ICT Innovation and Sustainability of the Transport Sector

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In this paper we address the influence of information and communication technology (ICT) on sustainable transport in two ways, i.e. by examining the relation between ICT use and transport demand and by examining the direct application of ICT in the transport system. Following a discussion of the various negative externalities of transport and a discussion of the latest insights into the impacts of ICT on transport demand, we examine the extent to which existing and potential ICT applications in the transport sector can assist in making transport sustainable or at least more sustainable than it is at present. We particularly focus on qualitative and quantitative impacts of several ICT applications on travel behavior (including fatalities) and on differences in the potential adoption of these innovations between the United States and Europe.

1. Introduction

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 (e.g. Newton, 1998). ICT differs in complexity, ranging from simple electronic communication, like e-mail, to interactive and highly intelligent applications in traffic management and control systems, and in value webs for particular manufacturing industries.

By adopting ICT, households and businesses increase their geographic reach and potential for network contact through an interplay between physical and virtual activities, also named human extensibility (e.g. Janelle and Gillespie, 2004; Shaw, 2004). A typical outcome of these changes, according to Couclelis (2000) is the fragmentation in time and space of formerly holistic activities (like working, leisure and shopping) and their recombination in new ways. For example, working activity can be detached from its traditional place and time, and so can shopping and some types of leisure. The impact of all these changes may include a reduction of transport (substitution) but also – as becomes increasingly evident – the generation of new transport demand. The extensibility impact of ICT use has allowed an acceleration of activities over *both larger and smaller* spatial scales, while serving an array of different purposes of households and business, sustainability of transport *not* being one of them (table 1). Trackability is another major attribute provided by ICT to persons, but also to vehicles and goods. It refers to real-time dynamic mapping of activity paths and routes. Accordingly, it opens ways to real-time detection and management of flows through transport and communication networks, and spans a broad range of applications to increase efficiency of flow. Such ICT innovations are implemented in the transport system, and accordingly have a much smaller scope than the above-mentioned extensibility and often have a more *local* impact, i.e. on key sections of links and nodes of transport networks. Sustainability is a major, but not the only purpose.

Table 1. Attributes of ICT and transport sustainability in a wider context

ICT attributes	Sustainable transport
Extensibility: speeds up and extends spatial interaction	Maybe an outcome but not a goal; sometimes the reverse: non-sustainable outcomes
Trackability: tracks and steers on vehicles and goods (traffic management)	One of the goals
Intelligence: speeds up data retrieval, processing and steering, and reorganizes value chains and their spatial pattern	Maybe an outcome but not a goal; sometimes the reverse: non-sustainable outcomes

The final, and probably most powerful, attribute that ICT provides to persons and organizations is intelligence (Kenney and Curry, 2001). This refers to the capability to collect, process, distribute, steer and monitor value chain processes in distributed places. In manufacturing and services, this leads to various types of reorganization of value chains for efficiency reasons, i.e. related with time, cost-effectiveness or product quality. As in the case of extensibility, sustainability of transport is not one of the goals. In some cases the outcome may be transport that is more sustainable, but in other cases it may be less sustainable transport.

Sustainability of the transport sector is a major concern today for different levels of government throughout the developed economies of the world. Although this 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, the excessively large number of vehicle accidents and their resulting fatalities and injuries, and congestion. In some parts of the world, notably Europe, there are also concerns for noise and vibration damage as well as some biological impacts on flora and fauna, but we will not examine these here. To some extent we are aware of how some of these externalities can be lowered.

The paper is structured as follows. After a brief discussion of transport non-sustainability, we will summarize the most recent insights into ICT use by persons and businesses and concomitant impacts on transport demand. In the next section, we take a closer look at the 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. Finally, we will consider differences in the potential for ICT applications being adopted by the transport systems of the US and Europe.

In large part we will draw upon research completed or discussed during the various sessions of the STELLA focus group on ICT and innovation in the transport system, but we will not be constrained by the materials that evolved from those sessions.

