The potential application of artificial intelligence in transport

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Abstract: The emergence of Intelligent Transport Systems (ITS) and their further development for road transport in years to come are considered. Artificial Intelligence techniques have potential applications for the vehicle, the infrastructure, the driver or transport user, and in particular the way in which these interact dynamically to deliver a transport service. The related concept of Ambient Intelligence (AmI) embraces greater user-friendliness, more efficient services support, user-empowerment, and support for human interactions. The overall function of ITS is to improve decision making, often in real time, by transport network controllers and other users, thereby improving the operation of the entire transport system. A future vision for ITS is described with reference to efficient road traffic management, services for "smart" travellers making inter-modal journeys, "smart" cars, co-operative systems and automated highways. The paper concludes that intelligent infrastructures are required that are dependable, manageable, adaptable and affordable.

1 Introduction

The term 'Artificial Intelligence (AI)' was coined in 1956 by John McCarthy at the Massachusetts Institute of Technology and refers to the branch of computer science that attempts to emulate human intelligence in a machine. Fields within AI include knowledge-based systems, expert systems, pattern recognition, automatic learning, natural-language understanding, robotics and others. Commercial applications of AI are diverse, including applications in medicine, financial systems and software designed to assist humans with impairments (voice, character recognition).

AI techniques potentially have applications for the operation of the entire transport system—the vehicle, the infrastructure and the driver/user—and in particular the way in which these interact dynamically to deliver a transport service. The versatility of the tools and their performance are well suited for the complexity and variety of transport systems. As transportation surveillance technology continues to advance, the measurement of more complete traffic information is becoming increasingly feasible.

The past decade has seen the emergence of intelligent transport systems (ITS), involving the integrated application of communications, control and information processing technologies to the transportation system. The overall function of ITS is to improve decision making, often in real time, by transport network controllers and other users, thereby improving the operation of the entire transport system. The acquisition of more reliable and complete data improves ITS strategies in all its application areas by reducing assumptions on traffic characteristics. The ITS Handbook [1], containing recommendations from the World Road Association, provides a comprehensive introduction to these methods.

Defined by the EC Information Society Technologies Advisory Group as part of a vision for the Information Society, the related concept of Ambient Intelligence (AmI) embraces greater user-friendliness, more efficient services support, user-empowerment and support for human interactions. In this vision, humans will be surrounded by intelligent and intuitive interfaces supported by computing and networking technology which is everywhere, embedded in everyday objects such as homes, vehicles and roads. AmI is fundamental to the concept of ubiquitous services advanced by the Korean Transport Institute and shown in Fig. 1 [2].

On the roads, AmI will improve the safety of the vehicle, its occupants and other road users with on-board driver assistance systems and improvements in traffic management, including a reduction in congestion. As far as environmental sustainability is concerned, AmI can be instrumental in the development of new technologies that use fewer natural resources, optimise energy efficiency and help reduce pollution or risks to health and safety.

Currently no computers exhibit full AI: the ability to simulate human behaviour. The greatest advances have occurred in the field of games playing and the best computer chess programs are now capable of beating humans. In the area of robotics, computers are now widely used in assembly plants but they are capable only of very limited tasks. Robots have great difficulty identifying objects based on appearance or feel, and they still move and handle objects clumsily. Natural language processing perhaps offers the greatest potential rewards because it would enable people to interact with computers without needing any specialised knowledge. Unfortunately, programming computers to understand natural languages has proved to be more difficult than originally thought. In the early 1980s, expert systems were believed to represent the future of AI and of computers in general. To date, however, they have not lived up to expectations.

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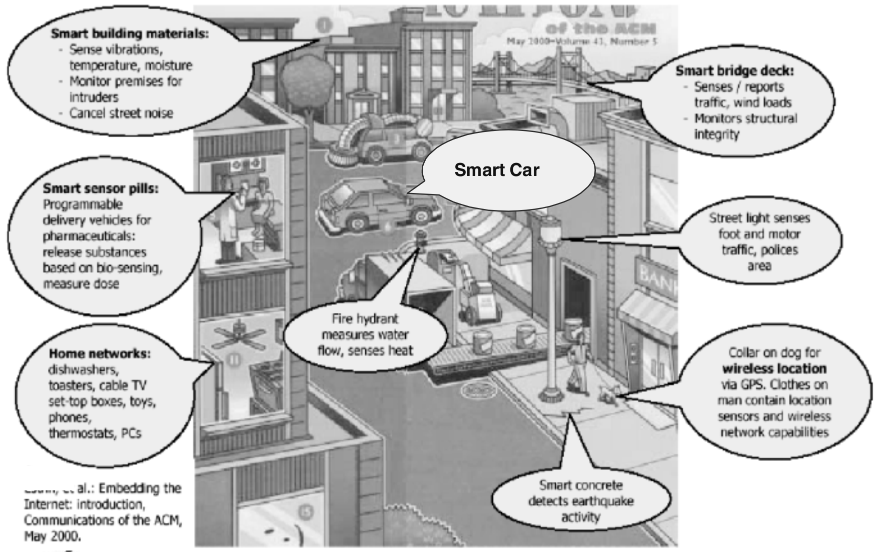

Fig. 1 *Ubiquitous services, as presented by the Korean Transport Institute, 12th ITS World Congress, San Francisco, 2005*

Many expert systems help human experts in such fields as medicine and engineering, but they are very expensive to produce and are helpful only in special situations. Dr Brooks (director of MIT AI Lab) suggests that AI is at about the same place as the personal computer industry was in 1978. The expectation is that AI applications will broaden and advance in the next decade.

1.1 Today's transport situation

Currently the operation and control of existing transport infrastructures are failing; too often we are confronted with capacity problems, poor safety, unreliability, environmental pollution and inefficiency. However there is considerable scope to use various AI techniques to contribute to the development of new, intelligent modes of operation for existing infrastructures. AI is already deployed in many areas of transport, for example in areas where learning algorithms are appropriate—e.g. intersection control on arterial roads, travel time predictions and vehicle fuel injection systems. These are examples of 'narrow AI'; narrow because it is within a specific domain.

The problems that different transport sectors are dealing with have much in common. How to use the available capacity to its maximum? How to do this in the most efficient way? How to prevent congestion, without neglecting the proper safety precautions? How to respond adequately to fast changing conditions and market demands? How to keep up the quality and reliability users are accustomed to? There are no easy solutions to these problems, because large infrastructure systems have many components and levels, involving different parties, all primarily pursuing their own local performance objectives.

1.2 Intelligence in transport

Before we consider the potential application of AI in transport in more detail, it is useful to explore the concept of intelligence in transport. Transport services and products are there for the benefit of potential users and intelligence is needed to ensure efficient and effective delivery. For example, data collection technology now has the capability to collect and process huge amounts of traffic data but this is only of any value if the output is useful and intelligible. It is helpful to distinguish between information, which—if relevant—can advise the user, and intelligence, which implies knowledge of the user's purpose, and an understanding of what information is relevant to his or her circumstances.

The concept of intelligence originates from psychology, where it has been defined as a human ability to act. Transport intelligence has relevance to two main categories of stakeholders—the transport producers on one hand and the transport users on the other. The first group apply their intelligence to construct, maintain and operate the transport networks and provide transport services; the second use their intelligence to make use of these networks and services for personal and collective travel needs and for the transport of goods. The needs of these two sets of stakeholders are often very different and their interrelationships need to be considered when implementing new (transport) systems.

Several qualities of transport intelligence have been described and some examples are given in Table 1 [3]:

- connective intelligence (connectivity with the transport user or operator, e.g. through speakers and speech recognition);
- self-recognitive intelligence (system knows the state it is in; a kind of consciousness);
- spatial intelligence (a more conscious understanding of location and positioning requirements and spatial expression);
- kinaesthetic intelligence (flexible, moveable and adjustable technology for 'smart moving') and
- logic (embedded sensors to monitor technology and users' daily activities, system integration).

ITS already exhibit some of these qualities, as illustrated in Table 1, but there are many opportunities for further application of AI methods in road transport, not least because society imposes performance requirements that are more and more demanding, especially in the areas of safety, efficiency, environmental pollution and reliability [4].

