaken in 2012. Initial results have already been published (Bergenhem et al., 2010). Key points are re-produced here.

Modelling conducted so far

Thus far the simulation tool, PELOPS, has been used to model three things:

- Use cases
- Limitations – string stability
- Required sensor accuracy

As yet there have been no results presented on the impact on traffic flow and other vehicles. However, "the consideration of how platoons interact with other non-platoon users is a central part of the project. A large element of the research is looking into this aspect and this will provide clear strategies that will be implemented in the prototype system."

> "Based on the defined use cases and concepts, several simulation scenarios have been generated to analyze the SARTRE platooning concept. Important aspects [can be investigated] like:
>
> - the proper gap size for joining and leaving,
> - the time needed for creating, joining or leaving a platoon,
> - string stability,
> - the influence on the traffic flow, e.g. at highway entrances and exits and fuel consumption etc

Simulation tool used – PELOPS

PELOPS is a "sub-microscopic" simulation tool, as described below:

> "PELOPS (Program for the DEvelopment of LOngitudinal Traffic Processes in System Relevant Environment) is a (sub)-microscopic traffic model and represents a combination of a detailed sub-microscopic vehicle model and a microscopic traffic model. This allows for the analytical investigation of the vehicle longitudinal dynamic behaviour as well as the traffic flow. The advantage of this method is to consider all interactions that take place between the driver, vehicle and traffic.
>
> PELOPS has been developed in co-operation with BMW within PROMETHEUS… Contrary to classical simulation tools in the automotive industry, which represent only a part system or single isolated vehicle, the core of PELOPS comprises the three significant elements of the traffic system - track/environment, driver and vehicle - and their interactions."

The text below explains how the platoons are modelled in PELOPS:

> "In order to allow the simulation of platoons according to the defined use cases and SARTRE concepts, the models in PELOPS have been enhanced…
>
> A generic platoon control, which can take over the longitudinal and lateral control of the vehicle in case of autonomous driving, can now be "built in" in the vehicle. The technical equipment controls the vehicle without driver involvement. This situation can only occur for a following vehicle. The lead vehicle is always controlled manually by the PELOPS driver. The platoon control is a dynamic link library (DLL) that is loaded at runtime.
>
> In order to simulate the HMI in the real vehicle, a virtual HMI manager has been developed. It manages the information to and from the driver like requests (e.g. leave, join, etc.), acknowledgements (e.g. dissolve, leave, join, etc), cancel (joining, leaving) or discard joining.
>
> Besides using a vehicle model from the PELOPS database, external vehicle models (e.g. MATLAB/Simulink models…) can be taken into consideration in PELOPS.
>
> Furthermore, in order to visualize the traffic simulation during runtime, PELOPS can be coupled to a visualization software…"

Preliminary Results - Use Cases

"In the first step, the following Use Cases have been simulated in different scenarios [type of vehicles and desired platooning gap size]:

- Create Platoon
- Dissolve Platoon
- Join Platoon from 1) rear, 2) side and 3) front
- Leave Platoon from 1) side and 2) front
- Maintain Platoon

The simulations show that all considered leaving and joining use cases are principally feasible."

Preliminary Results – String Stability

Figure 3 shows two simulation runs of a platoon, with one lead vehicle and nine following vehicles on a flat straight road. Each following vehicle has a target platooning distance of 10 metres. In the first graph, the lead vehicle varies its speed from 77 to 83 to 77km/h every 20 seconds and there is unstable flow in the following vehicles. In the second graph the lead vehicle drives smoothly and the platoon is stable.

