Projecting the economic value of licence exempt applications

Annexes to the report from Indepen, Aegis and Ovum

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This report was commissioned by Ofcom to provide an independent view on issues relevant to its duties as regulator for the UK communications industry, for example on issues of future technology or efficient use of the radio spectrum in the United Kingdom. The assumptions, conclusions and recommendations expressed in this report are entirely those of the contractors and should not be attributed to Ofcom.

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Appendix A: The ten applications

A.1 Application 1: Road User Charging (RUC) using Dedicated Short Range Communication (DSRC)

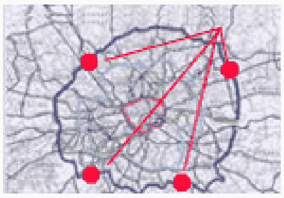
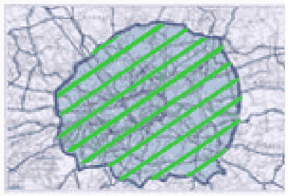
A.1.1 Description of the application

What is this application?

This profile describes the use of microwave technology operating in unlicensed spectrum to provide road usage charging services.

There is significant experience, both internationally and in the UK, of all-vehicle and lorry-only road charging schemes. Fuel duty provides a proxy for distance by charging according to fuel consumed, which is a function of distance (but also of engine efficiency and driving style). But essentially, charging schemes fall into four main types:

Figure A.1 – Examples of road user charging schemes

	Link charging	**Distance charging**	**Area charging**	**Zonal charging**
Description	Charging for the use of a linear section of infrastructure, usually a tunnel, bridge or section of motorway	Measuring the distance travelled, either actual or approximate	Charging for crossing a boundary around an urban area	Charging for driving within an urban area
				
Also known as			Cordon charging	Area charging
Examples	Dartford Bridge Tolling of motorways in many countries, e.g. in France and M6 Toll near Manchester Melbourne City Link Toronto	Switzerland, Germany	Several towns in Norway, e.g. Oslo, Trondheim	London Congestion Charge

Source: Department for Transport

Existing schemes can therefore be seen to be falling into the following categories according to the charging technology used (Figure A.1)[1]

[1] http://www.dft.gov.uk/stellent/groups/dft_roads/documents/divisionhomepage/032120.hcsp

Table A.1 – Technology for road user charging schemes

Technology	Permit	Microwave	Tachograph	Satellite position Fix & map Matching
Link		Melbourne M6 Toll SR91		
Distance	Not applicable	Not applicable	Swiss (distance charging)	German (road segment charging)
Area / zonal	London Durham	Singapore Trondheim		

Source: Department for Transport

These schemes all use one or more of the following methods of charging:

- Toll booths – cash or smartcard
- Self declaration – road users use telephone, internet, retail outlets and other mechanisms to volunteer payment to the charging authority
- Microwave tags – an electronic device in the windscreen, around the size of a pack of cards, communicates with roadside equipment to register that a vehicle has passed a certain point and that charge is payable via a separate account or credit card
- Automatic number plate recognition (ANPR) – cameras take digital photographs of vehicle number plates, which are then read by the system to identify the person liable for the charge.

Automatic number plate recognition is not widely used for charging. It is more commonly used as an enforcement mechanism to support one of the other methods, with the exception of London where congestion charges are based on ANPR techniques. However, Transport for London is currently seeking ways to improve and improve the efficiency of the charging mechanisms in place by complementary use of other technologies like dedicated short range communication (DSRC), as presented in subsequent sections.

The technologies presented above are all well proven. Microwave, in particular, is now in widespread use, for example as an alternative to stopping at a toll plaza on most tolled motorways and bridges. The main microwave technology used is DSRC at 5.8GHz. Some versions of it can be used to apply a charge to vehicles travelling at motorway speeds without requiring those vehicles to slow down. Microwave is now being used in some locations (e.g. Toronto and Melbourne) as the sole charging mechanism, with no toll plazas at all.

All of these schemes can be used to raise revenue. In the case of Dartford, this was the original intention of the scheme, where tolls were used to finance the investment needed to provide the infrastructure. The M6 Toll near Manchester is a similar example.

Who are the users?

The number of users can potentially be all motor vehicles registered in UK, assuming that a nationwide road usage charging scheme will be adopted and that hybrid systems using microwave technology will be deployed. The UK Government first announced its plans to introduce a countrywide road-user charge for trucks in April 2002, and implementation of the scheme. This would have involved a combination of satellite positioning and mobile communications systems and was expected to begin in 2006. However, on 5 July 2005, Secretary of State for Transport Alistair Darling announced that the government was cancelling the procurement process for the 'Lorry Road User Charge scheme' and not going ahead with the planned system. Instead, Mr Darling said that road charging for trucks would now be part of the wider and longer-term national road-pricing project.

By cancelling this project and tying road charging for trucks to the emerging plans for national road pricing for cars, the government has effectively delayed the introduction of charges for heavy vehicles by 10 to 15 years (i.e. 2015 to 2020).

Since then different road usage charging initiatives focusing on local traffic congestion problems across UK have been funded by the Department of Transport (DfT). These initiatives experiment with different technologies and no uniform approach has been finalised yet. Therefore, the number of users and the economic value of using licence exempt spectrum for RUC is heavily dependent on whether the UK government will include DSRC as one of its technological options regarding nationwide road usage charging scheme.

Supply chain of equipment

In the United Kingdom, the only charging schemes implemented so far that have not been associated with new road capacity have been the Durham scheme, introduced in 2002, and the London Congestion Charge, introduced in 2003.

Elsewhere in the world the need for demand management has led to road pricing schemes being implemented in various forms since the 1970s. They have become a useful component in achieving sustainable and integrated transport strategies. For example, Singapore was one of the first countries to implement road pricing to tackle the problem of increasing urban road congestion and has led the way in free-flow electronic fee collection.

Different charging technologies have been used in schemes around the world and vary according to the objectives and specifications of each. Most of the current schemes use either a daily licence or microwave technology. The German, Swiss and Austrian schemes use one or more advanced technologies including microwave, infra-red, satellite navigation and cellular networks (mobile phone technology), yet these schemes operate amongst Heavy Goods Vehicles (HGVs) only.

Microwave charging technology

Microwave charging is a mature technology and the dominant form of electronic charging in the world for both toll plazas and free-flow operations.

In a free-flow charging system an On Board Unit (OBU) is installed in each car. Typically an OBU is about the size of a pack of playing cards (Figure A.2). It is usually retrofitted to the vehicle behind the windscreen, though line fitting at the point of vehicle manufacture, to form a less obtrusive installation and powered from the vehicle electrical system, is feasible. Retrofit examples are normally powered by a battery with a life in the order of 5 to 7 years, after which a new OBU is issued and the old one returned to the issuer.

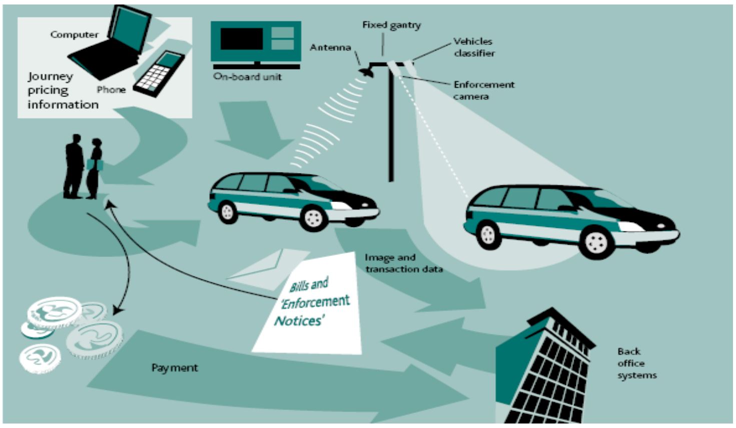
At the point on the road where a charge is to be collected and enforced, infrastructure is installed comprising microwave beacons and receivers, ANPR cameras, processing and a power supply. At each infrastructure site, the OBU will transact with the beacons (Figure A.3).[2] This allows for the location and identity of the OBU to be captured, which then permits the system to match transaction records with vehicle detection images from any co-located camera and vehicle detection sub-system. Several beacons are normally required to cover the full width of a multi-lane road.

Microwave charging equipment manufacturers in Europe nearly all comply with CEN[3] standards and interoperability has been demonstrated in trials between their equipment. A comprehensive trial of equipment and systems interoperability is part of the Department for Transport's DIRECTS project (Demonstration of Interoperable Road user End-to-end Charging and Telematics Systems).[4]

Figure A.2 – On board unit when microwave technology is deployed

Source: Department for Transport

Figure A.3 – Overview of microwave technology



Source: Department for Transport

[2] http://www.dft.gov.uk/stellent/groups/dft_roads/documents/divisionhomepage/032120.hcsp

[3] CEN – Comité Européen de Normalisation (European Committee for Standardisation)

[4] http://www.dft.gov.uk/stellent/groups/dft_localtrans/documents/page/dft_localtrans_503865.pdf

Schemes currently using microwave charging technology include: French Autoroutes, Austrian Lorry Charging, Singapore, Melbourne, Trondheim, Toronto, Italian Autostrada, High Occupancy Vehicle (HOV) lanes in California, Dartford River Crossing and the M6 Toll.

A.1.2 Technical characteristics

Frequency used for key spectrum components

According to UK Radio Interference Requirement 2030[5] for short range devices the minimum equipment requirements for road transport and traffic telematics are as follows:

- For the provision of short range data links which respond to a signal initiated by, in the case of categories (i) and (ii) below, a network operator; or by, in the case of category (ii) or (iii), a private system used and operated by the owner or persons authorised by the owner; so as to be capable of use only within either of the frequency bands and at a radiated level not exceeding the maximum for such frequency bands specified in the top half of Table A.2.
- For the provision of short range on-board vehicle radar so as to be capable of use only within the frequency band and at a radiated level not exceeding the maximum for such frequency band specified in the last row of Table A.2.

Table A.2 – Technical characteristics of spectrum for road user charging

Category	Frequencies or frequency band	Radiated level	Channel bandwidth	Music or speech permitted	Duty cycle	Reference standard[1]
i	5795 - 5805 MHz	≤ 2 W eirp	–	No	–	EN 300 674
ii	5805 - 5815 MHz	≤ 2 W eirp	–	No	–	
iii	5805 - 5815 MHz	≤ 2 W eirp	–	No	–	I-ETS 300 440
	76 - 77 GHz	≤ 55 dBm peak power	–	No	–	EN 301 091

1 Assumed to be fulfilled in frequency planning and defining the equipment type

DSRC system vs. RFID

Historically, the terms RFID and DSRC have been used synonymously to describe a technology based on tags and readers. But with the advent of the 5.8 GHz band, more attention is being given to differentiating these terms. Although the 5.8 GHz DSRC system essentially consists of tags and readers, it is different from traditional RFID in many ways. The DSRC system is more like a peer-to-peer system in which either end of a link can initiate a transaction whereas traditional RFID systems operate in a master-slave arrangement. This peer-to-peer architecture is necessary because many planned applications are vehicle-to-vehicle ones, not involving the roadside RFID readers at all.

DSRC and traditional RFID differ in other ways as well: DSRC uses a modulation type that breaks data down into small parts and transmits them in parallel within a wide channel, whereas traditional RFID sends everything in series over a narrow channel. This basic difference makes it possible for

5 http://www.ofcom.org.uk/static/archive/ra/topics/spectrum-strat/future/strat02/strategy02app_i.doc

DSRC to offer a much higher data transmission speed than RFID does. Compared with existing RFID toll applications, DRSC delivers data rates of 25Mbps, instead of 250kbps, and a range of up to 1km, instead of 10 meters. Because of its long read-range, DSRC must be able to operate in a condition of multiple overlapping communication zones – a condition that most RFID systems today could not meet. DSRC must also dynamically control such things as emitted power, channels and message priorities – things that current RFID systems cannot do.

Bandwidth required

Table A.3 summarises the technical characteristics of regional standards for DSRC[6] technology.