Table 1: Qualities of transport intelligence

Form of intelligence	Transport system			
	Networks	Services	Traffic	Vehicles
Connective	Control centre network diagrams	Internet sites, information kiosks and direction signs	Traffic message channel/video information highway	In-vehicle unit: user interface (voice announcements, audio warnings and graphical displays)
Self-recognitive	Area signal control; integrated corridor management	Journey time monitoring and near-term forecasting	Incident detection and emergency alert	Automatic fault detection
Spatial	Satellite navigation	Turn-by-turn route guidance	Lane keeping	Vehicle tracking and location monitoring
Kinaesthetic	Active speed control	Motorway speed advice and lane control	Speed/red light enforcement	Active cruise control
Logic	Signal fault report and maintenance systems	Ordering and dispatching systems	Dynamic traffic signal control	Over-speed warning
All	System integration			

The development of these concepts as they apply to road transport is now considered under four main headings:

- Vision of efficient road traffic management.
- Vision of smart travellers.
- Vision of smart cars.
- Vision of cooperative systems and automated highways.

2 Vision of efficient road traffic management

Current and projected traffic levels on the roads are a major threat to economic and social development, and environmental sustainability. Therefore we need to increase network capacity, flexibility and reliability, whilst at the same time recognising the increasing vulnerability of transport infrastructures. Today these systems are operated and managed by several parties, all of them acting in their own interests and pursuing different, sometimes conflicting goals. As a result it is sometimes difficult to keep a clear view of all the risks, let alone how to control them, and to maintain stability and reliability. The problem is multi-dimensional, for example:

> "Our goal is a road network that provides a more reliable and freer-flowing system for motorists, other road users and businesses, where travellers can make informed choices about how and when they travel, and so minimise the adverse impact of road traffic on the environment and other people" [5].

2.1 Challenges

When a traffic management system involves many thousands of vehicles using hundreds of streets and roads, each travelling independently with a different purpose, it can be difficult or impossible to tell whether use of the network is optimum and to predict how modifications to dynamic control parameters will affect the system. Consequently for traffic engineers it becomes increasingly difficult for them to make good control decisions in real time. In the absence of informed intervention, all too often a system can degenerate into a pathological state or process, in which progress slows or stops completely, as in the case of gridlock. Future dynamic traffic management systems are required to support network-wide, pro-active traffic management, instead of the locally oriented, reactive traffic management which is common today. As discussed earlier it is also important for any system to be able to provide the sort of 'intelligence' that is required by end users. Improved traffic management models are also necessary to deal with the huge amount of real-time traffic data generated from detectors and other sources (e.g. probe vehicles which are equipped to report their position and traffic conditions in real time) that need to be interpreted and analysed by the operators to support the decision making process.

2.2 Current situation

The application of knowledge-based and AI systems to traffic management operations has been an active research area for a quarter century or more. Introduced to reduce congestion and accidents in 1980s, urban traffic control systems, such as SCOOT (UK) [6] and SCATS (Australia) [7] were amongst the first transport applications to use AI. However, despite the long-lasting research and development worldwide, co-ordinated urban traffic control is still evolving in response to safety, environmental and operational concerns, and to capitalise on greater knowledge and information about the network, e.g. from probe vehicle data [8]. This calls for the employment of the most efficient actuated systems that respond automatically to the prevailing traffic conditions so as to reduce oversaturation, increase throughput, and reduce travel times in urban networks. In addition, with increasing congestion, more advanced systems that control traffic on motorways and inter-urban networks are also being developed.

There are several reasons for incorporating AI into integrated road transport management systems. Firstly, current traffic management and control systems show limitations when facing critical traffic conditions and wide-spread congestion. This is a recurrent problem in most metropolitan and urban areas in Europe, and is usually caused by a locally conceived analysis of traffic behaviour and requires more strategic, high-level control methods to be developed. Secondly, the role of operators of traffic management centres (TMCs) is still crucial in day-by-day operations—no matter how sophisticated and advanced the traffic control technology is, the 'man in the loop' paradigm still prevails in most centralised traffic control systems. Thirdly, the introduction and progressive integration of extended traffic monitoring and management facilities in the

Fig. 2 *Vision for road traffic management systems in the Netherlands 2003*
Source: Rijkswaterstaat/AVV Transport Research Centre

new generation of traffic management architectures (e.g. improved monitoring systems, incident detection, collective and individual route guidance systems, etc.) has led to demand for increased, on-line operator support tools to help cope with the complexity of both the information managed and of the resulting, integrated traffic management schemes.

Increasingly, AI techniques are being incorporated into intelligent traffic management models which are capable of analysing traffic behaviour and evolution in a similar way to an expert traffic controller. These systems are not intended to replace human operators but rather to act as intelligent assistants that cooperate in the task of defining and applying traffic control decisions. There are five stages where operators would benefit from this kind of assistance, as shown in Fig. 2, which is based on the *Sustainable Traffic Management Handbook* for the Netherlands [9]:

- know what you want to achieve;
- know what is happening;
- gain insight into solutions;
- make decisions and
- implement decisions.

Such concept of an Intelligent Traffic Management System embodies a knowledge model of traffic behaviour at a strategic level incorporating self-recognitive and spatial features to support the control logic. Several AI techniques are being applied in dynamic traffic management including evolutionary algorithms, knowledge-based systems, neural networks and multi-agent systems. It is possible to distinguish between

- direct control (measures using traffic lights, 'smart' barriers and variable message signs (VMS) to allocate traffic priorities in time and space) and
- indirect control measures like recommendations for drivers which focus on the behaviour of individual vehicles (e.g. radio broadcasts, before-trip information (e.g. via internet), in-vehicle routing and navigation systems).

Much of the research to date has been on direct control measures, however future applications are likely to focus more on logistics, journey planning and in-vehicle guidance individually tailored to meet users' requirements and requests. This is becoming an urgent requirement for commercial operations and the service sector because of the disruption that traffic congestion can cause to just-in-time delivery and mobile servicing of premises.

Many metropolitan areas are developing traffic management centres (TMCs) that monitor and manage traffic flow on streets and freeways using numerous real-time data sources ranging from traditional closed-circuit television cameras and fixed traffic and weather sensors to the information that is recorded by 'intelligent cars' and submitted over mobile and ad hoc networks respectively. Travellers can keep informed of possible problems via a personal information assistant or a car navigation system. TMCs are the building blocks for many other AI applications. Although there are many experimental new technologies (e.g. automatic guidance systems), the most commonly installed devices are VMS and traffic lights.

The TRYS model [10] developed for Barcelona is an example of a multi-agent traffic management system. So-called 'problem areas' are defined in a particular traffic situation. Each problem area has an agent assigned to it. An agent in this context is a computer system that is capable of autonomous action in order to meet its design objectives. The agents formulate actions to be performed and propose them to a 'coordinator' who makes a final decision in the case of conflicting plans.

Traffic management tools aim to optimise the operation of transport networks in time and space. Although there are clear benefits from 'smart' traffic management, it also introduces the risk of gridlock and a 'superjam' in the event of system failure, making things much worse. The systems need to be robust and intelligent enough to deal with worst case scenarios.

2.3 Incident management

Incident management is an integral part of transport network management and AI techniques are helping to detect, monitor and respond to accidents quickly. Speedy and reliable detection of an incident is the first requirement, and many automatic systems lose credibility because of a high incidence of false alarms. Image processing and 'artificial vision' using closed circuit TV cameras give immediate visual confirmation and provide better connectivity to the traffic controllers over the older inductive loop-based systems. 'Remote presence' also has great potential for saving lives, by connecting the paramedics attending an incident to hospital staff who can provide advice on first aid and gain information about serious injuries so that operating theatres can be prepared. The system works by using a headset incorporating a voice circuit in combination with a miniaturised CCTV camera which can relay images back from the scene of the incident over a broadband mobile phone network [Note 1].

Researchers in California [Note 2] are using robots to reduce both the delays and expense caused by incidents.

Note 1: See for example, http://www.cnn.com/2005/TECH/05/18/Spark.robodoc/index.html. 'Robo-doc' at St Mary's Hospital, London, is the first hospital in the UK to pilot a remote system. The robots will be trialled in a general surgery ward and the A & E Department. The robots stand in for a human doctor, who controls the machine remotely.
Note 2: For more information see http://cvrr.ucsd.edu/aton/ at the Computer Vision and Robotics Research Laboratory at the University of California, San Diego.

They hope to develop a fleet of Atons, named after the Autonomous Transportation Agents for On-Scene Networked Incident Management Project. Traffic would be continually monitored by clusters of video and acoustic sensors connected with multimedia workstations via high bandwidth communications links. The Aton control system would merge all of the information to construct a 3D image. Control centre personnel could quickly isolate accidents, dispatching pre-positioned Atons that could react faster than their human counterparts. The first Atons could begin appearing within 3 years.

