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ICT applications on the road to sustainable urban transport

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Abstract

This paper addresses the impact of information and communication technology (ICT) on sustainable transport by examining the direct application of ICT in urban transport. Following a discussion of various negative externalities of transport, the paper examines the extent to which existing and potential ICT applications in the transport sector can assist in making urban transport more sustainable than it is at present. The focus of analysis is on qualitative and quantitative impacts of several ICT applications on travel behaviour (including fatalities), factors that influence adoption, and impacts of adoption including potentially secondary effects. The literature suggests that ICT innovations are most effective in fatality reduction, but it seems that these are also quite effective in reducing fuel consumption through fuel-intelligent vehicles.

Keywords: Information and communication technology; Urban transport; Sustainability; Excessive driving; Congestion relief; Fatality reduction; Fuel-intelligence.

1. ICT applications and the road to sustainable transport

Car traffic in urban areas uses 50% more energy than car traffic in non-urban areas. Therefore, it makes sense to specifically focus on urban transport in the context of the need for an increased sustainability of transport. Various technology options are open to bring sustainability aims in transport nearer, like the use of electric vehicles, hybrid vehicles deriving electricity from hydrogen operated fuel cells or batteries, and the use of vehicles that are cleaner and more efficient in using fossil fuels. Many studies are devoted to the energy road towards sustainable transport, but only a few are concerned with the use of novel ICT applications.

This paper addresses the role of information and communication technology (ICT) in supporting urban transport to become more sustainable. It examines potential

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sustainability increases but also critical hurdles that prevent the adoption of particular applications and achievement of the right behavioural responses. We focus on qualitative and quantitative impacts of several ICT applications on travel behaviour, including fatalities. Broadly speaking, information and communication technology is a set of heterogeneous technologies (hardware and software) that allow for electronic communication, data collection and processing in distributed networks, and electronic guidance and management through sensor technologies. ICT applications in the transport system differ in complexity, ranging from simple electronic communication (signals) to interactive and highly intelligent applications in traffic management and control, and in car fuel management. Differences in complexity become also apparent if one considers the position of the new technology in the urban transport system perceived as a system of layers, i.e., infrastructures, services on these infrastructures, vehicles moving through the system of infrastructures, and persons and freight moving in these vehicles. Of course, from a *holistic* perspective, it would be necessary to also consider the extent in which the electronic devises used in the different solutions are manufactured in a sustainable way, like electric road screens and in-vehicle electronic devices and sensors. However, this perspective falls beyond the current study.

Sustainability of the transport sector in urban areas is a major concern today for governments throughout the developed economies of the world. Although the sustainability concern was focused on negative environmental externalities of the transport sector in the early 1990s, the term has a much broader meaning today. Concerns over greenhouse gas emissions and global climate change, as well as the potential depletion of petroleum, the world's major transport fuel, have been joined by concerns for urban air quality, excessively large numbers of vehicle accidents and their resulting fatalities and injuries, and congestion.

All of the major externalities related to non-sustainability are a function of traffic volume. Thus, in order for the transport system to become sustainable all that is necessary is to decrease the amount of transport consumed. The paper looks to ICT innovations in the transport system as possible ways of accomplishing the outcome of sustainability. To this purpose, we first introduce the layer model of urban transport systems. A main difference between ICT applications is their position in the system in that some of them are *fixed* (or semi-fixed) in the physical infrastructure (first layer), e.g. automated guideways (physical), on-road signing including variable messaging, and surveillance systems, and others are *mobile* in the sense that they are in-vehicle systems or personal (portable) systems. Another main difference between ICT applications resides in the type and number of layers in the urban transport system required to implement the application. Thus, some applications make use of one layer, while others make use of two or three of them. If more layers are involved, the technical complexity seems higher because of the additional infrastructure requirements; it also implicates the involvement of a larger number of different transport actors, potentially increasing social complexity and a delay in the adoption of the innovations concerned. ICT innovations in the transport system may also be categorized according to the role of the information concerned, ranging from information to support choices of car drivers and passengers, to information that serves to take over drivers' decisions. The last role is causing legal issues concerning responsibility and liability to enter the scene. Such a situation tends to delay the adoption of the innovations concerned.