Table A.3 – Regional standards for DSRC

Item	Japan (ARIB)	Europe (CEN)	America (ASTM)
Duplex	OBU: Half duplex	Half duplex	Half duplex
	RSU: Full duplex		
Communication System	Active	Passive	Active
Radio frequency band	5.8 GHz band	5.8 GHz band	5.9 GHz band
	80MHz bandwidth	20MHz bandwidth	75MHz bandwidth
Channels	Down-link: 7	4	7
	Up-link: 7		
Channel separation	5MHz	5MHz	10MHz
Data transmission rate	Down-link / Up-link:	Down-link: 500kbps	Down-link / Up-link:
	1 or 4Mbps	Up-link: 250kbps	3-27Mbps
Coverage	30m	15-20m	1,000 (max)
Modulation	2-ASK (1Mbps)	RSU: 2-ASK	OFDM
	4-PSK (4Mbps)	OBU: 2-PSK (sub-carrier modulation)	

Source: 11th World Congress on ITS

Requirement for harmonisation

The UK Department for Transport (DfT), and increasingly operators of tolled structures including motorways, bridges and estuarial crossings, intend that OBUs procured and issued through a variety of operators should all interoperate with other UK and European road charging schemes. Whilst there are a number of CEN/ISO standards covering some elements of interoperability, there is no one complete standard or set of standards. To address this issue, the UK DfT is developing a suite of specifications, the Open Minimum Interoperability Specification Suite (OMISS). OMISS aim is of fostering interoperability between electronic road user charging systems in the UK, and potentially with systems outside the UK. This specification contains the Department's view of current best practice for interoperable electronic road user charging systems in the UK, using 5.8 GHz microwave technology DSRC.

[6] http://www.itsforum.gr.jp/Public/E4Meetings/P03/kudohSS16.pdf

In addition to the development of effective technology, a parallel process of defining standards, especially for vehicles, needs to take place. The technology needed to implement a national distance-based scheme will need generally to be fitted to vehicles during the manufacturing process, since its complexity and the potential for interference between it and other electronic components, and the need for robustness, would make retrofitting difficult and expensive. This in turn will need a 'vehicle directive' from the EU.

The European Commission's Directive on the interoperability of electronic road toll systems seeks to define the technologies to be used for road charging throughout Europe, focusing on long-term migration to GPS-type systems. It is unlikely that there will be a substantial population of OBU-equipped vehicles in Europe before 2014. This indicates that although some solutions based on mobile positioning may exist, DSRC solutions are likely to dominate in the short to medium term. However, European motorways which use DSRC do not all work to the same standard and are thus not interoperable. DSRC interoperability may be feasible by 2009 for 80% of European users. If it were decided that an IR-based DSRC system should be implemented in London, users of the London scheme would potentially be compatible with other UK DSRC systems but users of these other systems would not be compatible with the London system, unless a dual system tag became standard.

The UK Government could take a lead in the European Union, which is the appropriate body for these matters, if it wished to ensure that progress towards national road pricing was maintained, without prejudicing the eventual decision as to whether or not to implement it.

A.1.3 Existing schemes and developments

M6 Toll

The M6 Toll is the UK's first tolled motorway which opened in December 2003. The 27-mile M6 Toll arcs to the north and east of Birmingham between junctions 4 and 11 of the existing M6 (see Figure A.4). It gives motorists a charged alternative to the often congested M6 through the West Midlands conurbation and the M5/M6 interchange. The strategic importance of the M6 Toll has been recognised with its designation as part of the Trans-European Road Network.

The need for an alternative route to the M6 was first identified over 30 years ago. Traffic flows on the M6 are typically up to 160,000 vehicles per day. Slow moving and queuing traffic is a daily occurrence within the conurbation. The M5 and M42 are similarly affected, though to a lesser degree.

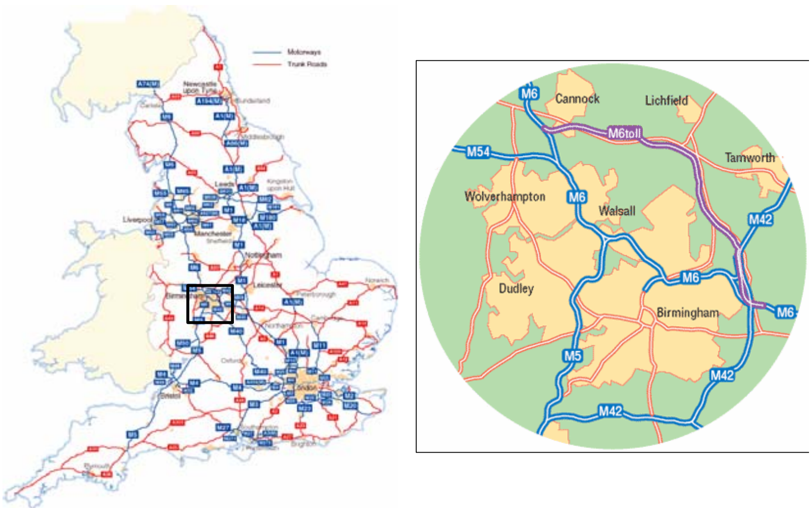
Initially planned in the early 1980s as a publicly financed scheme, the M6 Toll was proposed as a privately financed scheme in 1989. In 1992 a concession was awarded to Midland Expressway Limited (MEL) to finance, design, build and operate the new road. The concession is for 53 years: three years for construction, which started in 2000, and fifty years for operation. At the end of the concession the road will be returned to the Government. MEL is responsible for all aspects of operation including the setting of tolls.

The aim of the M6 Toll is to relieve the M6 of much of the longer distance traffic that passes through the West Midlands conurbation. Through traffic represents approximately 35% of the total on the M6 and transfer of some of this traffic to the M6 Toll will allow the increased capacity on the M6 to be used by traffic presently using congested local roads. The relief of local roads would have environmental benefits for nearby communities.

The Highways Agency published an evaluation study[7] a year after the opening of the M6 toll. Statistics comparing traffic volumes before and after the opening of the toll showed that:

- Week day traffic flows on the M6 toll showed substantial growth that is significantly higher than that seen by any other section of the motorway in the region
- On the sections of the M6 parallel to the M6 toll, i.e. between Junctions 4A and 11A, there were significant reductions in traffic flows across the week.
- On the M6 north and south of the M6 traffic volumes have increased as traffic re-routed from a variety of other routes to access the toll road.
- Traffic on other motorways and trunk roads showed significant reductions in traffic volumes.

Figure A.4 – M6 microwave toll system



Source: Highways Agency

London Congestion Charging Scheme

On February 17th 2003, London introduced the Central London Congestion Charge by Transport for London (Tfl), under the control of the Mayor of London, Ken Livingstone, which is in turn under the policy of the Department for Transport.

[7] Akins, "Post opening project evaluation. M6 Toll after study: Traffic and safety summary", 2005

Figure A.5 – The central London congestion charging zone

Source: Transport for London

The fee was initially set at £5, and raised to £8 on 4th July 2005. The daily charge must be paid by the registered owner of a vehicle that enters, leaves or moves around within the congestion charge zone between 7am and 6.30pm from Monday to Friday. On 19th June 2006 a new 'Pay-Next-Day' scheme was introduced, allowing drivers to pay their congestion charge until midnight on the day of travel, or pay £10 until midnight on the following charging day. Failure to pay by midnight means a fine of at least £50.

The congestion charging system is based on a massive CCTV monitoring system, coupled with ANPR technology. This scheme relies on about 700 CCTV cameras covering around 203 entrances/exits to the 21 square kilometre central zone. Each lane of traffic either entering or leaving the boundary of the zone is covered by a monochrome camera linked to an ANPR system. Each entry/exit road has at least one colour CCTV camera which streams real time pictures back to the central ‘Hubsite’, located just outside the charging zone near Brick Lane, with links to the Call Centres in Coventry and Glasgow. There are also about 10 white vans with mobile camera systems, and some 64 other cameras outside of the zone.

In February 2005, TfL completed its programme of testing different technologies and methodologies in an attempt to improve London’s existing congestion charging system.[8]

The trials addressed four different groups of technologies:

- Cameras and automatic number plate recognition (ANPR) technology
- “Tag and beacon” detection systems, of which Dedicated Short Range Communications (DSRC) is the leading solution for road tolling
- Satellite navigation using Global Positioning System (GPS) technology
- Digital mobile phone technologies using Global System for Mobile (GSM) technology

[8] http://www.tfl.gov.uk/tfl/downloads/pdf/congestion-charging/technology-trials.pdf

The first two groups of technologies are associated with identifying a vehicle as it passes a fixed point, whilst the second two groups are concerned with identifying the location of a vehicle, without any fixed detection points.

The programme results and overall conclusions for all of the technologies tested are summarised below:

Cameras and ANPR

New, improved ANPR systems generate number plate reads in excess of 90% for a single pass, compared to 70%-80% for a single pass under current systems. Further work is required to ensure that these results are not compromised when encryption and compression algorithms are added. It is feasible to deploy roadside ANPR systems; however, there are few systems available that have been ruggedised for roadside use.

DSRC systems

Where a 1.5m overhang of the carriageway is permitted, a DSRC beacon mounted at a height of 6m can achieve vehicle tag detection rates over a 2-lane (8m wide) highway in excess of 99% (typically 99.5% in the tests). In order to cover wider carriageway widths, a wider overhang would be required. As a general rule, coverage extends at least 4.5m beyond the end of the overhang.

Tag and beacon offers the opportunity to migrate customers to period-based billing instead of daily payments. Based on user surveys, a significant percentage of vehicles could migrate onto account-based systems, substantially reducing the loading on customers facing channels and hence reducing operations costs of such schemes. Tag and beacon and camera/ANPR solutions both support this, but with the latter being less accurate than the former.

To meet evidential requirements, a camera and ANPR system are required to work in conjunction with the DSRC solution in order to match DSRC transactions with ANPR images. According to TfL, estimated direct costs for introducing DSRC would be £21 million in setup costs and an average of £3 million in annual operating costs for the central and western extension zones combined. These setup costs assume that the existing CLoCCS enforcement infrastructure is entirely replaced with roadside ANPR on re-let, whether or not DSRC is implemented. DSRC setup costs would be additional to these replacement costs. About half of the annual operating costs relates to the purchase, distribution and recycling of the tags and is therefore directly dependent on the take-up of DSRC, assuming that TfL carries the costs of the tags. If TfL does not carry the cost of tags, annual operating costs would be £1.5m and not dependent on take-up. Currently, a simple tag costs approximately £10.[9]

Satellite Navigation systems

The accuracy of the GPS solutions trialled is such that, on average, a buffer zone of 60m around the boundary of the Central London Charging Zone (CLCZ) would be required to be 99% confident that a position reported as being within the zone was actually so. Around some parts of the boundary this increases to 250m or more. While the performance of different GPS on board units varied, none gave a significant improvement on this average result. This included GPS with additional support, such as dead reckoning or differential signals

[9] Section 7.2.8 London Congestion Charging Technology Trials Stage 1 Report, Version 1.0, February 2005 http://www.tfl.gov.uk/tfl/downloads/pdf/congestion-charging/technology-trials.pdf

Mobile phone technologies

Using the Location Based Services (LBS) of GSM mobile telephone networks to establish the position of a vehicle gave results with an average error, as quoted by the operators, of 800m and, as observed, of 2,400m. Clearly this level of accuracy is inadequate to support congestion charging.

Project conclusions

Overall conclusions and possible future implications for the application to the Central London Congestion Charging Scheme (CLoCCS) are:

- For charging purposes, GPS and GSM solutions would need development to become suitable to track vehicles to within a few metres. This and other required developments are unlikely to be ready until about 2014 and therefore would not be available for any re-procurement of the CLoCCS during or after 2008
- A DSRC solution could be applied as an overlay to the existing 203 camera sites. Ideally it would be integrated with the camera solution so that images and transactions were matched as they occurred at the roadside. It is possible that it could work as a separate overlay with DSRC and camera transactions being matched up later in the central system, but there are significant difficulties which make this less attractive
- A roadside ANPR and camera solution could be applied to the CLoCCS, but the cost savings may not be realised in the time left or the expiry of the current service contract, due in 2008 at the earliest

A national road user charging scheme is unlikely to have any on board unit technology selected before the end of 2007 at the earliest, and possibly as late as 2009. The Department for Transport's current thinking appears to acknowledge the current difficulties of using GPS based on board units for charging and in the short term anticipates that tag-based solutions with "off-board" charging will be more mature and deployable. The implications for the CLoCCS are:

- Current camera and ANPR technology, assumed to have a life until 2010, is unlikely to present a problem for national scheme interoperability; and
- When the CLoCCS scheme is re-procured (the earliest date being February 2008), the design could allow for eventual inclusion of any national scheme technology.