2.4 Demand management

Demand management for transport is one way of reducing congestion and this can involve relatively straightforward access control techniques or categorising vehicles (e.g. by their number plates) to restrict flows entering given areas. More intensive measures include charging for use of the road during congested periods, or the introduction of special high-occupancy vehicle (HOV) lanes. Increasingly electronic ticketing and electronic payment methods are utilised to pay for transport services and AmI technologies can be used to keep track of transactions, clients and other data useful for improving operations and providing customised services.

Recently, the Department for Transport has completed a feasibility of road pricing in the UK [11]. Their computer modelling showed that a considerable impact can be made on congestion with a relatively small reduction in traffic. The study has found that a national road pricing scheme would probably become technologically feasible in 10 years' time, although implementing it would be a massive and complex task, requiring concerted action and co-operation at all levels of government. The most promising scheme would charge on the basis of time, place and distance; and technologies that can charge on this basis are at the forefront of technological development. While the individual components are available, getting them to work together to the required standard is the challenge. This would entail the development of a complex 'box' on-board the vehicle that uses several different technologies (including position-fixing and communications facilities for transferring data to and from the charging authority). No such unit is currently manufactured for the mass market or has the necessary capability to be applicable for all vehicles.

National charging based on distance will require location, which in turn means using positioning technology. The most likely candidate for a reliable and accurate positioning technology is that offered by positioning satellites. The DfT study estimated that the equipment necessary to deliver a full position-based charging scheme using satellite technology will not be available in a mass market, low cost form, until at least 2014. The launch of the Galileo satellite network [Note 3], which is intended to go into commercial operation from 2008, will be a major step towards this particular solution, providing greater coverage and accuracy, even in the most challenging locations.

A true national road pricing system needs a new national mechanism which has the capability to charge by distance and for the level of that charge to be varied, up or down, to reflect conditions of time and place. Continuing advances in computer power will help to facilitate the implementation and operation of a scheme of this kind. The road pricing system would generate huge spatial datasets which in turn would require several iterations to calculate the particular price for the journey, invoice the user and then possibly collect the payment electronically. The data collected would also be used to manage the network better. Computationally intensive tools can allow more effective use of large datasets, more sophisticated and extensive simulations of complex spatial phenomenon, and the solution of complex location and distribution problems.

Note 3: The Galileo positioning system is a planned satellite navigation system, intended as a European complement to GPS.

3 Vision of smart travellers

Public (collective) transport modes (bus, rail, shared-taxi, metro, dial-a-ride), when fully integrated and combined with individual personal transport can provide flexible and efficient ways of moving large numbers of people on complex journey patterns in urban areas. Integrated public transport operations interfacing with traffic management systems will become increasingly important in metropolitan areas to provide reliable public transport services as well as reducing the traffic load and environmental burden. AmI technologies will play an essential role in the vehicles and for travellers, using a variety of platforms: public information kiosks, in-vehicle displays, hand-held or wearable devices. These devices offer the potential for real-time information on inter-modal connections and guidance for the traveller through an unfamiliar interchange. Other developments include navigation for blind and partially sighted pedestrians using low-powered infra-red beacons or radio-frequency tags.

3.1 Traveller information systems

Traveller information systems (TIS) give accurate information on traffic conditions so that travellers and fleet managers can adjust times, routes and modes of travel and delivery. Drivers can be warned to change their planned route to avoid incidents, congestion or severe weather conditions. TIS can promote greater use of inter-modal travel, e.g. by encouraging drivers to leave their cars at a Park and Ride and continue by public transport. Parking information systems also contribute significantly to reducing city-centre congestion and pollution by alerting approaching drivers to available spaces.

Research in the area of TIS has received a great deal of attention in the recent past and it is believed by both the research and commercial communities that traveller information is central to dealing with transport challenges in our congested towns and cities. Current applications for instance include dynamic road map displays in the vehicle and on large electronic graphics signs mounted above the road (Japan) which keep the traveller up to date with the current traffic situation. These displays give information about the length of traffic jams, about capacity reduction due to road works or lane closures or provide actual travel times over a given stretch of road. Research in this area is now focusing more on providing alternative route choices based on multi-modal travel and in real-time. Furthermore, the traveller will not just receive information from dynamic roadside displays but also in the vehicle itself.

In fact, personalised information services require some form of machine intelligence to deal with the specific context of the user. Is the user travelling by car or public transport? What are the time constraints on a trip? What are the user interface capabilities and preferences?

Timely traveller information is now regarded as a key feature for a successful transport system [12]. Changing demographics and technological progress are raising expectations. Today's transportation consumers must manage their time effectively, and significant uncertainty associated with waiting for a bus or train is unacceptable to most people. Many consumers are also unaware of all of their public transportation options. The use of personalised information-based technologies can expand traveller choices and facilitate delivery of more convenient services, potentially increasing public transport patronage. Personalisation, if it is to be of value, requires the development of a spatial logic and connectivity that is adapted to the particular user.

3.2 The information chain

The provision of travel information has advanced significantly over the past 10 years with the advent of new technologies, such as automatic vehicle location and advanced communications, and of new dissemination mechanisms and media, such as wireless application protocol, mobile telephones and personal digital assistants. 'Smart travellers' of today expect to have comprehensive information about multiple modes (including traffic information) available to them quickly, in one place or from one source, and on a variety of media.

The TCRP study [12] identified four key strategies for improving traveller information services and AI techniques have much to offer in each of these application areas:

- improving the data that provide the basis for TIS;
- completely integrating TIS with other traveller information, particularly traffic and destination information;
- providing more customer-focused and personalised information, such as bus stop-level schedules and route maps;
- providing real-time information using a variety of dissemination media.

It is important to note that underlying data of good quality are required in order for quality traveller information to be generated as it directly affects everything along the 'information chain'. AI techniques are already widely employed here, for example to process and 'interpret' some of the huge volumes of data that are collected from floating vehicles for traffic monitoring purposes. AI methods are also increasingly being developed to merge data from divergent sources (e.g. multi-modal) and to disseminate information to end-users. For example a system for visualising four-dimensional 'real-time' transport data for the major roads of Washington DC, Northern Virginia and Maryland has been developed [13]. The prototype system interacts with real-time traffic databases to show animations of real-time traffic data (volume and speed) along with incident data (accident locations, lane closures, etc.). A user can 'fly' or 'drive' through the region to inspect conditions at an infinite number of angles and distances.

The ATLANTIC Project [14] which reviewed traveller information services across Europe, Canada and America also concluded that it is the integration of information services that provides the most value to the user. Many current European projects are focused on the full integration of traveller information for all transport modes, such as Transport Direct [15], an internet-based one-stop shop for journey planning, which the UK Department for Transport is rolling out. In the next few years, multi-modal journey planning tools like Transport Direct are likely to be called on as an adjunct to a variety of other services, like arranging hospital appointments, interviews, university applicants' job searches or yellow pages inquiries. Fully integrated door-to-door journey planning requires extensive codification of detailed local knowledge concerning points of access to the transport network, frequency of services, timetables, etc. The constant upkeep and maintenance of reliable datasets is an area where AI systems may have a part to play in future.

3.3 Predictive, personalised systems

Short-term traffic prediction is of great importance to the real-time traveller information and route guidance system. Various methodologies have been developed for dynamic traffic prediction. However, many of the existing parametric studies focus on fixed size data and presume time-invariant models. More recent research is looking at ways of merging historical off-line data with current real-time data using various types of routing algorithms. The latest integrated systems use congestion information to guide routing, both in advance and while a journey is being undertaken. GPS is used to track vehicles while they undertake journeys, and the GSM short message service is used to maintain communications between a moving vehicle and a central planning service. At Cambridge University researchers have investigated possible ways to integrate congestion information from the Trafficmaster system with a route planner in such a way that the recommended route would reflect the congestion anticipated at the (future) time when the journey would be undertaken. Moreover, the traveller would be notified if congestion at the time of travel makes an alternative route preferable [16].

