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The logo for the International Transport Forum, featuring a stylized blue and green swoosh that forms a partial circle, with the text "International Transport Forum" in blue to its right.

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# WIRELESS TECHNOLOGIES AND THE TRANSFORMATION OF TRANSPORT

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The logo for the Organisation for Economic Co-operation and Development (OECD), consisting of a blue circle with a white stylized 'O' inside, and the letters "OECD" in blue below it.

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## EXECUTIVE SUMMARY

Automotive engineering has a fine record of innovation that has brought a wide range of new products to the market for both private and commercial motorists, together with a sustained reduction in costs. Generally this process has been one of steady evolution and year-on-year improvement but some recent developments point the way to possible large-scale and rapid change in many areas. The driver behind this is the idea of fitting a moving vehicle with a fast and high capacity wireless link so that information can be exchanged between the vehicle and its local infrastructure as well as with other vehicles. The result of that is well over 50 possible applications for:

- Improving safety;
- Better traffic and demand management;
- Reducing engine emissions;
- Reducing energy use;
- Improving provision of information or entertainment;
- Improving convenience and comfort for drivers and passengers.

Turning the concept of a wireless-enabled vehicle into reality requires the bringing together of automotive manufacturers, Intelligent Transport System (ITS) service providers, telecomms bodies and the infrastructure owners and operators. However, it also requires a re-think about how Society approaches safer driving, more efficient network management, etc. There has been a great deal of work on the technologies needed but much less on the associated legal, administrative and commercial aspects. As a result, progress is being hampered by concerns about risk and liability of safety-related applications, the complexity of data ownership, the weakness of business models and the lack of a common international approach to driver distraction, driver overload and driver underload.

Moreover most of the research, development and demonstrations have been carried out by just one of the various trade sectors as, for a number of reasons, there has been little apparent cooperative working between them. The potential benefits from wireless linking are very large and are needed at a time when environmental concerns are increasing, budgets are decreasing and pressures for greater capacity and reduced accidents are as strong as ever. In this area, as with many subjects, we seem to be far too apprehensive about taking the first steps towards doing things in a different way or indeed doing new things for the first time.

Perhaps the time is ripe for a different approach. First, a series of experiments sponsored at Government level in order to underwrite the risks and liabilities and thus clear the way to real testing, by groups comprising all classes of stakeholder, of the behaviour of drivers and systems with these new products. Second, the involvement of a heavyweight international body is important to bring more collaboration and integration to this sector and impose some wise central leadership so that the undoubted benefits are achieved for all stakeholders with minimum cost, lowest risk and highest end-user buy-in.

## Introduction

There have been a number of ‘revolutions’ that have given immense benefits to both private motorists and professional fleet managers or hauliers. If we look back 40 years or so seat belts were uncommon, anti-lock brakes (ABS) were deployed on aircraft rather than cars, neither Electronic Stability Control (ESC) nor air bags existed, and there was little understanding of the links between vehicle design, injuries and crash protection. The situation now is very different: The

mass market car has ABS and ESC as standard plus multiple air bags, inertia seat belts and specialised child seating; New Car Assessment Programmes (NCAPs) give simple consumer guidance on crashworthiness and have contributed to a massive increase in the protection now given to vehicle occupants as a result of clever design and advanced materials engineering.

Some of these developments – ESC for example – have only been possible as a result of another ‘revolution’ – the miniaturisation and cost reduction of electronics enabling the development of the personal computer and domestic information technology [IT]. If we again look back about 40 years we see computers in commercial use, usually in air-conditioned rooms with teams of support staff and with software that shared the computer’s resource between a number of simultaneous users. The processing power was impressive at the time but poor by today’s standards and the storage was small but physically large and expensive: for example a state-of-the-art disc drive in 1960 held 5Mb and weighed 1 tonne. The arrival of personal computers in the 1970s changed the whole model of IT provision and we are all now familiar with the immensely powerful yet affordable desk-top or lap-top computer that has a huge memory, more processing power than most users might ever need and works with USB pen drives that hold 16 Gb.

Over the last 8-10 years we have all been part of another ‘revolution’ – the arrival of Third Generation [3G] telecommunications. Portable telephones have been available for around 40 years but the early models were bulky and used analogue technology. Signal quality was poor and they were vulnerable to interference. The conversion to digital circuitry [2G] in the 1990s led to many improvements especially in reducing the size and weight of the telephone and the speed with which data could be transferred. This process has continued with 3G devices which exploit developments in telecommunications technologies and digital signal processing to increase the capacity of the wireless links to telephones.

This evolution and the installation of more transmitter stations have given us today’s scenario where we have connectivity almost everywhere and are able to download large volumes of data in seconds not minutes. We are offered a wide choice of lightweight phones equipped with a colour display and a great deal of memory and processing power so that they can also function as a camera, music store and player, navigation device, electronic payment terminal, e-mail and Internet browser, data and picture library, and portable video player to list just a few examples. We are becoming used to the availability of services at any time and any place so we expect to be able to send and receive e-mail messages, and manage our E-Commerce transactions, from a variety of devices regardless of whether we are travelling or stationary.