In the paper, a closer look is taken at various practical ICT innovations that can be used to reduce non-sustainable fuel use and other negative externalities by distinguishing between three sustainability areas, that is: (1) excessive driving, (2) congestion relief and (3) fatality reduction. We will focus on private cars (persons and freight) and public transport using roads in urban areas. For each of the applications addressed we discuss to what extent the applications are currently adopted and what the effectiveness is in terms of impact on sustainable transport. In the last context, attention is also given to compensation and circumvention behaviour of drivers causing a reduction of the overall impacts in the urban transport system. The source of analysis is a compilation of the recent international literature on transport behaviour and transport policy (last three years).

The paper is structured as follows. After a brief discussion of transport non-sustainability, a closer look is taken at the urban transport system concerned by examining ways in which applications of ICT in various layers of this system can lower (or alter) negative impacts of using the transport system. A distinction is made between excessive driving, congestion relief and fatality reduction. Finally, differences in the potential for ICT applications are indicated and positive impacts on sustainable urban transport are evaluated by considering appropriate behavioural response and by considering higher levels in the urban transport system than the level directly affected by the applications.

2. Transport non-sustainability and the application of ICT

Greenhouse gas emissions that lead to global warming, emissions leading to air pollution with its negative impacts on human health, the large number of fatalities and injuries, diminishing petroleum reserves, and congestion, are generally accepted as components of non-sustainability by most scholars working in this area today. They are the factors that will prevent future generations from carrying out transport in the same manner that the current population does, and in effect, this is what leads to non-sustainability (e.g. Black, 2003). Before examining the various ICT impacts on problems of sustainable transport it is appropriate to state what may be a very obvious relationship. It is that all of the major externalities related to non-sustainability are a function of or are influenced by the volume of traffic (Black and Van Geenhuizen, 2006). Stated quite simply the higher the vehicle miles or kilometers traveled in a country, the greater the level of total greenhouse gas emissions from the transport sector of that country. This is true of the criteria pollutants such as carbon monoxide, sulphur oxides, nitrogen oxides, and others, as well as traditional greenhouse gases, such as carbon dioxide. Motor vehicle accidents are also a function of traffic volume. This is so obviously the case that when researchers begin to examine these, one of the first things they do is divide accidents by flow volume and work with the resulting rate of accidents per million miles traveled or some similar measure. The use of gasoline, and therefore the eventual depletion of petroleum stocks, also increases with flow volume, not the volume on a single road, but the total vehicle miles travelled. It is certainly true that different vehicles and vehicle models differ in their fuel economy, but in general the greater the vehicle miles driven by a countries' motor vehicle fleet, the greater the amount of fuel that is used. Finally, as flow volumes increase, they begin to exert influences on other vehicles in the traffic stream and this creates congestion. The ECMT has defined congestion as "the impedance vehicles impose on each other, due to speed flow relationships, in conditions where the use of the transport system approaches capacity.” (ECMT, 2000, p. 220).

A major way to achieve a sustainable transport system is to decrease the amount of transport consumed. This is much easier to state than it is to accomplish. Regulatory policies could be formulated to achieve this end, or nations could encourage voluntary actions to accomplish the same end. It goes without saying that the former is very unpopular and the latter is unsuccessful. Therefore, various ICT innovations in the transport system are examined as possible ways of accomplishing the same outcome. To this end, first a simplified layer model of the urban transport system is introduced that applies to persons and freight transport, and clarifies the different actors involved and the targeted aspects of the system (Figure 1).

Layers	**Actors involved**	**Target of ICT innovation**
Layer 4. Persons and freight Persons (drivers), parcels, containers, bulk, etc.	Private car users Public transport users Freight transport users	Drivers’ behaviour: route selection, driving speed, reaction in driving, reduction of driving tasks. Passenger behaviour in public transport: mode choice and route selection. Quick first aid after accident. Freight: routing and load matching.
Layer 3.Vehicles moving through the system Trains, cars, busses, vans, bikes, vessels, etc.	Owners of private vehicles Logistics providers Chain organizers Vehicle manufacturers ICT manufacturers Public transport companies	Size of flow, speed of flow, identification of obstacles, in-between vehicle distance in flow (longitudinal, lateral), collision avoiding.
Layer 2. Services on the infrastructure Public transport services (time schedules) services for maintenance and transport management	Public transport companies Operators of links and nodes ICT system manufacturers Public authorities	Providing/preventing (or slowing down) access of public transport services to persons Improvement of matching different services (seamless connections)
Layer 1. Physical infrastructure (links, nodes) Rail, road, airline, pipelines, waterways, etc.	Infrastructure providers Infrastructure owners Public authorities	Providing/preventing access to infrastructure links and nodes to vehicles

Figure 1: A simplified layer model of the urban transport system.