However, such systems can only be successful if they are able to convince the driver to change his behaviour and although TIS have reached a high technical standard, the reaction of road users to this information is not well explored. We need to shift the focus of simulation systems to the driver itself and systems are necessary, which consider the behaviour of drivers. One of the problems is that the messages which are sent to road users by means of communication such as VMS or radio broadcasts are based on future predictions which themselves are affected by drivers' reactions to the messages they receive. This leads to an undesirable feedback loop. Increasingly multi-agent techniques are being used to model traffic scenarios since every road user can be naturally identified as an autonomous agent.

In a similar vein, fuzzy logic has been applied to evaluate driver perception of VMS [17]. All TIS by their definition have significant interactions between the systems and humans, whether they are vehicle operators, passengers or pedestrians. Given this circumstance, consideration of how drivers perceive and evaluate the service quality provided by these systems is an important factor in evaluating system performance. Fuzzy sets theory is a branch of set theory that is useful for the representation of imprecise knowledge of the type that is prevalent in human concept formation and reasoning.

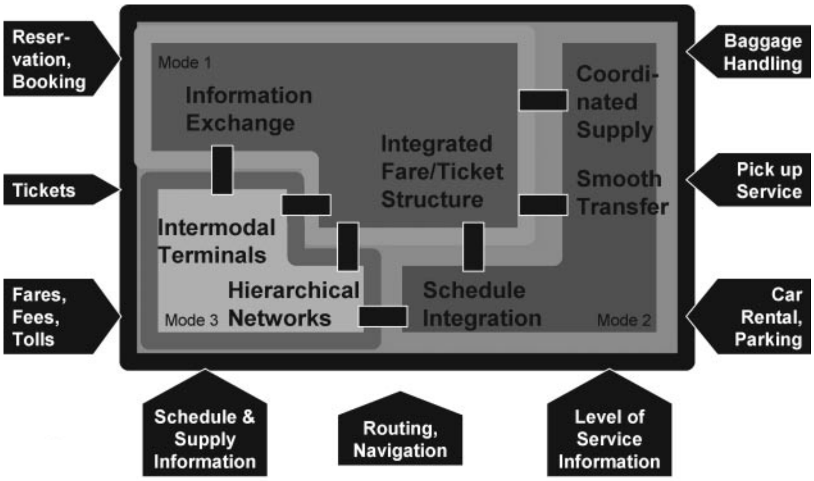

Fig. 3 *Vision: Integrated services for travellers in Europe*
Source: ROSETTA project 2003 Southampton University Transportation Research Group

Aside from users' perceptions of TIS, the potential impact of traveller information services on modal shift is unclear. Based on an extensive review of literature and concepts, it has been suggested [18] that uni-modal information services are not likely to cause a substantial effect on car-drivers mode choices, since the information they contain is unlikely to be searched for by probable car-users. However the next generation of TIS is more likely to be used by car drivers and may indeed change their perceptions and subsequent choice of mode. But travellers are only prepared to invest a minimum amount of effort, time, attention and money to obtain information and only highly relevant information of superior quality, provided by a service that is very easily accessible, has the potential to help change flawed perceptions of car-drivers regarding public transport, and in that way help realise a modal shift. This impact will probably still be fairly limited.

3.4 Intelligent navigation systems

Intelligent navigation systems support individual travellers (usually drivers) by providing information about the shortest possible routes, the actual traffic situation and alternative routes. AI technologies will also address the need for dynamic routing depending on information from TMCs and from other travellers. In combination with context information and personal profiles, navigation can become more intelligent. Route navigation systems are already a standard feature in top-class cars. The much wider take-up in Japan is impressive. Already there are 10 million vehicles on the roads with navigation systems equipped to receive real-time traffic information. However, although the systems have reached a high technical standard, the reaction of the road users to this information is not well explored.

In Europe, navigation systems are rapidly becoming more than just novelty playthings for the affluent, but the price is still too high for volume sales to take off. However as prices fall over the next 5 years or so, mainly due to standardisation of components between suppliers, built-in navigation units will be put in every vehicle except entry level within 7–8 years [19]. Systems of the next generation of on-board route-guidance will be able to cope with short-term disturbances such as roadworks, accidents or congestion, based on real-time traffic conditions. Already systems in Europe with radio data system traffic message channel are equipped to deal with real-time information by decoding, filtering and analysing digitally coded, language independent TMC data about traffic and weather conditions. The information obtained can then be used by the navigation system to calculate an alternative route. The SMARTNAV system [20] in the UK is approaching this level of functionality, although it relies on a human interface to offer rerouting suggestions around unexpected incidents.

The effectiveness of navigation systems in the longer term is less clear for relieving congestion. With a greater availability of navigation systems it is easily imaginable that congestion is simply transferred to the alternative routes suggested by the guidance system. Thus these route guidance systems as they exist today merely result in temporarily retarding existing capacity problems. However they will still be useful for guiding drivers from A to B, particularly where the driver is unfamiliar with either A or B or the route between them. In addition there may be safety benefits to be gained by providing drivers with extra information about their route and traffic conditions (e.g. anxiety and stress associated with navigating through the network are reduced).

3.5 Integrated Services

The vision of a smart traveller extends further than the provision of accurate route guidance and reliable travel information as the vision of 'Seamless Journeys' illustrates (Fig. 3). Associated with the need to move from point A to point B are a number of other services and facilities that are used. Traditionally they are provided by the travel agent or the logistics chain manager but the Internet has brought about a revolution in how these services are sold and marketed. On-line booking has changed the way we plan our journeys. Increasingly travel and other location-based services are being integrated into a single package.

3.5.1 Electronic payment and smart cards

Smart cards are already in use for payment of public transport fares and road tolls around the world. These will be considerable assets as integrated ticketing develops—as part of the drive towards integrated transport. Smart-card ticketing and automated fare collection provide a passenger-friendly basis for electronic payment that eliminates cash handling and fraud. AI techniques are already widely employed in smart card technology, for example, to combat fraud. The memory and processing capabilities available on smartcard microchips allow development of flexible and innovative products for paying fares and other transport-related charges. The technology is also capable of being extended into an 'electronic purse' for small cash payments at newspaper kiosks and convenience stores, and to store data that are personal to the card-holder, like club membership, building access codes or loyalty card details, as well as a record of payment transactions.

The high volume of cash transactions in public transport makes it particularly suitable for realising this concept; and for operators analysis of transactions provides a useful analytical tool for service planning and modification. Over the past few years there have been various initiatives to standardise smart card technology which it is hoped will simplify the use of smart cards, bring down costs and improve interoperability between modes and even between transport and other sectors.

A general problem of cash-less payment is the dependence on world-wide standards. The widespread use of credit and electronic cash cards has not replaced but complemented the general use of cash. Ticket-less public transportation will at first only be possible as an addition to current ticketing. However, with general use of smart cards, micro-payment systems and international standardisation, tickets may become obsolete in the future.

3.5.2 Location-based services With the recent advances in navigation databases, data processing and broadband telecommunications there is little doubt that tomorrow's mobile handsets and in-vehicle systems will exploit a greater amount of data, that the advice they provide will be more dynamic, more accurate, more in real-time and more focused on what services the individual traveller needs and prefers. Future systems will use spread-spectrum broadband networks to access the Internet, and they will communicate with the user by the usage of spoken language. Towards the end of the decade, with the Galileo constellation of global positioning satellites in place, users will also benefit from highly accurate location referencing. In this way, online, location-based information, concierge (yellow pages), tourist and entertainment services will be widely available—whether the user is on foot, a passenger in transit or driving. With an abundance of information available, the need for context- and user-specific selection will grow. There will be commercial value in applying successful AI methods to filter out the unwanted, and capture that which has value and relevance.

A significant component of future traffic systems will be in-vehicle devices. Other important components are real-time simulation and interactive vehicle control. In combination with personal travel assistance systems, agent-based route guidance devices can do much more for their user. Given the necessary investment in digital mapping and databases, they can guide him from door to door over any distance from a few metres to thousands of kilometres, using the full set of travel modes. They can look for ways of reducing costs for the traveller by offering transparency over time and cost components of the journey, by scheduling trips into less congested time intervals and by negotiating for services, which in return offers suppliers new means for advertising and customising their services. In the ideal case all the user has to do is to contact a service provider, e.g. by telephone, by Internet or by the usage of his in-vehicle route guidance system, and to inform this provider at what time he desires to be at which destination. In return he receives a completely elaborated itinerary including route guidance from his in-vehicle device, parking space reservation at the railway station or at the airport, a ticket reservation for a public transport provider and hotel as well as restaurant reservation at his destination. This may sound far-fetched but most of these technologies are already available as stand-alone systems. Thus it is just a question of time until these systems are combined and marketed as a service.