This paper is about the next ‘revolution’ and it is one for which the early stages are visible: the convergence of the advances in automotive engineering and IT on the one hand with the availability of high capacity wireless linking to and from moving cars. This gives us in our vehicles what we take for granted outside them: voice and Internet connectivity wherever we are. The possibilities are both exciting and daunting: will the delivery of films or music to the kids in the back seat be a source of distraction to Mum or Dad when driving? If we can assemble vehicles into small groups – ‘platoons’ – supervised by a traffic control centre we can save time and fuel for everyone AND reduce vehicle emissions but who is responsible if something goes wrong and how do we actually assemble and separate the platoons? If we fit clever sensors to a vehicle and have a satellite position fix we can detect that there has been an accident and automatically telephone for the relevant emergency services with details of location, numbers of passengers, who is not conscious, and what type of vehicle it is, all of which helps to save lives. But is this constant monitoring an invasion of privacy and thus too high a price to pay?

The next sections review some of the opportunities presented for transport by wireless technology as well as the major challenges involved in deploying it. We will look at questions such as who will assume liabilities, risks and costs, the implications for privacy and the protection of data, and how the related infrastructure might be put in place. Then finally we will examine some possible means of overcoming these barriers to innovation.

## *The different applications of wireless technologies*

The essence of the wireless revolution is the fitting of transmitter/receiver units to vehicles and widespread coverage of infrastructure to enable two-way traffic between a vehicle and its infrastructure or between a number of vehicles. The infrastructure is primarily but not exclusively the roads network. The potential stakeholders in the dialogue include telecoms companies, parking services, power distribution companies for recharging hybrid or electric vehicles, retail outlets, value-added service providers, the entertainment industry, healthcare providers, and services specifically aimed at travellers of all types.

The large range of potential techniques can be classified in different ways, for example by the primary application which might be safety; traffic and demand management; environmental impact covering both emissions reduction and better energy use; provision of information or entertainment; and improving convenience and comfort.

This paper will take a slightly different approach by looking first at a number of the application areas in turn and then drawing some general conclusions about deployment problems and then impact and benefits grouped under Personal Safety and Accident Reduction; Sustainability and Reducing Environmental Impact; and Efficiency or Comfort. The techniques that will be discussed are listed in the table with their main operating sector shown. Brief descriptions of some of the applications that are possible with a wireless-connected vehicle are given in the Annex.

### *It's good in theory; when will we see it on sale?*

The examples given in the Annex illustrate the huge range of potential benefits from wireless-linking in five main areas: Safety; Traffic and Demand Management; Environmental Impact; Provision of Information or Entertainment; and Improved Convenience and Comfort. Under **safety** we have listed the reduction of accidents through systems assisting the drivers and, in case of accidents, notification devices to improve rescue operations. A fleet of wireless-equipped vehicles, either private cars or larger commercial vehicles, is already being used in many countries as a group of probes delivering real-time information on the operation of road networks and receiving real time information on congestion, journey times and optimal routes to destinations. This real-time knowledge of loading and flow enables network control centres to **manage traffic and the demand** for access to the network.

Supplying the vehicle's engine management electronics with information about the network topography, local emissions or noise regulations, congestion, and typical journey times enables a lowering of the **impact of transport on the environment** through reduced fuel consumption and greenhouse gas emissions. The provision of **information and entertainment** to the vehicle by wireless is perhaps the most developed application at present, as evidenced by RDS-TMC traffic warnings for real-time updating of satellite-based navigation systems and the receipt of radio and television broadcasts. A range of products can improve driving **comfort and convenience**, e.g. parking information systems, in-vehicle electronic payment for parking and road use charges, and location based traveller assistance services.

But what is on sale, or being trialled in 'concept vehicles' or research projects, is a small fraction of the possible applications. What is holding back the availability of new services? Broadly speaking there are two classes of problem inhibiting the market: Complexity and Novelty.

Under **complexity** we have problems deriving from the ownership and availability of data; the difficulty of making business cases; lack of agreement as to who will fund and benefit from the installation of the necessary roadside infrastructure; and multiple business sectors working too independently on just their own aspect of a much larger picture. Under **Novelty** we have just about every possible problem deriving from doing something for the first time or delivering a familiar service in an innovative way. There's the difficulty of assessing risk; uncertainty regarding legal

liability in the case of a failure or accident; and concerns about driver distraction, driver overload and driver underload. We also have conflicting views from suppliers, users and regulators about data privacy and protection. These issues are explored in the following paragraphs.

