Towards Sustainable Town development: A Research on Deployment of Urban Sustainable Transport Systems

Deliverable 16

Summary Report

Project coordinator: TRG – University of Southampton (UK)
Contractors: STRATEC s.a. (BE)
SINTEF (NO)
INRETS (FR)
INRIA (FR)
PATH (USA)
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EXECUTIVE SUMMARY

STARDUST is an EC funded project. The objective of this project is to assess the extent to which ADAS (Advanced Driver Assistance Systems) and AVG (Automated Vehicle Guidance) systems can contribute to a sustainable urban development not only in terms of direct impacts on traffic conditions and environment but also in terms of impacts on social life, economic viability, safety, etc. Five types of systems were selected for investigation including: ISA, ACC, Stop&Go, Lane Keeling and Cybercars.

A step-wise approach was used to assess the impacts of the selected systems. It starts from user acceptance assessment (by user and operator questionnaire) and human factors/driver behaviour studies (through driving simulator experiments and floating vehicle trials). The results from such investigations were used to derive penetration rates and validate simulation models. Both micro and macro simulation were used to assess ADAS/AVG impacts. The aim of the micro-simulation was to sharpen the elements of the large-scale assignment models, so that they integrate the results on the penetration rate and the way the drivers behave with regard to the ADAS/AVG systems. The link between micro-simulation and assignment models has made the latter benefit from detailed modelling of micro-simulation such as time-flow relations, queues and delays.

Simulation results show that ADAS/AVG impacts on traffic efficiency vary with the systems, penetration levels and traffic conditions applied. In general, ISA is a system which has negative impacts on traffic efficiency in terms of increased journey time. Stop&Go has potentials to increase efficiencies of queue discharge either at junctions or in moving queues because of the short reaction time. A combined system of ACC+Stop&Go makes it possible to automate the task of longitudinal control at both high and low speeds. Lane Keeping and Cybercars can both contribute to the improvement of traffic efficiency by reducing private car use in the network.

One of the basic functions of an ADAS/AVG system is to automate some or all of the driver’s tasks. In doing so, the vehicle is controlled in a known fashion which can be used to communicate with the on-board diagnostics systems to achieve an operation with optimum mode in terms of fuel consumption and pollutant emission. ADAS/AVG systems can have impact on environment directly or indirectly: by smoothing vehicle movements (e.g. Stop&Go and ACC, Lane Keeping), changing speed profiles (e.g. ISA), and reducing private car use (Cybercars).

ISA is a system which can be used to reduce speeding and contribute to traffic safety. In addition, ISA can harmonize vehicle speeds between and within lanes and the reduce lane change rates. ACC and Stop&Go can contribute to the improvement of safety by smoothing vehicle movements which reduce the number of short time-gap and time-to-collision events.

The STARDUST project has revealed that driver support systems has a substantial potential in the urban environment regarding traffic flow and traffic safety. However, there is a need for more research on urban following processes and traffic flow mechanisms such as:

- influence on capacity (smoothing and increasing the flow)
- reliability of the systems under different traffic conditions and surroundings
- adaptation and interaction to the traffic environment
- effects of coupling between different systems
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- safety (looking at the driver behaviour and traffic processes, long term database for incidents)
- user acceptance and understanding of new technologies

From the road keeper and governmental point of view there is a need for more research to understanding the traffic management: opportunities and how best handle and regulation to avoid inappropriate technologies.

New technologies bring a need for new concepts to be developed for the allocation of road space/demand management and for the modification and enhancement of access control systems. These new concepts should be incorporated in traffic planning tools.

In addition to legal barriers and liability issues, there will also be privacy issues to be solved for some systems.

The appropriate introduction of new technology to the market is crucial, as many drivers still do not know how to operate ABS-brakes or ESP-systems, several years after they have become standard equipment. Some of the potential benefits may be reduced due to inappropriate system use.

The STARDUST project has not focused on the socio economic benefits from the implementation of ADAS/AVG systems. There could be substantial social benefits from such systems and new approaches need to be developed to bring together economic and financial benefits in ways which enable business cases can be developed for all stakeholders to work together. Such a process will also drive forward the systems functionalities and specifications in ways best suitable to all stakeholder interests.
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1 Introduction

1.1 Background
STARDUST is an research project initiated by the European Commission under the Fifth Framework Programme and contributing to the implementation of the Key Action "City of Tomorrow and Cultural Heritage" within the Energy, Environment and Sustainable Development.

The majority of ADAS (Advanced Driver Assistance Systems) and AVG (Automated Vehicle Guidance) systems were first designed to be used in an inter-urban context, i.e. on motorways. Now, progressively, they are considered for urban contexts and systems manufacturers are designing new prototypes adapted to urban contexts. To understand whether ADAS/AVG systems are better or worse than existing situations, it is necessary to assess the impacts of ADAS/AVG applications in the urban context.

1.2 Objectives
The objective of STARDUST project is to assess the extent to which ADAS (Advanced Driver Assistance Systems) and AVG (Automated Vehicle Guidance) systems can contribute to a sustainable urban development not only in terms of direct impacts on traffic conditions and environment, but also in terms of impacts on social life, economic viability, safety.

1.3 Systems investigated

Five systems were investigated in STARDUST: ISA, ACC, Stop&Go, Lane Keeping and Cybercars.

Intelligent Speed Adaptation
Intelligent Speed Adaptation (ISA) means speed limitation but under a more acceptable term. The concept now studied in various projects has basically three variants. The first one gives only a visual or audio warning if the speed limit is exceeded. The second variant implies a haptic accelerator pedal which allows the driver to maintain the maximum allowed speed without looking at the speedometer. At any moment, there is a possibility to go above the speed limit by pressing the accelerator above the threshold given by the system. This approach, which can be sold as a comfort system, has the preference of car manufacturers. The last approach is to limit the speed to the official limit without any possibility of override. All these systems are based either on a localisation through a navigation system where the maximum speed limit has been added by segments or on a local communication system with the infrastructure. This second system has the advantage of being more dynamic to take care of changing conditions (fog, rain, snow, road work, congestion, school hours, etc.).