4 Vision of smart cars

A new generation of technology is emerging which is going to change the driving experience for millions of motorists. Soon we will all have an impressive array of in-car high-tech gadgets to make driving a lot more fun and, in theory, safer [21]. Safety is directed towards reducing the risks of traffic which has been a goal of public authorities and the automotive industry for a long time. AI has become an important factor in this endeavour during the last few years particularly in vehicles. In the near future the combination of data from numerous sensors measuring the condition and behaviour of the car and the driver will make it possible to identify risks and propose and/or initiate countermeasures. The push to develop smart cars using AI is part of a wider effort on the part of car makers to respond to environmental requirements.

Cars continue to gain intelligence. Advanced driver assistance systems gradually acquire new functions. Extended use of electronics offers the benefit of ultra fast reactions and the unwavering alertness of sensors. Combined with ever-increasing intelligence and speed of data processing, this opens the possibility to actively support the driver and (in the far future) even to take over certain driver functions to enhance safety. Safety technologies already available include traction control, adaptive cruise control, intelligent speed adaptation, collision warning and avoidance systems, driver drowsiness detectors, night and bad weather visions systems, truck roll-over warning systems.

Certain models of BMW, Cadillac, Honda, Jaguar, Lexus and Mercedes now offer, or soon will offer, a dizzying array of high-tech features, many of these technological advances have spun off from military applications:

- Collision-warning systems that use a computerised voice, sound or light to alert the driver to a possible frontal or rear crash.
- Cruise control that maintains a safe speed and distance between vehicles, automatically slowing or accelerating as needed.
- Global positioning systems, wireless technology and call centres that enable drivers to call a virtual or human adviser for help in reaching a destination or locating the nearest cash machine, petrol station or hospital.
- Night vision systems that use technology developed by the US military to display see-through infrared images on the windshield to warn the driver of approaching obstacles.
- Voice control systems that allow the driver to 'talk' to the car. Drivers push a voice-activation button on the steering wheel and give simple commands such

as 'Temperature 20 degrees' or 'Radio on'. A computerised voice 'talks back' and confirms the command.

• Tyre pressure monitors warn drivers if the pressure is too low, thus unsafe.

• Parking alarms using radar in the back bumpers which sound a beep inside the car if an unseen obstacle is in the path of the moving vehicle are becoming commonplace in new vehicles.

The major car manufacturers believe that smart cars which actually sense all the traffic around them are 'just around the corner'. However some aspects of driver intelligence are proving hard to replicate using AI and other techniques. This point is illustrated by the results of the 2004 Grand Challenge Race [Note 4] which took place in the US and offered a $1 million prize. The race was a collection of autonomous ground vehicles travelling a 142 mile course through the Mojave Desert. The race was organised by the US Defense Advanced Research Projects Agency (DARPA) to accelerate technological development for military applications. No team won the race as no vehicles were able to complete the difficult desert route. 'Sandstorm' was the only vehicle to follow the course and travel autonomously—manoeuvring and deciding on alternative routes and avoiding obstacles—for the furthest distance of 7.4 miles! The 2005 DARPA Grand Challenge will be held in October in the desert Southwest. AI design, advanced storage development and giga-pixel imaging are just some of the technologies the Grand Challenge has put on the fast track.

So although car companies think they can create a car with enough electronic brains to cruise down a motorway, making turns and speeding up or slowing down with little or no help from the driver, it seems likely that this will take longer than anticipated. This would initiate the first age of fully automated motoring which, it is interesting to note, was first promised in General Motors 'Futurama' exhibition way back in 1939! Although many different technical developments are necessary to turn this image into reality, none requires exotic technologies, and all can be based on systems and components that are already being actively developed in the international motor vehicle industry. These could be viewed as replacements for the diverse functions that drivers perform every day: observing the road, observing the preceding vehicles, steering, accelerating, braking, and deciding when and where to change course.

There is also the question of how far human technology can take us. Does society require cars that, for example, change the oil as you are driving along the road, tell you if a passenger is feeling nauseous or even find a car parking space for you? We may require some of these things but realistically manufacturers are more likely to put money in to things that sell rather than what is necessarily best for society as a whole. How fast such systems start appearing in less expensive cars will depend, in the long run, on how popular they turn out to be with the public. Some experts though worry that drivers will find the new technology intrusive, confusing and possibly distracting ironically making driving more hazardous than less so.

The future belongs to innovative driver-assistance technology. Sooner or later, these systems will revolutionise active vehicle safety—much in the same spectacular way that electronic stabilisation programs have recently done. Their objective is to prevent accidents using control technology such as an automatic emergency brake assist or the attention control feature that prevents drivers falling asleep at the wheel.

Even when humans are experienced drivers they have little opportunity to learn how to control a vehicle under demanding crash conditions, so they do not get the benefit of learning that is available to artificial systems. In the longer term, as experience with artificial control systems grows, they will have the advantage over humans in that control algorithms can be learned and tuned over millions of hours of simulated and real driving. Eventually we may prefer automated control rather than human control in a growing number of situations. However increasing automation raises many issues of risk and investment management. There will be major issues about the rate of deployment of these vehicle control systems once it becomes clear that major reductions in accidents can be achieved by using such systems when compared with human drivers. Testing, responsibility and accountability are also major issues. Who will guarantee the collective behaviour of multiple vehicles?

There is some opinion that increasing automation may not necessarily lead to improved safety in the longer term due to effects sometimes described as risk homeostasis. Counterproductive behavioural adaptation is when drivers start behaving in riskier ways as a result of a perceived increase in safety provided by an ITS device (or any other device). These effects still have not been very well researched and are often speculative but must be taken seriously. Drivers of vehicles equipped with Anti Braking Systems (ABS), for example, have shown adaptation to the device and/or by increased speed under adverse conditions. On balance, ABS may have changed the types of accident rather than having decreased the number of accidents.

5 Vision of cooperative systems and automated highways

The idea of Automated Highway Systems (AHS) was 'all the rage' during the 1990s, as US DOT sponsored an ambitious program carried out by the National Automated Highway System Consortium. This work culminated in the celebrated Demo'97, in which more than 20 fully automated vehicles operated on Interstate 15 in San Diego, California, without a hitch, giving thousands of ITS professionals and public officials a taste of the future.

Back in the 1990s, there was a lot of talk about 'dedicated lanes' and 'platooning' which would have required the construction of specialised infrastructure, and which left infrastructure providers scratching their heads as to how they would squeeze in these lanes, even if the benefits were large. Since then the focus has changed to cooperative intelligent vehicle-highway systems, which offer the potential to enhance the effectiveness of active vehicle safety systems and which have entered the marketplace for light vehicles and heavy commercial vehicles. These systems are *cooperative* in that the vehicles can receive information from the roadway and respond appropriately, and vehicles can detect and report hazards to the roadway, for dissemination to other travellers as shown in Fig. 4. The systems are *intelligent* in that the ultimate response is determined by algorithms which evaluate multiple parameters.

Note 4: For further details see Grand Challenge website: http://www.darpa.mil/grandchallenge/.