2. The Basic Correlate of Transport Non-Sustainability

We have already noted what we consider the basic factors making transport non-sustainable. Certainly one could find arguments with the factors identified, or perhaps more precisely with the factors not identified. The components that we have noted, 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 by most scholars working in this area. 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.

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. 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, sulfur 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. Forecasts of vehicle fatalities over a holiday season (once more common than they are today) also take advantage of this relationship.

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 or kilometers traveled. 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). The fundamental diagram of traffic also illustrates this relationship between congestion and flow (see figure 1). As the figure illustrates the density of vehicles (a measure of congestion) varies with the volume of traffic; speed also is related to volume, and finally speed and density are interrelated with maximum density occurring when the speed has dropped to zero.

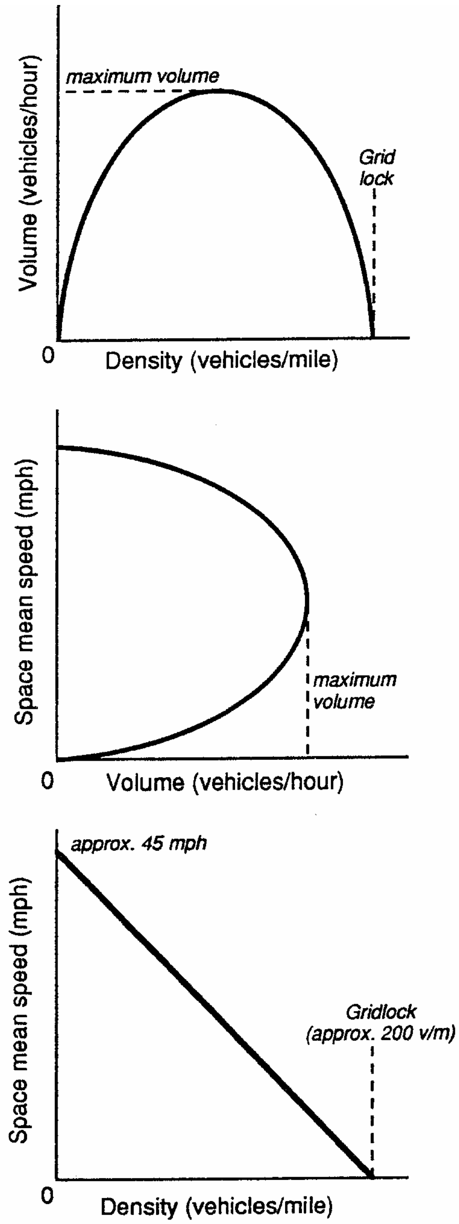

Figure 1. The fundamental diagram of traffic (after Black, 2003)

3. ICT Use and Transport Demand

It is now increasingly recognized that the links between ICT use and transport are inherently complex and far from a simple substitution model, and that this use may increase as well as decrease sustainability of transport both for passengers and freight. We will discuss various reasons for this complexity and illustrate them with major examples from passenger transport and freight transport (Banister and Stead, 2004; Van Geenhuizen, 2004a; Lake, 2003).

An increasing number of empirical studies suggests that the substitution of face-to-face contact by e-communication is limited and that ICT often adds an extra mode of contact to the existing array of communication modes, such as occurs in e-shopping and e-meetings (table 2). For example, e-shopping may substitute travel to low-order retail centers but may increase traveling to high-order centers because the face-to-face contacts needed and the "shopping experience" are increasingly offered only there. This type of development can also be observed in retail-banking (van Geenhuizen and Nijkamp, 2001). Similarly, the capability of a videoconference being a substitute for a conference that requires several people to travel to a single meeting place is quite real, but there are limits to such substitution impacts: key meetings requiring rich modes of communication, like kick-off meetings and creative sessions, preferably take place as face-to-face meetings (e.g. Banister and Stead, 2004). Videoconferencing technology will undoubtedly improve over the coming years in terms of visual quality, more user-friendly systems, and distributed modes, the latter enabling participation in such conferencing from one's computer as opposed to a videoconference room, but this might not change the basic limits.