The model comprises four layers, i.e., physical infrastructure, services to let the infrastructure work, vehicles moving through the infrastructure system, and persons and freight using these vehicles. In fact, a fifth layer can also be distinguished, that is the layer of institutions that influence regulations, arrangements between actors involved and legal and liability issues in case of accident and fatalities, etc. Impacts of interest for our analysis are mainly generated in the layer of vehicle flow (3) and the layer including persons (drivers) and freight (4). The main difference between ICT applications is that some of them are *fixed* (or semi-fixed) in layer 1 as they form part of the physical infrastructure, e.g. automated guideways (physical), on-road signing including variable messaging, surveillance systems, and on-road access and charging systems, while others are *mobile* in the sense that they are in-vehicle systems or personal (portable) systems. Another main difference between ICT applications resides in the type and number of layers required to implement the application. Thus, some applications make use of one layer, while others make use of two or three of them. If more layers are involved, particularly including layer 1, the technical complexity is greater, because of the additional infrastructure requirements, and investment levels are higher with higher user costs. A situation of more layers also implies the involvement of a larger number of different actors with different interests, and different problem-definitions and –solving; a situation potentially leading to delay in the adoption of the innovations concerned.

ICT innovations in the transport system can also be categorized according to the role of the information concerned in drivers' behaviour. A distinction can be made between information that:

a. *Supports choices* of car drivers and passengers, e.g. on-road information on upcoming congestion, routing advice from a navigation system to avoid congestion, driving advice to optimize the use of car fuel, or the real arrival time of public transport busses.
b. *Reduces options or limit drivers' behaviour*, e.g. avoiding parts of networks, or limits to driving speed.
c. *Alerts drivers or passengers* without constraining behaviour, e.g. various modes of advanced driver assistance, like collision avoidance and lane keeping systems.
d. *Serves to take over drivers' decisions*, fully or partly, like in electronic bonding of cars and in intelligent speed adaptation and intelligent fuel use adaptation.

The above roles played by information show different degrees of constraints upon drivers' free choices. A special case are ICT innovations that takeover drivers' decisions, because legal issues concerning responsibility and liability enter the scene and these still need to be settled, like responsibility and legal liability of drivers, ICT system manufacturers and the operators of network systems. This situation acts like a barrier and tends to delay the adoption of the innovations concerned.

3. A closer look at ICT innovations

Below several types of ICT innovations are examined that can be used to address the negative externalities noted above by distinguishing between the three sustainability areas, excessive driving, congestion relief and fatality reduction (Table 1). The focus of analysis is on private cars (persons) and public transport using roads in urban areas. For each of the applications addressed will be indicated whether it is fixed or in-vehicle (mobile), and whether it concerns private or public transport or both. Note that some applications show overlap because the systems may serve for example both reduction of excessive driving (reduction of fuel consumption) and congestion relief.

3.1 Excessive driving

Excessive driving contributes to fuel utilization, as well as the generation of air toxics detrimental to urban and global environments. The technologies intended to decrease the need for travel or to increase the efficiency of travel that does take place, to be discussed are signalization, navigation systems and ICT-based intelligent vehicles with reduced fuel consumption.

Signalization

ICT can decrease fuel use by increasing the efficiency of the movement that does take place. This outcome can be accomplished through improved signalization. Such signalization can be phased in some areas and demand responsive in other areas, but the objective is to decrease the amount of vehicle standing time while the motor is running. Under the former the traffic signals are set so that signals in a series will change at a set frequency so that the vehicle does not have to stop. In the latter case the signals will change in response to a vehicle approaching a sensor in the roadway. Signalization – both phased and demand responsive – are widely applied. In a more advanced mode, signalization forms part of Vehicle Guiding Systems aimed at the creation of continuous flow at certain sections of roads without stops.

Navigation Systems

Geographic positioning systems (GPS) in conjunction with geographic information systems (GIS) offer the possibility of decreasing the amount of time spent on search behavior by motorists. Assuming one inserts his/her origin and destination to the system, the shortest route will be proposed. Such navigation systems are already common today, either portable or fixed (in-built in the car). In an alternative mode, an increasing number of motor vehicles will undertake the way finding for you and minimize unnecessary travel. The use of mobile communication in route advising seems underestimated for private car use and deserves more attention (Townsend, 2004). It is obvious that for privacy reasons, this kind of systems is not yet popular among private car drivers (see, e.g., Lee-Gosselin, 2002).