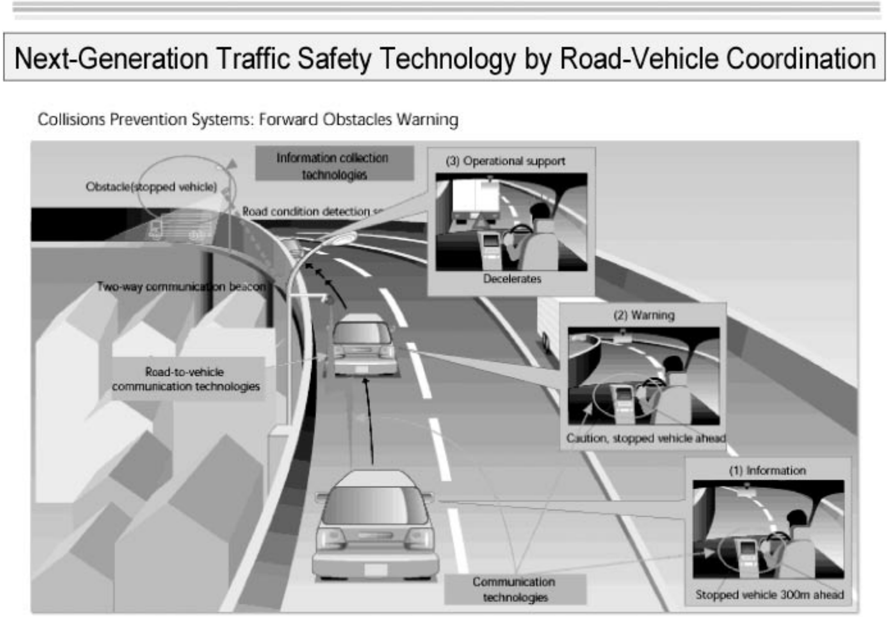

Fig. 4 *AHS in Japan.*
Source: Japan Automated Highway Systems Consortium, 2004

The first generation of vehicle-highway automation envisages automated vehicles operating on existing roads with no extensive infrastructure modifications required. As discussed above, most of the required intelligence is likely to be built in to vehicles rather than to the infrastructure. Early co-pilot systems would evolve to auto-pilots gradually [22]. These vehicles would operate at spacings a bit tighter than commuter flows of today, with traffic flow benefits achieved through vehicle-cooperative systems as well as vehicle-infrastructure cooperation. The vehicles may cluster in 'designated lanes' which are also open to normal vehicles, or may be allowed on HOV lanes to increase their proximity to one another and therefore get the benefits of cooperative operations. Stabilisation of traffic flow and modest increases in capacity are seen as the key outcomes.

Once this level of functionality is proven and in broad use, a second generation scenario comes into play which expands to dedicated lanes, presumably desired by a user population with a high percentage of automation-capable vehicles. With growing use, networks of automated vehicle lanes would develop, offering the high levels of per-lane capacity achievable through close-headway operations. However, this type of evolution could take a while. First generation vehicle-highway automation for passenger cars is at least 10 years away, with estimates for second generation implementation hovering around 2025.

Many driver assistance systems have graduated now from R&D curiosities to the realm of product development. Both European and Japanese car-makers are known to have active programs focused on automated driving [Note 5]. This is seen as a natural evolution of the safety and convenience systems they are bringing to market, such as adaptive cruise control and lane departure avoidance. In fact, Low Speed Automation (LSA) systems—which take over full vehicle control in congested stop-and-go traffic—could be available within 5 years or so. But even with an automated vehicle you may have the maximum inconvenience, but no help with the time spent in traffic jams—the cooperative vehicle-highway systems cited above must come into play to accomplish benefits for the aggregate traffic stream. So what is the likely timeline for deploying advanced driver assistance systems? Looking ahead from 2005 Table 2 shows some possible dates for likely deployments [Note 6].

These projected timelines are not all science fiction! Much is already technologically feasible and Toyota is rolling out its Intelligent Multimode Transit System (IMTS) [23] which will be a key link in transporting visitors within Expo 2005 in Japan [see Fig. 5]. IMTS is a driverless transit system which allows automated platoon operation on dedicated roads, as well as manual human operation on normal roads, i.e. a 'dual mode' concept. Lane guidance is accomplished by tracking magnetic markers embedded on the exclusive road. If any steering failures are detected, the vehicles automatically stop to avoid a collision. Guard walls are also in place to provide another layer of safety. The vehicles are longitudinally coupled by vehicle-to-vehicle communication using exclusive wireless LAN. Gap distance between the vehicles is managed by an automatic speed control subsystem. It is designed to prevent a collision even in the case of triple system failure. Gap distance is determined from vehicle speed, relative deceleration rate between the vehicles and control time lag.

It appears that AI for safety has become well established within the vision and research programs of major government programs worldwide. While some room for debate remains, a consensus seems to be forming that the information transmitted in cooperative systems will not directly control vehicles [23]. Instead, signals from outside the vehicle provide information only and vehicle system decides which actions are appropriate. Perhaps litigation and legal liability is not

Note 5: Visit www.smacar.com to view a video of automated driverless driving in Korea.

Note 6: Table derived from IV source.net: '2000–2030 Timeline for Advanced Driver Assistance System Deployment Activities'. March 2001.

Table 2: 2005–2030 Timeline for advanced driver assistance deployment

2005/06

- *California*—Caltrans-sponsored automated light vehicles demonstration
- *Netherlands*—plan for automated vehicle guidance complete
- *Korea*—first stage ITS implementation complete (vehicle-based warning services and initial/partial automatic driving)
- *Japan*—Smart Cruise Stage 2 deployment (road-vehicle coordination period) begins
- *Korea*—second stage ITS implementation begins (autonomous and cooperative control services for crash avoidance, and longitudinal/lateral control services for automation)

2007/08

- *Japan*—Smart cruise stage 3 deployment (full-scale AHS) begins
- *California*—vehicle-highway automation pilot envisioned
- *France*—Estimated availability date for low speed automation to be available to the public

2010/11

- *California*—Caltrans provides initial availability of vehicle-highway automation systems
- *California*—automated managed lanes for Interstate 15 in San Diego complete
- *US*—'stretch goal:' 10% of new light vehicles sold are equipped with IVI systems
- *US*—'stretch goal:' 25% of commercial vehicles sold are equipped with IVI systems
- *US*—'stretch goal:' 25 metropolitan areas have deployed the infrastructure portion of cooperative intersection collision avoidance systems
- *US*—possible target for deployment of intersection collision avoidance
- *Korea*—second stage ITS implementation complete (autonomous and cooperative control services for crash avoidance, and longitudinal/lateral control services for automation)
- *China*—development of 'whole sets' of ITS technology complete
- *Japan*—approximate timeframe for automated vehicle operation on dedicated roads
- *Korea*—introduction of automatic driving services for improved road capacity and safety

2015

- *Japan*—Smart cruise deployment complete (information, warning and control systems for optimal safety become widely available)
- *Japan*—feasibility study of automated cruise on specific routes complete

2020

- *Korea*—implementation of automatic driving services complete

2030

- *UK*—Automated car/truck lanes (with managed access, centralised control) implemented for major motorways in a 'Strategic Road Network', per Vision 2030
- *France*—Phase IV route Automatisée implementation likely complete (automated highway network; centralized network control allows higher safety and capacity)

Fig. 5 *Driverless 'Smartbus' concept for Expo 2005*
Source: Toyota Multimode Transport System

the 'monster' that some expected it would be which safety systems were envisioned 10 years ago. An example is the collision mitigation braking system which is now on the Japanese market and appears to be heading towards introduction in Europe and the US in a few years.

A spectrum of approaches can be envisioned for highway automation systems in which the degree of each vehicle's autonomy varies. At one end of the spectrum would be fully independent or 'free-agent' vehicles with their own proximity sensors that would enable vehicles to stop safely even if the vehicle ahead were to apply the brakes suddenly. In the middle would be vehicles that could adapt to various levels of co-operation with other vehicles (platooning). At the other end would be systems that rely to a lesser or greater extent on the highway infrastructure for automated support.

In the long term it seems unlikely that technological difficulties will hinder the widespread introduction of intelligent vehicles and highway systems but rather a wary public. How will humans cope with increased automation of the driving task and who wants to share the road with a convoy of 40 tonne driverless lorries? Or are we heading towards the time when human driving will become a form of extreme sport to be allowed only within controlled areas?

The key technical challenges that remain to be mastered involve software safety, fault detection and malfunction management. The non-technical challenges involve issues of liability, costs and perceptions. It is also important to recognise that automated vehicles are already carrying millions of passengers every day. Many major airports have automated people movers that transfer passengers among terminal buildings. Modern commercial aircraft operate on autopilot for much of the time, and they also land under automatic control at suitably equipped airports on a regular basis.

Given all of this experience in implementing safety-critical automated transportation systems, it is not such a large leap to develop road vehicles that can operate under automatic control on their own segregated and protected lanes. That should be a realistic goal for the next decade.

6 Future prospects

6.1 Place of AI in transport

The invention of the micro-processor and rapid advances in mobile communications have made it feasible to launch serious attempts at building ITS. In other fields, AI and robotics have produced significant results in planning, problem solving, rule-based reasoning, and understanding of images and speech. Intelligent vehicles and weapons systems can perform military tasks of great complexity with precision and reliability. Research in learning automata, neural nets, fuzzy systems and brain models provides insight into adaptation and learning, and the similarities and differences between neuronal and electronic computing processes. Game theory and operations research have developed methods for decision making in the face of uncertainty. Autonomous vehicle research has produced advances in real-time sensory processing, world modelling, navigation, trajectory generation and obstacle avoidance.