The idea of a substitution for motor vehicle travel is also well represented by teleworking or e-working (also known as telecommuting in the US) (table 2). In theory this would decrease the amount of travel time since the provision of a reasonable level of technology would allow the individual worker to work at home or at a teleworking center that is nearer the worker's residence than his/her usual work place. As obvious as this should be as a way of eliminating travel, it is not at all clear that this has been successful. This is due in part to the number of teleworkers that continue to work in this manner, the number of job types that lend themselves to telework and the frequency of telework in terms of days a week. Research by Wells and Nelson (2004) suggests that teleworking would have only a minor impact in terms of reducing emissions, and it is reasonable to assume that the same is true for fuel use and the other correlates of vehicles miles of travel. We should also note that the magnitude of positive impacts measured depends on the system level involved. Thus, small-scale empirical studies have clearly established the short-term transportation and air-quality benefits of teleworking at the disaggregate level (e.g. Lake, 2003), whereas system-wide the impacts are much more modest, due to relatively small amounts of teleworking and due to long-term (secondary) impacts counteracting the short-term savings (Mokhtarian, 1998). Results from a recent nation-wide study in the US suggest a reduction in annual vehicle-miles traveled by 0.8% or less only (Choo et al., 2005). There is, however, still some potential for growth of adoption of teleworking given the type of jobs that lend themselves to this practice; but actual teleworking remains below its potential level.

Table 2. ICT use by persons and transport demand

Type of ICT use	Impact on transport demand (persons)
Use of E-services: shopping, banking, education, entertainment, government services	Reduces travel needs for routine transactions, but may cause increase of travel demand to central places with high-level services (e.g. to enjoy "shopping experience"). May add extra mode.
On-line, last minute, booking (flights, hotels, holidays, theatre)	Causes new travel demand due to lower consumer prices.
Use of E-networking in social relations: personal communication, chat rooms, network games	Reduces travel needs for routine networking, but may cause new travel demand due to successful social networking.
E-working (at home or tele-center)	Reduces travel needs for individuals concerned but is nation wide very modest (0.8% reduction in annual vehicle miles, in US). May cause secondary impacts that counteract first impacts (substitution of work travel by not-for-work travel, and moving further to work).
E-office (internet, e-mail, portable computers, tele-servicing)	Possibly reduces travel during work. May cause increase of long distance travel because of more on-the-move working options.
E-meeting (tele- and videoconferencing)	Reduces travel needs to a limited extent, cannot substitute key-meetings (evaluation, preparation of major decisions, kick-off meetings, etc); maybe just adds an extra mode.

Source: Adapted from Banister and Stead (2004).

For businesses, ICT use provides opportunities to implement e-business models (b2c and b2b) whereas particularly the intelligence of ICT provides opportunities to introduce new models of value chains, value webs and models of remote diagnostics and monitoring (van Geenhuizen, 2005; Kenney and Curry, 2001; Koutsoutos and Westerholt, 2005; Lake, 2003) (table 3). The changes in value chains range from withdrawal from wholesale and retail segments (disintermediation) to the transformation of value chains into value webs. The latter are sets of fluid congregations of businesses coming together on the Internet to create value for customers. Whether freight transport demand increases or decreases following the changes in value chains depends upon the underlying strategy of these changes and connected physical production, e.g. time-oriented, transport cost-oriented, or product quality oriented. Remote diagnostics and monitoring by businesses is just in its infancy today. It spans a range of activities that can be performed without traveling of persons, for example, service engineers calibrating and maintaining advanced instruments at customers' locations from their business home base (van Geenhuizen, 2005).