Overall, TfL conclusions are in line with what is expected to be experienced in the UK market:

- In the short term (8-10 years from today), DSRC or hybrid DSRC/ANPR solutions will be implemented on a city/town/regional level
- Once satellite (either GPS or European Galileo) related road tolling eco-system is mature enough (10-15 years from today), UK government intends to deploy nationwide road charging scheme for all motor vehicles being backwards compatible with all other RUC systems in place

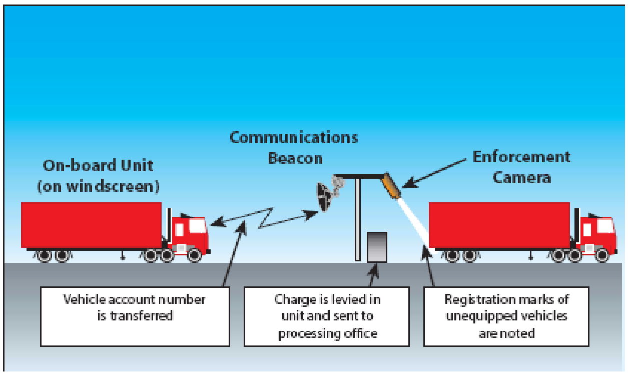
DIRECTS initiative

As mentioned above, several initiatives regarding RUC on a local level are still in progress. Different possible technological standards being tested in conjunction with defining UK's national RUC scheme. The most prominent one is called DIRECTS (Demonstration of Interoperable Road user End-to-end Charging and Telematics Systems). The DIRECTS project aims to provide the world's first demonstration of compatible electronic road user charging systems, using a Dedicated Short Range Communications (DSRC) system and a Mobile Positioning System (MPS), under free-flowing traffic conditions. The DfT is expected to use the specifications developed within its DIRECTS trials in

Leeds in 2003. The DIRECTS trials involved microwave DSRC systems from Kapsch's Combitech and Telecom divisions and CSSI; and a GPS/GSM system from Vodafone.

DIRECTS will show how two different electronic charging systems work. The first is a Dedicated Short Range Communications (DSRC) system. It uses equipment at the roadside to transmit signals to and from electronic units, about the size of an audio cassette tape, fitted on the inside of the windscreen or on the dashboard of vehicles. The data from the roadside equipment is then processed by a central administration office, which converts it into bills.

Figure A.6 – DIRECTS initiative: Use of DSRC



Source: DIRECTS

The second is a position fixing system. Vehicles are fitted with a receiver, about the size of a video cassette, which determines locations using the Global Positioning System (GPS) satellite network. GPS is already used for navigation in the road haulage, shipping and aircraft industries and in car navigation systems in the band of L1 (1.56 GHz – 1.61 GHz) and L2 (1.215 GHz – 1.26 GHz). The unit in the vehicle works like a car radio – it 'listens' to broadcasts from GPS satellites but it does not send signals back to them. The communication is one way and private. The receiver matches its position with an electronic map of charged areas and a table of charge rates, both stored inside the receiver. Then, as with the DSRC system, the data is sent to a processing office for billing. In the DIRECTS trial only the volunteers will be sent a 'bill' to test the system. They will not have to pay any money.

In a speech delivered on 9 June 2005, UK Transport Secretary Alistair Darling outlined the benefits road pricing could bring to the country, and how a high-tech charging system could be implemented.[10]

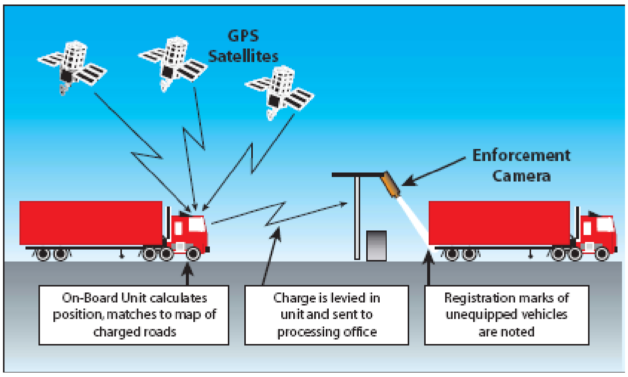
Mr. Darling proposed a revolutionary new scheme that would make drivers pay up to £1.34 per mile, according to the distance, time of day and route that they travel. Also, it must be taken into account that as of 2005 the average mileage per car in UK was more than 10,000 miles. The system, presented as the only solution to prevent gridlock in Britain's roads, would be extremely sophisticated and probably involve satellite positioning technology in order to cover the whole country. Current estimates indicate that it could become a reality in 10 to 15 years.

The UK government is currently examining the detailed technical issues about how road pricing might be introduced, including discussions with industry about future developments, inviting local authorities to come forward with innovative solutions to tackle congestion problems in their local area, and working to build political consensus. "*We need that consensus because moving to road pricing –*

[10] http://ec.europa.eu/idabc/en/document/4361/354

charging on the basis of distance travelled varied according to how congested a road is – would be a radical change from where we are now", explained Mr Darling, adding that "*planning and delivery would span several Parliaments*". In addition, Mr Darling said the government would set a framework for taking the national road charging debate forward.

Figure A.7 – DIRECTS initiative: Use of Position Fixing System



Source: DIRECTS

According to Mr. Darling, the proposed system would be revenue neutral, i.e. the charges would be globally offset by reductions in fuel tax. Despite strong opposition in some quarters, the proposed scheme received a boost from the results of a survey by Ipsos MORI suggested that drivers would be prepared to pay charges if this would effectively reduce congestion on the roads.[11]

Substitutes

The main substitutes for DSRC based RUC technologies are those which use the US Global Positioning Satellites (GPS) to identify the vehicle's position.[12] GPS satellites provide coverage throughout the UK. The results can be very accurate, but are not always so: signal loss due to high-sided buildings, mountainous terrain or forests must be taken into consideration. For example, existing systems can give a vehicle's position as being in the middle of a building rather than on a road alongside it. This may not matter for normal navigation or tracking needs, where software (often referred to as 'snap to map') can correct this error by assuming that the vehicle must be on the road. But the assumption may be wrong – the software may correct the vehicle's position to the wrong road. If the charges on the two roads are different, the vehicle may be wrongly charged. Where such error is possible, the legal enforceability of one charge rather than the other could be in doubt. There are potential ways of tackling this, for example by always giving a vehicle the benefit of the doubt where such errors are possible, or by adapting the charging structure. But the accuracy and reliability issue and its relationship with the charging structure is a complex matter, and is one of several areas which will need further work.

The equipment necessary to deliver a full position based charging scheme using satellite technology will not be available in a mass market, low cost form until at least 2014. The launch of the Galileo satellite network, which is intended to go into commercial operation from 2010, will be a major step towards this particular solution, providing greater coverage and accuracy even in the most challenging locations.

[11] http://www.mori.com/polls/2005/detica2.shtml

[12] And in future, the European Galileo satellite system

In addition to the development of an effective technology, a parallel process of defining standards needs to take place, particularly for vehicles. The equipment required to implement a national distance based scheme will have to be fitted during the vehicle manufacturing process. Retrofitting would be difficult and expensive due to the complexity, potential for interference with other electronic components, and the need for robustness of the equipment. This in turn will need a ‘vehicle directive’ from the EU. The UK Government could take a lead in the European Union, which is the appropriate body for these matters, if it wished to ensure that progress towards national road pricing is maintained and without prejudicing the eventual decision as to whether or not it is implemented.

A.1.4 Evolution of demand

Given the analysis we conclude that:

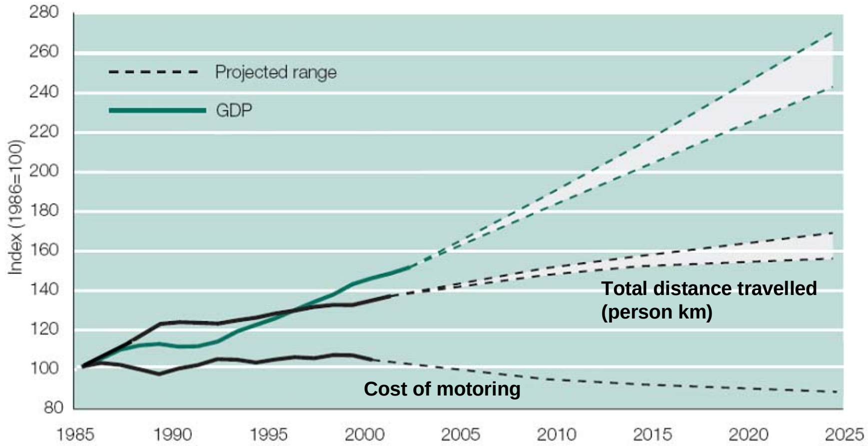
- Road usage charging (RUC) using wireless technologies (e.g. DSRC) is limited at the moment in the UK
- The UK Government wants to impose a nationwide RUC scheme for all motor vehicles, and is still considering different technological options. Several initiatives are currently still under way with DIRECTS being the most important one
- RUC will be based on a standard rate per mile according to the distance, time of day and route travelled
- In the short to medium term (2007 to 2015) RUC schemes based on DSRC (with ANPR for enforcement) is most likely. This approach could form the basis for a series of city centre congestion charging schemes and also be applied selectively to control congestion on motorways
- In the long term (after 2015) a satellite based system may form the basis for a nationwide road user charging scheme.

Car ownership and road congestion

In determining the future of UK transport policy the Department for Transport forecast that the total distance travelled will increase between 1.1% and 1.9% per annum over the next 25 years as a result of rising incomes and economic growth. Furthermore, lower costs of motoring and changing demographics encourages a continued shift to car journeys as the major form of travel.[13]

[13] Car journeys have increased from 79 per cent of the total distance travelled in 1980 to 85 per cent in 2002.

Figure A.8 – Forecasts of gross domestic product, costs of motoring distance travelled



Source: Department for Transport, "The future of transport: A network for 2030", July 2004

These changes have strong implications on the issue of road congestion. As demonstrated, a system of road pricing will allow travellers to make informed choices about how and when they travel, reducing congestion and the adverse impact of road traffic on the environment and other people.

Demand scenarios

We measure demand for RUC schemes in terms of the population in cities with congestion charging schemes. Based on the analysis set out above we assume that:

- The GPS/Galileo RUC system is mature enough for UK Government to proceed with the deployment of nationwide satellite based RUC scheme enforceable to all vehicles from 2020 on
- A nationwide satellite based RUC scheme is backwards compatible with previous RUC schemes such as the DSRC schemes considered in this profile
- Demand for DSRC is limited to the medium term (2007 to 2025) and to the main UK cities
- London will implement DSRC in 2008 and other major cities will follow according to the scenarios of Table A.4 and in order of decreasing population as set out in Table A.5.

Table A.4 – Demand scenarios for roll out of road user charging schemes using DSRC

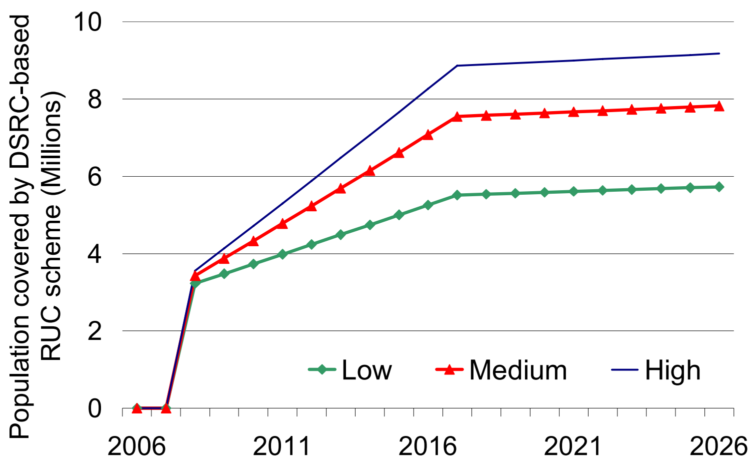
Scenario	Low	Medium	High
Start of implementation of DSRC in London	2008	2008	2008
Start of deployment of congestion charging scheme in other cities	2008	2008	2008
Rate of deployment (cities per year)	0.3	0.7	1
Maximum number of cities deployed	3	7	10
Full deployment by	2017	2017	2017

Table A.5 – List of cities poised for deployment of RUC schemes

City	Mid-year population in 2006	Annual population growth rate to 2026
Inner London	2,965,299	0.58%
Birmingham	1,001,973	0.48%
Leeds	722,051	0.17%
Glasgow	575,134	-0.22%
Sheffield	517,340	0.12%
Durham	496,502	-0.03%
Bradford	488,371	0.75%
Edinburgh	457,863	0.46%
Liverpool	444,500	0.00%
Manchester	440,422	0.39%
Bristol	396,746	0.36%

Source: Office of National Statistics, General Register Office for Scotland. Mid-year estimates for each city are available for 2004. The 2006 estimates are adjusted using the annual population growth rates.