What still eludes us is an understanding of the science of mind and brain at a level that would enable engineers to design and build intelligent systems with significant capabilities. The level of performance of current AI and robotic systems is extremely limited in comparison with biological systems. Early successes with toy problems in the laboratory have not scaled up to solve real problems in the natural world. Current laboratory robots are disappointingly incapable of performance that rivals any natural intelligence beyond that of some insects. Perhaps the biggest barrier to future progress is the lack of a theory with sufficient specificity to support the engineering design and construction of intelligent systems. Although we know how to build computers that can perform billions of computations per second, and we can write software programs that can defeat the world champion in chess, we still cannot duplicate the capability of a 6-year-old human in understanding natural language, or even in tying a shoe lace. We have only a vague understanding of how the brain represents knowledge about the natural world, and we have not been able to endow computers with common sense. We do not know how to build sensory systems that can perform as well as cats or squirrels in recognising and tracking objects of interest by sight and sound.

However various factors are now rekindling research interest in AI. Faster and cheaper computer processing power, memory, and storage and the rise of statistical techniques for analysing speech, handwriting and the structure of written texts are helping spur new developments, as is the willingness of today's practitioners to trade perfection for practical solutions to everyday problems. Researchers are building AI-inspired user interfaces, systems that can perform calculations or suggest passages of text in anticipation of what users will need, and software that tries to mirror people's memories to help them find information amid digital clutter. Much of the research employs Bayesian statistics, a branch of mathematics that tries to factor in common beliefs and discount surprising results in the face of contrary historical knowledge. Some of the new AI research also falls into an emerging niche of computer science: the intersection of AI and human–computer interaction.

Several industry trends also are helping move AI up on the agenda. The emerging field of wireless sensor networks, which have the potential to collect vast amounts of data about, for example, vehicle movements could benefit from the use of AI techniques to interpret their data. The Pentagon also continues to fund AI research, partly to lay the groundwork for intelligent vehicles and robots.

The concept of AmI, mentioned earlier, is particularly interesting for the transport sector, where people and vehicles are constantly on the move. AmI emphasises on greater user-friendliness, more efficient services support, user-empowerment and support for human interactions. In this vision, people will be surrounded by intelligent and intuitive interfaces embedded in everyday objects around us and an environment recognising and responding to the presence of individuals in an invisible way by year 2010.

This vision assumes a shift in computing from desktop computers to a multiplicity of computing devices in our everyday lives whereby computing moves to the background and intelligent, ambient interfaces to the foreground. The vision places the user at the centre of future development. Therefore it follows that the technology should be designed for the people rather than making people adapt to the technology. It is less clear however, how this can be realised.

The Information Society Technology Advisory Group (ISTAG) scenarios report on AmI [23] identified a number of key technological requirements for AmI to become real. The keywords are systems and technologies that are sensitive, responsive, interconnected, contextualised, transparent and intelligent. These are

- unobtrusive hardware (miniaturisation and nanotechnology, smart devices, embedded computational power, power consumption, sensors, activators, etc.);
- a seamless mobile/fixed web-based communications infrastructure (interoperability and dynamically reconfigurable wired and wireless networks);
- dynamic and massively distributed device networks (interoperable devices and ad hoc configurable networks, network embedded intelligence, etc.);
- natural feeling human interfaces (intelligent agents, multi-modal interfaces, models of context awareness, etc.) and

• dependability and security (robust and reliable systems, self-testing and self organising/ repairing software, privacy-ensuring technologies, etc.).

In addition, the ISTAG made a number of points about the roll-out of information society technologies (ISTs) which are highly pertinent to the use of AI in transport:

• People do not accept everything that is technologically possible and available.
• People need resources/capabilities to buy and use ISTs (money, time, skills, attitudes, language, etc.) that are not evenly distributed in society.
• People make use of new technologies in ways that are very different from the uses intended by suppliers (e.g. the Internet, SMS text).
• New uses of ISTs mainly emerge in interaction of users and producers of ISTs.
• User demands will only be met if costs are attractive for the suppliers.
• There is no such thing as a typical, standard user and use but rather a diversity of users and uses.
• There is a difference between ownership, usage and familiarity of ISTs. People own technologies but may not use them; people use technologies but may not have trust and confidence in them.

It is impossible to predict all the ways in which our lives and behaviour as transport users will be changed. In fact the response of road users in particular to ITS applications, as they are introduced, is the most critical factor for the safety effects of ITS. Political factors are also important. Public policy needs to address such issues as the digital divide and of access to ISTs. New technologies should not become a source of exclusion for society. Therefore security, trust and confidence have been recognised as key bottlenecks for the deployment of AmI [24].

Many of the devices that are intended to take over part of the driving task like autonomous cruise control, lateral driving support, etc. have been developed for operation under motorway conditions. As such they have been designed to ease and simplify the driving task. In the urban context, where the driving task is more complex, these devices should not operate inappropriately to cause the driver added complications. Research also indicates that individuals who have developed certain manual control skills and who then have those tasks automated will perform better in the supervisory role than individuals who have never developed those skills in the first place. This indicates the possibility of a long-term deterioration in driver performance and thereby also in road safety as more decision support and other AI assistance is provided for the driving task. If future generations are trained solely in vehicles with all possible support systems they will not develop the skills associated with 'manual control' that are required without support or with failing support.

As support systems become more complex, they may start to present the user with the additional problem of knowing and understanding what the system is currently doing. The driver who misinterprets the action of a complicated system may end up 'fighting' the system, which demands a lot of attention and is potentially very dangerous. There have been examples of such incidents in highly automated civil aircraft. Another potential problem with complex systems is that it becomes more difficult for a user to determine accurately whether the system functionality is deteriorating and has become substandard. Especially gradual deterioration combined with rarely used functions may lead to unpleasant surprises and hence to dangerous situations.

When ITS reduces the operator's role to supervision instead of active control, the supervisory activities can easily be neglected or omitted entirely, to free up capacity for other activities. What can happen then is illustrated by research with driving simulators. For instance, it turns out that drivers readily adapt to the use of anti-collision devices and will completely rely on the device after only a short learning period. If the simulated device is made to fail, more than half of the drivers tested fail to take effective action and crash! Again, these tests have been made under motorway conditions. In urban conditions, with a multitude of moving and stationary obstacles, failure of the automatic device is far more probable. This sort of adaptation could therefore prove even more dangerous in an urban setting.

What happens in the event of system failure is also critical from a safety viewpoint. Reliability analysis of systems is essential in order to be able to deliver good products or services or to avoid some catastrophic events due to failure of component(s). In communication networks, for instance, it is important to have duplicate circuits and reliable components in order to avoid frequent interruption in communications or unavailability for a long period. In some cases the systems reliability is a requirement from government agencies for the purpose of security (air-traffic for instance). For example in area traffic control it is technically feasible and inexpensive to introduce the concept of graceful degradation from a centralised network-wide controller into a distributed control regime for each intersection autonomously. This means that even if some (small number of) computational and communication units fail, traffic control does not collapse but satisfactory service—in particular traffic safety—can be maintained, possibly at a slower pace and of somewhat reduced capacity. The consequences of system failure for some of the more futuristic developments, such as automated vehicle platoons, are harder to imagine and would require considerable further research.

6.2 Short-term prospects (next 5–10 years)

The state of the art in transportation engineering has advanced dramatically over the last decade, and the application of new and more flexible traffic control devices, software systems, computer hardware, communications and surveillance technologies, and analysis methods has become commonplace. Many AmI transport applications will reach the marketplace in a very short time range due to the fact that systems for individual navigation and traffic management have existed for some 10 years and will get momentum from the availability of new mobile 3G+ networks.

In traffic management, first prototypes of AmI-based systems will be realised soon, although the success of such a system depends heavily on a dense network of street sensors, which is a costly undertaking now mostly reliant on public–private partnerships for funding. The existence of a TMC is often a pre-requisite for other AmI applications in this field, since they depend heavily on the data offered by the traffic management provider.

Both real-time traffic information for multi-modal traffic as well as travel assistance will reach full functionality around 2010.

The car will remain the most important traffic means in everyday life for the foreseeable future. The increase of car safety is therefore one of the most important needs to be addressed by AmI technologies. The distinctive feature, however, will be the awareness of the car of its environment and its driver's behaviour. In the literature the development of AmI applications has the goal to reduce the various risks associated with traffic and to build accident-free motorway-cars. Car manufacturers are trying to reach this goal within the next decade.