Table 3. ICT use by businesses and transport demand

Type of ICT use	Impact on transport demand (freight)
E-business (b2c), including e-marketing and customer services	Reduces transport for ordering and delivery of non-material goods (e.g. music, software); may add an extra mode. Delivery may be reorganized to decrease transport demand; but if time pressure, more frequent delivery with smaller loads. If more customers around the globe, distance may increase (more air transport) with smaller loads.
E-business (b2b)	Electronic ordering (sourcing) around the globe increases delivery distance (more air transport) probably with smaller loads. Whether reorganization of value chains influences transport, depends on underlying models, e.g. short assembly times may cause supplier villages around assembly plants and reduce transport.
In/outbound logistics, and real-time guidance in freight distribution	Better performance on time aspects, but may increase transport distance. Decrease in number of trips (through chaining and load matching).
Configuration of value webs	Influence on transport demand depends on underlying optimization, e.g. transport costs, production and delivery time, best available product quality. Impact on transport demand (persons)
Remote (simultaneous) development and design Remote diagnostics (monitoring)	Reduces travel demand of R&D personnel to some extent, but cannot substitute for informal creative meetings. Reduces travel demand of servicing engineers, but is still limited due to legal issues concerning responsibility and liability of partners, and due to network shortages (bandwidth).

Source: Adapted from Banister and Stead (2004) and van Geenhuizen (2005).

In general, greater attention is needed for the *causality* in ICT - transport relations, because it is not all that clear. The role of underlying business strategies and lifestyles in the adoption of particular ICT applications has often been overlooked in these relationships. For example, in the case of businesses it is primarily the cost-reduction strategy of global outsourcing that leads to more transport. The same is true for particular types of Just-In-Time-production and delivery through more frequent deliveries and smaller loads (van Geenhuizen, 2004a). If a high level of e-business adoption is found among these kinds of businesses, the conclusion at first may be that e-business leads to more transport. A more accurate interpretation, however, may be that particular strategies lead to larger distances and more frequent deliveries and that these urge the use of e-business. Likewise, early adopters of e-shopping include busy people who tend to make more trips even with e-shopping, meaning that their greater travel is one cause of their choice of e-shopping, not the other way around (Moktharian, 2004). This touches upon the fact that some general socio-economic trends today cause an increase in transport anyway, such as the increases due to economic globalization, the lifting of particular (trade) barriers followed by a growing integration of regions, and the rise of busier and affluent lifestyles (Banister and Stead, 2004). It is this kind of context that makes the relationships between ICT use and transport impacts highly differentiated and difficult to understand.

The above indicates a need for more refined research. We may forward the following:

- *ICT applications within a range of possible contact modes, including the possibility of generative effects*. The focus would be on circumstances under which ICT use substitutes for physical transport and the circumstances under which ICT use leads to additional transport demand (persons and companies).

- *Second-order adverse effects.* The focus would be on 1) short-term effects, like travel for non-work purposes by teleworkers, and 2) long-term effects, like relocation at a greater physical distance from work and service centers (telecommuters) and relocation at a greater distance from key suppliers (customers) (web-based companies).
- *Causal relations between ICT use and transport in the proper context of different business strategies and lifestyles.* The focus would be on the actual role of ICT use, i.e. reinforcing ongoing trends in business strategies (like globalization) or opening up ways to new business models (like network and web-based models); similarly, determining the role of ICT in different segments of the population, i.e. reinforcing ongoing trends in lifestyles (like individualization) or opening up new lifestyles (like cyberspace networking).