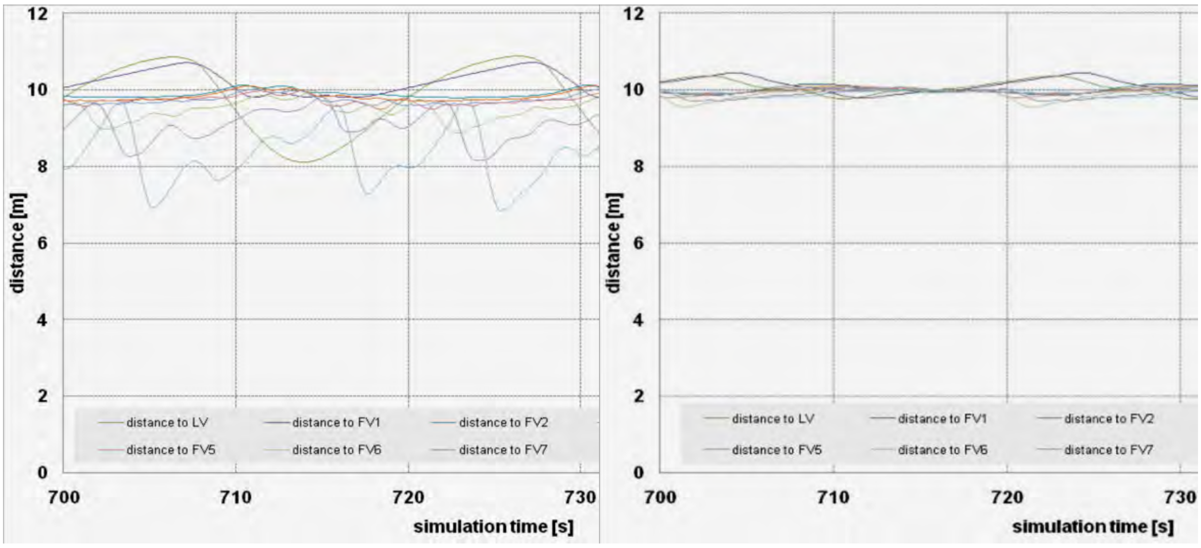

Figure 3 - Plots of distance between platoon vehicles with the lead vehicle having variable speed (Left) and constant speed (Right) (reproduced from Bergenhem et al., 2010)

Preliminary Results – Required Sensor Accuracy

"In order to analyze the influence of the inaccuracies in the sensor systems on the string stability, several simulations have been conducted with sensor noises and inaccuracy. Two variants of sensor accuracy level have been simulated. The first one is a +/-1% range and velocity inaccuracy level, which the current available sensors can offer. And the second variants is a +/-10% inaccuracy level. The simulation results showed that the sensor inaccuracy has impact on the string stability. But current available sensors have very low inaccuracy levels and thus the string stability can be achieved with real sensors."

Modelling still to be conducted

Currently results have only been presented for one individual platoon. However, discussions with the SARTRE consortium have indicated that in the remainder of the project, simulations are to be conducted with several platoons to assess the effect on the overall traffic flow.

Further info on SARTRE -> http://www.sartre-project.eu/.../publications/...

3.5.8 (ISA): Intelligent Speed Adaptation

Institute for Transport Studies, University of Leeds; 2003

Modelling package used: DRACULA

The University of Leeds conducted a micro-simulation study using DRACULA to assess the impacts of mandatory ISA on a small network (Liu, Tate, 2003).

Methodology

DRACULA usually consists of a microscopic demand model (route choice, departure time choice, individual drivers' learning) and a microscopic traffic model (simulation of individual vehicle movements). For the purpose of this simulation, the route choice was fixed and only the traffic micro-simulation part of the model was used.

Speed limits were set at 40 mph on main radial roads and at 30 mph on residential streets. The traffic model was modified so that if a vehicle was travelling above the speed limit upon entering the ISA zone, it decelerated gently to the speed limit and then used this as the maximum speed. Key aspects of the modelling were:

- The network consisted of two urban radial routes in East Leeds with residential side-roads. There were 250 links, 120 nodes and 70 zones.
- Both congested (morning peak) and uncongested (off-peak) flows were modelled.
- Penetration rates at 10% intervals were modelled (e.g. 10%, 20%, …100%), as well as the base case of 0%.

Results

In the morning peak period, traffic speeds were limited largely by congestion and therefore there was either no or very small changes due to ISA. However, during the off-peak period, there was a substantial amount of travel speed exceeding the regulated speed limits. With the implementation of ISA, these high speeds were limited, resulting in increased travel times and a reduction in average speed. In both peak and off-peak conditions, the speed distributions at lower speeds had not changed significantly, indicating that ISA had not induced additional queuing traffic.

Fuel consumption (dependent on acceleration) decreased significantly with increasing penetration rates. However, there were no significant variations found in total emissions (dependent on distance travelled).

3.5.9 (Traffic Info): Effect of in-vehicle and VMS route guidance on route choice during an accident

TNO (Netherlands); 2009

Modelling package used: ITS Modeller

The Dutch research organisation, TNO, used micro-simulation to assess the traffic impacts of traffic information during an incident, both from in-vehicle systems as well as from road-side Variable Message Signs (VMS). This research was conducted as part of the national TRANSUMO Intelligent Vehicles programme. (Faber, Klunder, 2009)

The challenge

It is challenging to assess the impact that dynamic route guidance has, because little is known about individual route choice behaviour.

