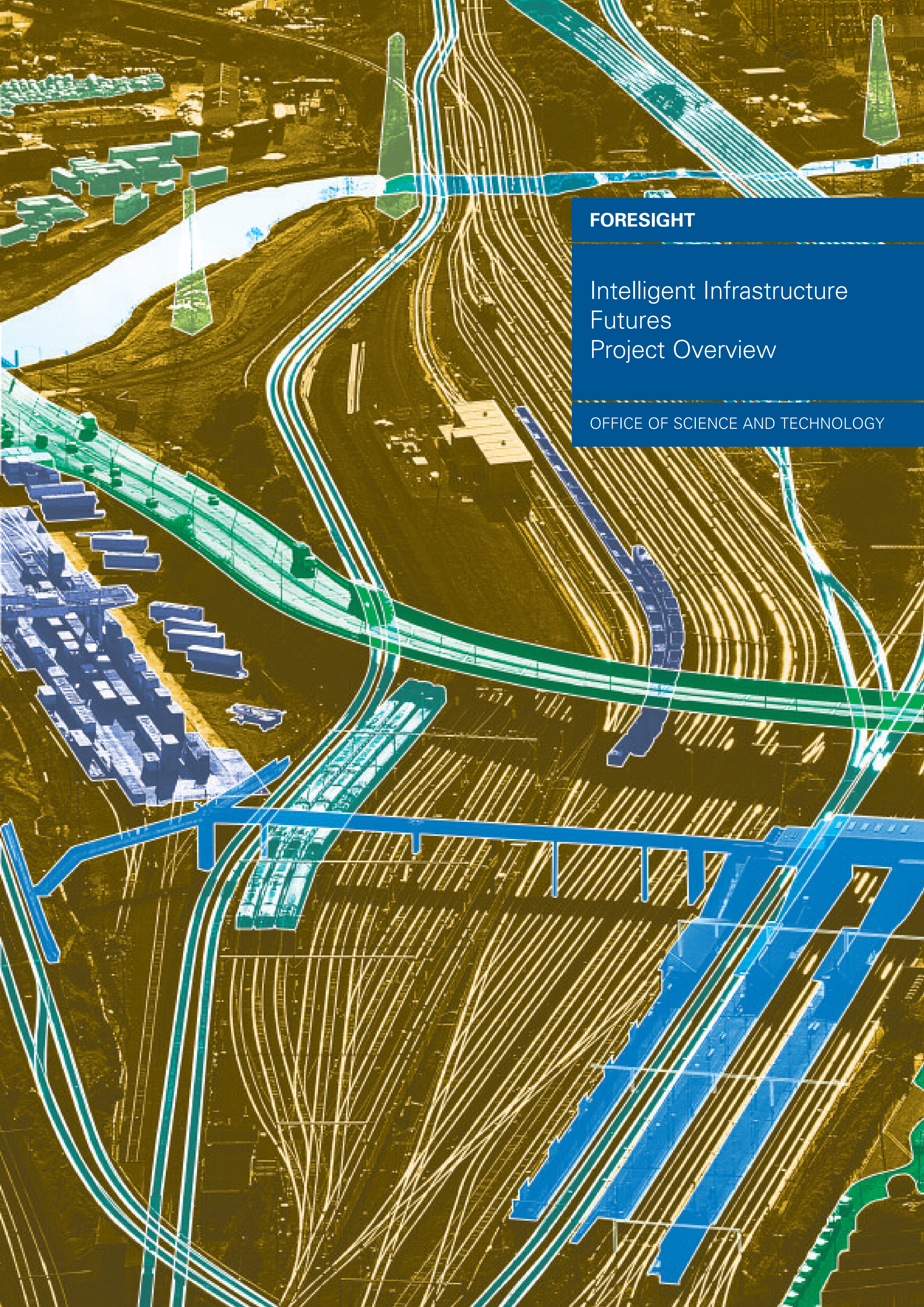

FORESIGHT

Intelligent Infrastructure Futures Project Overview

OFFICE OF SCIENCE AND TECHNOLOGY

Intelligent Infrastructure Futures

Project Overview

This report was commissioned by the Foresight Programme of the Office of Science and Technology to support its Project on Intelligent Infrastructure Systems. The views are not the official point of view of any organisation or individual, are independent of Government and do not constitute government policy.

Contact:

Foresight Directorate
Bay 327
1 Victoria Street
London
SW1H 0ET

www.foresight.gov.uk

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Foreword

In the west, and increasingly in other parts of the world, travel has never been cheaper. The media have opened our eyes to a global world of opportunity. We have embraced opportunities to travel and the choice of goods that global trade provides. However, we now face the challenges of global warming and limited supplies of oil, set against increasing demands for oil. At a national level, we face increasing congestion on roads and rail.

Just as science and technology gave us the freedom to move, they will play a key role in helping us to respond to these new challenges. Advances in sensor technology, computing power and telecommunications can allow us to build intelligence into the infrastructure.

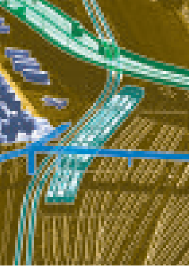
This could deliver a future where we have the freedom to choose whether we travel. It could see transport stimulating economic growth, through the seamless integration of different modes of transport and real-time intelligent support to help people along their way. An intelligent infrastructure could support us when we travel so that we can make productive use of every moment of travelling time, whether for our own pleasure or for work. In doing this, new technology could support a sustainable world of global trade.

We already have much of the technology to deliver such a system. But we need to learn how to implement it, and to do so in a way that is sustainable. This is unlikely to happen if we step back and wait for it to happen. We need to take positive action if we are to deliver this vision of the future: we also need to agree the direction we should head in and work together towards that vision.

Putting a human on the moon was the greatest transport challenge of the past half-century. The transport challenge of the next 50 years will be to use technology to deliver infrastructure that will stimulate economic growth, support social cohesion and be environmentally sustainable. The Foresight Project on Intelligent Infrastructure Systems has sought to explore the opportunities and challenges ahead as we seek to deliver this future in the UK.

Dave King

Sir David King ScD FRS
Chief Scientific Adviser to HM Government
Head of the Office of Science and Technology



Executive summary

The UK has an extensive transport infrastructure. We currently have: 724,000 km of road lanes; 16,600 km of railway track; 47 major ports, of which 20 account for 87% of traffic across all cargo types; and 28 major airports, 18 with more than 1 million scheduled passengers passing through them each year. As a nation, we travel approximately 500 billion km by road per year, 50 billion km by rail and 275 billion km by air (see Table 1 and Figure 1).

We invest around £8 billions* a year to maintain and develop the infrastructure for transport. Investments we make now will be with us for the next 50–100 years, possibly longer. As we make those investment decisions, we face a number of challenging aims. We need infrastructure that will:

- meet a growing demand for transport
- support economic growth
- be environmentally sustainable
- meet the wider needs of all elements of society
- accommodate future uncertainties
- be safe and resistant to shocks.

The Foresight Project on Intelligent Infrastructure Systems (IIS) set out to explore how science and technology could, over the next 50 years, bring intelligence into infrastructure to meet these demanding and sometimes conflicting objectives.

The project found that intelligence could help us to meet these objectives and perhaps do more. It could stimulate growth rather than simply supporting it, perhaps going so far as to permit manufacturing with virtually no waste. Intelligence could also support and promote a more inclusive society.

We face many uncertainties in the future that would affect the best way to use intelligence in our infrastructure. However, it is clear from all the situations we considered that, to achieve these aims, we must build intelligence into our infrastructure at four levels. We need:

- intelligent design, minimising the need to move, through urban design, efficient integration and management of public transport, and local provision of production and services
- a system that can provide intelligence, with sensors and data mining providing information to support the decisions of individuals and service providers
- infrastructure that is intelligent, that can process the vast amounts of information we collect and can then adapt in real time to provide the most effective services

*Total gross supported investment 2004–2005 DfT Annual Report 2003–2004 Appendix E.

- intelligent use of infrastructure where people modify their behaviour to achieve a more sustainable outcome.

Table 1: Transport in the UK. Derived from statistics available at www.dft.gov.uk and www.caa.org

	60,000,000	People
Road	32,000,000	Vehicles
	724,000	Kilometres of road lanes
	499,000,000,000	Vehicle-km per annum
	1,725,000,000	Tonnes road freight per annum
Rail	16,652	Km rail track (passenger & goods)
	1,000,000,000	Rail passengers per annum
	48,000,000,000	Rail passenger km per annum
	89,000,000	Tonnes rail freight per annum
Airports	59 airports	18 with more than 1m scheduled passengers
	216,000,000	Terminal passengers per annum
	273,000,000,000	Air passenger km per annum
	2,370,000	Tonnes air freight per annum
	221,000	Tonnes mail by air per annum
Seaports	51 ports	18 ports carrying 95% of container traffic
	573,000,000	Tonnes sea freight 250m tonnes in, 170m tonnes out per annum

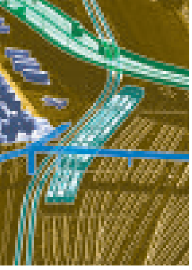
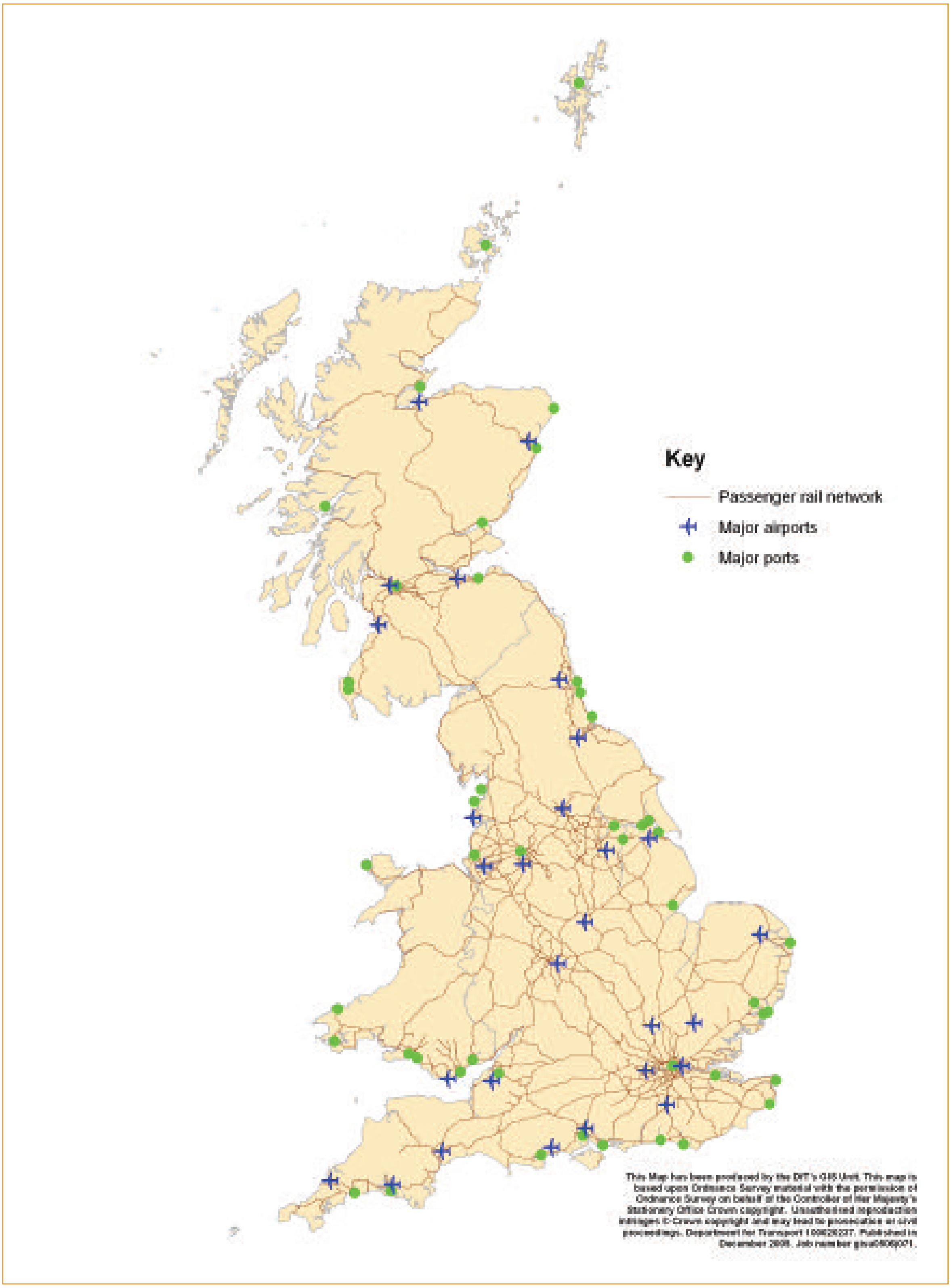