Adaptive Cruise Control
Adaptive Cruise Control (ACC) system automatically maintains a set time-headway between an ACC-equipped vehicle and a preceding vehicle. When traffic is encountered, ACC-equipped vehicles are provided the convenience of some relief from engaging, disengaging, or resetting speeds, as is the case of with traditional cruise control. When not in traffic, ACC function in a manner similar to traditional cruise control. Currently, most ACC systems are
on-board systems which take over part or all the control of the headway. The control of ACC is based on a sensor which measures the distance to the preceding vehicle and tries to reach the desired speed (set by the driver) while maintaining a selected gap (also usually set by the driver for given speed). The ACC is turned off automatically when the speed is below a certain threshold (about 30 km/h) and hence is not usable in city environments. The driver supervises the ACC and is in control of the steering.

**Stop & Go control**

Stop & Go control is designed for use in dense traffic with slow speed (e.g. less than 10 km/h). Sensors are used to detect the preceding vehicle and to achieve longitudinal and lateral control. Based on detection and processing, the controller acts on the accelerator, brake, throttle and steering (jointly or separately) to move and stop vehicles. There are currently two variants of Stop & go available. One automatically starts and stops the vehicle when first activated. The other (semi automatic) must be reactivated by the driver by pushing a lever or button on the steering wheel after each stop. The semi automatic variant of Stop&Go is developed to meet current liability issues.

In urban areas, drivers spend large amounts of time in heavy traffic and constant attention is needed for what seems to be a very primitive task: start and stop to follow the previous vehicle. Stop&Go control is particularly appropriate for driving in urban roads. One concern is about the legal issue when the system takes the control. Pedestrian safety is another concern for the application of this system in urban environment. Pedestrians may try to cross the street between vehicles with automatic start. With current limitations to sensors inherent in Stop&Go systems, pedestrian accidents may occur. Coupling with e.g. proximity warning systems may remove this risk.

**Lane keeping**

Lane keeping assistance helps drivers to keep the vehicle within the driving lane. Lane keeping could be used to improve traffic throughput by increasing the number of lanes and could also be used to increase traffic safety by reducing accidents caused by vehicles drifting off driving lane. There are two main sub-systems for lane keeping: roadway detection and steering control. Most road detection is camera based systems, e.g. by detecting lane markings or roadside through vision systems. Compared to lane departure warning, lane keeping assistance is a more complex situation with many safety issues; especially if it is coupled with ACC (the driver could easily fall asleep while the car continues). One concern is about the legal issue for systems to take over the control. It should be noted that evaluations in this project focus on single systems in operation. Safety issues related to coupling between ADAS systems may increase or decrease accident risk.

**Cybercars**

Cyber cars are fully automatic vehicles. They are equipped with a variety of systems including guiding systems, driving systems, obstacle detection and emergency systems to ensure maximum safety. They also contain practical information such as city and public transport maps. Passengers board at a stop point and pay using automatic payment devices. Because of using electricity to power the vehicle, it is less noise and less pollutant emission. It is expected that the system has great potential to be used to reduce the use of private cars in the urban areas and improve traffic efficiency and environment impacts. The potential negative impacts of using Cyber cars could be the increase of number of changes and out vehicle time.
2 Overview of the methods used

The following methods of measurements have been used throughout the evaluation process in STARDUST:

- The questionnaire (user acceptance, impact assessment)
- Field trials (floating vehicles)
- Driving simulator experiments
- Modelling (microscopic and macroscopic simulation)

The sites and approaches that have been applied are summarised in Table 1.

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The assessment of the impacts starts from the investigation of user behavioural acceptance and human factors and finally integrates them in large-scale traffic models. It goes from the assessment of the potential penetration rate of the systems, and the analysis of the behaviour of individual drivers, when they are provided with selected ADAS/AVG systems: this will raise issues such as acceptability of the systems, willingness to pay for them, willingness to use them, safety issues, etc. Both the assessment of behavioural acceptance and the driving behaviour analysis are key elements of the methodology, as they introduce the end users perception and behaviour in the evaluation process. This prevents from unrealistic conclusions, which would not take into account the actual user preferences.

The overall evaluation methodology then goes through micro-simulation, and finally to the large-scale modelling of the impacts, at the level of a whole city. Micro-simulation models allow representing traffic phenomena with a higher level of detail than the assignment models but within smaller areas. The aim of the micro-simulation has been to sharpen the elements of the large-scale assignment models, so that they integrate the results on the penetration rate and the way the drivers behave with regard to the ADAS/AVG systems. The link between micro-simulation and assignment models has made the latter benefit from detailed modelling of micro-simulation such as time-flow relations, queues and delays.

For evaluation at city levels, the measurement of impacts is mainly based on the network results. These network results come from local impact modelling (e.g. microscopic simulation) first, and then the results are expanded to the network. When the results of microscopic simulation make it possible to calibrate the parameters (capacity, speed/flow relationships, etc.) needed for macroscopic models, the assessment can be done from microscopic to macroscopic modelling as shown in Figure 1.
3 Key research results

3.1 Acceptance of ADAS/AVG systems

3.1.1 User questionnaire
User questionnaires were carried out in Brussels, Oslo and Southampton. The objective of the user questionnaire was to assess driver acceptance of the ADAS/AVG systems studied in STARDUST project: Intelligent Speed Adaptation (ISA), Adaptive Cruise Control (ACC), Stop&Go, Lane Keeping and Cybercars.

There is generally a positive approach from drivers to the ADAS/AVG systems surveyed. Respondents have relatively positive perceptions on the improvements those systems could bring about. They also have positive overall perceptions of the systems. This is particularly true for ISA and ACC, as well as for Cybercars, though this system is more long-term than the others. Respondent were slightly less positive towards Stop&Go systems. Opinions are less favourable for lane keeping systems.

Experience in STARDUST shows that, when correctly informed (for example after a trial in a driving simulator), perceptions and opinions of respondents were more favourable to ADAS/AVG systems than without being informed. Information campaigns would thus be useful before launching systems on a wide scale.