> 'Cars that do your thinking for you are just around the corner – they watch out for hazards, they listen to you, they read your lips, they even know when you're distracted'

Critical applications include driver vehicle surveillance. Most accidents are caused by driver inattention and following too closely. AmI technologies offer the opportunity to monitor the driver's physical condition, diagnose signs of incapability to drive, warn the driver and intelligently influence his behaviour. An important limiting factor may be the reluctance of the driver to external control. Vehicle and environmental factors also play a role in safety. AmI can be interpreted as a car knowing its own condition and its environment. The developments in safety applications depend mainly on the availability of sophisticated sensors and pattern recognition procedures.

A huge growth in mobile information and entertainment services is expected in the short term including information on traffic and mobility matters. AmI provides the opportunities to further personalise information and to make it contextually and action dependent. It is expected that within the next decade driver information systems will not only provide navigation aids but also integrate functionalities in the areas of entertainment, information and telecommunications for the driver and other passengers. Public transportation providers have also started to equip their vehicles with the infrastructure necessary for mobile information and entertainment.

6.3 Long-term Prospects (10–50 years ahead)

Although the term 'Artificial Intelligence' has existed since 1956, AI is arguably an example of how sometimes science moves more slowly than may have been predicted! Although playing chess has turned out to be very easy for computers it has proved very difficult to endow machines with 'common sense', emotions and those other intangibles which seem to drive much intelligent human behaviour. To a critical extent, the longer term application of AI and AmI to transport depends on the extent to which technological intelligence can mimic the function of human intelligence.

The longer term vision for AmI promises context-sensitive systems that autonomously detect the user's intention and offer the best solutions for travel and mobility on the basis of the actual traffic situation. Though navigation systems will become more and more context aware over the next 15–20 years, it is, however, very uncertain what degree of intelligence these systems will achieve. The realisation of context-aware driver surveillance is even more uncertain because manual interventions are not acceptable in critical situations. Therefore safety applications need even more reliable systems for the detection of the user's 'real intentions'.

AI has until now predominantly been a field characterised by complex research in laboratory scale environments and only recently has become a part of the landscape of technology in commercial applications. The main drivers of this area are the entertainment and military industries. Sustained very high level of investments into military R&D in the US could result in an acceleration of the developments in this area. The perspectives for AI in the following decades are much debated. Many argue that the area is not expected to experience radical paradigm shift within the next decade, but a continuous and sustained evolution of technologies that already exist or are in their infancy such as 'pattern recognition', 'fuzzy matching', 'speech recognition'. Concerning both 'Context-sensitive and affective computing' and 'Artificial Intelligent Agent' the diffusion of the technologies is therefore expected to occur later, maybe around 2010. Others believe that we are on the verge of another technological revolution. Ray Kurzweil, a formidable thinker who more than a decade ago predicted the emergence of the World Wide Web and that a computer would beat the world chess champion, forecasts that computers will exceed the memory capacity and computing speed of the human brain by 2020, with the other attributes of human intelligence not far behind.

AmI refers more to a mind-opening vision of the future information society than to a forecast. Whether this vision or part of this vision will come true depends on many enabling, facilitating, driving or on the contrary hindering or preventing factors. These could be technical or 'human' (economic, political, environmental, social and cultural, demographic).

7 Conclusions

AI techniques have a lot to offer to the field of transportation. The versatility of the tools and their performance are well suited for the complexity and variety of transport systems. AI holds promise for a wide range of transport problems, which previously have been approached using other mathematical frameworks. In transport modelling, they are relatively young, but they have been already implemented for a wide range of problems such as forecasting, traffic control, pattern recognition and optimisation. These techniques are appealing due to their flexibility, adaptability, possibility of innovation and to the fact that they are able to circulate and process highly dimensional, large sets of data. They have overcome the limitations of traditional mathematical methods regarding misspecification, biased outliers and assumptions.

Economic growth in the decades to come will generate pressures for more intelligent ways for society to organise its mobility requirements because of the heavy personal and commercial costs of transport inefficiencies. A long-term goal is to de-couple the rise in road traffic from economic growth. In the global economy that exists in the 21st century, failure to address the inefficiencies in the transport system will have an adverse effect on the country's competitive position as well as the quality of life. Security concerns are likely to become more prominent, and may impact transport services and international trade in ways that are unexpected and challenging. The potential for exploiting AI, on the face of it, appears considerable.

In our towns and cities, pressure to rationalise the competing priorities for road-space will grow, and it will be vital to harness the various qualities of AI to inform a variety of transport management measures. Self-recognitive systems are needed for traffic management, travel substitution and 'smart' access controls, taking account of the individual characteristics of the vehicle, the load and the journey purpose. On our highways, better logic, connectivity and knowledge of the spatial requirements is needed for the dynamic allocation of traffic priorities in time and space; also for journey planning, goods distribution and freight logistics; and for demand-responsive collective transport modes. The automated highway or a 'smart' intersection requires additionally a kinaesthetic capability.

As far as organisations are concerned, whether they are the producers or users of transport, intelligent infrastructures are required that are

- Dependable (applications are available to receive new work, reliable to complete the work in hand, and scaleable across a wide range of operating conditions).
- Manageable (intelligent infrastructures would be self-managing and would automatically respond to events, such as hardware failures, and not dogged by traditional cycles of complexity).
- Adaptable (new applications would be simply and easily deployed to the intelligent infrastructure).
- Affordable (built-in obsolescence is a thing of the past; infrastructures would be based on inexpensive, standard-based components).

These performance requirements are demanding and may prove hard to match, but the degree to which AI methods are adopted in the transport sector will be determined largely by these factors. Reliability and dependability will be crucial, for without these qualities the AI systems will be perceived as poor substitutes for exercising human judgement. This means in practice that the AI developers will need to consider the details of system performance when things go wrong—for example, a loss of service in crucial support areas, like failures in system logic, loss of communications or accurate spatial positioning, or a failure of sensors and other self-monitoring systems. In the case of safety-critical systems it means that the 'intelligence' will need to incorporate an appropriate level of self-checking and redundancy, as practised in the design of aircraft control systems. When the intelligence fails, for whatever reason, control must transfer gracefully and, if possible, seamlessly to the best available alternative, which could be a less-sophisticated local controller or a human operator.

In the short term, the combination of a mobile phone, smart card payment and GPS receiver is set to become the platform for a wide variety of information-based services, not only in the transport sector. Data accumulated on the card and replicated in centralised databases can be used to provide more accurate profiling of user needs and requirements—essential for delivering a personalised service. But with this technology comes new risks, such as theft of identity and other forms of fraud. Security checks (like 'chip and PIN') and other safeguards are required. Privacy and human rights issues are also a factor. People may become distrustful of having their movements monitored or being charged for services without immediate feedback. There is clearly a trade-off operating here between privacy and service convenience. For example, people are prepared to abandon privacy over their location if their vehicle breaks down, or in a medical emergency, and will accept a vehicle tracking system that can trace their whereabouts because it will locate the vehicle if it is stolen. Users will expect a degree of control over whether the systems report or conceal their identity and location. Getting the human factors right is essential to the success adoption of these new AI systems.

Regrettably, designers must also anticipate the possibility of hacking, sabotage, vandalism and criminal misuse, and a number of other 'worst case scenarios', not least regular accidental or wilful non-compliance with operating procedures. Murphy's law prevails. Self-recognitive systems will incorporate measures for detection, correction, prevention and elimination of these negative aspects. Flexibility to respond 'on the fly' in crisis situations, whether or not they are of man's own making, should also be written into the design. The consequences of a catastrophic failure must be assessed.

Quite how users will embrace and respond to the plethora of emerging new technologies in the transport arena is more difficult to forecast. There is a risk of over-dependency, with a corresponding loss of skill, and this can be unsettling if the AI systems fail. While choice is often promoted as a desirable objective, many people are overwhelmed by the reality of too many options. We need to consider the impact on people in a world of increasing complexity and change, of seamless near-ubiquitous connectivity, pervasive monitoring and information processing. What if things slow down because people refuse to take up new technology? Worse, what if a 'luddite' mentality takes hold or new under-class emerges who protest against the systems because they are unable to benefit? Will more bureaucratic control be required insetting rules and protocols to ensure that everything functions smoothly? Transparency in the regulation and certification of these systems may be central to securing public confidence.

Everything and everyone should connect. Only time will tell whether this is desirable or not!

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