Systems that optimize route choice have seldom the primary aim of reducing the environmental effects of driving (lowest total fuel consumption) instead of the traditional aim of shortest time or distance. In a study of real traffic driving patterns in the city of Lund (Sweden), the most fuel-economic route was extracted and compared with the original route choice (Ericsson et al., 2006). It was found that the drivers' route choice produced trips that could save 8.2% fuel by using a fuel-optimized navigation system. This corresponded with 4% fuel reduction for all journeys longer than 5 min. in Lund. Whether a fuel-optimized routing option can be included in existing navigation systems, how drivers in reality respond to the fuel-saving outcomes and what the fuel reduction turns out to be, remains unknown and will be clarified in future research steps.

Table 1: ICT applications, aims and effectiveness.

Application	*Aim*	*Adoption*	*Effectiveness*
Excessive driving reduction			
-Signalization (e.g. set in series) (fixed), (private, public).	-Decrease of vehicle standing time with running motor.	Broad	No available data, but seems effective.
-Navigation systems (in-vehicle) (private, public).	-Decrease of search time while driving.	Quickly increasing	No available data; seems effective in time but maybe longer journeys.
-Fuel-intelligent vehicles (in-vehicle) (private, public)	-Fuel-efficient routing.	No/limited	8.2% fuel saving (Sweden)
	-Prevent stop-start behaviour.	No/limited	33% fuel economy improvement.
Congestion relief			
-Video Surveillance and Response (fixed) (public, private).	-Monitors obstacles in the road network and sends help.	Broad, on critical links and nodes	No available data, but seems effective.
-Variable Message Signs (VMS) (fixed) (public, private).	-Give information on changing road network conditions ahead (persons and freight).	Increasingly, on critical sites	Overall travel time reduction by 1-2% in regular congested areas (EU).
-Advanced Traveller Information Systems (mobile) (private).	-Give customized information on network conditions ahead.	Limited	No available data.
-Advanced Drivers' Assistance (ADAS) (cruise control, speed adaptation) (in-vehicle) (private).	-Supports the longitudinal following task to reduce variation in acceleration and waiting time.	Limited but increasing	Reduces variation in acceleration by 40-50% (EU). ISA (a) reduces fuel use by 8% (UK).
-Dedicated Short Range Communication (between following and oncoming cars) (mobile) (public, private).	-Adapts speed. Information to reduce waiting time and searching time (mobile communication).	Limited to segments but increasing	No available data, but seems effective.
Fatality reduction			
-Accident Sensors (in-vehicle) (private).	-Reduce waiting time for assistance after accident.	Limited (up-market)	No data available, but seems effective.
-Extended Viewing Systems (radar, sensors, infra-red) (in-vehicle) (private).	-Alert drivers of cars behind, alert drivers on blind spot and obstacles during night.	Limited (up-market)	No data available, but seems effective.
-Speed Advisory/Control (fixed/variable) (private, public).	-Gives advice on (or enforces) speed reduction.	Broad	Decrease of speed, but compensation behaviour (US); reduction of crash potential by 5-17% (Canada).
-Advanced Drivers' Assistance (ADAS) (in-vehicle) (private).	-Controls positioning of vehicle (lane, vehicles, obstacles) and adapts speed.	Limited (up-market)	Reduction of fatalities and heavy injury up to 30-38% (dependent on road type) (NL).
-Automated guided vehicles (fixed/in-vehicle) (private, public).	-Fixes vehicle position in a flow at constant speed and distance (physical and electronic systems).	No	Several gains expected.

Source: adapted from Black and Van Geenhuizen (2006).
Note: (a) ISA: Intelligent Speed Adaptation.

Fuel-Intelligent vehicles

The demand for fuel-efficient cars has been growing in the previous years driven by the increased and still increasing price of oil. Hybrid electric cars have already found presence in the marketplace due to the promise of saving fuel by using an electric motor in place of the internal combustion engine during particular stages of driving. All the major car manufacturers have developed or are currently developing hybrid vehicles, with the earlier models being relatively small, like the Toyota Prius and Honda Insight and Civic, and larger model being currently released, like a hybrid Ford Escape and various Lexus models. Despite fuel savings, the primary disadvantage of the hybrid technology from an adoption perspective is the initial cost for consumers that can be as much as 70% more than an equivalently powered internal combustion engine-only vehicle (Manzie et al., 2007). At the same time, fuel-intelligent cars are being developed equipped with a relatively cheap sensor network.