**Classification of some wireless-enabled vehicle applications**

	Benefits						Information flow		
	Safety	Demand Management	Emissions Reduction	Energy saving	Infotainment	Convenience and Comfort	Vehicle to Vehicle	Vehicle to Infrastructure	Infrastructure to Vehicle
Adaptive Drivetrain Management		✓	✓	✓				✓	✓
Adaptive Headlight Aiming	✓							✓	✓
Blind Merge Warning							✓		✓
Blind Spot Warning and Lane Change Assistant	✓						✓		✓
Cooperative Adaptive Cruise Control		✓	✓	✓		✓	✓	✓	✓
Cooperative Collision Warning	✓						✓		
Cooperative Vehicle-Highway Systems	✓	✓	✓	✓			✓	✓	✓
Cross-Flow Turn Assistant	✓						✓	✓	✓
Curve Speed Warning	✓							✓	✓
Electronic Vehicle Identification	✓	✓	✓	✓	✓	✓	✓	✓	✓
Emergency Vehicle Warning	✓						✓	✓	✓
Emergency Vehicle Signal priority	✓						✓	✓	✓
Enhanced Route Guidance and Navigation					✓	✓		✓	✓
Entertainment services (static & mobile)					✓	✓		✓	✓
GPS Correction	✓	✓	✓	✓	✓	✓			✓
Highway/Railway Intersection Warning	✓	✓				✓		✓	✓
Intelligent Speed Adaptation	✓	✓	✓	✓		✓		✓	✓
Intelligent Traffic Lights	✓	✓	✓	✓		✓		✓	✓
Intersection Collision Warning	✓						✓	✓	✓
In-Vehicle Traffic Signs	✓	✓			✓			✓	✓
Lateral/Longitudinal Collision Warning	✓						✓	✓	✓
Low Bridge Warning	✓				✓			✓	✓
Non-Stop Tolling		✓				✓		✓	✓
Pedestrian Crossing Information	✓	✓			✓			✓	✓
Point of Interest/Parking Notification					✓	✓			✓
Pre-Crash Sensing	✓						✓		
Post-Crash Warning	✓					✓	✓	✓	✓
Road Condition Warning		✓			✓			✓	✓
Road Feature Notification	✓	✓	✓	✓				✓	✓
Safety Recall Notice	✓				✓	✓			✓
Stop Sign Violation Warning									
Traffic Data Collection – Probe vehicles		✓			✓			✓	✓
Traffic Signal Violation Warning	✓				✓	✓	✓	✓	✓
Vehicle Noise & Emissions Limiting		✓	✓	✓				✓	✓
Work Zone Warning	✓	✓			✓				✓
Wrong-Way (Ghost) Driver Warning	✓						✓	✓	✓

Designing worthwhile and reliable vehicle–infrastructure applications requires a guaranteed supply of raw data or/and processed data (information) from both the vehicle and the infrastructure. Let us consider the example of supplying a driver with details of the availability of parking at a number of alternative locations in a city centre. The vehicle needs to know its possible time of arrival at the various parking sites and the likely availability of a space at each once it has been told the likely arrival time by the vehicle's computers. To make this calculation it needs the location of the sites; and a connection to the local parking management system for each that will predict the availability of spaces at the time when it might arrive, calculated from knowledge of the sites' location and its own position on the network together with any relevant traffic flow information. The key message traffic might involve the owner of the parking site; the (contracted) operator of the site; the local authority managing the local roads network; the traffic authority managing the primary network where the vehicle is currently located; and a telecommunications provider.

There might be a single added value service provider who has sorted out the different data requirements and standards and entered into contracts with the different agencies involved in order to sell a simple application to the end-user. However, there is little doubt that the practical delivery of the product will be difficult because although the information to create it is mostly available it will almost certainly be held by a mix of private and public sector owners, and will probably not be organised under consistent standards. The creation of the parking application will fail if one link in the information chain cannot or will not join the enterprise. The EC's proposed ITS Directive contains a number of measures to encourage the wider availability of data and information but cannot have much of an impact on standards or data quality.

Staying with the parking example above, it is clear that assembling a business model that will cover costs and give a return to the supplier is going to be difficult. The owner or/and operator of the parking site might take the view that information on vacancies should be supplied at no cost as it contributes to a process by which business is encouraged to use one site rather than another and also helps to maximise the use of available capacity. But, on the other hand, the other participants, the two traffic authorities and the telecommunications company handling the messages, might each require a fixed fee for participation or a percentage of the overall transaction cost. These 'handling fees' might in total represent an unacceptable percentage of the likely overall profit.

This general area of real-time, location-specific, added value services is still relatively undeveloped and so there is not a great deal of information regarding how much users are prepared to pay, how to manage the return on investment, whether there is scope for agencies who only handle fee collection; and whether the initial market is likely to be mainly the commercial sector, where the value of time is well understood, or the private driver.

Similarly as a consequence of the relative newness of the area there is no general agreement as to who will benefit most from the installation of the necessary roadside infrastructure and thus who might fund it. Roads operators are for the most part not yet ready to move from giving information or instructions to vehicles through fixed position roadside display panels and instead broadcast a bespoke message to an in-vehicle display incorporated in the driver's instruments although there have been some very interesting trials in Japan that are moving in this direction.

We then have the consequences of multiple business sectors working too independently on just their own aspect of a much larger picture. For understandable reasons the in-vehicle equipment for use with wireless services is being designed to different patterns or standards in Europe, the Americas, and the Asia Pacific sectors. This is defensible on the grounds that vehicles tend to operate within one of the three rather than between them, but it presents problems for automotive manufacturers who look to establish global platforms to keep down costs. And, because technical studies tend to be carried out within an industry – automotive, telecommunications etc – there doesn't seem to be much attention to the levels of multi-functionality a user might expect. For example, should an e-Call unit be single function or able to

deliver infotainment services? There seems to be even less collaboration on design factors and the creation of a global approach to the human–machine interface. In other words there is little apparent lateral integration and cooperative working between the automotive manufacturers, ITS service providers, telecomms bodies and in particular between them and the infrastructure owners and operators.