A large number of respondents in the user survey did not have an opinion on the changes driver support systems would bring. Those persons would particularly benefit from such information campaign, and are, in our opinion, likely to view ADAS/AVG systems favourably. There are indeed very few respondents who systematically reject all the systems we proposed (0.3% in the UK, 1.6% in Norway).

From the public authorities point of view, ISA is the most likely system to receive support for implementation in the coming years. It is viewed as technologically more mature than ACC and Stop&Go, and bringing the most benefits. Lane Keeping, though perceived as technology mature too, generates less interest. Lane Keeping is the systems received least acceptance in both UK and Norway.

### 3.1.2 Operator questionnaire

Another survey was directed to public transport operators and infrastructure owners. We interviewed in total 16 of them in the 3 countries. The goal of this survey was to assess what are the barriers to implement ITS from their point of view.

Perceptions of these systems are quite different by country. Some 80% of the Belgian respondents see benefits to ACC and ISA. In Norway, ISA and Lane Keeping are the preferred systems. In Great Britain, respondents see obvious benefits for every system except Cybercars.

Another interesting point to note is that the bus operators seem reluctant to the implementation of Lane Keeping, which is however thought to have positive impacts on bus driving. The three main barriers to implement ACC are the lack of reliability of the system, the juridical and civil liability issues and the research and technology. Stop&Go is perceived in a similar way, though with higher barriers. For Lane Keeping barriers related to cost are the most important. Progress in research and technology and the lack of willingness from the decision makers are two other high barriers to implementation. One of the main perceived barriers for ISA systems is the acceptability by drivers. Important barriers are also the cost, possible problems of liabilities and the reliability of the system.
There was usually little interest on Cybercars. Overall, reduced costs (both investment and operating) are perceived as more important for the respondents that further technical progress or adapting the legislative framework. Let us note however that Very little is usually known about actual implementation costs of ITS.

3.2 Human factor investigation and driver behaviour studies

3.2.1 Human factor investigation

Models of driving behaviour suggest that behavioural adaptation can be expected when intervening with technology in the driving process. In a wider perspective, technology does not simply replace or “take over” a given function; rather it transforms human practice and forces people to adapt their skills and routines. The driver support systems focused in these simulator studies have all been studied before to a greater or lesser extent. However there is a lack of studies on how people adapt to these systems in an urban setting with an urban traffic flow, particularly those related to the learning phase and to the long term effects.

ISA system

The simulator trial of ISA indicates several behavioural adaptations to the new driver support system. There is a significant reduction in top speed for all urban settings studied (arterial roads, urban motorway, inner city streets) when driving with the haptic ISA system. This variant of ISA makes the accelerator pedal hard to press when speed limits are exceeded. In addition this variant of ISA gives the driver a noticeable “kick” under the foot at the moment the speed limit is passed. Analysis of separate urban road segments shows significant lower mean speeds on an urban four-lane motorway with ISA in use. Drivers appropriate a lower mean speed than the baseline condition and spend more time in their primary lane. Due to the speed limited by ISA system, overtaking other vehicles on urban motorways takes longer time with ISA. During overtaking manoeuvres on two-lane roads, drivers with ISA engaged spend more time in secondary lane. Whether this is an exclusive positive effect in terms of safety and traffic flow is open to discussion and will be followed up in the micro and macro simulations models of Oslo, Southampton and Paris.

Workload measurements show no difference with and without ISA. Post test questionnaires show that Norwegian drivers regard ISA as useful and assisting, but irritating. Post test interviews revealed that the irritation was attributed to the “kick” feedback when passing the speed limit and not to the fact that the accelerator became heavy.

ACC system

The simulator trial with ACC indicates that drivers choose significant lower top speed when using the driver support system. This was a finding not previously investigated in other studies. Further, ACC was linked to reduced mean in the majority of segments of the experimental scenario, yet not being a statistical significant pattern, rather, the difference was logical consistent in which drivers with the ACC system engaged had lower mean speeds. Previous studies have indicated reduced speeds as effects of ACC, our findings are thus as expected.
Drivers also used the brake and accelerator pedal more often and with more force than driving without the system. The latter was not anticipated, but can possibly be related to lack of faith in the technology or continued exploration of the system. Post test interviews indicated that the abrupt braking/disengagement of the ACC system was related to technology distrust. Drivers wanted to brake earlier than the ACC system and were prompted to use more force when they realized they had to brake. This is supported by results of workload, which shows that driving with the ACC system was perceived by Norwegian drivers as more mentally challenging (higher workload) than driving with ACC in low speeds (equalling to a Stop&Go function of the system). It can be discussed whether this effect may change with longer exposure to the technology or slight changes in the ACC algorithm allowing earlier system brake control. Other studies suggest that ACC requires an adaptation period, and during that period, certain traffic situations are linked to system distrust. These are similar to those observed in our study; cut-in of other vehicles, cut-in of own vehicle, and approaching moving vehicles.

Contrary to expectations the simulator trials indicate that drivers choose longer headway’s when driving with ACC than without. Further analysis of behavioural patterns suggested that variance of time headway was reduced. This pattern was not statistically significant, yet results indicated logical consistency in terms of the majority of segments showed lower variance with the ACC system engaged. Previous studies have not been conclusive in terms of effects of ACC on time headway, where effects have been found in some studies and not in others. The effects on time headway in this study may thus contribute to the body of data investigating the effects of ACC.

The significant lower top speeds with ACC may imply a considerable safety profit. The consequences of this behavioural pattern and the choice of longer headway’s will be studied more closely in the micro and macro simulations on a city level. Other studies have investigated the effect of driver style and effects of ACC, and such analysis might reveal findings in our present data material.