What is hampering the above research is the lack of standard statistics. Very often, statistics on the use of ICT are available for various population categories and classes of companies/business, but these are not linked with data on transport behavior; also, disaggregate data at the level of regions or cities is often not available. This situation may be explained by a lack of awareness among statisticians of the urgency to provide such data. Concerning households, the lack of statistics means a need for a smart mix of large-scale surveys, like travel diaries extended with information on ICT use for example, and small-scale in-depth studies (e.g. Casas and Thill, 2004; Kwan et al., 2004). Further, agent-based modeling seems one of the promising approaches to explore interactive relations among virtual mobility, transport and the urban environment, provided that it is based on solid empirical grounding and behavioral rules consistent with observed behavior (e.g. Nagel et al., 2004). With regard to e-business, information on more complex use in the value chains is not available at all in standard statistics. This generates a strong need for in-depth interviews to uncover the types of organizational and location changes, and transport impacts in different value chains, to be followed by large-scale surveys.
In the following sections we will discuss several ways through which ICT may impact on transport as it unfolds in and is introduced to the transport system.

4. ICT Applications in the Transport System

4.1 The Transport System and Electronic Information

It should be apparent that in order for the transport system to become sustainable all that is necessary is for society to decrease the amount of transport they consume. This is much easier to state than it is to accomplish. Regulatory policies could be formulated to accomplish 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. Because of this we look to ICT innovations in the transport system as possible ways of accomplishing the same outcome. To this end, we first introduce a simple model of the transport system that applies to persons and freight transport and clarifies the different actors involved and the targeted aspects of the system (figure 2).

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' behavior: route selection, driving speed, reaction in driving, reduction of driving tasks. Passenger behavior 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, services for maintenance and transport management	Public transport companies Operators of links and nodes ICT system manufacturers Public authorities	Providing/preventing access of public transport services to persons Matching different services.
Layer 1. Physical infrastructure (links and nodes) Rail, road, airline, pipelines, waterways, etc.	Infrastructure providers Infrastructure owners Public authorities	Providing/preventing access of infrastructure links and nodes to vehicles

Figure 2. A simplified layer model of the transport system

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. A situation of more layers also implies the involvement of a larger number of different actors, 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. We may distinguish between:

a. Information to *support choices* of car drivers and passengers, e.g. on-road information on upcoming congestion, routing advice from a navigation system, or the real arrival time of trains.
b. Information to *reduce options or limit drivers' behavior*, e.g. avoiding parts of networks, or limits to driving speed.
c. Information that *alerts drivers or passengers* without constraining behavior, e.g. various modes of advanced driver assistance, like collision avoidance and lane keeping systems.
d. Information that serves to *take over drivers' decisions*, fully or partly, like in electronic bonding of cars and in intelligent speed adaptation.

The above roles that information play, 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.

4.2 A closer look at ICT innovations

We will examine several types of ICT innovations 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 4). The STELLA Meetings did not cover all different transport modes in this respect; air transport, water and rail transport were beyond the STELLA scope. Accordingly, we will focus on private car (persons and freight) and public transport using roads. For each of the applications addressed, we indicate whether it is fixed or in-vehicle (mobile), and whether it concerns private or public transport or both (table 4).

Table 4. 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).	Decrease of search time while driving (persons). Decrease of distance, increase of load (freight).	Limited in private cars; broad in freight transport.	No available data; seems effective in time but maybe longer journeys.
Congestion relief			
Video Surveillance and Response (fixed) (public, private).	Monitors obstacles in the road network and sends help (persons and freight).	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 links and nodes.	Overall travel time reduction by 1-2% in regular congested areas (EU).
Advanced Traveler Information Systems (mobile) (private).	Give customized information on network conditions ahead (persons).	Very 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 (persons). Adapts speed (persons).	Limited but increasing.	Reduces variation in acceleration by 40-50% (EU). Reduces fuel use of 8% (UK).
Dedicated Short Range Communication (between following and oncoming cars) (mobile) (public, private).	Information to reduce waiting time and searching time (mob. communication) (persons and freight).	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 (persons).	Limited (up-market).	No data available, but seems effective.
Extended Viewing Systems (radar, sensors, infra-red) (in-vehicle) (private).	Alerts drivers of cars behind. Alert drivers on blind spot and obstacles during night (persons).	Limited (up-market).	No data available, but seems effective.
Speed Advisory/Control (fixed) (private, public).	Gives advice on (or enforces) speed reduction.	Broad.	Substantial decrease of speed, but compensation (US).
Advanced Drivers' Assistance (ADAS) (in-vehicle) (private).	Controls positioning of vehicle (lane, vehicles, obstacles) and adapts speed.	Limited (up-market).	Reduce fatality 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 (persons and freight) (physical and electronic systems).	No	Several gains expected.