Fuel consumption in urban environments is up to 50% higher than on highways, whereas one of the largest contributors to fuel use in urban areas is the stop-start behaviour of traffic flow. This phenomenon provides possibilities to address this area using ICT. Through the use of ICT, vehicles can communicate with the road infrastructure and other vehicles to obtain essential information to adjust driving behaviour. In recent simulation studies, using different times of preview information, it appeared that fuel savings could be achieved between 15 to 25% with 60 seconds preview and up to 33% with 180 seconds preview relative to an 'un-intelligent' baseline car. The development of a combined hybrid and ICTs equipped intelligent vehicle seems still under way with the optimal use of feedforward information as an ongoing research problem (Manzie et al., 2007).

3.2 Congestion Relief

Congestion is a function of the interaction vehicles have with each other due to speed flow relationships when volumes approach capacity (e.g., Black, 2003). It is not just vehicles going slow, or vehicles travelling at high speeds, that lead to congestion, although these contribute to the problem. The key to reducing congestion is controlling density, but this is not quite as easy as it sounds. Although the discussion thus far has focused on motor vehicles, the same observations could be made with regard to ships arriving at a port, or aircraft landing at an airport. There is a need to control the spacing (density) of these in a geographic or temporal sense.

Certain technologies that decrease the volume and density noted above will also go toward reducing congestion. The concern in this paper is for other types of ICT that will lessen the amount of congestion that takes place: Video Surveillance and Response, Informational Signing (variable messages), Advanced Traveler Information Systems, Adaptive Cruise Control, Intelligent Speed Adaptation, Congestion Free Zoning and Lanes, and Dedicated Short Range Communications. The ICT innovations that are *fixed* (or semi-fixed), i.e. Video Surveillance and Response, Informational Signing and the previously discussed Signalization belong to larger systems of Road Traffic Management that are currently in use in particular sections and nodes. In more advanced applications, *mobile* (in-vehicle) applications are being integrated with the fixed applications to arrive at a better fine-tuning of the systems and improve flow.

Video Surveillance and Response

Several cities maintain a continuous monitoring of key network locations to determine if traffic is moving or encountering congestion. Such monitoring can be done with strategically located sensors or television cameras. If flow interruptions are apparent they are usually caused by a disabled vehicle. Once these events are perceived, a repair/assistance vehicle is dispatched to the location. Upon arrival at the problem site, the objective is to remove the obstacle to flow and offer assistance (tire replacement, and so forth) or transport to the motorist.

Informational Signing (Variable Message Signs)

Electronic changeable message signs along the highway have proven to be of some assistance in communicating with drivers regarding major congestion points on the road ahead. Often these signs give directions as to ways to avoid upcoming congestion points related to accidents, congestion, and the like. It is important that such signs are not used on a continuous basis since drivers tend to ignore them if they always have the same type of message on them. A simulation study for different European city-regions on effectiveness of VMS (Variable Message Signs) on road network efficiency suggests quite modest results. Reductions in overall network travel times are 1-2% for the use of VMS in regular congested circumstances, provided that there is spare capacity in the network (Chatterjee and McDonald, 2004). Estimates for impacts on pollutant emissions and fuel consumption are similar to changes in overall travel time. Whereas the above changes are quite small, driver perceptions of the benefits turned out to be much higher. This points to a potentially important role for this application in the development of integrated transport strategies, because the provision of information may encourage the acceptance of demand management measures.

Advanced Traveller Information Systems

Personal information systems may take different forms and may be in-vehicle for car drivers and portable for passengers using public transport. Based on real-time information, the best route and connections (in public transport) are given. In advanced modes, opening times of facilities (shops, services, etc.) and the length of stays are used as an input, enabling an overall space-time optimization of activity chains. In the case of interruption (accident, congestion, etc.) new travel solutions are produced. Adoption of such traveller assistants - that are currently in an experimental stage - may be hampered by high costs but also by limited needs of travellers to plan their activity and their traffic chains. In a study of web-enabled information services on public transport carried out in England, Finland and the Netherlands, it was found that particularly the type of information provided matters (Molin and Timmermans, 2006). Real-time information turns out to be the most important attribute and this is followed by different planning options allowing search for routes that are not only shortest in time, but also cheapest and exclude interchanges. It appears that travellers are willing to pay for information under the condition that the information services provide added-value compared to existing information services.