Let us turn now to the novelty issues starting with liability and risk. The English classical scholar F.M. Cornford argued “never do anything for the first time. If you do and it succeeds you have set a precedent; if it does not work you have just shown why you should not do it”. This is the perennial problem of technology innovation, which is especially relevant here because of issues of safety. Many of the wireless applications described above require a fairly radical change in the way in which driving is perceived but we seem to be far too apprehensive about taking the first steps towards doing things in a different way or indeed doing new things for the first time.

It could be argued that the healthcare sector is far more innovative compared to transport because it has a much better understanding of and relationship to risk with a well-established route from “blue skies” research to deployment. The concept of a clinical trial to test the safety and efficacy of a treatment was first described by Avicenna in 1025 and is familiar to us today. In particular it is routinely accepted that a new treatment offering benefits to thousands should be and will be deployed after a rigorous clinical trial even if it has some unfortunate side effects for a statistically very small sample.

New surgical procedures, treatment regimes, or drugs can all be researched in a laboratory and then assessed in focused clinical trials subject to a risk–benefit assessment by an ethics committee. Innovations showing particular promise will then be tested in a wide-ranging trial, again subject to scrutiny by the ethics committee, to gather more evidence regarding the likely success in regular use and thus contact with far more variability of patient. And, in the final stages, an innovation – for example a new type of transplant operation – can make it to widespread use because the success rate from treating a large number of patients will be substantially higher than the ‘failures’ from severe side effects or even deaths in a very small percentage.

Why don’t we have such an approach in transport? Why do we allow good ideas to be shot down at an early stage because we have adopted a ‘Precautionary Safety’ approach which requires proof that something is ‘safe’? Why can’t we live with the situation that invariably there cannot be proof that something is ‘safe’ and instead have the transport equivalent of a clinical trial in which we test whether any increased risk of a severe injury or fatality for a very small minority is likely to be outweighed by a measurable benefit from our actions for the majority of travellers? Clearly the analogy of transport and medicine cannot be followed too closely because any side-effects of a medical trial will be felt only by those agreeing to participate in the trial, whereas the side effects of a vehicle technology trial could be felt by others on the road. The key issue is to accept from the beginning that the experiment proposed is a search for the greatest good for the greatest number and not the perfect solution for everyone.

There have been some transport equivalents of clinical trials. In 2000 the Minnesota State Legislature approved the closure of all 433 ramp meters in the Minneapolis-St. Paul area for eight weeks to test their effectiveness. And in 2006 the City of Stockholm switched on a congestion pricing system that was to run for a seven-month trial period after which there would be a referendum to decide whether it would be shut down or permanently retained. Also in 2006, the UK Highways Agency started a 12-month pilot project of a mix of active traffic management measures, including the opening of the hard shoulder as a running lane, to cope with peak demand on the M42.

For many observers the key issue is “Who is to blame if it goes wrong?” A fair question but we are entering a regime where not all actions are carried out by people. For example, and returning to the medical world for a moment, a large number of people are content to have their lives literally

controlled by heart pacemakers which they accept as resilient and 'safe'. Many years ago the driver controlled directly all the vehicle functions: there was no power steering, no brake boost, no ABS, no stability or traction control. Gradually over the years we have accepted the idea of driver support and with functions such as autonomous cruise control or "drive by wire" we are accepting that the driver is in **command** of the vehicle rather than directly in **control**. We even accept applications such as the operation of ESC, ABS and the activation of the airbag which are decided by the vehicle's sensors and electronics rather than the driver. There is an intriguing parallel with aviation where for many years it has been accepted that the activation of the controls of a modern aircraft is too complex for the pilot so a computer system translates the pilot's commands into electronic adjustments to the rudder, ailerons, flaps etc.

Who accepts the risk of malfunction? Who is liable if there is a malfunction and perhaps an accident? If the application is one that was supplied when we bought a vehicle then we probably assume that the manufacturer has accepted liability. The difficulty with the emerging wireless systems is that they have a much more extensive delivery chain than, for example, ABS because they involve information flows from beyond the vehicle. For example a Curve Speed Warning System gives drivers a warning message to indicate that vehicle speed is above that considered appropriate for an imminent very tight bend. Were there to be some sort of accident then the reliability of the measured speed, the parameters of the road, the suitability of the (general) speed warning to the specific vehicle, the timeliness of the warning, the timing and accuracy of the wireless transmission, etc. might all be called into question and each of these might be the product of a different supplier.

There has been increasing concern in many countries about the steady rise in the number of in-vehicle displays and the extent to which they might overload the driver with information. There is also concern that they are becoming a source of distraction because they need some form of driver input [eg putting a route into a SatNav] or their design is such that they are difficult to read with one short glance and need the driver's attention for a longer period. A relatively new concern is that of driver underload – a worry that fitting a vehicle with many support functions, comfort applications and accident-prevention devices encourages the driver to reduce attention on the driving task so that perception and reflexes are dulled. All of these issues are amenable to analysis in the light of hard research evidence. But hard research evidence is lacking in many areas and the experts are still not in complete agreement regarding the definition of the various domains of 'safe', 'safe enough' and 'not safe'.