Figure 1: Major ports, airports and railways (from *Future of Transport 2030*, DfT)



Process

Looking 50 years ahead created challenges for the project. It is very difficult to see how information technology might develop beyond a 5–10-year time horizon, let alone half a century. It is also difficult to see how, over a longer time frame, we will invest in the technology and how society might respond to those investments. To deal with these uncertainties, we investigated the future of IIS in three complementary ways:

- We commissioned leading researchers to write state-of-research reviews, which set out what all areas of science, including psychology, physical sciences and technology, could deliver within the next few years. The research reviews covered areas as diverse as artificial intelligence and data mining, through to how information affects our choices and the psychology of travel.
- We developed a technology forward look to review existing roadmaps for the development and application of the technology, and to consider how IIS might shape business in the longer term.
- We produced a set of scenarios that provide a range of credible and coherent pictures of the technology we might invest in, and how society might react to those investments.

Nearly 300 people participated in these exercises, ranging from research experts to those who deliver the services and those who take decisions on policy and investment at national, regional and local levels.

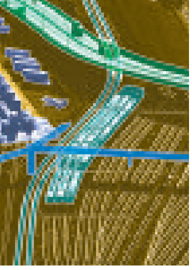
The project has provided:

- a view of the future technologies and an exploration in the scenarios of how we might deploy those technologies
- an understanding of how best to use those technologies to deliver our objectives
- a view of the opportunities and challenges that intelligent infrastructure will deliver
- an understanding of the presumptions that underpin the decisions we make
- the strategic choices that the UK faces, along with most other societies.

Technology capabilities of the future

Advances in science and technology could provide us with:

- information so that individuals and those delivering transport-based services can make better informed decisions
- the ability to manage the delivery of the services in real time, through the collection of information on the origin and destination of the user and real-time predictive modelling



- the ability to control the movement of goods and people, with vehicles connected to each other and to the surrounding infrastructure so they become an integral part of an 'intelligent' system
- infrastructure that is intelligent, so that it adapts itself to the needs of users
- an integrated system that includes all modes of transport, public and private
- integrated and intelligent supply and logistics chains that adapt continuously to provide the most efficient path from supplier to user
- viable alternatives to moving goods and people.

A number of new technologies would underpin these capabilities:

Distributed networks of sensors

Networks of tiny and inexpensive sensors which could collect data on the position of just about anything and everything and allow us to monitor the flows of people and goods.

Data mining

Software which could analyse masses of data collected from monitoring the whereabouts of people and objects. It could detect patterns that allow us to understand the behaviour of complex systems.

Agent-based software

Software agents could become the modern electronic equivalent of the butler, executive assistant or broker, taking instructions and venturing out into the connected world to perform various tasks on our behalf. The agent could help us to find the best financial packages, negotiate deals and, importantly, help us to manage our time.

Modelling and simulation technology

There is growing use of computer models of complex systems to support decisions using principles similar to agent-based software. This approach makes it possible to test ideas for investment decisions prior to spending the money in a way that reflects more closely the possible behaviour of the main actors, for example, commuters.

Advances in communications technology

The speed of transfer of information will continue to increase. In the USA they are already working on wire-free telecommunications technology that can download a movie as you drive past a video store.

Speech interface

The ability of computers to translate human speech is developing rapidly. The development of computers that can 'understand' speech is still a major challenge but there is broad agreement in the science community that this will be cracked in the next 20–30 years. So, in the future, we can expect this to become the primary mode of interaction with some IT systems, a development that could be especially significant in transport, either to communicate with information systems or to provide instructions to our cars, for example.

Self-monitoring complex information systems

Bringing together complex systems raises a number of issues where software can play an important role. Software could, for example, help to anticipate unusual behaviours that can develop when complex systems interact. These can have implications for stability, or may even bring unexpected but welcome benefits.

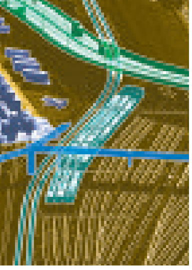
Software can already watch for signs of instability in complex systems and could perhaps even develop the ability to repair or stabilise the system when emergent behaviour could lead to failure, shutting down systems that are causing problems and breaking reinforcing loops that could cause damage.

How can technologies meet our objectives?

While we may have these technical capabilities, the key issue is how we should invest in them and how different social groups around the world might react to them. For example, would we cede control of our cars to a central system if doing so would see the end of congestion? And would we be willing to let the system have information on the origin and destination of all of our travel, as we do now for air travel?

Historically, when we have improved the transport system and reduced costs, people have travelled more. We changed our patterns of behaviour to reflect the increase in ease of travel – living further away from our place of work, developing cities and shopping facilities that are based around use of the car, and travelling for leisure on a national and international basis. While this has supported economic growth, it has led to congestion, rising costs of maintaining the infrastructure we already have in place, greater fragility of the system, and environmental costs.

A key issue is how to use the technologies to ensure that we not only improve efficiency, but also deliver sustainable and robust solutions.



Some of the project's research reviews provide us with important insights that help us begin to deal with these issues. Key points include:

Psychology of travel

People appear to have a need to travel to find resources and to socialise. Individuals have, on average, spent 55–65 minutes a day travelling since records were first kept. So most people would feel frustrated if they travelled less. We take decisions on how to travel based on cost (time and money), on the activities that the travel relates to, and on how we feel about the mode of travel (is it reliable, safe and pleasant?). Different people have different priorities when they travel. So, while, for most, reliability is the most important factor affecting our travel choices, some travellers like to explore and enjoy the uncertainty of a new route or mode of travel. Travel is embedded within long-established patterns of life and this can make change difficult. Whichever category we belong to, most of us want to use the minimum amount of energy to think about how we will get somewhere.

How we use information to make travel decisions

We make two types of decisions: day-to-day decisions on how to travel and longer-term decisions on where we should live and work. The second of these choices is affected by cost of property and the ease of access to our places of work, leisure and retail. Once we have made a decision on where to live, we are locked into certain travel patterns for the medium term. So we move from making decisions on whether to travel, to making decisions on how to travel to the places we have to get to. In taking day-to-day decisions on how to travel, we tend to follow habit; we find a route that is good enough rather than the optimal route.

Economics

The use of technology often evolves in unexpected ways. For example, individuals may invest in in-car navigation technology so that they know where they are and can find the best route. But over time that very same technology could become part of a system to charge for use of roads. This could mean that the cost of introducing road charging might be less than we expect and that people already trust the technology, because they use it regularly to stay in touch and to find routes when they are on the move.

If we are to ensure that we capture these wider benefits, and deploy them in ways that contribute to sustainability, then we will need to deliver choice to the individual. Equally important, we must also find ways to support changes in the very patterning of social life, realising, of course, that it may take time to effect those changes.

Choice

There are four broad ways in which we could seek to introduce choice:

Spatial planning

An important way to support choice is to minimise the need to travel so that people can live nearer to their place of work or education. Steps such as redevelopment of city centres, building safe cycle lanes into growth areas and having parking facilities near to public transport networks might play a part in this. But there are also many ways in which IIS can work with urban design to minimise travel and make it more efficient. Designing the urban environment to minimise the need to travel, and with the best available technology, will be important, building in resilience in case we face a shock that affects our freedom to move.

Virtual communications

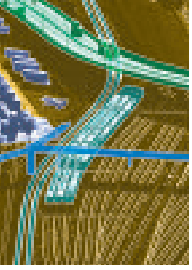
While information technology allows people to hold ever more sophisticated 'virtual' meetings instead of travelling, evidence suggests that people use email and telecommunications to maintain more geographically dispersed social networks. This can actually increase the distance they travel. People still need some face-to-face contact, so we travel to see the people in our social networks from time to time, creating demand for longer trips. There has been a slow increase in home working, but evidence so far suggests that this changes travel patterns rather than simply reducing travel. There might be a shift in travel patterns if there was a combination of increased telepresence capability and increased travel costs.

Intermodal choice

The ability to choose between different modes of transport can give people a more responsive and flexible service, which, in turn, can reduce the numbers of vehicles on the road. There are already signs of innovations in this area: a taxi company is using a text messaging system, with users sending origin and destination in advance, so that it can manage its fleet of taxis efficiently and provide a better service. Another company operates buses to a timetable in busy periods and in a more flexible demand-based way for the rest of the day, where people use their phone to bring the bus closer to them, thus ensuring responsive services for rural areas.

Local or agile production

Making things locally can reduce the need to move goods. We have already seen an increase in the use of communications technology to replace some commodities, notably music and software, which people increasingly download



rather than buy in a physical form. There is some shift from an ownership to an access economy. Developments in rapid prototyping have allowed complicated objects to be 'printed' in three dimensions for commercial processes. As the cost of this technology falls, it opens the possibility of local manufacture or even home manufacture – the individual simply downloads the design and then prints the product at home. Laboratory-on-a-chip technology could offer a similar capability for the local production of medicines.

Supporting behavioural change

There are two broad ways to support changes in social practices in the future:

Information to users

Providing information in a way that is easy to use, so that the traveller can choose the optimal route and modes of travel, rather than a route that is good enough. Also providing information on that new route so that there is less stress from trying something new.

Full-cost recovery

Ensuring that people pay the full costs for each journey would make people aware of the real costs of travel. There are a number of options, from charging per km travelled to selling 'slots' for journeys. A more radical option might be to give each person a carbon allowance, which would apply to all their activities, not just travel.

So, to deliver intelligent infrastructure which is sustainable, robust and safe, we need to invest in intelligence on four levels. We need:

- **intelligent design**, minimising the need to move, through urban design, efficient integration and management of public transport and local production
- a system that can **provide intelligence**, with sensors and data mining providing information to support the decisions of individuals and service providers
- **infrastructure that is intelligent**, processing the mass of information we collect and adapting in real time to provide the most effective services
- **intelligent use** of the system where people modify their behaviours to use infrastructure in a sustainable way.

Future opportunities

A fully integrated intelligent infrastructure system is not something we are likely to fall into. We have to decide what we need and how we can deliver such a future. But if we do invest in IIS, it could provide a wide range of benefits.

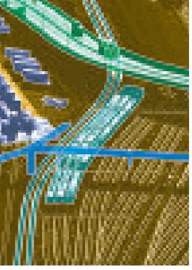
We could sustain **economic growth** at the same time as enabling a reduction in environmental impact, by:

- improving how much traffic can travel on the system at any time, reducing how much it costs to achieve the same carrying capacity
- making the system more durable, reducing replacement and maintenance costs, and energy waste through, for example, reducing the time aircraft spend stacking before landing, and reducing congestion on the roads
- reducing the need for travel as a result of spatial planning and local manufacture
- creating faster, more reliable services
- supporting work at home and on the move
- having more sustainable consumption and production of goods and services.

We could enhance **social cohesion** through increased access to services and improvements in urban design that support local communities. IIS could play a key role in supporting an ageing population, providing individuals with both independence and access to the services they need if their ability to find their way safely around outside the home becomes impaired. It might even address parents safety concerns, so that they allow their children to cycle or play near their home. The intelligent support provided by IIS could become integral to caring for vulnerable members of society.