Micro-simulation allows for experimenting with assumptions regarding route choice behaviour and the effects on the traffic flows on a network level. However, a difficulty with route choice in commercially available micro-simulation software is that the individual drivers' knowledge of the traffic situation is either too limited (drivers know only free flow travel times) or too complete (drivers know up-to-date travel times for the whole network). Other challenges include: modelling individual vehicles on large networks requires a lot of computational effort; and the task of validating large-scale detailed networks is usually very time-consuming.

Methodology – the simulation runs

Simulation runs were conducted of an accident occurring on the A28 motorway between Utrecht and Amersfoort during the evening peak hour. The network was medium-sized, with 1500 links, 700 nodes and over 100 zones.

Four scenarios were modelled:

- No incident, and no traffic info (base scenario);
- Incident, but no traffic info;
- Incident, with in-car route advice – it was assumed that 50% of all the drivers were equipped and that information on the traffic conditions were available for the entire network;
- Incident, with road-side VMS – information on only a small part of the network (i.e. on the motorway).

The incident occurred at the start of the simulation and was modelled by reducing the capacity of the motorway from two lanes to one lane, with a speed of 5 km/h. The traffic information was updated every five minutes.

Simulation package used – ITS Modeller

TNO used the ITS Modeller route choice model to assess the travel times during the four scenarios.

The elements of this were:

- **Route set generation –** generates a set of potential routes using a shortest path algorithm;
- **Route selection algorithm –** selects a route from the route set for each individual vehicle;
- **The influence of on-trip traffic info on the route set -** the traffic information influences the "cost" of each link, and the route sets are updated;

- **The influence of on-trip traffic info on the route selection -** with on-trip route switching decisions, drivers are at different places in the network and select different routes accordingly.

In summary, the route choice model of the ITS modeller adjusted the drivers' perception of the traffic situation based on individual traffic information, which allowed for realistic route choice behaviour in response to traffic information. The model was structured in such a way that the computational complexity was reduced to a minimum and simulation speed was optimized.

Validation

To validate the base situation, a network was used for which routes had been measured with number plate recognition cameras. The cameras measured the use of four routes between Utrecht and Amersfoort. The route set generated by the route choice model generated four routes, which were very similar to the real world data. The travel times during peak hour in the real situation were also compared to the simulated travel times and this was also satisfactory.

Results

The results of the study have shown that the model is able to model the effects of on-route traffic information in a realistic network on an urban area-scale.

The simulation showed that drivers who used the advice from the road-side VMS experienced a reduction in delay of approximately 40%. In the case of in-car traffic information, the benefit for informed drivers was a reduction in delay of 15-20%. In summary, the VMS provided more advantage for the fewer people that were informed, but the in-car information provided a smaller advantage for more people. However, overall the total effect for the entire network was about the same in the two scenarios.

Next Steps

The authors indicated three possible next steps:

- To validate the impact of VMS with real data from VMS that are currently in place on the case study network.
- To enlarge the network even further, in order to be able to model the western part of the Netherlands (the Randstad).
- To analyse individual route choice behaviour in order to optimise the route cost function that is used in the model.

3.5.10 (Infrastructure-based): Variable Speed Limits

Royal Institute of Technology (Sweden); 2009
Modelling package used: VISSIM

Advisory variable speed limits (VSL) have been introduced on the E4 motorway in Stockholm, which is subject to frequent congestion. A validated VISSIM micro-simulation model was used to model the effectiveness of VSL, dependent on drivers' compliance with the posted speed limits (Nissan, Koutsopoulos, 2009).

Results

Results showed that without VSL there were frequent problems of flow breakdowns, which may lead to shunt type accidents. The modelled VSL system with 100% driver speed compliance produced more uniform speeds. This provided more consistent journey times and less stop-start traffic. However, once capacity was exceeded, the VSL system only delayed the onset of congestion for a short while before both scenarios had crawling traffic.

The average travel times for the entire modelled motorway segment were reduced as a result of the VSL. It was shown that even with compliance levels as low as 25% there was a reduction in travel times due to the VSL.