A lot of work was done in Europe over 10 years ago to try to frame guidelines for the design of in-vehicle units and displays so that the information they contained could be transferred by multiple short glances or one longer glance and there was much progress especially with the creation of techniques for measuring the outputs resulting from different approaches to design. But less work has been done on the location of units within a vehicle and the very best designs are weakened considerably if they are placed inappropriately for aesthetic reasons. There is of course the problem that there is no such thing as a standard driver with average responses and skills, but nevertheless there is surely a strong case for a global research cooperation to pool the considerable international research knowledge and try to generate clear guidelines for manufacturers of devices and vehicles.

Our final inhibiting topic is personal privacy and data security. There is a great deal of misunderstanding regarding cooperative vehicle-highway systems and privacy with two particular problems. The first is the apparent enthusiasm on the part of newspaper and broadcast media to make allegations about 'tracking vehicles' or 'spy in the sky satellites' in some cases with a massive avoidance of the laws of physics. For example, it is frequently alleged that GPS satellites observe and track vehicle movements with the implication that someone is up in the sky watching. The GPS satellites are approximately 20 000 kilometres above the Earth and are certainly not inhabited; and they broadcast only time signals and do not **receive** any information other than operational messages.

It is certainly true that vehicles fitted with wireless devices for information, entertainment, safety, electronic payment, etc could have their movements tracked by accessing their message traffic. It is also true that law-abiding vehicles on the road are fitted with a front and rear plate displaying the registered alphanumeric of the appropriate country which makes physically tracking a vehicle extremely easy. It is also true that the physical movement of a mobile telephone can be monitored very easily – in fact an application that does just that is available for parents who wish to be reassured about the location of their children. And it is also true that people using credit cards and retail loyalty cards are disclosing a wide range of information about themselves to those organisations.

It is beginning to look as if we are deploying double standards. In our daily life we concede a lot of information, apparently without concern, about our physical location, personal finances and buying habits to supermarkets, on-line retailers, and search engines such as Google, Yahoo, and Bing. We either do not think about it or we tell ourselves that we have elected to have the ‘product’ so we are obliged to accept too the ‘price’ for signing up to, say, a store’s loyalty card. But we seem not to recognise that for the most part Government is only interested in tracking the movements of known or suspected criminals and if Government wanted to track the movements of millions of its citizens – as opposed to the few hundred individuals for criminal reasons – then a huge bureaucracy would be needed that could not be concealed.

I personally do not believe that “Big Brother” is ‘out to get us’ but this leads to the second problem, the extreme difficulty of proving that something is **not** the case. It is very easy to design the systems described above to function anonymously and to separate all factual transmissions of movement from any vehicle or person identification. There is, though, a major difficulty in proving to people, especially those with no deep understanding of information systems security, that personal information of any sort is NOT being routinely recorded or stored.

Various solutions to this problem have been discussed and a popular approach is the concept of the “Citizens Jury” which is 15 or so people nominated by the public as individuals whom they trust to be open and not conceal any information that Government would prefer to keep secret. Assuming that there are no experts on the Jury, the Jury members then select technical advisers whom they trust to work with them in deciding whether Government is spying on its citizens.

### ***Are the deployment problems too difficult to solve at present?***

The majority of the problems discussed so far are not technical but legal, administrative or institutional. The specific technologies for the numerous applications described nearly all exist as mature products and those that are not quite at this state are close enough to it to enable progress in designing useful and reliable services and other applications. The way to tackle some of the problems is almost certainly not by continued abstract intellectual arm-wrestling but by bringing the various sectors together to work jointly on finding practical solutions, then testing prototype products with users. And the way to do that is to launch serious field trials. Looking at this another way; the conventional markets have not been very successful so it is time for a market intervention.

The data, business case, infrastructure funding and narrow focus-agency issues described in paras 13-19 would all be taken much closer to solution if Governments were to fund 2 or 3 fairly large scale trials with the emphasis firmly focused on solving business and consumer problems rather than technical ones. Removing the key issue of ‘profit’ by contributing to costs as a research exercise would clear the way to designing some specimen collaboration agreements. This in turn would allow products to come to the market and so prompt feedback on how much users are prepared to pay; how to ensure a return on investment; how to handle fee collection; and the composition, behaviour and requirements of the initial purchasers.

Will it be possible to devise solutions to the liability and risk assessment issues described earlier? In a word 'Yes' provided that the various involved parties collaborate. Solving some of the problems should be relatively straightforward. Many of the applications are essentially advice to the driver and it is generally accepted that the driver must accept responsibility for his or her actions as the person in charge of the vehicle. The defence that some form of system gave the advice that led to the incident is not usually acceptable. This has certainly been the case when drivers have followed SatNav instructions without regard for the prevailing circumstances and have taken very large vehicles along very small roads, gone the wrong way in a one-way street, or driven off land into rivers, canals or the sea.

The more difficult cases are those where the driver has delegated control of the vehicle to a system, such as a collision avoidance or platoon driving application on the one hand or applications designed for Emergency Vehicles such as 'green wave traffic priority' on the other. The latter example seems easier to address as we already accept the situation where ambulances, fire appliances for example go through red traffic signals, drive on the wrong side of the road etc and the local or national Government accepts liability for any consequential damage.