We could enhance moves to **long-term sustainability** through the use of technology to support closed-loop production, the full information about goods being used to ensure that everything possible is recycled; improvements in the design of products to reduce environmental impacts throughout their lifecycle; and the encouragement of more sustainable consumption and production.

There could be wider benefits from the **use of information** gathered on social patterns of movement, to watch for health risks and explore the trends and drivers that may lead to future risks. For example, levels of obesity have risen from 6% in 1980 to 22% today, with an annual health cost to the UK of £3 billion a year. We might be able to spot the next 'obesity' before it reaches such a level and could seek to act before it imposes such costs on human lives and on the health service.



There could be **commercial opportunities** for businesses that develop the technologies that could underpin these developments:

- intelligent personal support (IPS), in which an agent-based telematic interface supports an individual's movements, possibly enhanced by the use of cameras and environmental sensors to watch for risks to the network of users
- a transport intelligence hub, to manage movement between different modes of transport in an efficient and dynamic way, supporting a flexible system that will respond to the changing needs of local, regional and national populations in real time
- SWARM technology, in which personal public transport vehicles operate as part of a more extensive integrated intermodal transport system. This reacts in a dynamic way to carry people to their destination, as their IPSs inform the central system of the origin and destination of all who are moving
- agent-based data mining, feeding into policy-directed simulations, mining all of the information on movement and activities and using it to support decisions on major public investments in infrastructure
- local, agile manufacturing technology.

If we invest in intelligent infrastructure, in addition to delivering these benefits it could revolutionise significant aspects of people's life:

- Individuals could choose whether they want to travel and, when they do, they could use their travelling time for other purposes, such as work or recreation.
- As government departments gain a clearer understanding of the effects of their policies and actions on movement, there could be more fluid and dynamic relationships between them. This could allow the integration and balancing of aims for all investments in infrastructure. Perhaps in 50 years there could be a Department for Intelligent Infrastructure!
- Investing in intelligent infrastructure could also deliver information and alerts on the changing patterns of movement, allowing early identification of changing social patterns. This would allow rapid response to emerging issues of health or crime.
- Business models could be reshaped, built on agile logistics chains, reconfiguring in real time to deliver optimum solutions, agile local manufacturing and perhaps closed-loop sustainable manufacture.

Challenges

People will adopt the technologies only if they perceive them to be safe, both in terms of security of any information surrendered to the system and physical safety. There will also be questions of who owns any data collected by the system and where liability rests if the system fails, as it will from time to time.

Our ability to realistically model complex processes in transport and other activities is increasing rapidly and has the potential to be a key tool in decision making. However we will need to establish a means of quality assurance for those simulations. This will be a challenge, especially as more and more software works out for itself how to meet its objectives, but the programmer will not necessarily have complete knowledge of how it works.

Widespread use of agent-based software approaches to support decision making could create social division between those who can and those who cannot afford the best software agents. Also, what will the effect be of the use of agents on the psychology of the user if people become dependent on and, in some cases, emotionally attached to an agent or avatar?

A further question concerns out ability to connect different computerised systems to provide a seamless IIS. Integration could fail for a number of reasons. To begin with, the cost could be prohibitive. Systems running on different standards might not be able to talk to one another. Unexpected emergent behaviour could also prevent effective co-operation between systems. These obstacles could drive us more towards a situation where there are many systems, only some of which are integrated.

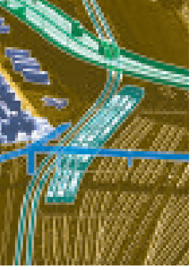
Uncertainties

As we make decisions on investing in intelligent infrastructure, we face numerous uncertainties, many of them played out in the futures scenarios. Two key uncertainties form the framework for those scenarios. The section on challenges highlights the first: will society embrace a world where we track, and perhaps control, the movement of all goods and people? The second is whether or not we develop an alternative source of energy for transport that has minimal impact on the climate. If we do have this energy source, we would want to use IIS to support as much movement of goods and people as we desired. If we don't, we would want to use IIS to minimise the movement of goods and people, while still supporting economic growth.

Research needs

It is possible to mitigate some of these risks, but to do so we might decide to invest in a number of areas of research:

- the development of systems that can manage information without knowing the identity of the people who are moving around in that system
- good design of systems for major ICT projects, so that when they fail they degrade in a safe, progressive, and structured way
- software that will allow effective interoperability between systems and isolate failing systems, to prevent a domino effect



- the development of forensic ICT tools to respond to the crime and other security threats from increasing dependence on a system
- consideration of how society will react to a world supported by intelligent agents
- analysis of the social conditions under which new technologies are taken up and can transform practices. Specifically, the examination of an array of small changes that might engender a tipping point so that the current steel and petroleum car gets replaced by new intelligent intermodal 'pods'.

Strategic choices

This project has highlighted a number of strategic issues around the four levels of intelligence we need to consider. The decisions are not 'either/or', it is rather a question of finding the right balance. But we do need to consider and decide how to invest in these areas.

The urban environments where the majority of people live are complex evolving ecosystems where the next stage of evolution could be driven by information and communications technologies which become integral to all parts of our domestic and shared infrastructure.

Table 2: Strategic choices highlighted by the IIS project

Should we seek to deliver choice through investment in 'virtual alternatives' to travel?	Should we invest in urban design and spatial planning to minimise travel needs?
Should we develop centralised information systems?	Should we develop devolved information systems?
Should we invest in intelligence that will improve the reliability of the services?	Should we invest in systems that provide users with information so that, however the transport network is operating, people can use it effectively?
Should we charge full costs for transport, and, if so, how should we balance economic, environmental and social costs?	Should we have a carbon allowance covering all forms of activity?

Presumptions to support investment decisions

The presumptions that underpin the decisions we make as we invest in the infrastructure change over time. It would not be wise to use the presumptions of 1955 as the basis of decisions we take for the infrastructure that will support us for the next 50 years. For example, we cannot presume that:

- we will have cheap oil for the next 50 years
- we can respond to increasing demand by building more capacity

- the market will find the most efficient solution to the transport needs of the UK
- we will continue to have the right to move as and when we like
- it will be sufficient to just plan for shocks.

We must recognise new presumptions, such as:

- We should be prepared for the post-oil world of personal transport.
- We will seek to deliver a sustainable solution and will have the capability to build intelligent infrastructure which can meet all of the pillars of sustainability.
- Technology will help us to decide whether we should move, and, if we do, the best way of getting where we want to.
- There will be shocks in the future that will affect our freedom to move and move things, we need to build an intelligent infrastructure to support us even at these times of pressure or be willing to deal with the consequences.

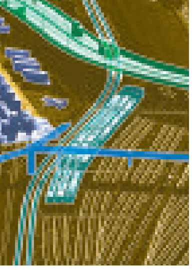
The way ahead

The Foresight Programme is committed to taking forward the work of the project. We are working with a wide range of organisations to consider how we should respond to the findings of this project. Many organisations have already made commitments to respond. Broadly, working with Foresight, they will:

- test policies for robustness using the scenarios. This will ensure that we can effectively manage long-term risks while taking advantage of opportunities
- see how we can take advantage of the commercial opportunities highlighted by the project
- use the material to inform specific strategies
- communicate the project's findings to their members and the public.

The project's high-level stakeholder group, which is chaired by Dr Stephen Ladyman, MP Minister of State for Transport, will review progress against the plan in one year's time.

We have published details of the plans to take this work forward in the project's action plan.



Introduction

The Intelligent Infrastructure Systems Project

The Foresight Project on Intelligent Infrastructure Systems set out to examine the challenges and opportunities for the UK in bringing 'intelligence' to its infrastructure – the physical networks that deliver such services as transport, telecommunications, water and energy. In particular the project explored how, over the next 50 years, we can apply science and technology to the design and implementation of intelligent infrastructure for robust, sustainable and safe transport, and its alternatives.

While many of the issues that the project highlighted apply to more than one of these individual 'infrastructures,' we illustrate them with particular reference to transport. Transport not only presents a more manageable subject for study than the entire infrastructure, it also involves many more players in both public and private sectors than most other services, which are increasingly dominated by private companies. Thus there is a clear need for public policy to ensure that the future infrastructure system meets social needs as well as commercial goals.

Transport also stands out from other issues in that it is inextricably linked with the development of the built environment, especially the way in which our urban areas evolve.

We face stark choices in transport: we can build more capacity to meet growing demand; we can find better ways to use existing capacity to meet growing demand; or we can find ways to reduce demand. Whichever road we choose, perhaps all of them, we will want to do so with intelligence.

Context

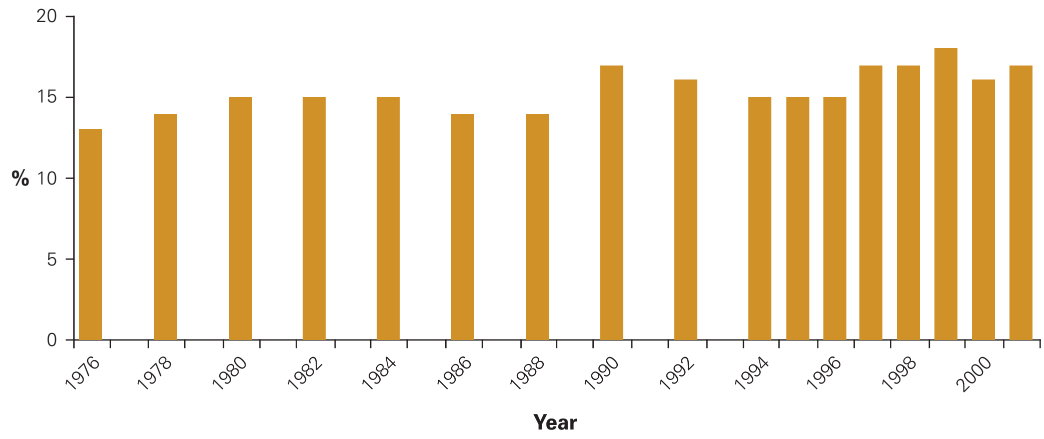
The UK is a small and, in comparison with many other developed countries, crowded space, with 80% of the population living in urban areas. Thus economic growth puts increasing pressure on the infrastructure that we use in the UK to move people, goods and services.

The transfer of information and energy also have to keep up with growing demand, but the infrastructure under greatest pressure is that involved in the movement of people and goods – the roads, railways, air corridors and so on that make up the transport network. For example, comparisons with the rest of Europe show that the UK is the most congested.

While it is not obvious that historical growth trends will, or have to, continue unchanged into the future, it is wise to work on the assumption that the demand for the movement of people and goods will continue to increase. If so, the UK faces the choice: can it increase the physical infrastructure, building more roads, runways and railway lines; or can it make more effective use of existing networks, putting more cars, planes and trains on to the existing infrastructure.

An important economic factor in the growth of transport has been the steadily declining relative cost. Travel and motoring costs remain a significant part of household budgets. (See Figure 2).

Figure 2: Motoring and travel as percentage of total household expenditure (from *Family Spending 2001–02,* Office of National Statistics, 2003)

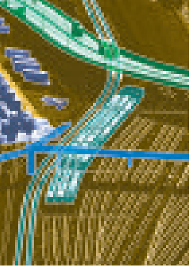


If we do not want to increase capacity to meet growing demand, either by building more infrastructure or by using technology so that existing infrastructure can carry more traffic, a third choice would be to try to reduce the growth in the demand for movement. Here the issue can be the need to differentiate between mobility and accessibility. If it is not necessary to travel to gain access to the activities and services that we need, such as sociability, shopping, education and medical care, people may reduce the range and/or their frequency of travel.

In reality, we are not likely to choose one or other of these options – to build more capacity, increasing the carrying ability of our current infrastructure or to reduce the demand for travel – but a combination of them. In either case, better use of the existing infrastructure clearly offers the greatest potential in terms of cost and transition to meet growing demand without creating even more undesirable environmental effects.