Adaptive Cruise Control

Adaptive Cruise Control (ACC) is concerned with in-vehicle assistance to the driver in the longitudinal following control task. The main aim is to help to reduce congestion and smooth traffic flow, but an improvement of traffic safety is also hypothesized.

Experiments in Europe indicate that following with an ACC system can provide considerable reductions in the variation of acceleration compared to manual driving (40 to 50% reduction of standard deviation) (Marsden et al., 2001). However, this is true for long following sequences, whereas the results indicate that ACC systems may not be appropriate in those situations in which the driver needs most assistance, i.e. dense driving conditions.

Intelligent Speed Adaptation (ISA)

These systems also use in-vehicle electronic devices enabling one to automatically regulate vehicle speed. Like the previous technology, experiments indicate a higher effectiveness in less congested conditions (UK) (Liu and Tate, 2004). High speeds can be effectively suppressed, leading to a reduction of speed variation, but more slow moving traffic cannot be induced. In addition, it was found that ISA with full penetration could lead to a reduction of fuel consumption by 8%.

Dedicated Short Range Communications

These systems are based on information exchange between cars and may pertain to accidents, weather conditions, road construction, and similar events. In more comprehensive options, technical performance of the car can be communicated with the serving garage. Also, by integrating navigation systems, information about empty parking places and similar information can be transmitted to the driver. These systems partly rely on mobile communication between vehicles on the same route (oncoming and following traffic) and are still in the stage of development. "Early versions" are currently used in public transport (busses, taxi's) and in freight transport.

3.3 Fatality Reduction

Road traffic accidents killed an estimated 1.2 million people in 1998 according to the World Health Organization (2004). More recent data are available for the EU 15 where there were 35,905 fatalities in 2003 (ERF, 2005). Comparable numbers for the US in 2003 were 42,643 fatalities (FHWA, 2005). For the most part and with some minor fluctuations, annual traffic fatalities have been falling in most of the developed nations of the world. At the same time forecasts continue to all for 1.2 million fatalities as far in the future as 2020 with decreases in the developed world more than compensated for by increases in the developing nations.

It is reasonable to examine what can be done technologically to improve the safety of road systems. Major improvements can be expected in two areas: vehicle safety and network safety. In terms of vehicle safety it is probably reasonable to expect a failsafe vehicle will be developed over the next decade or two. However, more important are those systems that improve vehicle-driving behavior. It is estimated that some 90% of all traffic accidents can be attributed to human failure, such as a lack of alertness or fatigue (Marchau et al., 2005). Vehicle radar technology is already available that warns drivers of obstacles in their path. The same technology could be tied into an on-board computer system and used to make it nearly impossible for the vehicle to crash into other vehicles or objects. It would do this by accelerating, decelerating, or stopping the vehicle. Today, advanced in-vehicles technology is available as options in up-market car models, like of Mercedes, Lexus and Citroën (NRC-Handelsbad, August 5, 2005).

Network safety seems to be heading primarily in the direction of automated guideways that would control the movement and speed of cars. Note that the technologies aimed at the previously discussed congestion relief sometimes also serve to reduce fatalities. Below, we address one "curative" approach, i.e. In-vehicle Accident Sensors and a range of accident "preventive" approaches, i.e. Vehicle Radar Warning, Blind Spot Information Systems and Night View Systems, and applications that serve both congestion relief and reduction of fatalities, i.e. Out-of-Vehicle Speed Control Systems, Advanced Drivers Assistance and Automated Guideways.

In-Vehicle Accident Sensors and Radar

It is generally recognized that many seriously injured individuals can survive such incidents if they can be transported to a medical facility quickly. The use of ICT in this case is intended to ensure this. A number of motor vehicle models being manufactured today come with sensors attached to the air bag system. Once the air bags are deployed, a communication of this event is sent to a dispatcher. The dispatcher in turn can communicate with the driver or other occupants of the vehicle and determines if any type of assistance (repair vehicles, ambulance, and so forth) is necessary. At this time several high-end models offer this service, however all models of General Motors in the US offer this. It should enable faster response to accident scenes than has been typical previously.