In both cases the key seems to lie in designating a primary stakeholder then carrying out a rigorous assessment of the various functions that underpin the whole system, testing them in extreme circumstances, testing their cooperative operation and adding double or even treble redundancy where functions are considered to be safety critical. Over the last 10 years massive advances have been made in developing ways to test that computer software will perform as designed in a range of circumstances. The aviation world has adopted 'fly by wire' techniques that are transferrable to land transport from both the aspect of system design but more importantly from the aspect of system testing. We also know far more now about ways to verify the operation of complex systems without physically building them.

It seems to me that Cooperative Vehicle-Highway Systems designed to enhance safety can be achieved if we:

- begin with a partnership of a vehicle manufacturer and an infrastructure operator;
- carry out our research and development with inputs from other transport modes and other operators of complex systems;
- accept from the beginning that failure is going to be very, very unlikely but not impossible;
- engage national or regional Governments from the beginning so that liability issues are recognised and a confrontational approach is discouraged.

How many of us drive our cars worrying that at any moment the airbag in front of us might fire? How often do we read of this in a newspaper?

## Conclusions

So where are we likely to be in, say, 15 years' time if the technology trends I have outlined continue, the problems I have described are solved and there are no surprises affecting national economies, oil prices etc. A high percentage of vehicles, and the majority of inter-city and urban infrastructure, will be wireless-enabled and by working together will deliver many benefits:

- better, anonymous data from a vehicle on its own performance and the prevailing traffic and environmental conditions;
- better information to the vehicle on hazards, congestion, amenities and incidents;

- use of more of the infrastructure's theoretical capacity; and how to optimise the journey's emissions and energy consumption;
- a safer trip overall with support for the driver on headways, steering, speeds, and routes.

The driver of a 1980s car that started to get into trouble would have few technology aids. Power steering and ABS braking would reinforce the driver's actions to avoid a collision but if one did occur then the degree of injury would rest on seat belts, airbags if fitted, and the structural strength of the vehicle. By contrast the technologies, wireless connectivity and sensors fitted to a 2025 vehicle will constantly exchange information with roadside infrastructure, monitor local conditions, identify dangerous or potentially dangerous situations, warn the driver of them and assist the driver to avoid them.

The 2025 car will have Intelligent Speed Adaptation to warn of, or prevent, accidental – or deliberate – exceeding of speed limits. There will probably be a Driver Drowsiness Monitor that vibrates the driver's seat if measurement of blinking suggests that attention is lapsing. Similarly a Lane Departure Warning System will alert the driver if the vehicle appears to be crossing lane markings without signalling. Overall, the vehicle might be under the control of a Cooperative Vehicle-Highway System, and its presence on the network will have been noted from signals exchanged with the vehicle's Electronic Vehicle Identification. Private cars will be relatively slow to opt in and subscribe to these devices, but commercial vehicles – trucks, buses for example – will welcome the gains from fuel savings and priority on the network.

If the vehicle starts to make a dangerous manoeuvre the first alerts to the driver are likely to come from a Lateral/Longitudinal Collision Warning System that monitors traffic flows around our vehicle, exchanges information with the roadside, and warns the driver that the change of speed or direction that has been started cannot be safely completed. Should the driver ignore the warning then the system could be designed to over-ride the driver's wishes and block the manoeuvre. If the driver continues with a dangerous course of action then the Electronic Stability Control will detect extreme forces and selectively brake individual wheels, and reduce engine output, until the vehicle is under control again.

If despite all attempts the vehicle is still out of control, or the Lateral/Longitudinal Collision Warning System concludes that a collision is inevitable, then the vehicle will prepare for the worst. It will boost brake system pressure ready for an emergency application; it will wind in any slack on seat belts; it will adjust the pattern of the air-bag triggers to reflect the type of impact expected and the number and weight of passengers; and it will stiffen or relax the front/rear suspension depending on the expected impact. As the collision occurs the air-bags will inflate and the vehicle will eventually stop moving. A new system known as e-Call will then make an automatic telephone call to the emergency services to give the incident location and will report whether it has been possible to talk to the driver or any passengers.

There is a very old Chinese proverb: "When two people ride on a horse one must ride behind". This is a good description of the difficulties surrounding the development of Cooperative Vehicle-Highway Systems based on a wireless-linked vehicle. All the industry sectors – telecommunications, automotive, network owners and operators, added-value systems providers – think that they should be in front and that they are the organisation that is in front. None of them seems to see the need for a partnership where their role might be that of second rider or, to stretch the analogy a little, not actually on a horse but sitting with other travellers in a carriage drawn by two, three or even four horses. Few of them seem to recognise that priority is needed to deliver cooperation on the legal, administrative and institutional issues and not on the technical ones.

There is an urgent need for a heavyweight international body to bring more collaboration and integration to this sector and impose some wise central leadership so that the undoubted benefits are achieved for all stakeholders with minimum cost, lowest risk and highest end-user buy-in. The

'C' in CVHS stands for Cooperative; the 'C' in OECD stands for 'Cooperation'. OECD – we need you to start a true multinational debate. It may well be that the ultimate way forward is separate initiatives in the Americas, Asia-Pacific and Europe but many of the issues, for example research into driver distraction and the assimilation of information from in-vehicle displays, would benefit hugely from a pooling of resources and a truly global approach. There are very few bodies in a position to make a serious contribution.