Old presumptions

The challenge for the future is to get the balance right between more intelligent use of the existing infrastructure and expanding that infrastructure. More specifically, the challenge is to devise a transport infrastructure that is not built on the basis of dated presumptions.



Many of the decisions that shaped today's infrastructure go back at least half a century when it was assumed that we would have cheap oil; that we could respond to increasing demand by building more capacity; and that the market would find the most efficient ways to meet the country's transport needs. Fifty years on, these 'predict and provide' presumptions seem inappropriate.

Energy is not cheap, and is most unlikely to be cheaper 50 years hence. Indeed, most people would anticipate significantly higher prices. The idea that the UK could build new roads at the same pace as it did during the past half-century is simply untenable – 'road protests' did not exist 50 years ago. As to market forces, the new presumptions of future circumstances – that we have to anticipate and ameliorate the likely impacts of climate change, and that sustainability now deserves as much attention as economic growth – make it hard to see how the private sector alone can make the difficult choices.

We can summarise the presumptions for the future as follows:

- We need to prepare for the post-oil world of personal transport.
- We will be seeking to deliver a sustainable solution and we will have the capability to build intelligent infrastructure which can meet all of the pillars of sustainability.
- Some technologies may assist us in our decisions on whether we should move, and if we do what would be the best way of getting where we want to.
- There will be shocks in the future which will affect our freedom to move and move things, so we need to build an intelligent infrastructure to support people's activities even at times of pressure or be willing to deal with the consequences.

Fortunately, we can also assume that we will have the technology that we will need to live in this changed world and to bring intelligence to our infrastructure.

Intelligence

In the context of the Foresight Project, the term 'intelligence' is used in the same way that it is used in information technology and brain science, rather than in any security sense. Intelligence needs to operate at four levels to deliver a solution which is sustainable, robust and safe. Effective IIS will depend on applying intelligence when designing transport systems and their alternatives, and in creating a built environment and infrastructures for transportation that deliver choice. No matter how much ICT we throw at our infrastructure, it will come to nothing if the transport systems do not create an environment of easy access with choice on whether we travel.

It is essential to design infrastructure *for* intelligence. An infrastructure system can be intelligent only if it contains the ability to gather data about its own performance and to inform owners, operators and users. That information then allows users to make intelligent decisions.

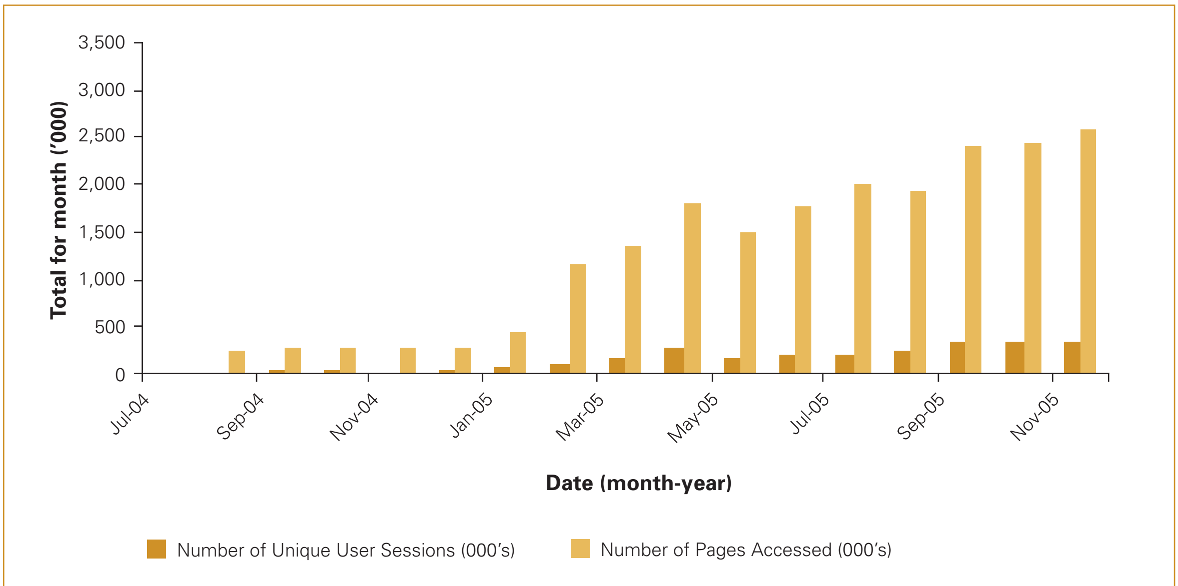
We must also design intelligence into infrastructure. For example, autonomous systems that respond to environmental and usage issues to optimise the use of the network and improve the safety of transport.

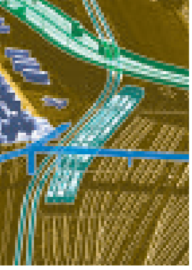
Finally, there has to be intelligent use of the intelligent infrastructure. Achieving such a fundamental change in behaviour will take sustained efforts at education and public awareness, and charging for the full costs of travel. The transition to this new behaviour depends on understanding how information can affect choices, and the psychology and economics that affect choice. So the Foresight Project includes insights into these aspects as well as the technological issues and challenges.

Intelligent infrastructure

Many of the components of an IIS are already coming into use. Mobile telephones, global positioning systems (GPS) and the Internet, for example, enable much greater use of intelligence in our travel. Mobile telephones, for example, already offer 'on the hoof' details of the current state of train and air services. There are also services that road users can consult during their journeys so that they can respond to changing traffic conditions, for example 'Transport Direct' (www.transportdirect.info) (see Figure 3). Operators of commercial fleets also make increasing use of such technologies as radio-frequency identification (RFID) and vehicle tracking to improve the efficiency of the supply chain.

Figure 3: User statistics for 'Transport Direct'





Intelligent infrastructure systems already exist, albeit it with a fraction of the power they will possess 50 years from now. The research carried out for the Foresight project shows that intelligence, as we have described it, already pervades the transport infrastructure. The pace of change will only quicken as such technologies as RFID spread throughout supply chains; as cars become ever more intelligent; and as mobile telephony and the Internet combine to make travellers increasingly aware of the state of the transport system, and their options.

From the policy makers' viewpoint, the challenge is to use the tools of government to influence the development of IIS in ways that bring about improvements that may well not happen if left to market forces. Without some intervention – so that, for example, urban planning and transport work together – we may lose out on opportunities to minimise such adverse impacts as noise and environmental pollution, and to improve energy efficiency, reducing congestion and the emissions of carbon dioxide.

Driven by technology

The growing ability to route data intelligently over existing networks has allowed the information infrastructure to grow to meet the explosion in demand. Broadband telecommunications, for example, have delivered thousandfold increases in the speed and capacity of communications with minimal increases in the physical network. Operators have certainly expanded their networks, but not to the same extent that they have increased the traffic that those networks carry.

Unlike telecommunications, which moves 'information', transport depends on the physical movement of people and goods, but there is still a massive opportunity to use intelligence to increase the capacity of the infrastructure. An obvious example here is the railway system. How is it that jumbo jets with more than 400 people can land every minute or so at a busy airport while trains need greater separation?

The answer to this question is that the 'intelligence' of the railway network – the business of gathering, processing and communicating information – harks back to the 19th century. Using coloured lights by the rail side as a major component of that intelligence seems perverse in a wireless world where navigation systems can track moving objects with great accuracy and speed, and where communications systems could manage the railway system much more effectively. One reason for this is the cost of replacing it.

The vision for the future is of an intelligent infrastructure system. Defining quite what this terms means, and raising awareness of its importance, is one objective of the Foresight project. The concept includes such notions as intelligent transport systems (ITS), the application of electronics and communications to transport.

One definition of ITS, from Canada, described it as: 'a broad range of diverse technologies used to make transportation systems safer, more efficient, more reliable and more environmentally friendly, without necessarily having to physically alter existing infrastructure'.

Concepts such as ITS and IIS will not alone deliver a sustainable and safer transport system. That will also depend on intelligent investment and intelligent planning in the more traditional responses to transport needs. So, while the Foresight project cannot ignore conventional issues, such as planning, road pricing or climate change, it considers them in the light of their relationship to the development and implementation of IIS. For example, we need to reduce the emissions of greenhouse gases; IIS can contribute by making transport more efficient.

Social issues

Consideration of future transport needs has to build on knowledge of social practices and of the psychological bases of travel. These both shape, and are shaped by, travel patterns.

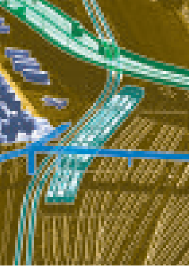
Human behaviour changes gradually over time. For example, there have been significant changes in social behaviour that influence how and when we choose to travel. In recent years the emphasis has begun to switch from visiting exotic places for their own sake to visiting the friends, family and workmates who make up our social networks. In other words, people will arrange to meet at a destination away from where they live in order to sustain their family and friendship networks.

This reflects the changes in the social networks that we engage in. These networks will affect how we travel for work and, especially, for leisure. For example, people migrate from country to country for education and work. Not only does this itself involve travel, it leads to further travel as people make regularly visits to maintain their connections with family and friends in the 'home' country.

Urban structures

The development of 'non-transport' infrastructure has been perhaps the most important factor in shaping past development of the transport infrastructure. We have built roads and railways to connect places where people live and work. That transport infrastructure then influenced urban development, as commuter towns grew up around railway stations, for example.

The intelligent future development of non-transport infrastructure is clearly important. It will influence not just the robustness, sustainability and safety of transport, but many other aspects of society.



What science and technology will be available?

The road towards IIS will be paved with diverse technologies. These will be complex combinations of hardware and software, at dimensions that range from nanotechnology through to large-scale infrastructure.

The technologies of IIS will fulfil a multitude of functions. At one level they will gather, process and disseminate the information needed to create informed travellers who can, with some technological assistance in the shape of 'intelligent' computer systems, manage their journeys much more effectively. Technology will also improve infrastructure so that it becomes more intelligent, and self-managing, in itself. Then there is the need for technology that reduces the environmental burdens that we impose on the transport infrastructure as we travel.

In many cases, these technologies will not be the exclusive property of transport. For example, many different activities involve gathering, processing and disseminating information. Indeed, this whole phenomenon is known as pervasive computing, or ambient intelligence, labels that describe a world in which we are surrounded with objects that communicate with one another and with the wider connected world.

Ambient intelligence (AmI) is a vision in which we are 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 will enable greater user-friendliness, more efficient services, user empowerment, and support for human interactions. For example, intelligent support services could provide context-specific information to travellers, advising on the best travel choices at the time of the journey.

Sensors

The size and cost of sensors is decreasing as rapidly as their capability increases. Sensors that can collect and process data are already widely used to monitor the flows of goods. This has created a market for tags and is the driver for the development of cheaper sensors with greater capabilities. By 2025, micrometre-sized sensors could cost less than a penny each and could form networks that collect and process data locally. By 2050, we expect the same cost and performance from 'nanoscale' sensors.

Radio-frequency identification

An existing example of this connected world is the spread of radio frequency identification. RFID depends on the ability to apply inexpensive electronic tags to items as they wend their way from production through distribution to the final destination. RFID tags extend the concept of bar codes, without the need to scan items. Instead, RFID tags respond to radio signals, reporting back on their identity and location.

Businesses are already implementing RFID, with early applications focused on higher-value goods, monitoring the progress of valuable items through the supply chain. For example, the German mail order retailer, Otto, has started using RFID to track high-value goods such as cameras, mobile phones and jewellery on their way to the customer and to pinpoint where items are lost en route.

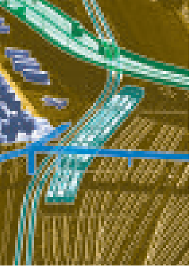
RFID can do much more than monitor inventory, which is why major supermarkets in the USA are encouraging their suppliers to adopt the technology. For them, it offers enterprise-wide information management. RFID could also play a part in meeting the European Union's requirement for traceability in the food chain.