Source: a scan of transport journals (2004/2005)

4.2.1 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 and navigation systems.

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 is willing to input one's origin and destination to the system, the shortest route will be proposed. 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 system is not yet popular among private car drivers (see Lee-Gosselin, 2002). The situation is different for freight transport, where systems of tracking and tracing are being introduced in finding most efficient network connections, e.g. in the routing and bundling of freight.

There are also some interesting ideas about home delivery of goods. If we have a very accurate geographic information system for an area and a very reliable global positioning system (GPS), it would be possible to have small delivery vehicles programmed to deliver groceries, mail, and similar items to a residence. The vehicle used would need to have (electronic) access to a temperature controlled area in the case of groceries. Freight villages could be set up to handle all different types of distribution, removing such vehicles from the road network. Current GIS databases and GPS technologies in general are in most cases not accurate enough to be used in this way, but the technology exists to make these systems better.

4.2.2 Congestion Relief

Congestion as we have already noted is a function of the interaction vehicles have with each other due to speed flow relationships when volumes approach capacity. It is not just vehicles going slow, or vehicles traveling at high speeds, that lead to congestion, although these contribute to the problem. As can be seen in figure 1 the key to reducing congestion is controlling density, but this is not quite as easy as it sounds. Although the diagram and the discussion thus far have 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. Our concern 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, sometimes called Amber Alert signs in the United States, give directions as to ways to avoid upcoming congestion points related to accidents, congestion, and the like. It is important that such signs not be used on a continuous basis since drivers tend to ignore them if they always have some 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 Traveler 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 traveler assistants - that are currently in an experimental stage - may be hampered by high costs but also by limited needs of travelers to plan their activity and traffic chains.

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%.

Congestion-Free Zones and Lanes

The decision to have congestion pricing in a zone or on a highway is essentially a policy decision today. However, the success of such a system will usually depend on some type of ICT. The typical system involves the use of transponders that allow vehicles to automatically enter a zone (as in the case of London), or lane as is the case on numerous toll roads in urban areas of the US. In general, individuals set up accounts and the transponders initiate a withdrawal of funds from the account based on use of the facility. In Europe, experiments are being done with automated fee retrieving for the use of particular public transportation facilities, also critically depending on ICT that connects facility access with personal accounts.

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, taxies) and in freight transport.

4.2.3 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 call 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, such as 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.

<u>In-vehicle Accident Sensors</u>

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 heretofore.

<u>Vehicle Radar</u>

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). In addition, there seems a trade-off between the level of enforcement on driving behavior 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. 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.

<u>Automated Guideways</u>
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.

We may conclude this discussion with the observation 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.

5. Potentials for Adoption in US and Europe

In general, there are three constraints for adoption of new ICT applications in the transport system, (1) high costs for users and operators compared with the perceived benefits, (2) risk of use due to a lack of robustness of the technology under particular conditions, like in specific weather (environmental) conditions and in interference with other electronic systems, 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 system (e.g. drivers, manufacturers and operators of the systems). The factors that may cause a different potential for adoption in US compared with Europe mainly reside in:

1. different driving circumstances, e.g. larger distances in US, more annoyance by road congestion in Europe, lower maximum speed on highways in US compared with Europe;
2. different needs for car driving, e.g. more automobile use in US, and more, but decreasing public transport use by persons in Europe;
3. a different car culture, e.g. more a symbol of freedom and status symbol in US, a higher value of "driving experience" in US;
4. different institutions, e.g. more government involvement in Europe, a stronger focus on legal liability issues in US, less taxation in US meaning cheaper prices.