Stop&Go system

Stop & Go support was tried both by Norwegian and French simulator drivers. It must be noted that the Stop&Go scenarios studied differed in several aspects. In initial analysis, the Stop&Go part of the Norwegian studies show no significant behavioural adaptation in comparison with the baseline drive in terms of changes in headway, neither mean or variance. Yet, further investigation of subgroups of subjects revealed indications of Stop & Go system giving rise to lower mean speeds and lower variance of speed. The French studies showed no marked change in beaviours (headway, lane choice...). Norwegian drivers experienced an urban scenario of a four-lane motorway with slow traffic, stand stills and little opportunity to change lanes. French drivers experienced a three-lane city boulevard with traffic lights and, in two of four scenarios, ample opportunity to change lanes.

It must be noted that the previous Stop&Go studies have been, primarily, related to the system itself (algorithm, technologies...) or the potential impacts on the traffic flow. Few previous studies concern the driver behaviour.

Lane Keeping system
This Lane Keeping system helps the driver to keep its vehicle within the driving lane. To study the impacts of the system, the French drivers had to drive on the possible “future” city boulevard, i.e. a dedicated vehicle lane becomes a dedicated bus lane and the other lanes are narrower. This case may induce a loss of level of service: due to the difficulty of vehicle guidance in narrow lanes, the drivers’ speeds would be lower; this decrease of speed would induce a loss of capacity. Studies of Lane Keeping aim to evaluate the impacts of system relate both to the traffic capacity and the traffic safety. As for the Stop&Go system, few previous studies were related to the drivers’ behaviours.

The main results from the French trials are:

- More subjects drove on the left side of the narrow lane without the system than with. The system helps them to keep the vehicle in the lane.
- More subjects maintain their average speed during the drive with the Lane Keeping system ON. With the system OFF, most subjects drove with a lower speed.
- The general feelings about the system are mainly positive. At least 50% of the subjects declared to be ready to use Lane Keeping on their own vehicle.

The positive implications this behavioural adaptation exposed in simulator trials may have on urban traffic flow will be studied further in micro and macro simulations on a city level. Lane Keeping as a driver support system was considered useful by French drivers.

3.2.2 Driver behaviour studies

The data were collected by using an Instrumented Vehicle which is equipped with a laser radar rangefinder. The data collection covered urban motorways, urban arterial roads and city streets in three European cities: Oslo (Norway), Paris (France) and Southampton (UK). A total of over 65 hours of field data were collected in the three cities. The analysis was focused on low speed traffic behaviour especially in Stop&Go traffic, the main parameters investigated included time gap, distance gap, acceleration, deceleration, braking frequency, start delays and stopping-distance-gaps.

Time gaps and distance gaps on motorways across wide speed ranges were investigated. The results from the three sites show that time gaps decrease as following speeds increased when in low speed situations (e.g. <60km/h), and became relatively stable when at high speed (e.g. >70km/h). The results also show that time gaps were more variable when at low speeds than those when at high speeds. Whilst, distance gaps were less variable when at low speeds than those when at high speeds. The average time gaps and their standard deviations in the speed ranges between 10 and 40 km/h were 1.90 seconds and 0.74 seconds, compared to 1.15 seconds and 0.36 seconds when at speed higher than 70km/h. Constant time gap assumptions are used studies on ACC and Stop&Go. The results from this study suggest that variable time gaps might be more appropriate for simulation.

Most vehicles experience delay when starting to move in a queuing event because of driver reaction time, maneuver delays, mechanic delays and human error. In this research, start delays at signalized intersections and on non-junction roads were investigated. The results from the three cities show that start delays on motorways were significantly higher than those on urban streets. The mean start delays on motorways was 1.27 seconds, compared to 0.93 on urban streets which implied that there could be greater benefit using Stop&Go on motorway than on urban streets, because Stop&Go systems use sensors to detect the movement of the preceding vehicle which can significantly reduce driver reaction time.
Stopping distance gap is a parameter which concerns driver behaviour in static traffic conditions. The results show that the average stopped-distance gap on urban streets was 1.79 m, whilst on the motorways the average stopping distance gap was 1.98 m. Distance gaps at stop on urban streets were compared between the three cities. The distance gaps at stop in Paris were found significantly higher than those in Oslo and Southampton. Stopping distance gap is a parameter directly linked to the storage capacity of a road, any reductions in stopping distance gap or its variability would suggest a benefit in increasing storage capacity and possibly the traffic capacity of the road link.

3.3 Assess ADAS/AVG impacts through simulations

3.3.1 Microscopic simulation

The assessments were based on micro-simulation results from three cities: Oslo, Paris and Southampton with local traffic conditions being considered in the simulation. The impacts of ISA, ACC and Stop&Go and their combinations on urban motorways, urban arterial roads and urban streets were targeted with the focus being on the traffic efficiency and safety impacts. The assessments were based on micro-simulation by comparing traffic performances between those at baseline conditions and those when ADAS systems were applied. In the scenarios of urban arterial roads and urban streets, the typical urban traffic conditions of signal controlled junction and roundabout were considered. For each system or system combination, four levels of penetration were simulated: 0% (baseline), 20% 80% and 100%.

For simulating longitudinal impacts of the ADAS systems, a linear car following model was applied which was calibrated and validated by using observed data collected by floating vehicle approach in the three cities. Two types of simulation models were used in the simulation: AIMSUN (Oslo and Southampton) and ARCHISIM (Paris). Several performance indicators were selected for the assessments including average journey time, average speed, average stops and stop time per vehicle, time-headways and time-to-collision. Two types of measurement were used: detectors at a fixed location and tracking vehicles over the whole journey.

ISA applications were investigated by simulation on three types of road: urban motorways, urban arterial roads and urban streets. Off peak traffic was targeted when no congestion occurred. In each sites, typical local traffic conditions and speed limits were considered in the simulation. The safety benefits from ISA applications can be evidenced by the reduction of speed and speed variations, the reductions of lane change rates and the number of short time-headway and small TTC events. The obvious negative impact of ISA applications was the increases in journey time. Based on the simulation results, the increase of journey time were in a range of 0%-15% which depended on factors including ISA penetration levels, baseline speeds, and road types applied.