Tags can also identify us when we pay tolls to use roads, pay for the petrol to fuel our cars, or try to gain access to buildings, or even to a country. The USA is discussing the use of RFID technology in future generations of passports.

In essence, some see a future in which the idea is 'if it moves, tag it'. But for that to happen, the cost of tags would have to come down. There would also have to be significant progress in handling the torrent of data that would come from billions of constantly moving tags. They would also need to become more intelligent, taking on for themselves a larger role in communication and data management.

Here, such concepts as wireless sensor devices, or 'motes', can play a part. This idea, also known as 'smartdust', builds on the idea that nanotechnology will enable the production of inexpensive tags the size of a grain of sand. But these tags would do more than communicate with one another and report their identity. 'Motes' would also monitor their environment, to test for a particular chemical for example, or to measure the local temperature. Assemble 'motes' to sense different attributes, and we could have a self-sensing and self-adjusting environment.

The acceptance of RFID will not rest solely on getting the technology right. There will also have to be public acceptance. It is not obvious that consumers will accept tags as enthusiastically as retailers, for example. Privacy issues have already affected the use of RFID, with one retailer withdrawing its systems after consumer protests.



Concerns are not solely at the consumer level. While individuals worry about the privacy implications of tagging, businesses that use them are concerned about information security. Researchers have already successfully broken the encryption of tags deployed in trials.

Encryption will require industry-wide agreement on what is acceptable and what will work. If it wants to achieve interoperability of RFID between enterprises and for diverse applications, there will also have to be international standards covering communications and many other aspects of RFID.

While governments can probably leave it to the private sector to develop the technologies behind RFID, they have a role to play in the issues of standards, public acceptability, and privacy, where it may be necessary to introduce legislation. Industry would doubtless like to be left alone to regulate RFID, but this is unlikely to find favour with the public.

A connected world

RFID is a part of the wider phenomenon of pervasive or ubiquitous computing, a world in which many other devices can communicate with one another. Other connected devices could be our cars, or even the entire transport network. In such a scenario, cars could communicate with one another, without driver intervention, maintaining their distance to avoid collisions. Vehicles could even arrange themselves into platoons, travelling closely together at high speed in designated lanes. Early experiments have already demonstrated this concept, in California, for example.

There are many other potential uses of IT in cars. Most are within the general domain of vehicle telematics, a term drawn from the words ‘telecommunications’ and ‘informatics’. Telematics encompasses such ideas as the growing use in cars of global positioning systems (GPS) and mobile telephony.

Telematics enables a two-way process, with information travelling to and from cars and trucks. Current applications of telematics include monitoring the location of fleets of trucks and other vehicles so that operators can manage their use more efficiently. Truck operators can also use telematics techniques to monitor tyre pressures on their vehicles, another aid to more efficient and safer operation. Along with other monitoring techniques, tyre sensors can assist in the management of vehicle servicing. We can expect to see these ideas entering the car sector, with vehicles booking a service slot when it is needed.

Other applications of telematics are already developing. For example, in-car navigation based on GPS is rapidly becoming a commodity item. What started as a built-in accessory for expensive marques is increasingly common in new vehicles. The ability to monitor the position of vehicles on the road – with GPS, road-side monitoring and other positioning techniques – and to communicate with drivers could lead to new generations of traffic information systems that are far more sophisticated than today’s road signs and local radio messages.

The infiltration of telematics into transport raises issues surrounding safety and liability. The technical possibilities on offer could have profound impacts on what we allow people to do in their cars. The idea of the 'breathalyser ignition key' has been around for some time, but it is just one of many ways in which technology could be used to enforce the law. For example, when cars have electronic controls to assist the driver, it is but a short step to require that those controls prevent drivers from speeding.

Complex data

In-car navigation systems are just one example of the growing importance of information in transport. Information will underpin any development of intelligent infrastructure. RFID and the technologies that collect information on the state of the rail, air and other parts of the transport infrastructure will generate torrents of data. The challenge is to collect data from many diverse sources, and then to turn that data into information.

Data now comes from sensors embedded in trunk roads. In future we can expect newer, less invasive approaches to monitoring the state of the transport infrastructure. Inductive loops buried beneath roads may give way to microwave radar, infrared sensors, ultrasonic detectors and acoustic devices. The GPS systems used by drivers and fleet operators to manage their journeys can also provide data that can assist in the effective management of the transport system.

Data mining

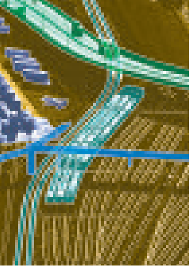
Google has largely set the visible standard in this arena. The technology is already being applied to wider areas; for example, it helps to mine mountains of genetic data. We already have data that no individual could effectively process and use by hand.

There are well-established techniques for making the most of data, with such concepts as data mining and data fusion important aspects of information management. The detection and exploitation of patterns in data is an example of data management in action.

Our dependence on technology will increase, but it will bring with it an order of magnitude increase of capability, yielding a finer-grained and faster analysis of complex data sets.

Data mining, fusion, and information management, could create a step-change in the effectiveness with which we exploit our transport infrastructure. For example, the techniques could enable much better integration of public and private transport. Resulting reductions in congestion could bring about significant energy savings as just one of the many possible positive side-effects.

The current picture is one in which many people collect and organise data and information. Thus there are no agreed standards, and it is difficult to share data.



Even if the technology was in place to allow this, there are issues surrounding the ownership of the information.

From information to knowledge

The final link in the cognitive chain, after we have turned data into information, is to derive knowledge from that information. At the moment, it takes human intervention to complete this transformation.

If the aim is to make life easier for travellers, and to reduce their need to expend mental effort on interpreting information, we will need advanced information-processing techniques to assist in data interpretation. The discipline of artificial intelligence (AI) attempts to emulate 'human' intelligence with computers. AI and the related concept of ambient intelligence (AmI) are well suited to handling the mass of increasingly complex and varied data needed to describe the operations of transport systems and how people use them.

AI is already deployed in many areas of transport. It supports the decisions made by traffic managers, assists in controlling traffic at intersections on arterial roads, provides travel-time predictions, and supports fuel-injection systems for engines. Similar approaches help us to detect, monitor and respond to accidents on roads.

Agents

Agent-based software can be programmed to undertake certain functions for the user. Agent-based software is already available and has been used to do things like collect information about the interests of a web user – the sort of CDs they buy, whether they are interested in the cinema or the theatre – and then watch the web for the user and alert them to any offers in their areas of interest.

As the amount of information available increases, agent-based software is likely to play a key role in supporting data mining, with the agent being given user-determined policies that define the types of issues it should look for, mining the data available and then alerting the user to any interesting information. It might even provide the interface between data mining and simulation technology so that the information provided to the user includes the potential implications of the information it has collected. In 50 years, agent support for individuals and collective decisions is likely to be embedded in society.

For a more detailed description of agent technologies and the wider implications of their use, please see the earlier Foresight Project on Cyber Trust and Crime Prevention.

Modelling and simulation

There is growing demand for and investment in models to support decisions. An exciting area of development here is agent-based modelling. In agent-based modelling, the characteristics of the players in the system are factored in as a set of rules for an independent piece of software to follow. It is then possible to change the environment and watch how the actors behave and the impact of those changes on the overall performance of the system. This allows investment decisions or strategies to be tested before they are enacted. In the future, it is likely that all significant investments will be tested in such simulations. Predictive modelling could also allow us to optimise the efficiency of the transport infrastructure from information on an individual's point of origin, destination, and time of travel.

Energy and transport

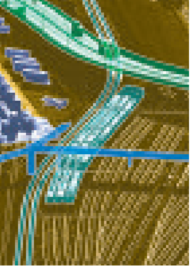
While much of the progress in intelligent infrastructure will come through the application of ICT, developments in other technologies will amplify many of the benefits we derive from this shift. Indeed, if the objective is to enhance the sustainability of transport – through, for example, better use of energy – we will need developments on all fronts, including large gains from new fuel and engine technologies.

Those changes in transport technology will also represent new challenges to developers of IIS. They will have to anticipate, for example, the future of car engines, if hydrogen will supplant petrol, and, if it does, whether the conversion of energy into movement will be in internal combustion engines or fuel cells.

Gains in energy consumption will also arise from the development of lighter materials and new ways of using existing materials to create much lighter vehicles. The transport infrastructure itself makes massive use of energy-intensive materials such as steel and concrete. These materials, particularly the latter, can benefit from new production technologies. There is, though, little to suggest that the needs of our infrastructure will be a driving force in the development of new materials, or that a shortage of new materials technologies will be a major hindrance in the development of IIS.

Guerrilla technology

A factor that is often overlooked in discussions of technological possibilities is the propensity for users to subvert the intentions of the creators of the technology. Mobile telephone companies, for example, did not set out to create a generation of 'texting' youngsters. There are many other examples of people resorting to 'jury-rigged' technology to achieve functions beyond those foreseen by their originators. Mobile telephones and the Internet, for example, have developed in unforeseen ways. We are likely to see similar phenomenon as intelligence becomes embedded in transport. For example, we could see people using their autonomous vehicles to go and collect their shopping for them.



What could IIS look like?

The shape of the future

The technological opportunities, and social factors, are such that IIS could develop in many different ways. The direction will depend on the direction that society takes. The Foresight project investigated many different futures. It identified 60 different drivers of change. While it is difficult to say how these drivers will change the future, the project created four scenarios of how the future might look to illustrate the possibilities.

The future is unlikely to look like any of these individual scenarios. It may well contain elements of all four. While the scenarios do not purport to be predictions of the future, they do allow us to see how certain combinations of events, discoveries and social changes could change the future. As such, the scenarios allow us to see what we might need to prepare for and the opportunities that await us if we set the right path ahead.

This section investigates some of the changes that we may see in the infrastructure system, especially transport. Over the next 50 years there will be changes that reflect all four of the 'intelligences' that we believe have to be applied to the infrastructure of the future: in developing infrastructure that provides us with intelligence; in intelligent use of the infrastructure; the design of the infrastructure; and in building infrastructure that is intelligent.

Infrastructure that provides intelligence

An IIS will look very much like today's infrastructure. There will still be roads, railways and airports. They will, though, be very different in how they operate, and what they do for those who use them.

In particular, the transport infrastructure, the main focus of the Foresight project, will be much more 'intelligent'. It will provide travellers with real-time information, enabling them to make informed choices in their travel plans.

New approaches to information processing, such as artificial intelligence, will reduce the mental effort needed to navigate a changing transport system. The same technologies may even allow travellers to delegate to the technology many of the tasks they now perform themselves, such as responding to disruptions in public transport or driving their cars on a motorway. The result of this use of information, and new technology, will be a transport system that can carry more traffic, more efficiently, with less congestion and using less energy, all on the same infrastructure.

In the longer term, an IIS may well persuade us to travel less, not because the experience is unpleasant, but because society is less centred around a transport system that is built on presumptions that are at least 100 years old – both railways and petroleum cars have their origins in the 19th century.

Travellers may make different choices when they are aware of the true costs – financial, social and environmental – of their journeys.

Having said this, we can safely assume that people will continue to travel. But that travel may be for different reasons. More people may work from home. Thus the daily commute will be different. Work, play and housing may once again be in closer proximity to one another, further changing travel patterns.

However, people show little inclination to pay for travel information-making it hard to devise a commercial business case for such services. If it were found that people would change their behaviour on the basis of better information for the benefit of society, government might decide to intervene to facilitate the provision of better travel information.

Intelligent use of the infrastructure

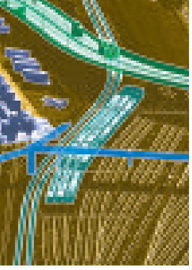
Today's traffic management depends very much on a 'low information' approach. On the roads, the most that drivers can expect are road-side signs and radio announcements, with a small but growing number of people also assisted by GPS navigation systems. There is much more that technology can do.