3.5.11 (Infrastructure-based): SCOOT-VISSIM Link

TRL; 2010

Modelling package used: VISSIM

SCOOT (Split Cycle Offset Optimisation Technique) is a tool for managing and controlling traffic signals in urban areas (www.scoot-utc.com, 2011). It is an adaptive system that responds automatically to fluctuations in traffic flow through the use of on-street detectors embedded in the road. SCOOT has proven to be an industry-leader in Urban Traffic Control that typically reduces traffic delay by an average of 20% in urban areas.

TRL developed the capability to simulate SCOOT within a micro-simulation model, with the SCOOT-VISSIM link.

3.5.12 Summary of how micro-simulation has been used

As discussed in §3.1, the impact of a particular ITS application may be determined through assessing a combination of "measures", depending on the purpose of the application. Table 3 is not fully comprehensive, but illustrates how micro-simulation is suitable for assessing some ITS applications and other methods are better for other measures.

Table 3 – Summary of how micro-simulation has been used to assess the impacts of ITS

Policy Theme	Measure of the Impact of ITS	Microscopic simulation	Mesoscopic simulation	Macroscopic simulation	FOTs / Measure Before & After	Estimate Benefits
Efficiency	Average speed (increase=good)	Yes - §3.5.1, §3.5.2, §3.5.3, §3.5.4, §3.5.5, §3.5.6, §3.5.7, §3.5.8, §3.5.9, §3.5.10, §3.5.11	Yes	Yes	Yes §3.2.1	
Efficiency	Journey times	Yes - §3.5.1, §3.5.2, §3.5.3, §3.5.4, §3.5.5, §3.5.6, §3.5.7, §3.5.8, §3.5.9, §3.5.10, §3.5.11	Yes	Yes	Yes §3.2.1	
Efficiency	Throughput	Yes - §3.5.1, §3.5.2, §3.5.3, §3.5.4, §3.5.5, §3.5.6, §3.5.7, §3.5.8, §3.5.9, §3.5.10, §3.5.11	Yes	Yes		
Efficiency	Route choice	Possible	Yes	Yes §3.3		
Efficiency	Smoothness of the flow	Difficult				
Efficiency	Occurrence of flow breakdown and shockwaves	Difficult	Yes			
Safety	Number of accidents involving fatalities	Not suitable				Yes
Safety	Number of conflicts / heavy braking	Yes - §3.5.4, §3.5.5				
Safety	Number of failed lane changes	Yes - §3.5.5				
Safety	Average speed (decrease=good)	Yes - §3.5.1	Yes	Yes		
Environment	CO2 and other emissions	Yes - §3.5.1, §3.5.2, §3.5.8			Yes §3.2.1	
Environment	Noise	Yes - §3.5.1			Yes §3.2.1	
Public transport	Public transport utilisation	Not suitable	Yes	Yes §3.3	Yes	
Public Transport	Public transport journey times	Not suitable	Yes	Yes §3.3	Yes	
Public Transport	Modal shift	Not suitable	Yes	Yes §3.3	Yes	
Traveller info	Route choice, based on individual real-time info	Possible - §3.5.9	Yes §3.4.1			
Traveller info	Modal shift	Not suitable	Yes	Yes	Yes	
Freight	Freight utilisation/ costs	Not suitable	Yes	Yes	Yes	
Freight	Freight journey times	Not suitable	Yes	Yes	Yes	
Security	Num of reported crimes	Not suitable			Yes	

3.6 Complexity Theory and Emergent Behaviour

Some measures are particularly difficult to simulate using any of the above techniques, such as the occurrence of flow breakdown and shockwaves, and smoothness of the flow (i.e. the proportion of vehicles travelling in clusters). Concepts such as Complexity Theory and Emergent Behaviour are more appropriate than micro-simulation in attempting to understand these phenomena. These concepts are introduced briefly below:

- "A system is complex when it is composed of a group of related units (subsystems), for which the degree and nature of the relationships is imperfectly known. Its overall emergent behaviour is difficult to predict, even when subsystem behaviour is readily predictable… small changes in inputs or parameters may produce large changes in behaviour." (Sussman, 2000)

3.7 Pervasive sensors / ubiquitous data

In particular, more and more traffic data has become available over recent years and will continue to do so in coming years; for example there is now MIDAS loop data, probe vehicle data with radar to record headways, traffic simulator data, video data, mobile phone data, satellite map data, motes, RFID chips mixed in with tarmac when laying new roads, and so on. As such, this presents a new opportunity to combine these multiple sources of data and to develop new approaches to understand and predict traffic flow.