Figure A.9 – Population covered by DSRC-based RUC schemes under the three demand scenarios



A.1.5 Economic value

We assess the economic value of DSRC based RUC schemes against a counterfactual in which London continues to use an ANPR based scheme and the other cities specified in the scenario of Table A.4 also implement ANPR based schemes. We considered an alternative counterfactual in which other cities did not implement an RUC scheme at all. But we rejected this alternative. It is clear, from the estimates made by TfL for the London scheme, that the net benefits of implementing an ANPR based scheme are substantial and that it makes logical sense for other cities to follow London's lead, even in the absence of DSRC technology. The additional economic benefits from DSRC technologies is to lower the costs of RUC when compared with ANPR schemes and so increase further the net benefits of RUC.

We assume that the economic value grows in proportion to the growth in the population of the cities that have implemented RUC schemes. We assess the economic value attached to the use of DSRC technology only. Other options, such as the satellite based systems, used licensed spectrum, and are therefore outside the scope of our study.

Benefits from reducing congestion

The main costs regarding road congestion for all involved parties include:[14]

- Time due to congestion delays, discomfort, fuel and other resource costs, fuel duties, and risk of accidents to the road users
- Wear and tear and marginal costs of use to the infrastructure provider
- Contribution to climate change, noise and air pollution, and indirect accident costs to the community around the road network

The benefits of RUC principally arise from the time savings and improved journey time reliability for those using the road network in and around the congestion charging zone as a result of reduced congestion. There are also fuel savings from reduced car travel (although it may be offset by turning to public transport), which in turn reduces emissions of carbon dioxide and other pollutants. Others benefits include a reduction in road accidents, and reductions in noise, community severance and other nuisances. Furthermore, the better use of the network that would result from pricing would minimise the impact of and need for new road infrastructure.

In London, compared to pre-charging levels in 2002, there was an average reduction in congestion of 26 per cent inside the charging zone with a corresponding 18 per cent reduction in traffic volumes. Transport for London also report that reliability of buses improved markedly since the introduction of the charging zone: additional waiting time for passengers due to service irregularity fell by 30 per cent, and disruption to services due to traffic delays fell by 60 per cent.

Costs of RUC schemes

As shown in the London congestion charging scheme, any road pricing system needs to incorporate more than charging technology. It needs an enforcement mechanism; and it needs systems to process charges and payments and handle enquiries. The daily licence schemes using ANPR cameras for enforcement in London have affordable setup costs, although this sort of technology has significant processing overheads and corresponding back-office costs.

The use of DSRC system will enable migration of end users to account-based charging instead of daily payments and substantially reduce customer-facing operations costs. Based on the analysis performed by TfL for Central London congestion charging scheme significant savings can arise. More specific, overall savings in using DSRC solution over a 5 year contract starting in 2008/2009 (when existing contract expires) could be as high as £20 million, compared to a solution using roadside ANPR and broadband communications and the current payment system.[15] According to TfL the London scheme operating and other costs amounted to £110 million in 2004/05, so switching to the DSRC solution would reduce these costs by almost 20 per cent.

The introduction of a road user charging scheme in London cost £110 million in 2004/05, which includes the initial setup costs, administration and enforcement of the scheme, and additional investment in public transport. This brought about total net benefits of £200 million. We assume that

[14] http://www.dft.gov.uk/stellent/groups/dft_roads/documents/divisionhomepage/032120.hcsp

[15] Transport for London, "London congestion charging technology trials. Stage 1 report", February 2005

with the DSRC technology, the London charging scheme will benefit from a cost reduction of £20 million per annum. For the 2.9 million people in inner London, this equates to benefits of around £7 per person per year.

Given our counterfactual, the total annual benefits from DSRC schemes are given by multiplying this annual saving per person (as set out in Table A.6) by the population covered by DSRC schemes.

Table A.6 – Assumptions on reduction in the running of RUC schemes (£ per person per year)

Scenario	Low	Medium	High
London and candidate cities	£5	£7	£9

A.1.6 Economic valuation projections

Figure A.10 shows the annual net benefits for the UK from using DSRC based RUC schemes and Table A.7 the NPV of these net benefits. In estimating the NPVs we assume that the termination value of net benefits post 2026 is zero. This reflects our assumption that satellite based technology will replace DSRC based schemes from 2020 on.

Finally Table A.8, Table A.9 and Table A.10 summarise the calculations of the net benefits under the low, medium and high demand scenarios.

Figure A.10 – Annual net benefits from DSRC based RUC schemes (£m, 2006 prices)

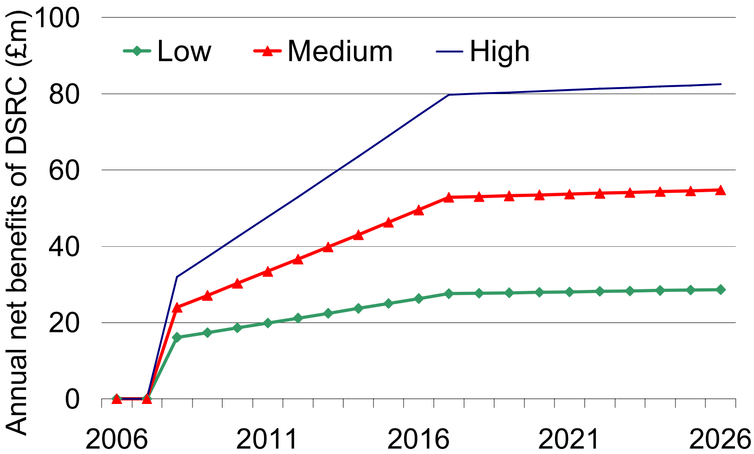


Table A.7 – Summary of net present value of RUC schemes (£m, 2006 prices)

	Net benefits from DSRC-based RUC scheme (£m)
Low	317
Medium	577
High	853

Detailed forecasts for each of the scenarios are summarised as follows.

Table A.8 – Annual benefits of DSRC based RUC schemes – Low demand scenario (2006 prices)

	2006	2011	2016	2021	2026
Reduced cost of DSRC-based RUC scheme (£ per person)	5	5	5	5	5
Total population covered by DSRC-based RUC scheme (000s)	0	3,982	5,256	5,609	5,730
Total benefits per annum (£m)	0	20	26	28	29

Table A.9 – Annual benefits of DSRC based RUC schemes – Medium demand scenario (2006 prices)

	2006	2011	2016	2021	2026
Reduced cost of DSRC-based RUC scheme (£ per person)	5	5	5	5	5
Total population covered by DSRC-based RUC scheme (000s)	0	4,779	7,078	7,667	7,823
Total benefits per annum (£m)	0	33	50	54	55

Table A.10 – Annual benefits of DSRC based RUC schemes – High demand scenario (2006 prices)

	2006	2011	2016	2021	2026
Reduced cost of DSRC-based RUC scheme (£ per person)	5	5	5	5	5
Total population covered by DSRC-based RUC scheme (000s)	0	5,298	8,260	8,997	9,170
Total benefits per annum (£m)	0	48	74	81	83

A.2 Application 2: Use of automotive radar to reduce traffic accidents

A.2.1 Description of the application

Table A.11 – Technology for road user charging schemes

Technology	Permit	Microwave	Tachograph	Satellite position Fix & map Matching
Link		Melbourne M6 Toll SR91		
Distance	Not applicable	Not applicable	Swiss (distance charging)	German (road segment charging)
Area / zonal	London Durham	Singapore Trondheim		

Source: Department for Transport

In the UK, ten people are killed and 110 people seriously injured every day on the roads.[16] Compared to the other EU countries, this is one of the lowest. There is a long history of making roads safer against the backdrop of increasing number of motor vehicles and higher traffic densities. The economic cost of accidents involving deaths or injuries is thought to be in the region of £3 billion a year. Across Europe, the estimated cost is around €160 billion, or 2 per cent of the GDP in Europe.[17]

In its second Road Safety Action Programme (1997-2001), the European Commission favoured an integrated approach to road safety, in which measures to prevent accidents from happening and measures to reduce the impact of accidents play an important role. In the third Road Safety Action Programme (2003) the Commission incorporated the objective of halving the number of deaths on EU roads by 2010.[18] This objective was translated to a maximum figure of 25,000 fatalities a year after the 2004 enlargement.

Current safety technology includes restraint systems such as air bags. These are based on vehicle deceleration signals and are deployed in the first fraction of an impact. There is no doubt that air bag systems have significantly reduced the number of severe and fatal injuries. Active and passive safety systems recognise critical driving situations with increased accident possibility. It triggers preventive measures to prepare the occupants and the vehicle for possible crash by evaluating the sensors of the Electronic Stability Program (ESP) and the Brake Assist (BAS). Reversible belt-pre-tensioners for occupant fixation, passenger seat positioning and sunroof closure are also activated.

[16] DTI, “Tomorrow’s roads: safer for everyone”, http://www.dft.gov.uk/stellent/groups/dft_rdsafety/documents/page/dft_rdsafety_504644.hcsp

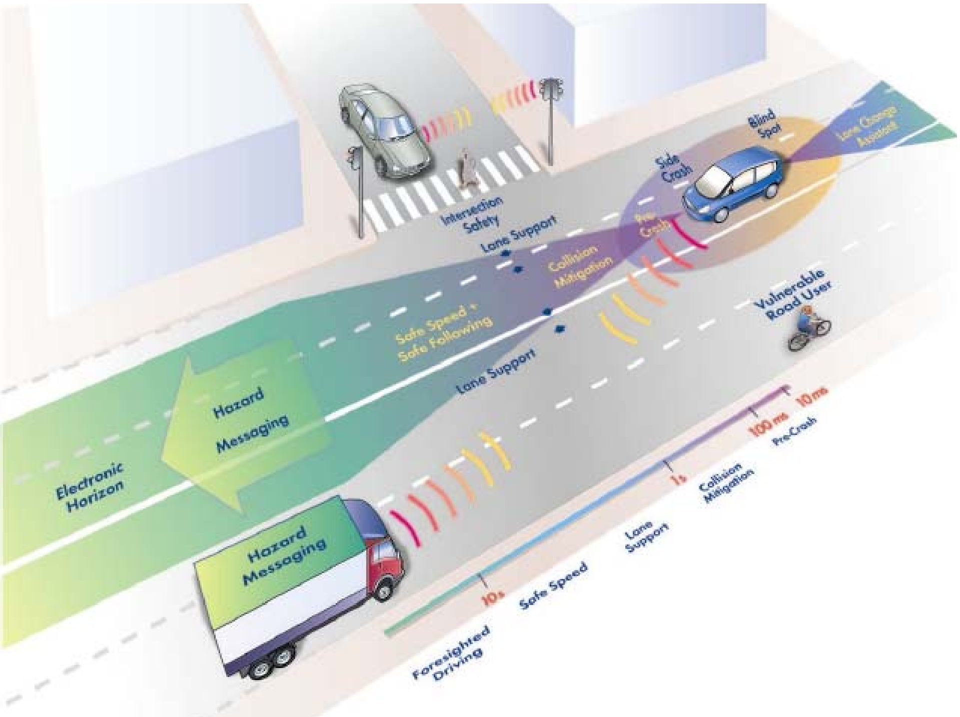
[17] European Commission, “Information and communications technologies for safe and intelligent vehicles”, 2003 http://europa.eu.int/eur-lex/en/com/cnc/2003/com2003_0542en01.pdf

[18] European Commission, “Halving the number of road accident victims in the European Union by 2010: A shared responsibility”, 2003, http://europa.eu.int/eur-lex/en/com/cnc/2003/com2003_0311en01.pdf

Next generation technology will take near-range environment into consideration, and short range radar (SRR) technology is thus expected to be the key enabler of this. Placing SRR sensors at intervals around the car leads to a "virtual safety belt" that explores several safety and assistance functions, such as collision warning, pre-crash sensing, preconditioning of restraints and air bags, lane change aid, blind spot detection, recognition of traffic members etc. These sensors can detect objects within a range of up to 30 metres, and plays an important role in providing the 360-degree sensing coverage and enhancing the active and passive safety of all road users as indicated in Figure A.11.