The applications of Stop&Go on urban roads were investigated by studying its impacts on traffic efficiency and safety in conditions of signal controlled junctions and roundabouts. Positive impacts on traffic efficiency were identified in conditions of both signal controlled junctions and roundabouts. At signal controlled junctions, the saturation flows can be increases up to 29% when all vehicles become equipped, such increases in capacity can be attributed to the more efficient use of time and space by the equipped vehicles (short reaction time). At roundabouts, Stop&Go benefits in efficiency were much dependent on the
congestion levels on approaching arms. In situations of both signal controlled junction and roundabouts, significant reduction of small TTC events was found when Stop&Go was applied.

ACC+Stop&Go on urban motorways and urban arterial roads were simulated in situations where both cruise driving and “stop and go” driving exists. The main objectives of such studies were to assess the longitudinal impacts of the systems on traffic efficiency and safety. Positive impacts on traffic efficiency have been noticed. On motorways, the journey times were found to reduce by up to 15%. The effects of ACC+Stop&Go on efficiency are much dependent on the congestion levels encountered during the journey. The heavier the congestion and the longer the length of the queues, the more benefits in traffic efficiency. Significant reductions of small TTC events were found which could be attributed to the smooth movement of equipped vehicles. The comfort benefits from ACC+Stop&Go was evidenced by the reductions of the number of stops.

3.3.2 Network modelling at a city level

To assess ADAS/AVG impacts at a city level, the following scenarios were investigated by network modelling: ISA applications, Stop&Go on urban roads, ACC+Stop&Go on urban arterial roads and motorways, High Capacity Buses, Cybercars in city centre areas.

Simulations were performed based on traffic conditions in the three case cities: Brussels, Oslo and Southampton. Two kinds models were used: SATURN (in Brussels) and CONTRAM (in Oslo and Southampton). The assessments were focused on two kinds of impacts: traffic and environment. Three penetration levels were considered for each system/scenario: 0%, 20% and 80%. Each penetration level was run with high and low of expectation of effects corresponding to micro-simulation results from WP50. In addition, simulations at different traffic demand were performed to test the sensitivity of the results to traffic demands.

ISA impacts

The ISA effects of reducing excessive traffic speed in the network, hence improving safety generally results in increases in journey time over the network. This was dependent on the penetration level of ISA systems, and the simulation results showed that network journey time increased as ISA penetration rates increased. No significant changes in network distance were found in Southampton and Oslo which indicated that ISA did not cause much change in the general patterns of assignments, with most of drivers keeping their original routes. ISA impacts on fuel consumption and pollutant emissions are dependent on road types applied. ISA have positive impacts on fuel consumption on high speed roads, but negative impacts on low speed roads. CO₂ and NOx emissions were found to have similar trends with fuel consumptions. ISA is more effective in non-congested traffic conditions when drivers are able to exceed a speed limit, thus the effects of ISA are sensitive to traffic demands.

Stop&Go impacts

Stop&Go have potentials to increase saturation flows of signal controlled junctions because of short reaction times. Unlike infrastructure based measures, the increases of saturation flows at a signal controlled junction are the cumulative effects of individual vehicle in the fleet. Therefore, such impacts are dependent on traffic demands and penetration levels of equipped vehicles. When 80% of vehicles operate the system, the network queuing times were found to reduce by up to 19%-25%, and a reduction of journey times of 7.5%-15% (it is assumed that the system characteristics and traffic benefits lead to general use).
In general, Stop&Go has positive impacts on environment. Stop&Go can contribute to improvement of environment by smoothing vehicle movements and reducing queuing time at junctions.

A key assumption made for this simulation was that levels of traffic flow were sufficiently high to cause saturation on approaching arms of the junctions. If the flow was under saturation level, there would be fewer benefits from using Stop&Go. It was also assumed that Stop&Go had no significant differences in its effects on increasing saturation flows between ahead and turning traffic. Thus, the results should be interpreted with caution, and may be considered to represent the limit of the gains which could be made with a Stop&Go system designed both to support the driver and to optimise efficiency in network management.

**ACC+Stop&Go impacts**

The effects of introducing a combined system of ACC+Stop&Go were simulated for large scale networks in Brussels, Oslo and Southampton. In Brussels and Oslo, the system was applied in the whole network, whilst in Southampton, ACC+Stop&Go was applied only to those motorway and arterial links identified from baseline results for which traffic would be likely to benefit from a combined ACC and Stop&Go operation, i.e. a long queue was formed at a bottleneck on a high-speed road (e.g. approaching junctions on congested motorways or approaching to a large roundabout). Some ‘cruise’ driving was experienced before encountering the queue on the link. For equipped vehicles, longitudinal movements were considered to be controlled by an ACC+Stop&Go system in both high and low speed following process. Based on the simulation results from the three cities, the following conclusions can be made:

- The application of ACC+Stop&Go has positive impacts on traffic efficiency in terms of reduced network journey times. The network effects of ACC+Stop&Go depended on the penetration levels. As the penetration rate increased, network journey time savings increased. At an 80% penetration level, network journey times were reduced by 2.4%-6.4% in Brussels and Oslo respectively. In Southampton, the network journey timesaving was only 0.8%, much lower than in Brussels and Oslo, mainly because of the small number of ACC+Stop&Go links being considered.

- Traffic demand has significant impacts on the benefits of ACC+Stop&Go. The higher the traffic demands, the more the congested traffic, and the more the opportunities for using ACC+Stop&Go.

In Brussels and Oslo, the implementation of the ACC+Stop&Go in the model was achieved by modifying speed-flow relationships or saturation flows based on the micro-simulation output from WP50. In Southampton, the implementation of ACC+Stop&Go was achieved by applying the changes of journey time from micro-simulation directly to those links identified. The main differences in the journey timesaving between Brussels/Oslo and Southampton come from assumptions made for the simulations. In Brussels and Oslo, ACC+Stop&Go was applied to the whole networks, assuming that Stop&Go traffic occurring on all motorway and arterial links, whilst in Southampton, ACC+Stop&Go was applied only to selected road sections which were identified as having with potential Stop&Go traffic.