Numerous accidents occur when a vehicle in the process of moving in reverse hits a person or vehicle. Higher priced motor vehicles are now being produced that include radar installed in the back of the vehicle that alerts drivers of obstacles behind them. Mercedes (S-class) combines long-distance and short distance radar. The long-distance radar measures distance to cars in front of the driving car; the short-distance radar measures distance nearby in front of the car but also on both sides of the car. Of course, it will take quite some time before these systems are found in all vehicles of the fleet. In addition, there is also the problem of lower income drivers maintaining these and similar systems even if they are present (see Black, 2000).

Blind Spot Information Systems and Night View Systems

A number of accidents occur due to blind spots. To prevent such accidents, digital cameras are installed in the two outside mirrors that scan a zone on the sides of the car and produce a light signal if a car enters this zone. Volvo uses this system. Night View Systems, using infrared cameras are already available as an option in the most advanced models of Cadillac, Mercury, Lexus and Honda. These systems mainly serve to detect crossing passengers and animals during night. The problem is how to project the image without diverting attention of the driver from the road. Mercedes will install a small night-screen in the dashboard in the near future.

Out-of-Vehicle Speed Control Systems

Out-of-vehicle systems that control speed are quite commonly installed along roads in the US and EU and relate to adverse weather conditions and other incident conditions. A study in the US suggests that messages are significantly reducing speed in the area of adverse conditions, but that drivers tend to *compensate* for this reduction by increasing speeds downstream where such adverse conditions do not exist. Accordingly, this pattern casts some doubt on the *net* safety effects of speed advisory systems (Boyle and Mannering, 2004). A simulation study in Toronto (Canada) suggests that real-time variable speed limits can reduce overall crash potentials by 5-17% (Lee et al., 2006). However, this study ignored the above-mentioned potential for compensation behaviour. In general, there seems a trade-off between the level of enforcement on driving behaviour and sustainability effects concerning emissions. A study in Portugal suggests that signal control schemes work differently for stopping cars compared to reducing speed of cars. Systems that stop a relatively large share of speed violators also yield higher pollutant emissions, whereas signals inducing speed reduction result in a decrease in relative emissions (Coelho et al., 2005).

Advanced Drivers Assistance

In the context of improving safety, we discuss the in-vehicle Automated Cruise Control (ACC) and Intelligent Speed Adaptation (ISA). Automated Cruise Control that primarily serves vehicle safety, performs both the longitudinal and lateral control task. Citroën today installs a system that warns the driver as soon as he/she moves to another lane without using the signal, by drawing attention through moving his/her seat. The lateral control task works by infrared sensors that measure variation in reflection of the standard markers on the road surface. In the EU, much research is currently devoted to *in-vehicle* collision avoidance based on sensor systems replacing infrastructure measures. An ultimate configuration is a 360^0 car surround system as a “safety belt”. The systems that are currently studied vary in terms of technology, e.g. different radar sensors, infrared and visible spectrum imaging, laser technology, and in terms of distances and speeds involved (Lu et al., 2005). Research into such systems is in progress today, but the systems are still in an experimental stage waiting for solutions that are more robust, i.e., not vulnerable to influence of weather/atmospheric conditions and interference with other electronic systems, and more acceptable in cost or price. For example, Lexus plans to introduce lighting systems that monitor speed, braking performance and weather conditions, and automatically adjust the amount and type of lighting as a warning (active lighting).

Quite some attention has been paid to the impacts of Intelligent Speed Assistance (ISA). We mention estimated safety effects of full automatic speed control devices up to a 40% reduction of injury accidents and 60% reduction of fatal accidents (e.g. Marchau et al., 2005). For the Netherlands, estimates reveal a fatality and heavy injury reduction of up to 30 and 38% on roads with speed limits up to 90km/h. In addition, estimates of the impact of automatic positioning and collision avoidance systems indicate similar maximum reduction levels for particular systems on particular types of roads.

A special category of in-car safety systems are brake control systems, e.g. working through an alarm. New in this respect is the “intelligent brake control” that becomes activated as soon as the driver shows a panic reaction (release of pedal). It prepares the brake control in such a way that all braking power becomes available as soon as the driver puts on the brake. If necessary, electronics takes over mechanical power in brake control because it reacts quicker and more refined in terms of using the right braking pressure.