3.7.1 (Network monitoring): Integration of ITS and 'grid-enabled' pervasive sensors

Imperial College, Universities of Cambridge, Leeds, Newcastle and Southampton; 2006-2009

Modelling package used: AIMSUN; VISSIM

The MESSAGE project demonstrated the potential of diverse, low cost sensors to provide data for the planning, management and control of the environmental impacts of transport activity at an urban, regional and national level. This included implementation of 'pervasive sensors' at a trial site in Gateshead on vehicles and people to act as mobile real-time environmental probes, sensing transport and non-transport related pollutants and hazards (Bell et al., 2009).

Validating the micro-simulation

Three different types of pervasive sensors were included in a common data processing system:

- Personal devices (e.g. mobile phones).
- 'Smart-dust' network using Zigbee 'motes' (IEEE 802.15.4) – Motes are cheap sensors that can monitor traffic occupancy, location temperature, humidity, noise and emissions; they can be deployed pervasively due to their low cost and can operate for six months with the same battery; they can be mounted road-side or in probe vehicles and can communicate wirelessly with a central server.
- A network that utilises WiFi (IEEE 802.11.g) and WiMax (IEEE 802.16).

Existing AIMSUN and VISSIM traffic micro-simulation models of Gateshead were validated automatically using motes. There were motes both on fixed links for validating flows, as well as in probe vehicles for validating journey times. Emissions were estimated from the traffic simulation model and these were then validated, again using the pervasive sensors.

This feedback loop is the novel approach of all pervasive sensors: they can help validate the base case, which can then simulate various scenarios; when the solutions are implemented, the sensors can again be used to measure the impacts and assess the accuracy of the model's predictions.

Further info on MESSAGE -> http://research.cs.ncl.ac.uk/message/

4 Summary of ITS impact studies

Table 4 summarises the ITS impact studies that have been reviewed in this report. The 'traffic light scale' indicates the extent of the work in each area.

Table 4 – Summary of ITS impact studies reviewed in this report

ITS Application	Examples of existing work to assess impacts
Co-operative Vehicle Highway Systems (§2.1)	CODIA (§3.5.1) Pre-Drive C2X (§3.5.2) iTetris (§3.5.3)
Semi-autonomous vehicles / in-vehicle warning and control systems / advanced driver assistance systems (§2.2)	EuroFOT (§3.2.1) ACC Congestion Assistant (§3.5.4) Co-operative ACC (§3.5.5) ACC Traffic Assistance System (§3.5.6)
Platoons / car-following technologies / automated road-trains (§2.3)	SARTRE (§3.5.7)
Intelligent speed adaptation (§2.4)	University of Leeds (§3.5.8)
Driverless cars and other autonomous technologies (§2.5)	Limited existing Work
Traffic information during an incident (§2.6)	Micro-simulation (§3.5.9) Mesoscopic simulation for real-time decision support (§3.4.1)
Variable speed limits (§2.6)	Swedish Royal Institute of Technology (§3.5.10)

Co-operative vehicles and autonomous / semi-autonomous control systems

The original scope of this literature review was to focus primarily on co-operative vehicles (CVHS), semi-autonomous vehicles (e.g. ACC) and fully autonomous vehicles (e.g. platooning and driverless cars). In §3.5 there were multiple examples of where micro-simulation has been used to assess the traffic and emissions impact of such systems. Typically these examples involve modelling the ITS application on a short section of motorway (approximately 1 to 5 km) and then comparing against a baseline scenario. If it is necessary to understand the network-wide effects of these systems, the traditional approach is to model on a short section and then scale-up to the whole network by the occurrence of the scenarios, as in CODIA (§3.5.1). However, an alternative approach is as in the recent iTetris project (§3.5.3), which has developed the capability to simulate co-operative systems at a regional city-wide level.

Dynamic route guidance during incidents

Additional case studies have also been included in the review, which require the modelling of large numbers of individual vehicles. In particular, two examples of dynamic route guidance during traffic incidents were reviewed:

- §3.4.1 – The PREDIKT project (Sweden) extended the Mezzo mesoscopic simulation model to provide decision support for incident management. During an accident, Mezzo is able to model the current situation and test several short-term routing information strategies to assist the traffic managers in making decisions. On a network with 6000 links, the mesoscopic model works approximately 200 times faster than real-time, which is fast-enough to be of use to decision makers.