- Applications which enhance passive safety include obstacle avoidance, collision warning, lane departure warning, lane change aid, blind spot detection and airbag arming.
- Applications which enhance active safety include stop and follow, stop and go, autonomous braking, firing of restraint systems and pedestrian protection.

Figure A.11 – Short Range Radar – Functions relevant for enhancement of road safety



Source: WWW.PREVENT-IP.ORG

Complementary to SRRs described above are Long Range Radars (LRRs) which are sometimes referred to as Automatic Cruise Control (ACC). These operate at 77GHz and have a range of about 150 metres are designed to scan the path in front of the vehicle and determine the distance to the vehicle ahead in order to maintain a constant minimum safety distance. The frequency band around 77 GHz has now been reserved for vehicle and infrastructure radar systems.[19]

Short Range Automotive Radar Frequency Allocation (SARA), the industry group that represents companies involved in the development of such radar devices, has successfully lobbied for an allocation in the 24GHz band. Compared to 77GHz, the 24GHz SRR technology allows a design at reasonable cost today and can keep the product size small enough to fit in the space available while

[19] See Annex 5 of ECC/REC 70-03

providing useful range resolution and object separation required for tracking of objects around the vehicle.

The European Commission adopted a decision in early 2005 that allocated the 24GHz band to short range radar (SRR) devices for a time-limited period across the EU. Beyond 2013, the number of cars using SRR may grow to a level where other wireless services operating in this band could be affected. As a result, 79 GHz frequency band has been approved for automotive radars, and new applications will be required to use this band after this date.

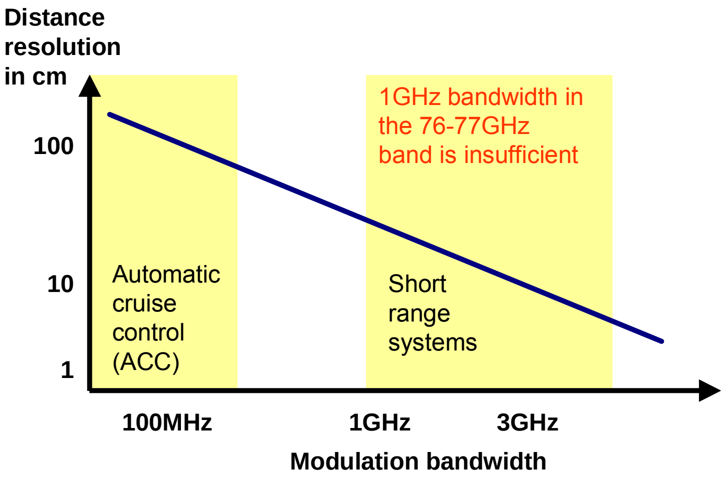
In the wider context of road safety, and with a spectrum-centric view, it can be noted that car-to-car and car-to-roadside/gantry communications will eventually be involved in making use of and/or distributing the data generated by the sensors on-board vehicles. Likewise, sensors will be utilised at the roadside or on gantries to improve overall road safety. The discussion that follows is restricted to on-board Short Range Radars as a self-contained application, noting that it may be difficult to separate out the benefits attributable to SRR rather than the rest of any transport safety infrastructure based on future developments in information, communications and technology.

A.2.2 Technical characteristics

The short range radar devices combine two functions. A precise speed measurement is obtained from the Doppler properties of a narrowband continuous wave emission. Radial range information (5 to 10 cm resolution) of objects is determined using a very wideband signal. Processing this information allows for the positions of objects to be determined and possible crash impact points and closing angles to be determined. The system can then alert the driver or execute counter-measures to prevent collisions or avoid / circumvent obstacles autonomously.

The range resolution is inversely proportional to the occupied bandwidth as shown in Figure A.12 below. For a 5cm resolution it can be determined that the minimum occupied bandwidth is approximately 5GHz. It can therefore be said that such a device will therefore have to operate either as an underlay or at much higher frequencies where such wideband emissions would be accommodated much more easily. The current frequency allocations reflect this situation.

Figure A.12 – Resolution versus bandwidth requirements



Source: ETSI TR 102 263 V1.1.2 (2004-02) & ETSI TR 101 982 v1.2.1 (2002-07)

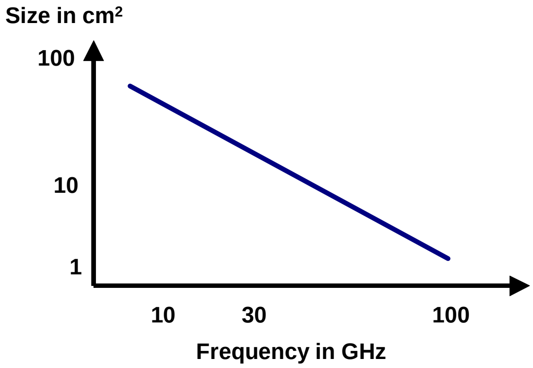
In the short term SRR devices will be allowed to be installed and operate in the 24 GHz band (21.65 – 26.65 GHz) on an underlay basis (until 30 June 2013 by virtue of EC Decision 2005/50/EC). Operation in this band has been limited because once the penetration of SRR reaches a certain level there is a potential for harmful interference to fixed links operating in the band. Operation beyond the cut-off date will be permitted for devices already installed or replacement devices. The 79 GHz band (77 – 81 GHz) has also been harmonised for SRR use (EC Decision 2004/545/EC) so a migration path is already in place.

This situation whereby use of the 24 GHz band is time limited arose because manufacturers of SRR devices had effectively undertaken the research and development necessary to put the devices into production before establishing that the frequency band was available. On requesting the regulatory authorities (through CEPT) for authorisation to use the band it became clear that there was the potential for SRR devices to interfere with fixed links (largely cellular backhaul) already operating in the band. The potential for interference only arises when there is a high density of SRR devices operating in the band (i.e. when the SRR market is mature). It was finally agreed that the 24 GHz band could only be used for a defined period with the expectation that 79 GHz devices would be developed to satisfy the demands of a mature market.

The attractiveness of different parts of the radio frequency spectrum is not just determined by resolution and hence bandwidth requirements, there is also the question of device size and manufacturing / commercial issues. The device size is dominated by the antenna and it has been stated that the automotive market accepts and area coverage of 50cm2. It can be seen from the unit size dependency with operating frequency shown in Figure A.13 below (15dBi gain) that frequencies below 15GHz are not usable.

Future automotive applications are planned for 63-65GHz and the 140GHz band in the longer term.

Figure A.13 – Relationship between frequency used and antenna size for 15 dBi gain



Source: ETSI TR 102 263 V1.1.2 (2004-02) & ETSI TR 101 982 v1.2.1 (2002-07)

A.2.3 Evolution of demand

While research into Short Range Radar has been going on for some time the most recent driver for wide scale adoption has come from the European Commission. In order to achieve the Commission's target of reducing road fatalities by 50 per cent by 2010, they published a European road safety action programme where Intelligent Transport Systems (ITS) were identified as one element of this. DG Enterprise and DG Information Society have therefore established the eSafety initiative jointly which aims to accelerate the development, deployment and use of Intelligent Integrated Safety Systems of which Short Range Radar is an element. The Commission Decisions harmonising the 24 GHz and 79 GHz bands for SRR are directly related to this initiative.

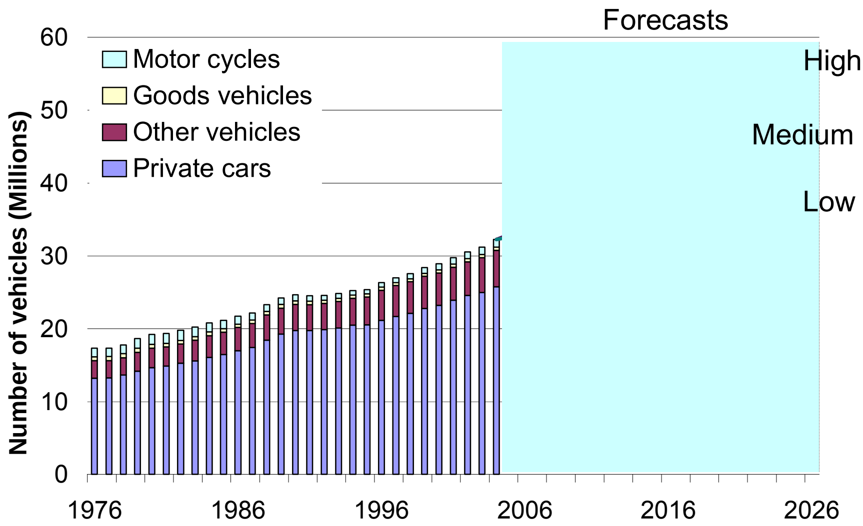
Motor vehicles

The Department for Transport publishes statistics on the number of vehicles registered in the UK.[20] Private cars make up around 80 per cent of all vehicles, and since 1970, the total number of vehicles has increased steadily at around 2.3 per cent per annum. We assume that road safety technology will be available to all vehicle types such as private cars, motor cycles, goods vehicles, and public transport vehicles.

Table A.12 – Summary of model assumptions for addressable market

	Low	Medium	High
Number of motor vehicles in 2006 (Millions)	33.78	33.78	33.78
Annual growth rate (%)	1%	1.50%	2.30%

Figure A.14 – Number of motor vehicles licensed, historical and forecasts



Source: Department for Transport

Demand scenarios

We use as our measure of demand the number of cars using automotive radar. In the original ETSI Technical Report relating to 24GHz SRR suggest a more than doubling of SRR penetration every 5 years between 2005 and 2015 then flattening off slightly to give a 40% penetration in 2020 shown in Table A.13.

[20] Department for Transport, “Transport Statistics for Great Britain 2005 edition”, January 2006.

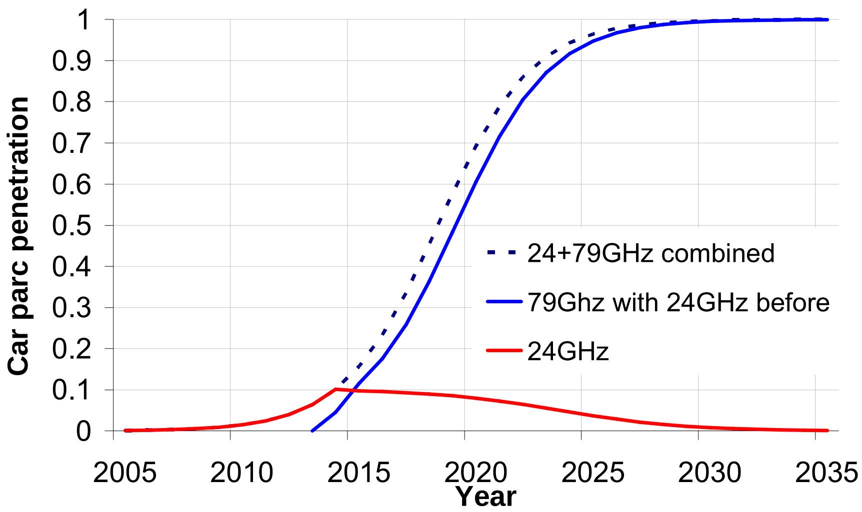
Table A.13 – Demand for SSR (Original ETSI report)

	2003	2004	2005	2010	2015	2020
Car production rate (Millions of units /year)	17	17.5	18	18.6	19.1	19.7
Car using SSR (%)	0.06	0.3	5	12	26	40
Cars using SSR (Thousands of units)	10	53	900	2,232	4,966	7,880
Average units per car (Units)	4	6	8	6	5	4
Price per sensor unit (EUR)	65	60	50	32	20	15
Value per car including others (EUR)	460	510	490	250	130	78
Total value per car (Million EUR)	4.7	26.8	441	558	645.6	614.6

Source: ETSI TR 101 982 v1.2.1 (2002-07)