How and why individuals arrive at their decisions, and finding ways to influence them, lie at the heart of travel behaviour. And that behaviour leads to patterns of mobility and the demands on our transport systems. The effectiveness of intelligent infrastructure will depend, in part, on how it assembles and disseminates information that can influence our travel choices.

Advances in ICT give us an opportunity to gather, manage and communicate vast amounts of information to the traveller. Information for travellers is currently limited to online information services available via a phone call or through fixed or mobile Internet access. This is gradually extending to cover mobile telephones, but this information is rarely, if ever, brought together for different modes of transport. So, while it is possible to find live details of train and flight movement, and to monitor road conditions, no one provides a complete picture of this information.

Another way that we could make intelligent use of our infrastructure is to develop alternatives to movement.

One way to reduce movement is to improve the efficiency of the way we move. In theory we could encourage delivery of freight to the ports closest to the freight's final destination, rather than shipping into, or out of, one port and then using roads to carry goods the length of the country to and from the port (see Text Box, page 30). The scale of movement reduction that might be feasible in practice depends upon many commercial and technical factors, but improved information management within and between organisations across the whole supply chain could make this possible.



We understand that the Department for Transport intends to undertake a review of ports policy during 2006. One of the underlying issues for that review will, in effect, be the balance between economies of scale in port and shipping operations. And another will be the desirability and feasibility of internalising the costs of onward transport, whether by road, rail or coastal shipping.

Tagging technology could facilitate the development of new models of logistics, for example, making it possible to transport completed goods from their place of assembly or manufacture to the purchaser or shop, eliminating the need for a series of warehouses.

Intelligent use of infrastructure could also support such ideas as car and truck pooling, reducing the number of vehicles that travel the country loaded far below their full capacity.

Modelling the impact of intelligent infrastructure: international freight

IIS could provide us with information on the origin and destination of much of the freight we move around the UK. This information could help the logistics industry to manage those movements to optimise how it uses the parts of the infrastructure that are under greatest pressure. It may, for example, be possible to reduce the amount of freight travelling on the roads by finding opportunities to ship goods leaving the country from a port closer to their origin or, for goods arriving in the UK, bringing them into the country at a port closer to their destination.

The project investigated this idea with the GB Freight Model (see www.dft.gov.uk). We conducted computer runs of the model for all road freight movement, including containers. The study did not include analysis of rail's share in inland distribution to and from ports. This could be a significant consideration in practice.

In the hypothetical 'best case', modelled inland road transport movements fell by around 75%, an annual saving of 3.1 billion vehicle-kilometres, which reduced the average trip from 210 km to just 47 km. That amounts to a theoretical maximum saving of nearly 1% of annual road traffic movements. Any such savings in road mileage have to be balanced against the economies of scale of moving goods through a smaller number of ports.

We ran the model to explore what would happen if we applied this approach just to container movements. At a potential reduction of up to 54%, the maximum savings were less, accounting for an annual 210 million vehicle-kilometres, but still significant.

Clearly, the study contains many assumptions, but it illustrates the kind of benefits that might be derived from the intelligent use of information to optimise transport movements.

Intelligent design of the infrastructure

The third input is designing in choice. We can do this through:

- spatial planning
- local or agile manufacture
- integrated intermodal transport
- virtual alternatives.

Spatial planning

Getting the right technology is but one part of intelligent design. Just as important is the way we use planning to make our approach to infrastructure work with other policies rather than leaving it to try to catch up with developments, as is often the case today.

For example, designating areas for housing development without looking at the impact on transport in the wider sense, looking beyond the need to build new roads and railways lines to connect the developments to the transport network, might well reinforce behaviour that goes against everything that we have described in this report.

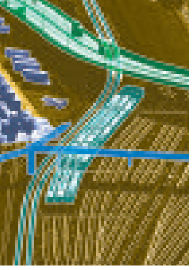
Local or agile manufacture

Other factors will also influence the shape of IIS, not least the ways in which we organise manufacturing. Over the past 50 years we have seen huge changes in the location and distribution of manufacturing. No longer do most developed countries have domestic production of most of the commodities they consume. The globalisation of production has seen the manufacture of electronic equipment, for example, move from country to country, as economies rise and fall.

Just as work patterns are changing, so are the ways in which we manufacture and sell the goods that are, increasingly these days, sold in out-of-town superstores. With the rise of online shopping, we can already see changes in the distribution system, changes that could change the nature of transport. Further ahead, there could also be changes in the patterns of manufacturing.

Globalisation and the quest for even lower prices have seen much manufacturing move offshore. We can expect to see the location of manufacturing continuing to move as economies rise and fall, but perhaps more futuristic is the idea that new technologies will reverse the trend to make things offshore.

Businesses now seek to develop agile manufacturing capabilities so that they can deliver economies of scale and meet increasing demands for the personalisation of goods from the same machine. If the developed world cannot find another source of cheap labour to manufacture its products, these machines may produce local goods in the future.



Research has already begun to create machines that can 'print' 3-D prototypes of new designs. Could this trend move on to create the ability for the local manufacture of consumer goods? Could a 'lab on a chip' lead to local manufacturing of medicines, cosmetic products, cleaning materials and so on?

If local production of some sort did come about, perhaps encouraged by rising energy costs, there would be significant implications for the transport infrastructure.

Integrated intermodal transport

Integrated intermodal transport could give greater choice of mode of transport. Ultimately, all vehicles could become part of the infrastructure and would no longer be privately 'owned'. This could evolve into a central system managing the movement of the vehicles, whether on road, rail or in the air, which respond in a dynamic way to meet our demands. The vehicles would operate like a 'swarm' to deliver the most efficient service. Also, this could involve a central service recycling all such materials and reducing how long vehicles are unused for much of the day.

Virtual alternatives

Intelligent design of the infrastructure must also accommodate today's work practices, with the rise of 'hot desking' and home working. Added to this is the phenomenon of the connected world. No longer is the daily commute to work just a period of transition between home and work for many travellers. The 'unwired' world, with the merger of mobile communications providing 'always on' 'e-connectivity,' has increasingly made the journey into a part of the working day.

These changes have happened in less than a decade. It is hard to envisage how much more change we will see in this area over the next 50 years. Flexibility must therefore be the goal for any future infrastructure.

While government may have little direct control over the development of the telecommunications infrastructure, it can influence access to that infrastructure, ensuring that sections of society are not excluded. For example, libraries in the UK already serve a valuable role in providing Internet access for many people.

Building infrastructure that is intelligent

Intelligence will be built into the infrastructure, which will be self-adapting to the needs to the users. It will adapt both in real time to changing needs and learn the flows and patterns of changing demand to introduce changes in system capacity.

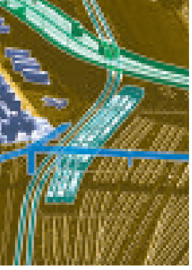
Assisted driving

Artificial intelligence will also be applied to vehicles. It has the ability to take on much more of the responsibility for driving a car. Modern vehicles already have proximity detectors to assist in parking, and to warn a driver when they are getting too close to the car in front. Some cars also have systems that warn the driver when they are straying out of their lane. Bring these together and allowing the technology to take control of a car could bring a number of benefits. For example, 'trains' of cars or trucks could come together to travel along designated lanes at high speed, connected by an 'electronic towbar', but perhaps more important is the potential to maintain the mobility of drivers who are impaired, be it through age or disability. Intelligent vehicles could see the end of age restrictions on the use of private vehicles, bringing enormous benefits to an ageing population.

While maintaining mobility would in itself benefit many people, there could be greater safety gains from automation. Driverless vehicles, for example, could reduce one of the major causes of death and injury on our roads, accidents that involve trucks, which are much more likely to be involved in accidents than cars.

The energy factor

No consideration of the future shape of IIS can ignore possible changes in our patterns of energy use. Will oil give way to hydrogen? Or to biofuels? Either would require changes both in the infrastructure of energy production and distribution and in the transport infrastructure as seen from the traveller's perspective.



How can we deliver IIS?

Tempting as it may be to see the delivery of IIS in terms of technology, and technology will certainly be important, we have to remember that it is people who travel, not their cars, for example. So, delivering IIS will be as much a matter of understanding the psychology of travel, the social circumstances of the travelling public and of influencing their decisions as it is about technological development.

For example, it may seem that implementing systems that provide information will enable travellers to make the best use of the transport system. In reality, information is but one factor. People may not even want the 'best' travel option, merely something that fits in with their preferences and habits. Any policy that sets out to encourage the development of IIS must recognise these psychological factors.

Policy must also tackle the related social issues. For example, many of the fundamental choices that we make – where we live and work, for example – have a profound impact on how we use transport.

The road to IIS requires careful thought for each of the four areas where intelligence is important: the design of the infrastructure; developing infrastructure that provides us with intelligence; building infrastructure that is intelligent; and the intelligent use of infrastructure.

Intelligent design of the infrastructure

Modern travel started as a luxury and some travel, like Concorde, remained so. However, policy on the design of infrastructure, among other things, set out to make transport and communications available to as many people as possible at low cost, where 'costs' included such non-monetary factors as time and comfort. A consequence of this is that transport policy encouraged particular social patterns. For example, people choose to commute to work because they can afford to. This and the relative costs of housing, which is itself influenced by transport costs, prompted people to live some distance from their workplace.

Thus, the growing availability of affordable, rapid, safe and comfortable travel has encouraged the spread of commuter 'catchment zones' around major cities. The growth in personal car ownership has also facilitated new modes of shopping, with the spread of out-of-town retail developments, for example. Transport has also influenced the location and nature of businesses, making it possible to specialise and to concentrate production in larger units, expanding markets for manufacturers and, in turn, increasing productivity.

Our legacy of design based on presumptions of limitless oil and that we should build to meet demand has created our current congested and unsustainable infrastructure, with its inefficient use of energy. If we are to deliver safe infrastructure that can cope with shocks, while avoiding the need to build significant excess redundancy and capacity into the system, we need an infrastructure that supports our travel and transport needs and allows us to use as little energy as possible. This can only come about through an approach that abandons the notion that we build infrastructure to meet demand and, instead, sets out to reduce travel needs and bring about changes in our choices about where we live and enables basic services to be delivered locally.

Reliable and robust infrastructure

The delivery of IIS must also account for the issues of safety and reliability that we described in the previous chapter. A system is built up by many different players; but a system with many 'bolt-ons' risks being fragile. There is also a risk that parts of the system will not work with other parts – in different geographical areas or different travel modes, for example.

Intelligence is important in designing infrastructure that is robust, safe and reliable. Good systems design will increase robustness. This is particularly important when we consider increasing reliance on ICT. The challenge is to devise systems that are not liable to the catastrophic failures or malicious attacks that have affected other systems that rely heavily on ICT.

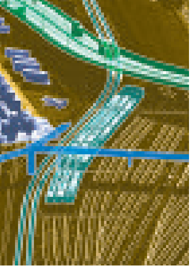
The approach to robust system design is likely to change over the next 50 years. At present, the most robust systems, such as air traffic control, have a specific and focused function, follow clear design principles and are built by a single organisation. It is unlikely that there will be a single architect and plan for the delivery of the IIS. It is more likely to evolve as separate offerings are developed and sold to the markets.

If this is the case, we will need software that automatically configures the interfaces between different components in the system, and software that adapts as new parts are added to the system. One possibility is that we will see the development of software that looks for patterns that suggest possible unexpected 'emergent behaviour', which may be an unexpected but welcome capability or an unanticipated failure.

Delivering a robust and interoperable IIS will depend on setting a framework for the system and ensuring that the different components are designed to work well together. Such considerations, which cut across public and private agencies and require co-ordination across different geographical regions, national and international, are clearly issues where governments must take the lead.

Infrastructure that provides intelligence

We need to know where everything is on the system so that we can ensure that we move everything around in the most efficient way. Intelligence in the infrastructure could allow us to provide an integrated transport system with seamless interchanges. As individuals, intelligence will also increase our choice and help us to find the best way to get to where we want to go.