- §3.5.9 – As part of the TRANSUMO Intelligent Vehicles programme (Netherlands), micro-simulation was used to assess the traffic impacts of traffic information during an incident, both from in-vehicle systems as well as from road-side Variable Message Signs (VMS).

Platooning

The SARTRE project is currently determining platooning strategies and is due to conduct detailed modelling of these strategies in September 2012 (see §2.3 and §3.5.7).

Driverless cars

No examples of micro-simulation applied to driverless cars were found as part of this literature review.

Combination of multiple local micro-simulation models to an area-wide model

It was noted that there are multiple local micro-simulation models across various cities and it may be beneficial to combine these into one large model for each city.

Pervasive sensors

The novel approach during the MESSAGE project (see §3.7.1) of using pervasive sensors to automatically validate micro-simulation models is of interest.

Appendix A Futures and visioning – EC "Future of Transport", 2011

The EC has been considering its 'Future of Transport' strategy for a long time and this has been published very recently (28/03/2011). This is a key document setting out the future deployment path for European transport. The 20-page paper is called "Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system" (EC, 2011).

The introduction on the website is as follows:

> "The European Commission adopted a roadmap of 40 concrete initiatives for the next decade to build a competitive transport system that will increase mobility, remove major barriers in key areas and fuel growth and employment. At the same time, the proposals will dramatically reduce Europe's dependence on imported oil and cut carbon emissions in transport by 60% [compared to 1990 levels] by 2050.
>
> By 2050, key goals will include:
>
> - No more conventionally-fuelled cars in cities.
> - 40% use of sustainable low carbon fuels in aviation; at least 40% cut in shipping emissions.
> - A 50% shift of medium distance intercity passenger and freight journeys from road to rail and waterborne transport.
> - All of which will contribute to a 60% cut in transport emissions by the middle of the century."

With regards to ITS, Section 3.2 of the White Paper, "Innovating for the future – technology and behaviour" states the following:

> "Technological innovation can achieve… a more efficient and sustainable European transport system by acting on three main factors:
>
> - vehicles' efficiency through new engines, materials and design;
> - cleaner energy use through new fuels and propulsion systems;
> - better use of network and safer and more secure operations through information and communication systems…"
>
> "Transport research and innovation policy should increasingly support in a coherent way the development and deployment of the key technologies needed…
>
> To be more effective, technological research needs to be complemented with a systems' approach, taking care of infrastructure and regulatory requirements, coordination of multiple actors and large demonstration projects to encourage market take-up.
>
> The Commission will devise an innovation and deployment strategy for the transport sector, in close co-operation with the Strategic Energy Technology Plan (SET-plan), identifying appropriate governance and financing instruments, in order to ensure a rapid deployment of research results."

Annex 1 of the White Paper lists 40 actions that the EC has committed to; these actions are split under the following headings:

- 1. AN EFFICIENT AND INTEGRATED MOBILITY SYSTEM
  - 1.1. A Single European Transport Area
  - 1.2. Promoting quality jobs and working conditions

  - 1.3. Secure Transport
  - 1.4. Acting on transport safety: saving thousands of lives
  - 1.5. Service quality and reliability
- 2. INNOVATING FOR THE FUTURE: TECHNOLOGY AND BEHAVIOUR
  - 2.1. A European Transport Research and Innovation Policy
  - 2.2. Promoting more sustainable behaviour
  - 2.3. Integrated urban mobility
- 3. MODERN INFRASTRUCTURE AND SMART FUNDING
  - 3.1. Transport infrastructure: territorial cohesion and economic growth
  - 3.2. A coherent funding framework
  - 3.3. Getting prices right and avoiding distortions
- 4. THE EXTERNAL DIMENSION

Actions 24, 25 and 26 relate to the "European Transport Research and Innovation Policy" and are reproduced below.

24. A technology roadmap

Fragmentation of research and development efforts in Europe is most harmful, and joint European efforts will bring the greatest European added value in areas such as:

- Clean, safe and silent vehicles for all different modes of transport, from road vehicles to ships, barges, rolling stock in rail and aircraft (including new materials, new propulsion systems and the IT and management tools to manage and integrate complex transport systems).
- Technologies to improve transport security and safety.
- Potential new or unconventional transport systems and vehicles such as unmanned aircraft systems, unconventional systems for goods distribution.
- A sustainable alternative fuels strategy including also the appropriate infrastructure.
- Integrated transport management and information systems, facilitating smart mobility services, traffic management for improved use of infrastructure and vehicles, and real-time information systems to track and trace freight and to manage freight flows; passenger/travel information, booking and payment systems.
- Intelligent infrastructure (both land and space-based) to ensure maximum monitoring and inter-operability of the different forms of transport and communication between infrastructure and vehicles.
- Innovations for sustainable urban mobility following up the CIVITAS programme and initiatives on urban road pricing and access restriction schemes.