## ANNEX 1

### BRIEF DESCRIPTIONS OF SOME WIRELESS-ENABLED APPLICATIONS

**Adaptive Drivetrain Management:** Electronic systems can control engines more effectively than people but overall fuel consumption and emissions still depend on the driver's right foot. In this system the infrastructure reports upstream traffic and geographic features to the vehicle so that the driver can be recommended a strategy for minimising emissions and consumption without affecting journey time and the engine can be kept in its optimal operational zone.

**Adaptive Headlight Aiming:** Systems are emerging for using inputs from steering to change the 'aim' of headlights for better illumination of bends. A new approach is to take information from the infrastructure on the local topography and combine this with the vehicle's knowledge of its position and speed for optimal illumination of the roadside.

**Blind Merge Warning:** The physical lay-out of many grade-separated intersections with space restrictions often requires sharply curving lanes for merging with poor sight-lines for drivers. Systems are being trialled that monitor vehicles' movements and present messages at the roadside or inside a vehicle informing and warning of the presence of another unseen vehicle.

**Blind Spot Warning:** Most vehicles have a 'blind spot' behind and to the side of them where an overtaking vehicle is momentarily invisible; in the case of a large truck this space can conceal a car for a short time. This system monitors movements at the rear and alerts the driver to an approaching, overtaking vehicle together with a warning should the driver start to move sideways into the other vehicle's path. It can also alert the approaching vehicle of the intention of the vehicle in front to change lane.

**Cooperative Adaptive Cruise Control:** Simple cruise control enables a speed to be set which a vehicle will keep automatically. Adaptive Cruise Control monitors the distance to the vehicle in front and slows the host vehicle if it is closing too quickly, maintains a set gap, then automatically restores the set speed when it is safe to do so. Cooperative ACC takes this process a stage further and uses traffic flow reports from the infrastructure plus real-time information from the lead vehicle to maintain a much smaller gap automatically.

**Cooperative Collision Warning:** Vehicle-to-vehicle communication is used to tell following vehicles of problems or sudden manoeuvres by the lead vehicle so that drivers have more time to take evasive action.

**Cooperative Vehicle-Highway Systems:** The high-level, general term for systems that link an intelligent vehicle with an intelligent highway by wireless for safety, environmental, efficiency and comfort benefits. The ultimate CVHS is often thought to be the operation of platoons of vehicles ('road trains') under the control of infrastructure with pre-booked paths and preferential access to the network but a more probable early application is the use of a motorway hard shoulder by buses or emergency vehicles.

**Cross-Flow Turn Assistant:** A form of cooperative collision warning that helps a left-of-road driver turning right and vice versa.

**Curve Speed Warning:** Where there is a very tight bend on a road the infrastructure can measure an approaching vehicle's speed and send a warning message directly to the driver and/or trigger a roadside message display; or the vehicle can broadcast its speed to the infrastructure and be ready to receive an excess speed warning.

**Electronic Vehicle Identification:** A system that uniquely identifies a vehicle using an electronic device that allows secure remote interrogation of a range of vehicle parameters. An EVI system can contribute to preventing vehicle theft, road user charging, access control and many enforcement activities such as speeding and red light running.

**Emergency Vehicle Warning and EV Signal priority:** An emergency vehicle on a duty call can alert other vehicles in its vicinity using vehicle-to-vehicle links and thus clear a path through traffic. By connecting with the infrastructure, EVs can send a request for priority passage through traffic signals: a "Green Wave".

**Enhanced Route Guidance and Navigation and GPS Correction:** Many route guidance products use an in-vehicle, satellite-based position location system which can be slow to respond in some circumstances and will be subject to interference and weak signals in built-up areas. A roadside-based supplementary transmitter can remove most of these problems and ensure a much more precise in-vehicle signal.

**Entertainment services:** The high capacity of third Generation wireless enables the delivery of films and computer games to travellers in the vehicle.

**Highway/Railway Intersection Warning:** If a vehicle is regularly notifying the infrastructure of its position then it can be given very early warning that it is going to cross a railway and, if there is an infrastructure/rail link, it can be also be advised whether it is likely to have probable clear passage or will need to stop and wait.

**Intelligent Speed Adaptation [ISA]:** ISA is a system that monitors a vehicle's speed and the speed limit on the road being used and intervenes if the vehicle is detected exceeding the speed limit. The intervention can be advisory where the driver is warned of the excess, or mandatory with automatic control of the driving systems of the vehicle to reduce speed to the prevailing limit. ISA acquires the local speed information by one or more techniques: matching the known position to an on-board digital map that includes speed limit information; receiving a wireless broadcast from a roadside transponder that notifies speed limits and changes to them; or through feature recognition technology that detects and interprets speed limit signs.

**Intelligent Traffic Lights:** Traffic signals in urban areas have moved away from fixed time allocations for roads at junctions and intersections to a system whereby flows are measured over a large area and signal timings are managed to maximise movement and minimise waiting for all users. Intelligent signals take this approach a stage further by linking the infrastructure directly to the vehicles. If the control system receives a message from a vehicle that it is about to ignore a red signal it can delay giving a green to drivers on intersecting roads to maximise safety. Also, with the much earlier knowledge of traffic flows approaching junctions the system can reduce waiting by adjusting the timings of the green phases in the light of how much traffic is building up on each road.