While knowing the location of everything on the transport system is essential for its efficient operation, we have to achieve this without compromising privacy. At least, we must not get ahead of public acceptance. If drivers going about their lawful business do not want everyone to know their location, the system has to be able to accept this. That everyone who carries a mobile phone effectively broadcasts their location is no reason to dismiss concerns about privacy.

Such concerns will be reduced through technology that allows the system to know where a traveller is without the system knowing who the traveller is. Location-specific services would still be possible as we choose the information we want to attach to our 'traveller identification number'.

It would be important to protect this information, as much from the point of view of handling possible 'spam' on location-specific services as any other concern. Properly designed, our intelligent support could filter out much of the personal information, but the spammers would use their intelligent support to counter these defences – the software arms race would continue.

As with the need to ensure robust systems, governments will hold the responsibility when it comes to issues of privacy. The law as it now stands has not caught up with the Internet age, hence the curse of spam. The information explosion that will arise from IIS will only heighten the challenge.

Infrastructure that is intelligent

As the system carries more information, we will need it to support us by making decisions for us to help manage the movement of goods and people. We need a system that can adapt to the needs of the users and the demands on the system.

Intelligent use of infrastructure

Even if we are more intelligent in our planning processes and alter urban design to reduce travel needs, it does not mean that people will change the way they live. It may well be that any change in the pattern of development that reduces congestion will only encourage travel, making it easier for people to commute longer distances to work.

A shock in the shape of energy shortages, or much higher prices, might force people to change their way of life, but the aim has to be to create an infrastructure that will allow us to ride the shocks.

The challenge will be to find ways to persuade people that there are alternatives to travel. There are two key elements in this: providing information to the user and supporting decision making through economic incentives.

Providing information

In addition to longer-term decisions on where people live and the different activities they become involved in, the system would also need to support change in the individual decisions people make about their method of travel. People tend not to try to find the optimum mode of travel, they tend to find one that works and then stick with that.

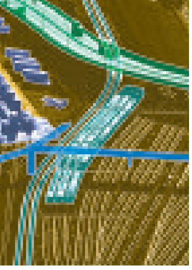
Finding alternative travel routes involves costs, both financial and the mental, or cognitive, effort involved. Along with habit, this creates inertia and a resistance to change in the individual in day-to-day travel decisions. An intelligent system can support this by reducing the costs, economic and cognitive, to the individual by finding out what would be the best approach for them to get to their intended destination. A simpler approach, though, might be, for example, to build on schemes that offer free public transport for a short period to young adults so that, as they start to explore the wider world, they become confident about using public transport, rather than simply buying a car.

Economic incentives

In addition to individuals making well-informed decisions, we will need to add in approaches that manage overall usage by society. So road charging might be based on the full costs not just the costs of building the roads. As an alternative, we could ration the use of transport infrastructure.

Charging is a tried and tested approach that has been applied to manage demand in many other areas. It works where there is elasticity of demand. But the downside is that it is those with the least who suffer.

The approach to charging could be through set rates per mile or we could be charged for particular journeys. The latter would allow a market mechanism to set the price for the use of all modes of transport in a very dynamic way, truly reflecting the level of demand on the system.



Modelling the impact of intelligent infrastructure: smart markets and congestion

Congestion is a daily challenge for many people as they try to get to work. Most of us have to, or feel we have to, work '9 to 5' and so large numbers of people are on the move at the same time.

One area affected by congestion is Gateshead, in the north-east of England. Some 16,000 cars an hour pass through a limited number of roads and over the bridges that link Gateshead to Newcastle during peak morning flows, slowing traffic to 3–4 mph.

Foresight asked researchers from Essex, Newcastle and Cranfield Universities to model how the number of cars affected traffic flow, and what price users would have to be charged to keep the traffic flowing freely. Their model assumed that people had to bid for a 'slot' to use their car on those roads.

The research team are grateful to Gateshead Council for persmission to use the underlying data and traffic model. This research is independent of the council and does not reflect the policies of Gateshead Council.

The work was based on detailed data and a model of the Gateshead area*. The model was calibrated for emissions and pollution. It showed how speed dropped and pollution increased markedly when more than 11,000 vehicles passed through the system each hour.

Analysis of the geographical distribution of the road traffic showed how the location of types of house and jobs affected the flows of vehicles from north to south, and vice versa, through Gateshead's main arterial roads.

The researchers investigated the possible impact of 'road pricing' on congestion in the area by combining a model of Gateshead with another model which simulated the behaviours of individuals choosing whether to buy a slot to drive in an online bidding process. By setting the number of 'slots,' they explored the price that people would pay to be able to travel. At nearly 17,000 'slots,' that value was zero, but grew rapidly as the number of 'slots' reduced. In return, these travellers enjoyed higher average speeds and reduced their impact on the environment.

This combination of models provides a means of testing one approach to congestion management.

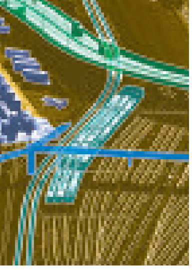
* The research team are grateful to Gateshead Metropolitan Borough Council for permission to use the underlying data and traffic model. This research is independent of the council and does not reflect the policies of Gateshead Metropolitan Borough Council .

Rationing of transport could be through a personal allowance for private travel or through a personal allowance for CO_2 emissions. This initially appears equitable but it is inevitable that there would eventually be markets to trade in these commodities, the rich again benefiting, because of their buying power.

Whichever system is adopted, the real costs of travel will change behaviour as people find ways to maximise the utility of what they can afford. A 'carbon allowance' would allow individuals to make choices between travel and other activities that create CO_2 and would have far wider-reaching effects on behaviour.

Private versus public ownership of vehicles

Ideas such as charging vehicle owners for non-use of their vehicles would encourage people to share vehicles, offering lifts or carrying goods for other businesses. Such an approach, when woven together with some of the other potential advances, might encourage society to move towards a world of private travel in public vehicles.



What are the consequences of developing IIS?

Perhaps the question should be, what are the consequences of *not* developing IIS? It would be all to easy for infrastructure to evolve as it has in the past, in a piecemeal way, responding to population shifts and social changes. One consequence of this is that transport and urban development, for example, have been in conflict. Applying the four levels of intelligent infrastructure can resolve this and other such conflicts to deliver an infrastructure that is sustainable, robust and safe.

A ubiquitous and pervasive IIS that reaches everybody and operates across different travel modes could provide the information needed to focus transport management on the people and things transported rather than on the vehicles they use. In this way, we could begin the journey to separate economic growth from increased demand for transport.

Robust, sustainable and safe infrastructure

The Foresight project set out to explore how science and technology could help us to design and implement intelligent infrastructure for robust, sustainable and safe transport, and its alternatives.

A robust or resilient infrastructure is one that can withstand 'shocks,' both anticipated and unexpected. Anticipated shocks might include massive and sudden increases in energy costs, or the effects of climate change, such as widespread flooding in vulnerable parts of the country.

IIS can ameliorate energy shocks by reducing energy use, and by providing alternatives to travel. When it comes to the effects of climate change, information can guide transport around flooded areas.

Sustainability also depends very much on the use of energy, and the way in which we use materials in the infrastructure. More efficient use of the infrastructure automatically reduces energy consumption. When it comes to materials, self-repairing materials and materials with embedded sensors could extend the life of the physical structure.

Improved safety can come about in many ways with IIS. For example, intelligence can assist drivers, reducing the risk of impacts through such technologies as proximity detectors and lane-deviation monitors.

The UK as a test bed for IIS

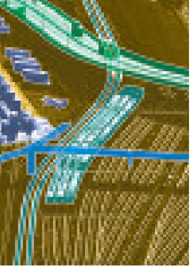
While the project set out to look at ways in which IIS could deliver infrastructure that is robust, sustainable and safe, there are many other benefits that could come from the wider use of ICT. For example, British businesses could develop profitable businesses as technology suppliers.

With its relatively large population and high population density, the UK suffers more from congestion than most other developed nations. It therefore has a more pressing reason than some countries to develop IIS. A consequence of this could be that the UK becomes a leader in the development and commercialisation of the many technologies and systems required for effective IIS. There is, therefore, an opportunity for British businesses to profit from the development of IIS.

Mobility and age

People in the UK are living longer and are relatively healthy well into their old age. Just as this forces us to rethink policies on pensions and retirement, we must also look seriously at the implications of an ageing population for transport and personal mobility.

IIS can offer solutions to these issues by helping to maintain personal mobility and by making it possible for an ageing population to access services without having to travel. For example, with increased automation of cars, older drivers could drive more safely. Ironically, the same technology could also apply to younger drivers, forcing them to drive more safely, or, as we have already seen in commercial trials, using GPS technology to make insurance available to younger drivers at more affordable prices.



Foresight scenarios

Introduction

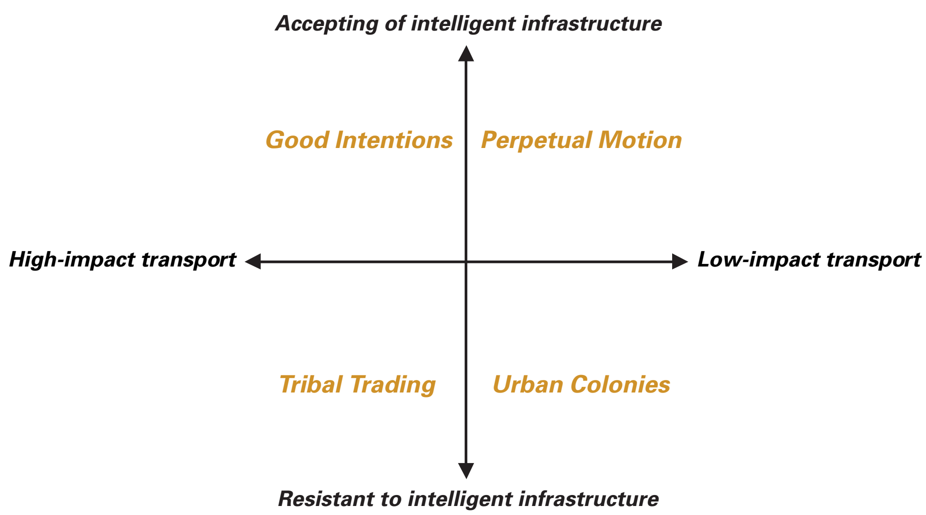
The Foresight project investigated many different futures. In preliminary workshops we identified 60 different drivers of change.

It is difficult to say how these drivers will affect the future. To illustrate the possibilities, and guide its thinking and analysis, the project created four scenarios of how, under the influence of these drivers, the future might look (see separate report *Foresight Futures*) and how science and technology might be applied to infrastructure over the next 50 years.

The main uncertainties we used were: whether or not we will develop low-environmental-impact transport systems; and whether or not people will accept intelligent infrastructure. These uncertainties became the 'axes of uncertainty' for the scenarios exercise. These axes encapsulate the range of uncertainties for the future, together with the range of possible outcomes.

The scenarios reflect their position on the two-dimensional grid (see Figure 4). The names of the scenarios are intended as short-hand labels that capture the essential feature of each 'possible future'. It is worth restating here that these scenarios are just that, pictures of how the future could develop, with no special preference for a particular outcome, nor any likelihood that the real future will resemble any of these 'science fiction' views of tomorrow.

Figure 4: Axes of uncertainty and scenarios



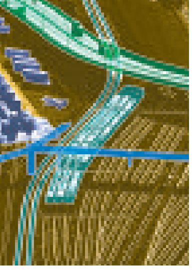
The experts attending the workshops narrowed the discussion down to four scenarios that make it possible to investigate the ways in which the 60 key drivers of change might play out over the next 50 years.

The future is unlikely to look like any of these individual scenarios and may well contain elements of all four. While the scenarios do not purport to predict the future, they do allow us to see how certain combinations of events, discoveries and social changes could change the future. As such, the scenarios allow us to see what we might need to prepare for and the opportunities that await us if we set the right path ahead.

We have labelled the scenarios:

- Perpetual Motion
- Urban Colonies
- Tribal Trading
- Good Intentions.