25. An innovation and deployment strategy

Identify the necessary innovation strategies including the appropriate governance and the financing instruments in order to ensure a rapid deployment of results developed in the research process. Examples are:

- Deployment of smart mobility systems such as the air traffic management system of the future (SESAR), the European rail traffic management system (ERTMS) and rail information systems, maritime surveillance systems (SafeSeaNet), River Information Services (RIS), ITS, and the next generation of multimodal traffic management and information systems.
- Definition and deployment of an open standard electronic platform for vehicle on board units, performing various functions including road charging.

- Development of a plan for investment in new navigation, traffic monitoring and communication services to allow for the integration of information flows, management systems and mobility services based on a European Integrated Multimodal Information and management Plan. Demonstration projects for electro mobility (and other alternative fuels) including recharging and refuelling infrastructure and intelligent transport systems focussing in particular on those urban areas where air quality levels are frequently exceeded.
- Smart mobility partnerships and demonstration projects for sustainable urban transport solutions (including demonstrators for road pricing schemes etc).
- Measures to promote increased replacement rate of inefficient and polluting vehicles.

26. A regulatory framework for innovative transport

Identify the necessary regulatory framework conditions through standardisation or regulation:

- Appropriate standards for CO_2 emissions of vehicles in all modes, where necessary supplemented by requirements on energy efficiency to address all types of propulsion systems;
- Vehicle standards for noise emission levels;
- Ensure that CO_2 and pollutant emissions are reduced under real-world driving conditions by proposing at the latest by 2013 a revised test cycle to measure emissions;
- Public procurement strategies to ensure rapid up take of new technologies;
- Rules on the interoperability of charging infrastructure for clean vehicles;
- Guidelines and standards for refuelling infrastructures;
- Interface standards for infrastructure-to-infrastructure, vehicle-to-infrastructure, and vehicle-to-vehicle communications;
- Access conditions to transport data for safety and security purposes;
- Specifications and conditions for transport related smart charging and payment systems;
- Better implementation of existing rules and standards.

Read the White Paper-> ec.europa.eu/transport/strategies/2011_white_paper_en.htm

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Glossary of terms and abbreviations

ACC	Adaptive Cruise Control (see §2.2)
ADAS	Advanced Driver Assistance Systems (see §2.2)
AIMSUN	Micro-simulation traffic model
ANPR	Automatic number plate recognition
ASV-4	Advanced Safety Vehicle, Phase 4; Japanese project on co-operative vehicles
Automated Highway	American demonstration project of driverless cars
BAE Systems	British weapons company
C2X	Car-to-X (e.g. Car-to-Car or Car-to-Infrastructure or Car-to-Nomadic device etc)
CACC	Co-operative Adaptive Cruise Control
CHAUFFEUR I	European project on platoons
CHAUFFEUR II	European project on platoons
CIVITAS	Institute for the Study of Civil Society
CODIA	European project on micro-simulation of co-operative vehicles
COMeSafety European ITS Architecture	European project on the European ITS Communications Architecture
CONTRAM	Macroscopic/Mesoscopic simulation traffic model
COOPERS	European project on co-operative vehicles
COPERT	Emissions model
CVHS	Co-operative Vehicle Highway Systems (see §2.1)
CVIS	European project on co-operative vehicles
DfT	Department for Transport (UK)
DLL	Dynamic link library
DRACULA	Micro-simulation traffic model
DynaMIT	Mesoscopic simulation traffic model
DYNASMART	Mesoscopic simulation traffic model
EC	European Commission
E-FRAME	European project on extending the European ITS Architecture to co-operative vehicles
EPSRC	Engineering and Physical Sciences Research Council (UK)
ERTMS	European rail traffic management system
ETSI	European Telecommunications Standards Institute