**High Capacity Bus impacts**
A system with High Capacity Buses based on Lane Keeping system in the buses seems to be an interesting solution and a technology that may reduce the distance travel in the network. A large modal shift requires however a substantial improvement in the travel time for buses compared to private cars. This may also be obtained by introducing more inconvenience for the cars users as higher toll prizing as well as congestion management.

**Cybercars in city centre areas**

Cybercars were used in this study as a convenient, user-friendly and non-polluting (at the point of operation) transport system to cover the ‘last mile’ of a commuting trip to workplaces in the city centre. The success of this application is based on the assumed large modal shift from private car towards a P&R application. The simulation has shown large potentials for improvements in network speeds and reductions in levels on congestion on a network-wide level. Due to the modal shift towards the use of buses large improvements were also possible for inbound trips in the morning peak on the six main bus corridors considered in this study.

But these journey time savings have to be reduced when considering the whole journey time for the multi-modal journey including waiting times, transfer times and cybercars travel times. This complete journey time is likely to be higher than the current journey by private car in the baseline scenario. Although this would still generate environmental benefits, the end-user would be unlikely to accept these increased journey times, unless the costs are much lower than costs for the private car. Therefore subsidies and/ or instruments like road user charging or higher vehicle/ petrol taxes might have to be applied.

Future large-scale applications of cybercars, based on this small-scale test or demonstration, replacing the multi-modal journey by a direct door-to-door cybercars service has the potential of providing lower or at least similar travel times compared to the private car, whilst still maintaining the environmental benefits.

### 3.4 Legal issues

**Advisory, Overridable and Mandatory Systems.** Where a vehicle is equipped with an ADAS / AVG, responsibility for the driver’s behaviour will, in most cases, remain with the driver. Even where an ADAS / AVG fails, if the system is merely advisory in nature (such as an ISA system which warns the driver that they are about to break the speed limit, but exerts no haptic control over the vehicle) then the driver is likely to remain liable for his response. Where the ADAS / AVG is haptic but overridable, the liability of the driver will depend upon the circumstances of each case. Finally, where the ADAS / AVG is mandatory, with no possibility of driver override, the driver’s liability for any accident caused as a result of the system’s intervention decreases, because he does not retain ultimate control over his vehicle.

**Training.** With each ADAS / AVG, driver training would seem to be a vital prerequisite to use of the system. No matter how remarkable the design of the system, it will only be safe and beneficial if drivers are fully trained in its use.

**Warnings.** For ADAS/AVG systems, warnings to the user from the system/vehicle manufacturer are extremely important. When assessing whether or not a product is defective the courts have regard to the nature of any warnings or instructions issued with the product. If a claimant chooses to disregard a manufacturer’s warning or instructions as to the use or limitations on use of a product, the court may decide that the product was not defective.
The Urban Environment. In the case of each ADAS / AVG, numerous difficulties arise when the system is considered in respect of an urban environment. The source of these difficulties is the number and complexity of interactions between the driver, the system and the external environment. This is particularly true in relation to Stop & Go. The challenge will be to introduce such a system with acceptable safety risks, given the inherent limitations of the technologies within the context of the urban environment. Where, on the other hand, the limitations of a system are relatively easy to appreciate and there are fewer requirements placed on the driver, the risk implications of the system will be correspondingly reduced.

General Approach. In considering the risks of implementing these systems, they can be analysed systematically according to certain common factors. First, what are the inherent limitations of the system in the environment within which it is to be used? Secondly, how frequently are these limitations likely to manifest themselves? Thirdly, where the system requires regular driver intervention, how reasonable is it for the average driver to make the correct intervention? The answer to this third question may rely in part on the feasibility of effective warnings/training in relation to the particular system and partly on the feasibility of the driver reacting promptly and properly to the situation. The answers to these questions may allow a systematic risk analysis to be performed on the various systems.

4 Conclusions and recommendations

4.1 ADAS/AVG impacts

User acceptance

There are generally positive opinions to driver supporting systems. Respondents have relatively positive perceptions on the improvements those systems could bring about. They also have positive overall perceptions of the systems. This is particularly true for ISA and ACC, as well as for cybercars, though this system is more long-term than the others. Respondent were slightly less positive towards Stop&Go systems. Opinions are less favourable for lane keeping systems.

Experience in STARDUST shows that, when correctly informed (for example after a trial in a driving simulator), perceptions and opinions of respondents were more favourable to the systems than without being informed. Information campaigns would thus be useful before launching systems on a wide scale.

Traffic impacts

Intelligent Speed Adaptation (ISA): The ISA effects of reducing excessive traffic speed in the network results in increases in journey time. Overall, network journey times were found to increase in a range from 4.3% to 6.0% at 80% of penetration level. There were more increases in journey times on high speed roads (e.g. motorways) than those on low speed roads (e.g. urban streets). No significant changes in network distance were found which indicated that ISA did not cause much change in the general patterns of assignments, with most of drivers keeping their original routes. ISA was fund to be more effective in non-
congested traffic conditions when drivers are able to exceed a speed limit, thus the effects of ISA are sensitive to traffic demands;

Stop&Go on urban roads: Stop&Go have potentials to increase saturation flows of signal controlled junctions because of short reaction times. In addition, Stop&Go can smooth vehicle movements which result in reductions of small time-gap and time-to-collision events. Unlike infrastructure based measures, the impacts of increased saturation flows at a signal controlled junction depend on the number of equipped vehicles in the queue. Therefore, such impacts are dependent on traffic demands and penetration levels of equipped vehicles. When 80% of vehicles operate the system, the network queuing times were reduced by up to 19%-25%, and a reduction of journey times of 7.5%-15% (it is assumed that the system characteristics and traffic benefits lead to general use).

ACC+Stop&Go on urban arterial and motorways: A combined system of ACC+Stop&Go makes it possible to automate the task of car following at both high and low speeds. In general, traffic impacts of such combined systems are similar to those when an individual system is used. ACC+Stop&Go can smooth vehicle movements in both high and low speed traffic. The application of ACC+Stop&Go can have positive impacts on traffic efficiency in terms of reduced network journey times which depend on the headways chosen by drivers and how extensive the system is used.