These labels are for convenience, and make no judgement on the desirability, or otherwise, of the individual scenarios. They do, however, capture the essence of the society that develops in each scenario. As emphasised elsewhere, the real world 50 years from now will probably contain elements of all four scenarios.



Good Intentions

The need to reduce carbon emissions constrains personal mobility.

Traffic volumes have fallen and mass transportation is used more widely.

Businesses have adopted energy-efficient practices: they use wireless identification and tracking systems to optimise logistics and distribution.

Some rural areas pool community carbon credits for local transport provision, but many are struggling.

Airlines continue to exploit loopholes in the carbon enforcement framework.

Perpetual Motion

Society is driven by constant information, consumption and competition. In this world, instant communication and continuing globalisation has fuelled growth: demand for travel remains strong.

New, cleaner, fuel technologies are increasingly popular. Road use is causing less environmental damage, although the volume and speed of traffic remains high. Aviation still relies on carbon fuels – it remains expensive and is increasingly replaced by 'telepresencing' for business, and rapid trains for travel.

Tribal Trading

The world has been through a sharp and savage energy shock. The global economic system is severely damaged and infrastructure is falling into disrepair.

Long-distance travel is a luxury that few can afford and for most people, the world has shrunk to their own community.

Cities have declined and local food production and services have increased.

There are still some cars, but local transport is typically by bike and by horse.

There are local conflicts over resources: lawlessness and mistrust are high.

Urban Colonies

Investment in technology primarily focuses on minimising environmental impact.

Good environmental practice is at the heart of the UK's economic and social policies: sustainable buildings, distributed power generation and new urban planning policies have created compact, dense cities.

Transport is permitted only if green and clean – car use is energy-expensive and restricted.

Public transport – electric and low energy – is efficient and widely used.

Drivers for change

Many factors will affect the future of transport and the way we use intelligence in supporting movement. These factors, which can range from rising tensions between freedom of information and privacy to autonomous vehicles becoming safer and more efficient, are generally referred to as 'drivers for change'. Preliminary workshops for the project identified some 60 drivers that could influence the future direction of intelligent infrastructure.

Growing demand for mobility – passengers and goods

Growing skills shortage as infrastructure acquires the skills

Increasing migration (and emigration)

More frequent clashes of multicultural values – faith vs. secular, for example

Growing awareness of the importance of 'employee liveability'

Increasing importance of the knowledge economy

Ageing, yet more active, population

People face increasing time intensity

Growth in 'cyberfraud'

Emergence of better physical and virtual management systems

Satellite location devices

Smart antennas

Increasing use of 'telepresence' technology

Converging revolutions in biotech, nanotech, infotech and cognitive science

Culture of control

'Real time' everywhere

Growing debate on housing density in inner cities

Growth of Asian economies

Growing global energy deficit – increased demand and consumption

Emergence of radical solutions to climate change

Declining trust in institutions

Growing crisis in higher education puts the science base under threat

Decline in power of national governments

Increasing world trade

Emergence of networked organisations, clusters and supply chains

New decision-making frameworks

Proliferation of choice

The rise of pan-regional hubs

The end of affluence

Increasing emphasis on sustainable design

Rise of 'zero waste' movement

Changing patterns of demand for housing in some areas

E-commerce continues to grow

Increasing focus on tourism and its contribution to climate change

Decoupling of tourism and transport

Rising tension between freedom of information and privacy

Emergence of megacities

Changing family and household structures

The rise of 'slow'

Growing utilisation of 'embedded' technology

Continued growth of an 'always on' culture

Semi-autonomous/autonomous vehicles becoming safer and more efficient

Grids and networks create shared capacity

'Digital natives' – the new generation growing up accustomed to technology

Reducing cost of ICT and enhanced data processing

High-speed rail travel

Growing gap between rich and poor

Continued capital underinvestment

Growing impact of climate change

Increasingly localised/decentralised energy production

Relatively low spend on energy research and development

Increasing consumer desire for social and environmental responsibility and transparency

Growth of the surveillance society

Complex just-in-time models are vulnerable to external shock

Demand management of transport provision

Changing data storage: from desktop to network

Movement away from office-based working

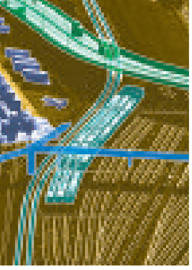
Emerging debate around provision of 'citizen's income'

Rising importance of local provision

Taxation increasingly based on resource consumption rather than income

Move towards full-cost accounting

Emerging infrastructure, emerging cultural forms



About Foresight

This project is one of a number of projects run as part of the Foresight Programme of the Office of Science and Technology. The aim of the programme is to produce challenging visions of the future in order to ensure effective strategies now. Five other projects have already launched their findings:

Cognitive Systems

Looked at developments in the physical and life sciences on thinking systems. The main objective of the project was to consider whether there would be value bringing the two communities together to share their learning. At the start of the project, they were sceptical about the value of such a collaboration, but by the end they thought there were three or four areas they could not take forward without collaboration. The project led to a cross-council initiative to develop some of these ideas. The project also explored emerging and future technologies, for a wide range of applications – transport, defence, leisure, and so on. The Economic and Social Research Council is now working with the Department of Health on the ethical, social and legal implications of the developments in relation to healthcare.

Flood and Coastal Defence

Explored the future potential risks of flooding up to 80 years in the future and the impacts of that flooding in five future scenarios to provide an idea of the range of possible future threats. A second set of scenarios then considered how we might respond to those risks and the costs of introducing responses that brought risks back to current-day levels. DEFRA is leading a cross-Whitehall action plan responding to the findings of the work.

Exploiting the Electromagnetic Spectrum

The UK developed the laser but makes little money from it. This project looked at future electromagnetic spectrum technology, with a view to ensuring that the UK captures the commercial benefits. The project looked across the whole field and identified a number of key areas for investment: optical switches, near-field technology, medical and defence imaging and photonic manufacturing, and optical tools for 'lab on a chip' technology. The project developed details of the technologies in each of these areas, and produced roadmaps for the delivery of step-change capabilities.

Cyber Trust and Crime Prevention

Looked at developments in information and communications technologies and trust. The project considered future crime risks and what we might do to reduce them. In addition to a detailed report on future technologies, it produced a set of scenarios that a number of government departments have used in workshops to test their policies for robustness in a range of possible 'cyber futures'.

Brain Science Addiction and Drugs

Considered how we might manage the use of psychoactive substances for the benefit of individuals, communities and society at large. It explored what those substances might be in the future, what their effects might be and what methods we have for managing their use. This project encouraged open and creative discussion between natural and social scientists, policy makers, health professionals and others on our future ability to treat, alter and perhaps improve the brain. It provided an evidence base on both medical and leisure drug use to inform policy development. It produced a series of science reviews, a report on the general public's views of some of the issues, an analysis of the pharmaceutical industry's perspective on the future of neurological drug futures, an examination of how drug use might be modelled to inform policy, as well as a series of scenarios exploring how society might use future advances.

Two other Foresight projects are running at the moment:

Detection and Identification of Infectious Disease

Is considering future technology that will help us to spot new and emerging threats from human, animal and plant disease. The project has identified the key user needs and is developing detailed roadmaps that set out the science and technology we will need to deliver those capabilities. It is also mapping potential future risks and the events and decisions that could lead to new threats of disease.

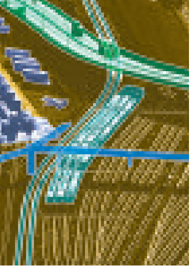
Obesity

Has just started and will be looking at the risk factors affecting levels of obesity and how we might use this information to inform our response.

OST Horizon Scanning Centre

The centre aims to provide a broad context of future opportunities, risks and developments across government, with a particular focus on spotting the implications of emerging science and technology. It aims to explore novel and unexpected issues as well as persistent problems or trends. The centre supports government organisations with their own horizon scanning activities and is currently undertaking two scanning exercises: a broad strategic scan across the public policy remit, and one providing a greater depth of analysis of emerging developments in science and technology.

Further information on this and the other Foresight projects can be found on the Foresight website: www.foresight.gov.uk



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Stakeholder group

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Professor Frank Kelly, Chief Scientific Adviser, DfT
Hugh Norie, Project Representative, Mott, Parsons, Gibb
General Sir Kevin O'Donoghue, Chief of Defence Logistics, Ministry of Defence
Professor John O'Reilly, Chief Executive, Engineering and Physical Sciences Research Council
Dr Alf Roberts, Chief Executive, The Institution of Electrical Engineers
Archie Robertson, Chief Executive, Highways Agency

Advisory group

Professor Peter Allen, Cranfield University
Professor Philip Blythe, University of Newcastle upon Tyne
Professor Brian Collins, Cranfield University
Paul Davies, The Institution of Electrical Engineers
Dr Janet Efstathiou, University of Oxford
Dr Mike Farrimond, UK Water Industry Research
Professor Nigel Gilbert, University of Surrey
Professor Peter Guthrie, University of Cambridge
Chief Superintendent Jim Hammond, Association of Chief Police Officers
Professor Angela Hull, University of the West of England
Michael Kenward, Kenward Words
John Loughhead, UK Energy Research Centre

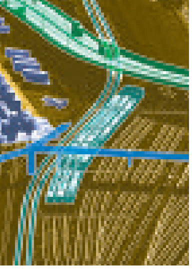
Dr Paul Nightingale, University of Sussex
Paul O'Neill, Deloitte Touche
Dr Dan Osborn, Natural Environment Research Council
Eric Sampson, Department for Transport
Professor Nigel Shadbolt, University of Southampton
Professor Will Stewart
Dr Martyn Thomas, Martyn Thomas Associates
Dr Lesley Thompson, Engineering and Physical Sciences Research Council
Professor John Urry, Lancaster University
Dr Alister Wilson, Waverley Management

Project key science experts

Professor Philip Blythe, University of Newcastle upon Tyne
Professor Glenn Lyons, University of the West of England
Professor Will Stewart
Professor John Urry, Lancaster University

Authors of state-of-research reviews

Professor Kay Axhausen, ETH Zurich
Professor David Banister, University College London
Professor Margaret Bell, University of Leeds
Professor Michael Bell, Imperial College London
Dr Tijl de Bie, University of Southampton
Dr Seth Bullock, University of Leeds
Professor Dave Cliff, University of Southampton
Dr Nello Cristianini, University of Southampton
Professor J Richard Eiser, University of Sheffield
Professor Erol Gelenbe, Imperial College London
Professor Phil Goodwin, University of the West of England
Professor Peter Guthrie, University of Cambridge
Professor Alan Harrison, Cranfield University
Robin Hickman, University College London
Dr Jonathan Köhler, Tyndall Centre for Climate Change
Dr Stephen Little, Open University
Dr Yinyang Li, University of Southampton
Professor Glenn Lyons, University of the West of England
Professor Mike McDonald, University of Southampton
Dr John Miles, Ankerbold International Ltd



Professor John Shawe-Taylor, University of Southampton
Professor Stephen Stradling, Napier University
Dr Alan Tully, University of Newcastle upon Tyne
Janet Walker, Ankerbold International Ltd
Dr Andrew White, Cranfield University

Project communications consultant

Michael Kenward, Kenward Words

Authors of scenario reports and case studies

Andrew Curry, Henley Centre
Rachel Kelnar, Henley Centre
Dr Alister Wilson, Waverley Management

Modelling

Professor Peter Allen, Cranfield University
Professor Philip Blythe, University of Newcastle upon Tyne
Dr Sheri Markose, University of Essex
Gateshead Metropolitan Borough Council

Systems mapping

Tony Hodgson, Decision Integrity

Technology Forward Look

Bill Sharpe, The Appliance Studio

Foresight team

Gordon Baker, Foresight
Samuel Danquah, Project Support
John Flack, Project Coordinator
Andrew Jackson, Deputy Director, Foresight
Christine McDougall, Project Manager
Andrew Scurry, DfT
Dr Miles Yarrington, Project Leader

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