The more recent ETSI Technical Report relating to 79 GHz SRR has changed the original forecast so that the take-off point (5% penetration) has slipped from 2005 to 2012 followed by a much accelerated increase in penetration such that the 40% penetration is reached by 2018 as shown in Figure A.15. It can be seen that the same growth (5% to 40% penetration) originally anticipated over a 15 year period is now forecast for a six year period. This curve is consistent with the assumption that all new cars from 2014 on are fitted with automotive radar and that the retrofit market for these devices is modest.[21]

Figure A.15 – Demand for SSR (New ETSI report)



Source: ETSI TR 102 263 V1.1.2 (2004-02)

For the purposes of our study, we assume that the take up of SSR devices as forecast in the new ETSI report is applied to the stock of motor vehicles. We recognise that the majority of the

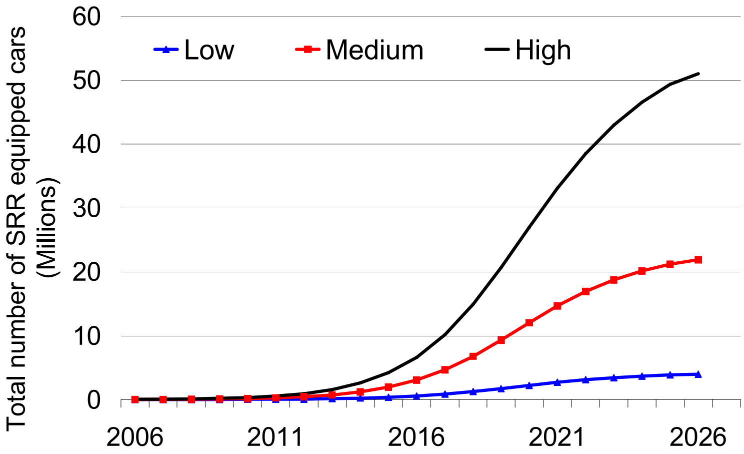
[21] According to one observer, it is 5 per cent or less.

installations in the early stage will likely be in newly manufactured cars, which will gradually encourage the take up in existing cars. We consider three scenarios.

- High demand. Demand follows the latest ETSI projection (Figure A.15) with 100 % of UK cars using automotive radar by 2035
- Medium demand. Scale the ETSI projection so that 50% of UK cars use automotive radar by 2035
- Low demand. Scale the ETSI projection so that 10% of UK cars use automotive radar by 2035

Furthermore, we assume that once installed, these devices have to be replaced every 12 years and that the replacement costs are the same as installation costs. Thus after 2018, around 8 per cent of the installed base of SRR devices will be replaced every year at current cost.

Figure A.16 – Forecasts of demand for short range radar devices (Millions of cars)



A.2.4 Economic value

We quantify incremental economic benefits against a counterfactual in which automotive radar is not fitted to cars in the UK. Table A.14 specifies which costs and benefits which we quantify and those which we exclude from our projections.

Table A.14 – Quantified costs and benefits

Benefits	Quantified?	Costs	Quantified?
Reduction in injury to people	Yes	Costs of automotive radar units in cars	Yes
Reduction in damage to cars and other property	Yes		
Increase in road capacity as a result of fewer accidents	No		
Need for additional road capacity reduced	No		
Congestion reduced because drivers feel safer and drive safer	No		

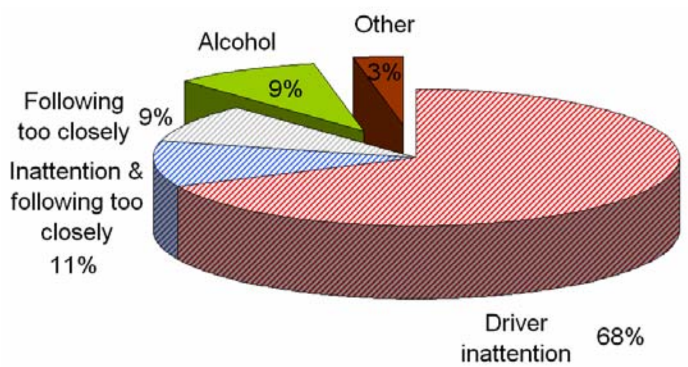
The benefits revolve around the saving of lives and avoidance of injury, as well as avoiding damage of goods, whether the vehicles themselves or other objects with which the vehicles would otherwise collide. However there are other less direct benefits that accrue which we do not value in this study. In the first instance, there will be a reduction in congestion resulting from accidents which translates into shorter journey times. Furthermore, the use of such devices will allow for a greater density of vehicles on the road which translates into savings in road building. We expect these benefits to be minor in comparison with those quantified.

We also assume that the current trend towards more and better enforced speed limits will continue, thus behavioural changes in driving attitudes (such as driving faster) that might be brought about by SRR devices will be ignored.

Road accident reduction

With the rise in the number of cars and higher traffic densities across the EU, there is a need to introduce measures that help prevent and avoid road accidents. According to the 2004 ETSI report, “every second accident involving vehicles is related to traffic situations in which a faster reaction of the driver could have avoided crashes”. SRR has been identified as the key enabling technology for enhanced active safety systems and the mitigation of rear-front crashes, which leads to a reduction in damages of property and saving of lives. Some estimate that as high as 88 per cent of rear-front crashes could be prevented.

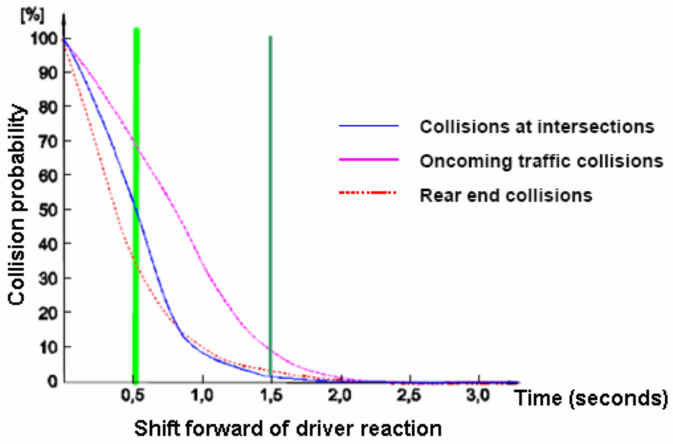
Figure A.17 – Causes of rear-front crashes



Source: ETSI TR 102 263 v1.2.1 (2004-02)

The degree of benefit to be obtained in preventing collisions can be seen to be related to improving driver reaction as shown in Figure A.18. Improving a driver’s reaction time by half a second reduces oncoming collisions by 30%, rear end collisions by 65% and collisions at intersections by 50%.

Figure A.18 – The effect of SSR on car reaction times



Source: 7th International Technical Conference on Experimental Safety Vehicles, 1979 Enke, DaimlerChrysler

SARA[22] suggested that collision warning systems and automatic vehicle intervention effectively shifts the reaction forward by 1.5 to 2 seconds thereby reducing collision probability by 94 per cent. This is evidence of a significantly greater reduction in accidents through use of automotive radar than that assumed by Ofcom in its cost benefit analysis of 2005.[23]

Using the take up of anti-lock braking (ABS) and electronic stability programme systems (ESP) as an analogy, Ofcom estimate that SRR penetration will increase from 1% to 13% between 2010 and 2014.[24] Assuming that the installed equipment may only be able to stop 5% to 10% of accidents involving vehicles with the equipment installed, Ofcom estimate the NPV of the benefits to be in the range £139 million to £279 million for the period. These figures do not include benefits accruing from the avoidance of damage-only accidents.

We assume that:

- Without automotive radar accidents and damage remain at 2002 levels,[25] i.e. new car technologies and regulation (such as speed limits) offset the increase in traffic over the next 20 years
- With the introduction of SRR devices, reductions in road accidents will be proportional to the growth in adoption of these devices
- We ignore the case of multiple collisions. A car which causes a multiple collision might avoid this accident if fitted with automotive radar and so increase overall benefits. On the other hand the faster reaction times of a car fitted with automotive radar fitted car might cause following, unequipped, cars to collide with it, so lowering benefits. We propose to assume that these factors balance each other and ignore the effect of multiple collisions. In any case most accidents involve one or two cars
- Over the forecast period there will be an annual reduction of:

[22] SARA, "Ultra wide band 24GHz radar sensors for automotive radar", UWB Workshop, 11 April 2002

[23] Ofcom, "Notice of Ofcom's proposal to exempt the use of automotive short-range radar equipment at 24GHz from Wireless Telegraphy licensing. Consultation document.", April 2005

[24] Note that this assumes devices operating in both the 24 GHz and 79 GHz bands. The 24 GHz cut-off date is 2013 and the penetration of 24 GHz devices is required to be kept below 7%.

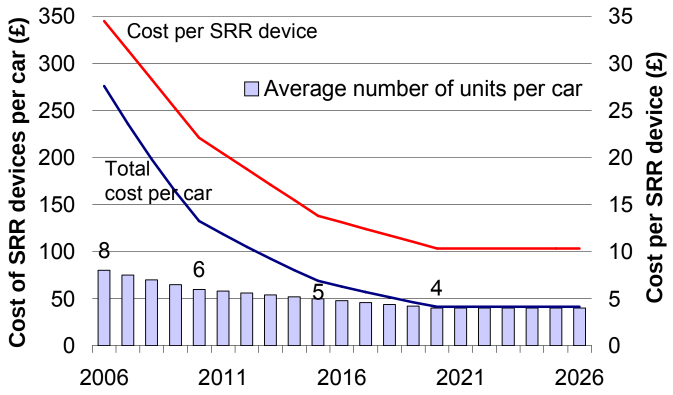
[25] This is broadly consistent with accident rates over the past ten years in the UK. In the period from 1990 to 1997 traffic accidents rose and then fell by a similar amount in the next 5 years

- 50% in road accidents as indicated by SARA and ETSI (high impact scenario)
- 10% in road accidents as assumed by Ofcom in its cost benefit analysis (low impact scenario)
- 30% in road accidents (medium impact scenario)

Costs of SRR devices

Using the cost estimates shown in Figure A.19, we will assume that the number of sensors per car will decrease from 8 in 2006 to 4 in 2020, with the price per unit falling from €50 to €15 over the same period. These estimates are based on the ETSI projections of Table A.13.

Figure A.19 – Cost of short range radar devices (£ in 2006 prices)



Benefits of road accident prevention

The 2005 Ofcom Regulatory Impact Assessment (RIA)[26] used estimates from the 2002 Department for Transport's Highway Economics Note on the valuation of the benefits of prevention of road accidents and casualties. This note is revised annually, and the most up-to-date version of this study was published in December 2005.[27] The values for the prevention of fatal, serious and slight casualties include the following elements of costs:

- Loss of output due to injury, calculated as the present value of expected loss of earnings plus any non-wage payments paid by the employer, such as national insurance contributions
- Ambulance costs and costs of hospital treatments
- Human costs, based on willingness to pay values, which represent pain, grief and suffering to the casualty, relatives and friends, and for fatal casualties, the intrinsic loss of enjoyment of life over and above the consumption of goods and services

In 2004, 2,978 fatal accidents, 26,748 serious accidents and 177,684 slight accidents were reported. In cost benefit terms, the value of preventing these 207,410 injury accidents was estimated to have been £12.9 billion in 2004 prices. In addition, there were an estimated 3.1 million damage-only accidents valued at £5,104 million, giving a total value of prevention of road accidents of just over £18

[26] Ofcom, "Notice of Ofcom's proposal to exempt the use of automotive short-range radar equipment at 24GHz from Wireless Telegraphy licensing. Consultation document.", April 2005

[27] Department for Transport, "2004 Valuation of the benefits of prevention of road accidents and casualties", December 2005, http://www.dft.gov.uk/stellent/groups/dft_rdsafety/documents/divisionhomepage/030763.hcsp

billion. The average value of prevention is around £86,810 per accident, which includes an allowance for damage only accidents. Details are provided in Table A.15.

Table A.15 – Average value of prevention per accident by severity and element of cost (£, 2004 prices)

Accident severity	Average value of prevention (£)
Fatal	1,573,220
Serious	184,270
Slight	18,500
All injury	62,200
Damage only	1,650
Average cost per injury accident including an allowance for damage on accidents	86,810

Source: Department for Transport (2005)

Note that there is usually more than one casualty involved in an accident. In 2004, there were approximately 2 casualties per accident, i.e. the average cost per casualty is around half the average cost per accident.