Automated Guideways

Ultimate network safety can be reached with automated guideways. Test facilities of automated guideways have been developed by Honda and Nissan. One could pull the vehicle onto such a guideway and the system would take over control of the vehicle. A somewhat related idea would have vehicles linked electronically if they were traveling to the same destination. Such bonding would probably be possible on existing roadways and would increase vehicle density without necessarily decreasing speed. Of course, legal issues concerning responsibility and liability between drivers, network operators and ICT system manufacturers are quite different from conventional driving and need to be settled.

4. Evaluation

The above discussion suggests that ICT innovations in the transport system seem to be most effective in fatality reduction. The literature gives an estimated reduction of fatalities up to 30 and 40% and even 60% by particular types of Advanced Drivers' Assistance in particular sections of road networks. What seems a fortunate situation is that Advanced Drivers' Assistance at the same time may serve congestion relief, although the results seem much less convincing than in fatality reduction. At the same time, most recent research suggests fairly high potentials of fuel-intelligent cars that 'communicate' with the road infrastructure and other vehicles to adjust driving behaviour in optimizing fuel use, i.e. a reduction by approximately 30%.

In general, there are three constraints for adoption of new ICT applications in the urban transport system, i.e., (1) high costs for users compared with perceived benefits, with user costs increasing if more than one layer in the system is involved, including fixed infrastructure, (2) technological and actor complexity, similarly if more than one layer is involved, and (3) legal issues that are not sufficiently settled, e.g. concerning responsibility and liability of the actors involved in the case of failure of the new application (e.g. drivers, manufacturers and operators of the ICT systems). Taking these factors into account, it seems that systems of Automated Guideways, either fixed or electronically, face the smallest potentials to be adopted in the short and medium term. Based on the above factors, it seems plausible that potentials for adoption in various countries and urban regions may differ according to various circumstances (Black and Van Geenhuizen, 2006):

- driving circumstances, e.g., larger or smaller distances, a different occurrence of high-density urban areas leading to different levels of annoyance of road congestion, and different maximum speed levels on particular types of urban roads;
- needs for car driving, e.g., automobile use to satisfy needs for 'driving experience' in relation to public transport use;
- car cultures, e.g., cars may be more or less a symbol of freedom and status;
- institutions, e.g., a weak or strong government involvement in transport, a weak or strong focus on legal liability issues, different levels of taxation of car ownership and use, and different systems of incentives in promoting sustainable transport.

The above factors indicate quite some differences like between the US and countries in Europe.

5. Conclusion: quite some ignorance

The above discussion on impacts of ICT use on the working of the transport system provides ground for the following observations. There is still some *ignorance* about the sustainability impacts of various ICT innovations in transport, (e.g., Van Geenhuizen and Thissen, 2006). This situation is mainly caused by:

- A fragmented character of the research that has been done; exceptions are the impacts of ICT use on fatality reduction, particularly off-vehicle speed limitation and in-vehicle driver assistance; fragmentation in research is caused by a widely varying interest of market parties to push new ICT applications.
- Simulation-based research without sufficient small-scale *real-life* experiments and large-scale research on real travel behaviour that can increase the validity of results.
- A limited scope of much research, namely confined to particular parts of the transport network; as a result there is an ignoring of potential compensation behaviour elsewhere in the network and of potentially secondary adverse effects like relocation of households at a larger distance from work due to a more efficient commuting.

It is clear that additional research is needed to fill the above indicated knowledge gaps, particularly the question whether significant improvements in particular parts of the transport network go along with sufficient overall network performance.

ICT innovations seem to be most effective in fatality reduction. The literature mentions reductions on a level of 50 to 60% and on a level of 30 to 40% for particular types of advanced divers' assistance in particular road network sections. Measures to relieve congestion seem much less effective and work only under restricted conditions, namely spare network capacity and lower levels of congestion (density). The latter suggests that the ICT innovations concerned cannot yet fully work under conditions that they aim to solve, that is under high congestion levels. This calls for further research to identify ICT technology that is particularly effective in such conditions, or that will improve the existing applications that are currently less effective. Policy efforts, for example to increase R&D on particular ICT applications or to make particular applications less expensive for users, need to focus on those applications that don't suffer from technological uncertainty and from uncertainty due to legal aspects or inherent actor complexity. Accordingly, it seems more realistic to promote the adoption of a smart set of relatively simple applications than the adoption of comprehensive systems.

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