Table 5 provides a list of the previously discussed ICT innovations and estimations of different potentials for adoption of these innovations in the US and Europe. The major differences emerge in higher potentials in the US for those types of equipment that add to the "driving experience", add to the car as a symbol, and improve inherent car safety without interfering in drivers' decisions and introducing liability issues. This refers to Navigation Systems, Dedicated Short Range Communication, In-vehicle Accident Sensors, Extended Viewing Systems and simple modes of Advanced Drivers' Assistance.

Table 5. ICT applications and potential for adoption in US and Europe

Application	**Different potentials**
Excessive driving reduction (as well as lower emissions and fuel use)	
Signalization (e.g. set in series) or demand responsive (fixed), (private, public).	Set signals common and already broadly adopted in both areas. Demand responsive growing in the US, less likely in Europe.
Navigation systems (in-vehicle) (private).	Larger potentials in US (private cars) as (status) symbol, also less expensive. Smaller potentials in US (freight transport) due to smaller needs.
Congestion relief	
Video Surveillance and Response (fixed) (public, private).	No difference, already broadly adopted on critical links and nodes.
Variable Message Signs (VMS) (fixed and mobile) (public, private).	No difference, already broadly adopted on critical links and nodes.
Advanced Traveler Information Systems (mobile) (private).	Higher potentials in Europe, due to larger use of public transport.
Advanced Drivers' Assistance (ADAS) (cruise control, speed adaptation) (in-vehicle) (private).	Higher potentials in Europe, due to stronger annoyance of drivers by congestion and more government involvement.
Dedicated Short Range Communication (between following and oncoming cars) (mobile) (public, private).	Higher potentials in the US, as part of "drivers experience".
Fatality reduction	
Accident Sensors (in-vehicle) (private).	Maybe more potentials in US due to lower prices.
Extended Viewing Systems (radar, sensors, infra-red) (in-vehicle) (private)	Higher potentials in US due to more often and long-lasting driving, and lower prices.
Speed Advising or Control (fixed) (private, public)	No difference, already broadly adopted on critical links and nodes.
Advanced Drivers' Assistance (ADAS) (in-vehicle) (private)	Smaller potentials in US, if legal liability of system manufacturers and operators is not settled satisfactorily. Maybe smaller potentials in US because of decrease of "driving experience" (smaller needs for ISA due to lower max. speed). Maybe higher potentials in US of simple modes due to lower prices.
Automated guided vehicles (fixed/in-vehicle) (private, public)	Smaller potentials in US, if legal liability of system manufacturers and operators is not settled satisfactorily. Smaller potentials in US because of decrease of "driving experience".

Source: The authors

6. Concluding Remarks

The above discussion on the impacts of ICT use on transport demand and on 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. This is mainly caused by the fragmented character of the research that has been done. Exceptions are impacts of teleworking on travel demand and the impacts of ICT use in the transport system on fatality reduction, particularly off-vehicle speed limitation and in-vehicle driver assistance. In addition, most of the outcomes on impacts are based on simulation. There is a need to move to small-scale real-life experiments and large-scale research on real travel behavior to increase the validity of the results. Another point is the limited scope of much research, namely confined to particular parts of the transport network. Additional research is needed to identify whether significant improvements in particular parts of the 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 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. Legal aspects are concerned with privacy issues and with issues of legal liability. Liability issues enter particularly if drivers' decisions are taken over. Inherent actor complexity arises if many actors are involved, i.e. from different layers of the transport system. In terms of differences between US and Europe, we foresee better adoption chances in the US for those applications that generally address car safety, particularly those in-vehicle applications that are cheaper than in Europe, contribute to (and not decrease) the "driving experience" and are free from legal liability questions. If the past is any indicator, most of the innovations and prototypes of new technologies take about 25 years to become common in the transport fleet. This suggests that the third decade of this century will see a more sustainable transport system than what exists today. Completely sustainable transport seems an illusion.

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