Table A.16 – Average value of prevention per casualty by severity and element of cost (£, 2004 prices)

Injury severity	Lost output	Medical & ambulance	Human costs	Total
Fatal	475,922	817	907,698	1,384,463
Serious	18,336	11,108	126,128	155,563
Slight	1,938	822	9,233	11,991
Average, all casualties	9,192	1,962	32,495	43,649

Source: Department for Transport (2005)

Based on these statistics, the prevention of 1 per cent of accidents in the UK would provide a benefit of around £129 million in 2004 prices. Similarly, avoiding 1 per cent of damage-only accidents would bring about benefits of around £51 million.

We use the Department's methodology and up-rate these estimates to 2006 prices by the percentage increase in nominal GDP per capita from 2004 to 2006. This is based on the assumption that the real cost of each element of accident costs (such as labour costs) will increase in line with increases in output. We adopt the Department's GDP per capita growth figures of 2.96% for 2005 and 2.46% for 2006. In line with the HM Treasury Green Book,[28] we assume that real long term growth of GDP in the UK is 2 per cent per annum beyond 2006. Coupled with the Office of National Statistics[29] estimate of a 0.5 per cent increase in population per annum, we apply an annual growth rate of 1.5 per cent to

[28] http://greenbook.treasury.gov.uk/annex06.htm#long

[29] http://www.statistics.gov.uk/StatBase/Product.asp?vlnk=6303

the value of prevention of road accidents over the forecast period which reflects growth in GDP per head.

Summary

We assume that the use of automotive radar reduces the probability of road accidents and use the valuation estimated by the Department for Transport. By using the value of prevention per accident rather than per casualty takes into account the fact that accidents will typically involve more than one casualty.

Table A.17 – Summary of model assumptions for costs and benefits of SRR devices

	Low	Medium	High
Replacement cycle of SRR devices (years)	12	12	12
Cost of SRR devices		See Figure A.19	
Number of road accidents in 2006	207,410	207,410	207,410
Annual growth rate (%) in road accidents	0%	0%	0%
% of accidents involving SRR equipped cars		Same as % of cars equipped with SRR	
Reduction in probability of accident for cars fitted with SRRs	10%	30%	50%
Value of prevention per accident in 2006	£86,810	£86,810	£86,810
Growth rate in value of prevention	1.50%	1.50%	1.50%

A.2.5 Demand valuation projections

Using the assumptions of Table A.13 applied to the SRR take up of Figure A.15 gives the net benefit projections of Figure 1.10 and the NPVs of Table 1.7. In calculating the NPVs we assume that, beyond 2026, the net benefits will continue, although they are discounted by the probability that future communications technologies will present superior alternative solutions and diminish the value of the benefits attached to this particular application. We assume this probability will increase by 10% per annum.

Figure A.20 – Annual benefits of using automotive radar to reduce accidents (£m, 2006 prices)

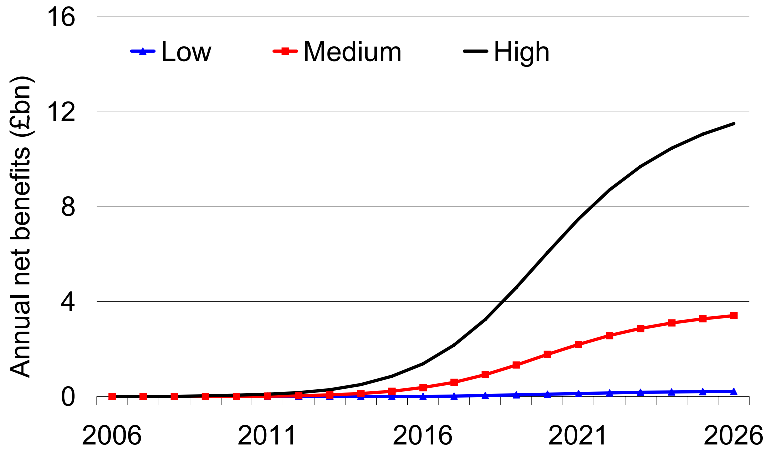


Table A.18 – Total net present value of using automotive radar to reduce accidents (£m, 2006 prices)

Scenario	Total benefits (£m)
Low	1,560
Medium	26,007
High	88,242

Detailed forecasts for each of the scenarios are summarised as follows.

Table A.19 – Annual benefits of automotive radar devices – Low demand scenario (2006 prices)

	2006	2011	2016	2021	2026
Total number of motor vehicles in the UK (Millions)	33.8	35.5	37.3	39.2	41.3
Total number of vehicles with SRR devices (Millions)	0	0.1	0.6	2.7	4
Annual take up of SRR devices (Millions)	0	0	0.3	0.6	0.4
Installation cost per car (£)	-276	-118	-63	-41	-41
Installation cost per annum (£m)	-1	-5	-22	-26	-18
Average cost per road accident (£000)	87	94	101	109	117
Number of accidents prevented	3	31	324	1,438	2,001
Benefits from reducing road accidents (£m)	0	3	33	156	235
Total net benefits from automotive radar (£m)	-1	-2	11	130	217

Table A.20 – Annual benefits of automotive radar devices – Medium demand scenario (2006 prices)

	2006	2011	2016	2021	2026
Total number of motor vehicles in the UK (Millions)	33.8	36.4	39.2	42.3	45.4
Total number of vehicles with SRR devices (Millions)	0	0.3	3.1	14.7	21.9
Annual take up of SRR devices (Millions)	0	0.2	1.9	3.5	2.4
Installation cost per car (£)	-276	-118	-63	-41	-41
Installation cost per annum (£m)	-4	-24	-116	-144	-97
Average cost per road accident (£000)	87	94	101	109	117
Number of accidents prevented	39	467	4,867	21,566	30,021
Benefits from reducing road accidents (£m)	3	44	491	2,345	3,518
Total net benefits from automotive radar (£m)	-1	20	375	2,200	3,420

Table A.21 – Annual benefits of automotive radar devices – High demand scenario (2006 prices)

	2006	2011	2016	2021	2026
Total number of motor vehicles in the UK (Millions)	33.8	37.9	42.5	47.7	52.8
Total number of vehicles with SRR devices (Millions)	0	0.6	6.7	33.1	51
Annual take up of SRR devices (Millions)	0	0.4	4.1	8.2	5.5
Installation cost per car (£)	-276	-118	-63	-41	-41
Installation cost per annum (£m)	-9	-51	-257	-338	-227
Average cost per road accident (£000)	87	94	101	109	117
Number of accidents prevented	129	1,555	16,224	71,888	100,069
Benefits from reducing road accidents (£m)	11	146	1,636	7,815	11,726
Total net benefits from automotive radar (£m)	2	95	1,379	7,477	11,500

A.3 Application 3: Active medical implants

A.3.1 Description of the application

Technological improvements in both ultra low power transceivers and battery technologies now make it possible for doctors to implant wireless sensors, pumps and other devices within the body. These then communicate, often using licence exempt spectrum, with monitors, recording devices and drug delivery devices. There is a range of devices which use LE spectrum in this way. They include:

- ***pacemakers*** to keep the heart beat regular following a heart attack. A well established application, pacemakers increasingly use wireless for reprogramming and for delivering data for clinical evaluation
- ***defibrillators*** which are implanted into patients with certain heart conditions. They reduce the likelihood of severe and possible fatal heart attacks by keeping the heart action regular when an attack occurs[30]
- ***neuro-stimulators*** to relieve chronic pain. These implants stimulate nerves, especially in the spinal cord, to bring relief to patients suffering from otherwise intractable pain. Wireless transmitters allow doctors to adjust the form of nerve stimulation
- swallowed ***micro video cameras*** which relay video images of the patient's intestines to doctors for diagnostic evaluation
- ***heart condition monitors***. Patients recovering from heart attacks use on-body or in-body sensors to record key functions which are relayed wirelessly to a monitoring station. This allows patients to start therapeutic exercise earlier than was previously possible.
- ***glucose sensors*** for patients with Type 1, and possibly Type 2, diabetes. We have selected this application for detailed evaluation.

Figure A.21 shows the general model for all of these applications:

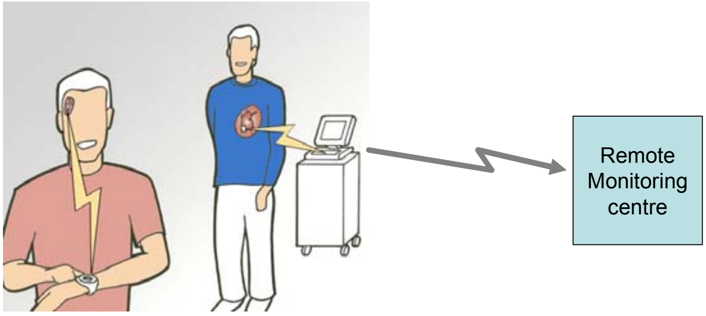
- The implant within the body transmits information to an external monitor or receives instructions from it. Often this monitor is carried by the patient. The wireless signal typically travels through the body for up to a metre. The FCC and the ERC of the CEPT have allocated LE spectrum is range 402 to 405 MHz for such radio communications.[31] This frequency range was chosen because it propagates well through the body and so reduces the power used by the wireless implant
- Information gathered by the external monitor may then, depending on the application, be relayed to a remote monitoring station within the hospital for diagnostic and/or monitoring purposes. This wireless link gives the patient more freedom and allows him or her to remain under close supervision whilst taking therapeutic exercise. In the USA the FCC has allocated spectrum in the 608 to 614 MHz, 1395 to 1400 MHz and 1429 to 1432 MHz ranges for exclusive use by wireless medical telemetry services (WMTS). Spectrum is lightly licensed. Users must register with a co-ordinator to manage interference. Use is limited to healthcare providers who must not interfere with co-users of the spectrum[32]. There are also strict limits on transmission power. ETSI ERM TG30 is currently planning new frequency bands for WMTS in the EU.

[30] 150,000 die in the UK from sudden cardiac arrests each year. 85% of these deaths are preventable if a defibrillator is used immediately to prevent a condition known as ventricular fibrillation

[31] This is now known as the medical implants communication services (or MICS) band

[32] For example. radio astronomers

Figure A.21 – Use of wireless with active medical implant devices



MICS – typically 1 metre WTMS – typically 400 metres

Medical equipment manufacturers supply these wireless implants together with associated equipment and supplies to hospitals for use with patients as appropriate.

A.3.2 Technical characteristics

Active medical implants in the US now increasingly use frequencies in the 402 to 405 MHz band. In Europe ETSI has developed reference documents for use of ultra low power active medical implant devices (ULP-AMID) for frequency bands:

- 9 to 315 kHz
- 12.5 to 20 MHz
- 30 to 37.5 MHz
- 401 to 406 MHz.

In general the devices using these frequencies are characterised by:

- modest bandwidth requirements
- a low duty cycle (typically less than 1%)
- short distance propagation requirements (1 to 2 metres)
- a requirement for harmonised use at a global level. Patients using active medical implants travel to other countries where they may require hospital treatment
- few interference concerns given the short range and ultra low power of the devices

WMTS are more challenging because transmission ranges are greater and interference more likely. Given the safety-of-live nature of these applications the FCC has an established, dedicated and light licensed band for this use. The CEPT is also considering dedicated allocations.

A.3.3 Evolution of demand

Currently around 400,000 active implanted medical devices are used in the UK.[33] This number is expected to grow substantially over the next 10 to 20 years given that:

- use of active medical implants is in its infancy for many applications
- the chip sets required for efficient performance are only now emerging onto the market

[33] CEPT ECC Report on SRDs (FM(06)091 Annex 09 estimates that there are 3 million such devices in use in the European Economic Area

- the population of the UK is aging fast. Currently 4.4 million are over 75. This will grow to 8.4 million by 2030, so stimulating demand for medical treatment[34]

It is very difficult to get estimates of the value of the market for active medical implants. One study[35] estimates that the market for implanted medical devices in the US was worth $18 billion in 2004 growing to $25 billion by 2007. If scaled for UK expenditure on health care, this translate to a market worth £900 million per annum in 2004 growing to £1280 million per annum in 2007 for the UK.

The drivers and barriers to take up for active medical implants are specific to each application. We have chosen for a valuation the use of glucose sensors in the treatment of diabetes. Demand for this application is potentially very substantial but highly uncertain. Nonetheless there is a clear need for more effective treatments of diabetes.