**Intersection Collision Warning:** This is similar to Highway/Railway Intersection Warning. Roadside sensors coupled with in-vehicle position and speed broadcasts are used to monitor traffic approaching dangerous intersections and warn vehicles of approaching cross traffic, via roadside signs or directly to in-vehicle displays. The extreme version of this system is not a warning but over-riding of the driver and the automatic application of brakes as with Intelligent Speed Adaptation.

**In-Vehicle Traffic Signs:** A vehicle-infrastructure link is used to give information or a warning to a driver of the content of an upcoming roadside sign.

**Low Bridge Warning:** The approaches to an especially low bridge can be protected by installing roadside sensors to measure the vehicle's height and then sending a warning to a driver via roadside signs, or directly to in-vehicle displays, and activating a red traffic signal to stop the offending vehicle.

**Lateral/Longitudinal Collision Warning:** This refers to a system that monitors traffic flows around a vehicle, exchanges information with the roadside and other vehicles, and warns the driver that a change of speed or direction that has been started cannot be safely completed. Should the driver ignore the warning then the system could be designed to over-ride the driver's wishes and block the manoeuvre.

**Non-Stop Tolling:** Vehicles can pay road-user charges without stopping in two main ways. They may fit a registered on-board device that is interrogated by roadside infrastructure to test for a guaranteed line of credit that leads to an off-line invoice, or they may exchange journey and financial information with the roadside that leads to real-time payment or an invoice.

**Pedestrian Crossing Information:** Pedestrian safety systems can help reduce accidents by alerting drivers that they are approaching a crossing, together with any speed limit changes, then automatically activating in-pavement or overhead lighting to alert drivers that pedestrians are using the crossing.

**Point of Interest/Parking Notification:** Once the infrastructure learns the location of a vehicle and the expected arrival time, site-specific information can be sent to a driver via roadside signs, or directly to in-vehicle displays.

**Pre-Crash Sensing:** If a lateral/longitudinal collision warning system concludes that a collision is likely it can prepare the vehicle by boosting brake system pressure ready for an emergency application; winding in any slack on seat belts; adjusting the pattern of the air-bag triggers to reflect the type of impact expected and the number and weight of passengers; and stiffening or relaxing the front or rear suspension depending on the expected impact.

**Post-Crash Warning:** If a collision has occurred, and especially if air-bags have inflated, the vehicle can automatically make a telephone call to the emergency services to give the incident location, and possibly some information about the type of vehicle and any structural damage, and report whether it has been possible to talk to the driver or any passengers.

**Road Condition Warning:** This system uses vehicles as probes to collect information in real-time about road conditions – accidents, temporary speed reduction zones, hazardous weather conditions, operation of a vehicle's stability control, etc. – for transmission to neighbouring vehicles and the infrastructure operator.

**Road Feature Notification:** The infrastructure alerts oncoming vehicles with early warning of physical road features such as chicanes, roundabouts, traffic calming installations and road markings such as segregated cycle lanes or bus lanes.

Road Feature Notification and Road Condition Warning are aspects of an application often referred to as **Visibility Enhancement** – giving the driver information about situations beyond or outside the direct line-of-sight.

**Safety Recall Notice:** Normally a manufacturer's safety recall notice is sent to the postal address of the purchaser. This application sends a message directly and immediately to an affected vehicle.

**Stop Sign Violation Warning and Traffic Signal Violation Warning:** These applications both use knowledge of a vehicle's position and speed, combined with information about the physical infrastructure, to predict whether the vehicle is likely to over-run a stop sign marked on the road or pass through traffic signals at red. A warning can be sent to the driver directly using an in-vehicle display or via roadside signs. The knowledge of a possible contravention can also be used to alert other traffic flows at the site.

**Traffic Data Collection – Probe vehicles:** Vehicles equipped with an application using wireless (SatNav for example) or carrying a mobile telephone can be used as sensors to determine the traffic speed on the road being used. The probe vehicles anonymously report their position, speed, direction of travel and time information. Based on these data the degree of congestion can be estimated, travel times calculated, and traffic reports generated. In contrast to traffic cameras or sensor loops embedded in the roadway no additional or fixed hardware on the network is necessary.

**Vehicle Noise & Emissions Limiting:** This is a modified version of Adaptive Drivetrain Management where instead of advising a driver of strategies to minimise emissions the infrastructure 'commands' the vehicle to comply with specific local regulations.

**Work Zone Warning:** Carrying out repairs on a live carriageway usually involves temporary speed limits, lane changes, lane merges and contraflow running which are managed by temporary signs and portable physical barriers to divide lanes. A linked vehicle-infrastructure system offers much more flexibility enabling faster reconfiguring of the work zone and allows precise alerts and instructions to drivers regarding lane choices, speeds, too-close following of preceding vehicles etc.

**Wrong-Way (Ghost) Driver Warning:** Many countries report that the number of drivers travelling in the wrong direction on a road has been increasing. Such incidents frequently lead to serious accidents and certainly create insecurity among other travellers. Systems have been designed to detect a driver going on to a road on an exit ramp and then activating flashing red lights in the road as a warning as well as sending messages and instructions to the driver via roadside signs, or directly to an in-vehicle display.