Lane Keeping: Lane Keeping can be used to help drivers to keep vehicles in narrow lanes which are assumed to be dedicated to public transport. A Lane Keeping based bus service has the potentials to reduce the private car use when urban roads become heavily congested or become restricted (e.g. congestion charges). To make it effective, large modal shifts are needed from private car to public transport. This requires however a substantial improvement in the travel time for buses compared to private cars.

Cybercars in city centre area: In the scenario of city centre areas being reserved for public transport, Cybercars can be used as a supplement to mass public transport by feeding and distribution. The simulation has shown Cybercars have positive impacts on traffic at a network level in terms of reduced total trips and increased speeds. In this condition, complete journey times is likely to be higher than the current journey by private car in the baseline scenario, because of the multi-modal journeys including waiting times, transfer times and cybercars travel times.

Safety impacts

ISA impacts on safety can be evidenced by the reduced maximums speed and speed variations. In addition, ISA can harmonize vehicle speeds between and within lanes and the reduce lane change rates. As longitudinal control systems, ACC and Stop&Go can contribute to the improvement of safety by smoothing vehicle movements which reduce the number of short time-gap and time-to-collision events.

Environment impacts

One of the basic functions of an ADAS/AVG system is to automate some or all of the driver’s tasks. In doing so, the vehicle is controlled in a known fashion which can be used to communicate with the on-board diagnostics systems to achieve an operation with optimum mode in terms of fuel consumption and pollutant emission. ADAS/AVG impacts on environments can be achieved directly or indirectly: by smoothing vehicle movements (e.g.
Stop&Go and ACC), changing speed profiles (e.g. ISA), and reducing private car trips (e.g. Lane Keeping and Cybercars). As longitudinal control supporting systems, Stop&Go have positive impacts on fuel consumption and pollutant emission because of smoothed vehicle movements. ISA impacts on environment are dependent on traffic conditions applied. Simulation results show that ISA have positive environment impacts when being applied on high speed roads (e.g. motorways), but negative impacts on low speed roads (e.g. urban streets).

4.2 Recommendations

The STARDUST project has revealed some important issues regarding the deployment of ADAS/AVG systems. It seems clear that the driver support systems will come into use in a certain extent in the coming years. To move forward and reach a level of use that will have a major influence on traffic flow and safety there are some main concerns that have to be dealt with. The way these issues are solved will have an important impact on the development and deployment of driver support systems:

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

To governments

- Through the Kyoto agreement (1997), the EU has agreed to an 8% cut in emissions of a range of climate change gases in the period 2008 to 2012, compared to the 1990 levels. The challenge to meet this within the transport sector is recognised by DGXI as “acute..., where a significant growth in emissions has occurred and will continue to occur if no action is taken.” Most ADAS/AVG systems offer potential benefits to the environment. From this point of view, government polices should prioritized developments and implementation of environment-friendly systems such as Stop&Go (especially in urban areas).

- Many European cities are facing the problems of increasing congestion and pollution. Restricting private car trips to city centre areas has been recognised as a fundamental measure to control traffic demands (e.g. congestion charge in London). It is expected that the idea of “A car free city centre” would be accepted by more and more cities to protect urban environment. Under this condition, ADAS/AVG technology could be one of the solutions, for example by using High Capacity Bus (based on ADAS technologies such as Lane Keeping, Platoon) and Cybercars.

- For safety critical devices, e.g. Collision Warning and Collision Avoidance devices, the design of these products balances detecting rare unsafe situations and providing warnings and/or corrective control assistance to the driver with developing systems that do not create too many false alarms. Clearly, the introduction of such systems should have a positive net effect on safety within a urban road network. Other devices such as ACC,
Stop&Go and Lane Keeping will help improve the quality of the driving experience and reduce unsafe situations brought about by human error. This has to be balanced by designing the systems to achieve optimum workload for the drivers and not developing latent problems through a loss of driver skill when operating without the systems. Whilst this is a great challenge in the development of such systems, there is enormous potential to reduce the number, but also the severity of road traffic accidents.

- There is a rather positive perception from end-users on the improvements of driving safety, comfort and convenience, especially for ISA, ACC and Stop&Go. It seems clear that driver support systems will come into use in a certain extent in the coming years. However, these systems can provide wider network benefits with regards to traffic flow and more throughput of traffic – but may as well cause disbenefits if not co-ordinated between manufacturers and government. On the background of the concern regarding legal and liability obstacles for the development of driver support systems, there seems to be a need to develop a robust policy to encourage the manufacturers to move in certain directions. This policy should be based on a compromised understanding between the government and the manufacturers. To reach this understanding and develop policies and strategies, it seems necessary to work with both local/regional/national/European authorities.

- The EU has a number of new approach Directives that detail the testing and certification of products and services particularly those that may have some impact on public safety. European states often implement the Directives in different ways to integrate within their existing legal framework. Technical regulations are often used to detail the performance requirements while other states rely on the National Standards Organisations documentation to detail the requirements. The alternative is to adopt harmonised standards. Harmonised Standards are European Standards, which are adopted by European standards organisations, prepared in accordance with the general guidelines agreed between the commission and the European standards organisations, and follow a mandate issued by the commission after consultation with member states. The level of importance attached to the health and safety issues determines the process for testing and whether self-certification is appropriate. The regulating body and the manufacturer need to address these issues.

- To make a substantial step forward regarding deployment rate, it seems necessary for the government to look at regulations making some of the systems mandatory (for safety systems such as ISA). It is also important that infrastructure owners to cooperate with vehicle manufacturers to increase the network benefits of ADAS/AVG systems (e.g. Lane Keeping systems).

To local governments
Many ADAS/AVG systems are under developments. ISA, ACC, Stop&Go and Lane Keeping are the systems which have significant impacts on congestion and would reach markets in the next five to ten years.

- ISA can be used to reduce the number and severity of accidents. Using ISA can help local authorities to achieve the objective of increasing safety, especially on roads around schools. For vehicle based ISA, users would pay for the cost of the systems. The main cost of local governments is to provide the accurate location information and relevant
speed limit data. To achieve this object, it would be necessary to the level of monitoring required for a particular network to support the information chain. Safety policy (e.g. speed enforcement) can affect the driver choices of different ISA functions (warning, voluntary and mandatory).