EU25	European Union (with 25 countries, before Bulgaria and Romania joined)
FCD	Floating Car Data
FESTA	European project on methodology for FOTs
FOT	Field operational test (see §3.2)
GEONET	European project on co-operative vehicles
GM	General Motors
GPS	Global Positioning System
HA	Highways Agency (UK)
HBEFA	Handbook Emission Factors for Road Transport
HDM	Human Driver Model; Micro-simulation car-following model
HGV	Heavy goods vehicle
HMI	Human Machine Interface
iCS	iTETRIS Control System
ICT	Information and communications technology
IDM	Intelligent Driver Model; Micro-simulation car-following model
InnovITS	The UK ITS Centre of Excellence
IntelliDrive	American project on co-operative vehicles
ISA	Intelligent Speed Adaptation (see §2.4)
iTetris	European project on city-wide micro-simulation of co-operative vehicles (see §3.5.3)
ITS	Intelligent Transport Systems (see §1.2.1)
ITS Modeller	Micro-simulation traffic model, specifically for assessing ITS
KONVOI	German project on truck platoons
Macroscopic	(see §3.3)
MATLAB/Simulink	Commercial tool for modelling, simulating and analyzing dynamic systems
Mesoscopic	(see §3.4)
MESSAGE	European project on pervasive sensors (see §3.7.1)
Mezzo	Mesoscopic simulation traffic model (see §3.4.1)
Microscopic	(same as "micro-simulation")
Micro-simulation	(see §3.5)
MIDAS	Motorway Incident Detection and Automatic Signalling
MIXIC	Micro-simulation traffic model
MOBIL	Micro-simulation lane-changing model
Motes	Pervasive sensors

NS-2	Communications model
NS-3	Communications model
OPNET	Communications model
Paramics	Micro-simulation traffic model
PATH	American project on platoons
PC	Personal computer
Pe	Engine power
PELOPS	Sub-microscopic simulation traffic model
PHEM	Emissions model
Platoon	(see §2.3)
PREDIKT	Swedish project on micro-simulation of traffic information during incidents
PRE-DRIVE C2X	European project on co-operative vehicles (see §3.5.2)
PreScan	Simulation environment for the development of ADAS
PROMETHEUS	European project on driverless cars
RFID	Radio-frequency identification
RIS	River Information Services
RPM	Engine speed (Revolutions per minute)
SafeSeaNet	Maritime surveillance systems
SAFESPOT	European project on co-operative vehicles
SARTRE	European project on platoons (see §2.3 and §3.5.5)
SCOOT	Split Cycle Offset Optimisation Technique
Sentience	UK project on ISA
SESAR	Single European Sky ATM Research
SET-plan	Strategic Energy Technology Plan
SEVECOM	European project on co-operative vehicles
SISTM	Micro-simulation traffic model
Sub-microscopic	(see §3.5.5)
SUMO	Micro-simulation traffic model
TRANSUMO	Dutch project on Intelligent Vehicles
TSB	Technology Strategy Board (UK)
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle
VCOM	Communications model
VERSIT+	Emissions model

VII	Vehicle-Infrastructure Integration; American project on co-operative vehicles
VISSIM	Micro-simulation traffic model
VISUM	Macroscopic simulation traffic model
VMS	Variable Message Signs
VSimRTI	Simulation Runtime Infrastructure for V2x Communication Scenarios; a framework which enables the preparation and execution of V2X simulations
VSL	Variable Speed Limits
WG	Working Group

Intelligent Transport Systems (ITS) – latest developments and the use of micro-simulation assessment

This report provides an overview of the latest developments in Intelligent Transport Systems (ITS), with a particular focus on applications relevant to micro-simulation, including autonomous/semi-autonomous driving technologies and co-operative systems. Furthermore, there is a review of several examples where micro-simulation has been used to assess the impacts of ITS. Many ITS applications are currently being deployed, or are being sought to be deployed, and some form of verification or testing is required to assess their impact. There are several different approaches for doing this, of which micro-simulation appears to be one of the most powerful methods in some cases. This document is intended to be read in parallel with the accompanying report, which gives a review of the state-of-the-art in micro-simulation. The purpose of these two documents is to provide a baseline understanding of the state-of-the-art in ITS and micro-simulation.

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TRL
Crowthorne House, Nine Mile Ride
Wokingham, Berkshire RG40 3GA
United Kingdom

T: +44 (0) 1344 773131
F: +44 (0) 1344 770356
E: enquiries@trl.co.uk
W: www.trl.co.uk

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IHS
Willoughby Road, Bracknell
Berkshire RG12 8FB
United Kingdom

T: +44 (0) 1344 328038
F: +44 (0) 1344 328005
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