- **Lane Keeping systems would be useful for implementing narrow lanes in urban areas to improve bus efficiency and reliability in urban areas.** This is particularly important in the scenario that access to city centre areas is controlled. One option is to establish narrow bus lanes to connect city centres and Park&Ride around urban areas. In such cases, it is also possible for the buses to be operated in platoon to increase traffic efficiency over the network.

- There are a number of applications that are vehicle based within the ADAS systems such as ACC, ISA, and Stop&Go. These don’t need any special facilities to be provided by the local authorities. These applications may, however, influence the traffic patterns and control options and the control centres need to be aware of the implications as the level of penetration for a particular application increases. The local authorities have an important roll to play in identifying the opportunities to utilise a range of ADAS applications and to support the implementation of these advancing techniques.

- **STARDUST results show that drivers with experiences of recurrent long queues have higher levels of acceptance of Stop&Go systems than those without such experiences.** With increased traffic congestion in urban areas, it is expected more and more people would accept Stop&Go systems. As a convenience featured system, Stop&Go can also contribute to improvement of safety by reductions of rear-end collisions and environment by smoothed vehicle movements. Stop and Go may change the driving patterns, which impact may impact on the control algorithms. The local operators will have to understand the changes if full use of the application is to be achieved.

To manufacturers

- **To look into how different systems can be combined in order to both achieve the benefits and minimize the liability concern, e.g. longitudinal control systems (ACC and Stop&Go) and collision warning and avoidance systems.** These strategies will probably also lead to development of more robust systems under different traffic situations.

- Another important part of the issue is the market needs and how market requirements are met regarding information, training and user support.

- System manufacturers are picking up small but still important gains for their own benefit. To make a substantial step forward however there is a need for infrastructural involvement regarding e.g.:
  - establishing data bases for speed limits
  - initiate standardisation work

- It is an important issue, if or how, driving instructors and car manufacturers introduce drivers to the new technology. Many drivers still do not know how to operate ABS-brakes or the ESP-system, several years after they became standard equipment.

**STARDUST road map**
The STARDUST project has revealed some important issues regarding the deployment of ADAS/AVG systems. It seems clear that ISA, Stop&Go and Lane Keeping systems will come into use in a certain extent in the coming years.

Based on the ADASE concept, the technologies studied in the STARDUST project can be illustrated as shown in Figure 2. Figure 2 also includes the parameters traffic efficiency and environmental aspects in the description of how the systems contribute to society goals in addition to safety enhancements.

The complexity indicator is a way of illustrating where each system stands in the development phase and the challenge in the further development of each system.

STARDUST road maps are one dimensional and focus only on the benefit and complexity of the systems. For the purpose of giving advice to the different stakeholders how to act with regards to driver support systems it seems appropriate to introduce a time scale or time horizon. One way of doing this is illustrated in Figure 3.
In Figure 3 the high level product relates for instance to a fully automatic Stop&Go system that might be active for a journey through the city centre. The basic level product relates to a Stop&Go system that needs to be reactivated after each stop. The later technology might be activated by the driver to avoid legal problems within conflicts between cars and pedestrians.

**Implementation path**

To move forward and reach a level of use that will have a major influence on traffic flow and safety there are some main concerns that have to be dealt with. The way these issues are solved will have an important impact on the development and deployment of driver support systems:

- Legislation (mandatory or not)
- Infrastructure investments
- Combination with other applications
- Robustness of the systems in different traffic situations
- Liability issues
- Market needs (user acceptance, training, long term effect, maintenance)
To make a substantial step forward regarding deployment rate, it seems necessary for the government to look at regulations making some of the systems mandatory. It is also important that the infrastructure owners give ADAS / AVG systems priority in their investment budgets.

One key issue will probably be to look into how different systems can be combined in order to both achieve the benefits and minimize the liability concern. These strategies will probably also lead to development of more robust systems under different traffic situations. Another important part of the picture is the market needs and how market requirements are met regarding information, training and user support.

Figure 3 illustrates that the way forward is not a static process and the success measured in benefits to the road users and society and degree of implementation is dependant of a certain work process. This can be illustrated as shown in Figure 4 on next page based on an idea originally distributed for the NETMOBIL project where STARDUST is one of four cluster projects.

The implementation path diagram is a way of indicating the various key activities for various areas of research and development. The coloured keys detail the particular elements of the activity. These elements are based on the activity bar reproduced in section 5.2.3 from another NETMOBIL activity covering the three key sections: Users / feasibility, pilot and implementation. The activity bar details the process of developing standards as a consequence of directives - the third stage on the bar.

Figure 4 Possible approach to developing An Implementation Strategy

The proposed approach can be summarised as follows:

- identify and agree indicative future scenarios and an implementation path
- identify the barriers and risks from the common areas and elsewhere
- identify the critical activities and hence the critical path
- develop an implementation strategy
- identify the dissemination activities needed to support the strategy
The STARDUST project has revealed some important issues regarding the deployment of ADAS/AVG systems. To move forward and reach a level of use that will have a major influence on traffic flow and safety there are some main concerns that have to be dealt with. The way these issues are solved will have an important impact on the development and deployment of driver support systems:

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

### 4.3 Future research and other needs

The STARDUST project has revealed that driver support systems has a substantial potential in the urban environment regarding traffic flow and traffic safety, but also that there is a need for more research on urban following processes and traffic flow mechanisms:

- influence on capacity (smoothing and increasing the flow)
- reliability of the systems under different traffic conditions and surroundings
- adaptation and interaction to the traffic environment
- effects of coupling between different systems
- safety (looking at the driver behaviour and traffic processes, long term database for incidents)
- user acceptance and understanding of new technologies

From the road keeper and governmental point of view there is a need for more research in connection with the understanding of the traffic management implications:

- opportunities
- handling and regulating inappropriate technologies
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