Diabetes in the UK

Diabetes is of two types:

- Type 1 diabetes develops, usually before the age of 40, if the body is unable to produce insulin to regulate the level of glucose in the blood. Around 12% of UK diabetics are in this category. To date Type 1 diabetes has been treated with insulin injections.
- Type 2 diabetes develops when the body is unable to produce sufficient insulin. This type of diabetes normally first appears in people over 40 and is typically treated through diet, exercise and tablets. It is closely associated with obesity and is more prevalent amongst certain ethnic groups.

Without treatment diabetes is usually fatal. It is also difficult with conventional treatment to keep the blood glucose levels within health limits. Too much glucose in the blood (hyper-glycaemia) and too little glucose in the blood (hypo-glycaemia) both damage health. Attacks of hypo- and hyper-glycaemia are common, especially in the substantial proportion of diabetics who do not follow their treatment regimes rigorously. As a result diabetics suffer from substantially increased risk of strokes, heart disease, kidney failure, blindness and lower limb amputations than the rest of the population. This leads to substantial reductions in life expectancy. Estimates of the reduction in life expectancy range from 12 years[36] to 20 quality adjusted life years.[37]

The incidence of diabetes is rising rapidly as the population ages and becomes more obese. Figure A.22 illustrates for the UK. In 2005 over 2.1 million people diagnosed with diabetes in the UK (over 3 per cent of the population) and a further estimated 1 million undiagnosed Type 2 cases.[38] The number of diagnosed diabetics is expected to grow to around 3 million in 2010[39]. This does not include the number of undiagnosed Type 2 diabetics.

[34] Key Note, "Medical Equipment Market Report", November 2003

[35] Freedonia, "Implanted Medical Devices", 2005

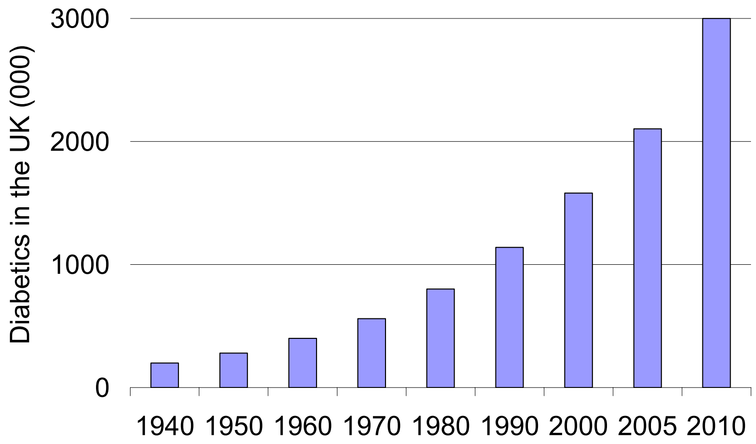
[36] Health related quality of life in Ontario 1996 to 1997, Diabetes Care, 2004, D Manuel and S Shultz

[37] Lifetime risks from diabetes in the US, Venkat Narayan et al, Journal of the American Medical Association, October 2003)

[38] Diabetes UK, "Diabetes - The state of the nation 2005", 2005

[39] Audit Commission, "Testing Times. A review of diabetes services in England and Wales", 2000

Figure A.22 – Growth of diabetes in the UK



The Yorkshire and Humber Public Health Observatory, in collaboration with the Department of Health and the National Diabetes Support Team developed spreadsheet model that generates expected total numbers of persons with Type 1 and Type 2 diabetes mellitus (diagnosed plus undiagnosed combined) in 2001 for England.[40] Phase 2 of the PBS diabetes population prevalence model estimates the total number of diabetics in England to be between 2.2 million to 2.6 million in 2010 (or 4.2 to 5.1 per cent of the population in England), depending on the assumptions of trend in obesity. Compared to their 2001 estimate, this represents an annual growth rate of 0.2 per cent under the declining obesity scenario, 1.1 per cent per annum under the static obesity trend scenario and 2.1 per cent per annual under the increasing obesity scenario.

Table A.22 sets out the assumptions we make use to make projections of the number of Type I and Type II diabetics.

Table A.22 – The future incidence of diabetes in the UK

Measure	Type 1	Type 2	Source
UK population (m)	60.5	60.5	Office of National Statistics
Population growth 2006-2076 (%)	0.2%	0.2%	Government Actuary Department
Number of diabetics in 2006 (Millions)	0.25	1.85	Diabetes UK
% of population with diabetes in 2006	0.4%	3.1%	
Age expectancy (Years)	60	60	
Maximum long term % of population with diabetes	1%	20%	Based on US projections

[40] http://www.yhpho.org.uk/resources_diabetes.aspx

Demand scenarios

Measure of demand: Take up of in body glucose sensors by both Type 1 and Type 2 diabetics.

There are a number of studies which demonstrate that tight control of blood glucose levels substantially cuts the risk of complications from diabetes and so increases life expectancy. These include:

- Diabetics Control and Complications Trial in the US in the mid 1990s
- UK's Prospective Diabetes Study on Type 2 diabetics in the late 1990s.

Key to achieving effective and continuous control of blood glucose levels 24 hours per day is the development of an accurate and responsive sensor of blood sugar levels. This might then be linked to an insulin pump which would automatically inject minute amounts of insulin into the blood and so create an artificial pancreas.[41]

There is a number of continuous glucose sensing devices now on the market or in development. These are three main types:

- ***transcutaneous sensors*** e.g. the Glucowatch G2. These are non invasive devices[42] designed to reduce the risks of hypo or hyperglycaemia rather than to provide accurate monitoring of glucose levels
- ***enzyme based sensors*** e.g. the Medtronics Mini-med GGMS. Such devices are implanted into the subcutaneous tissues where they measure the level of certain enzymes. This is highly correlated with blood sugar levels
- ***intravenous continuous glucose sensors*** which are implanted in one of the patient's veins. These devices are now in prototype development.

The first two device types both require repeated[43] calibration. This is normally done by the patient taking a finger prick blood sample for analysis. The third type, which uses transcutaneous telemetry via the 402 to 405 MHz (MICS) band to relay information on glucose levels to external monitors, is more responsive and potentially more accurate. But it is clearly more expensive to install and potentially increases the risk of thrombosis. It is this third type of device for which we make projections of demand and economic value.

Given this analysis we conclude that:

- The current levels of use of licence exempt spectrum for glucose sensors in the UK is zero
- Take up is at least 5 years away. Prototype sensors are now under development, but will require approval[44] before they are used on a widespread basis within the NHS
- The addressable market is very substantial. There are nearly two million people diagnosed with diabetes in the UK and this number is growing at 9% per annum. Most Type 1[45] and some Type 2 diabetics might benefit from in-body glucose sensors in future

But any projections of demand for in body glucose sensors are speculative:

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[41] According to Medtronics, a leading supplier of insulin pumps, 1 in 1000 diabetics in the UK use such pumps. In Germany and the US the ratio is 1 in 7.

[42] For example, on body rather than in body

[43] 4 times per day or more

[44] For example by the National Institute for Clinical Excellence (NICE) in the UK

[45] 15% of UK diabetics

- There are a number of substitutes for in-body glucose sensors which do not use LE spectrum. There is a significant probability that these other devices will provide the required continuous monitoring function so that demand for in-body glucose sensors becomes negligible
- In body sensors are still in laboratory trials. There is a good chance that the technology will fail
- In body sensors must be subjected to evaluation by NICE, who might reject them
- Even if proved cost effective by NICE, the NHS might decide to spend its budget in other ways.

In the light of this analysis we propose the demand scenarios set out below. Table A.23 tabulates the assumptions which make up the three scenarios on demand for in body glucose sensors (IBGS) together with the associated probabilities of each scenario being realised. Figure A.23 then graphs the projected growth in the number of diabetics and the take up of IBGS for the high demand scenario.

We estimate the number of IBGS installed each year (separately for Type I and Type II diabetics) as:

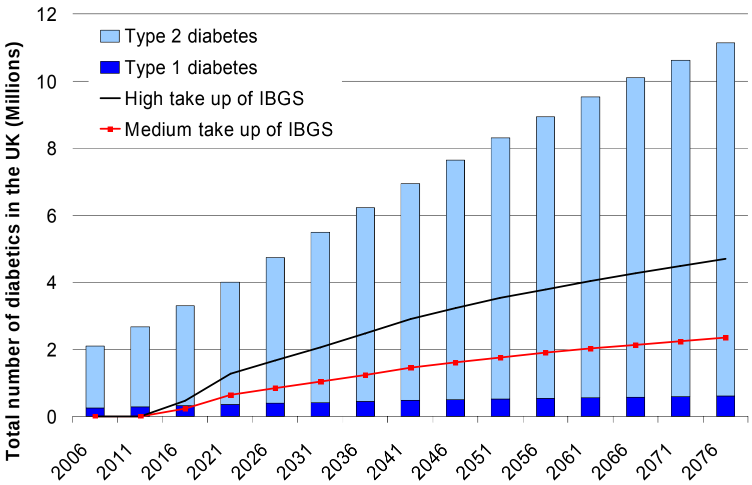
- The increase in the number of diabetics plus
- The deaths of diabetics (estimated by dividing the number of diabetics by their life expectancy) and multiplying by
- The proportion of diabetics using IBGS.

This gives us an estimate of the number of new patients who are treated using in body glucose sensors. To this we then add a small and transient component for the treatment of existing diabetics with IBGS.

Table A.23 – Take up of in body glucose sensors

Scenario	Low	Medium	High
Start date for use of in body glucose sensors	Never	2011	2011
Maximum % of diabetics who use IBGS long term			
Type 1			
Existing patients	0%	20%	40%
New patients	0%	40%	80%
Type 2			
Existing patients	0%	10%	20%
New patients	0%	20%	40%
Number of years it takes to reach maximum take up	10	10	10
Life expectancy	0%	20%	40%
Scenario probability	60%	20%	20%

Figure A.23 – Projections of growth in diabetics and IBGS use in high demand scenario



A.3.4 Economic value

We use as our counterfactual a scenario in which in body glucose sensors are not adopted in the UK. Table A.24 specifies the costs and benefits which we quantify in our projections.

Table A.24 – List of quantified costs and benefits

Benefits	Quantified?	Costs	Quantified?
Increased life expectancy for diabetics	**Yes**	**Cost of device**	**No**[1]
Time saving for patients who no longer attend diabetic clinics so often	**No**	**Cost of implant**	**No**[1]
		Cost of patient care	**No**[1]

1 We assume that these costs are negligible compared with the benefits

There is considerable economic value from using an accurate continuous glucose monitoring device – especially if it is coupled with use of an insulin pump.[46] Such an artificial pancreas would use a closed loop system, probably using a wired rather than wireless connection. But it would still need licence exempt spectrum to relay information on blood sugar levels back to external monitors for clinical evaluation.

There are as yet no studies to show how such devices might extend the quality adjusted life expectancy of a diabetic patient. However one study did suggest that more intensive monitoring of glucose levels in Type 2 diabetics using conventional detection and treatment methods extends life expectancy by 0.27 years.[47] We would expect extensions of life expectancy to be substantially greater than this for both Type 1 diabetes and for use of the more accurate control of glucose levels which in-body sensors should make possible.

[46] Perhaps implanted into the stomach wall

[47] PM Clarke et al, "A model to estimate the lifetime health outcomes of patients with Type 2 diabetes", Diabetologia, 2004, 47, 1747-1759

Given this finding and given the reduced life expectancy for diabetics between 12 and 20 years, we propose making the following assumptions to estimate the economic value of using license exempt spectrum for in-body glucose sensors:

- In-body sensors, when used, extend the quality adjusted life expectancy of ***Type 1*** diabetics by ***two years*** and of ***Type 2*** diabetics by ***one year*** when compared with other techniques
- The benefits, which are highly speculative, substantially outweigh the costs. So we ignore the costs in our calculation
- Every quality adjusted life year (QALY) gained is worth £30,000. This estimate is based on the way in which health care budgets in the UK and the US are spent. On average medical treatment costs £30,000 per QALY[48]
- Increases in life expectancy are enjoyed 20 years (Type II) and 40 years (Type I) after the treatment is started. The different time lags reflect the fact that Type I diabetes is normally diagnosed in childhood and Type II diabetes in middle age

In addition to extending quality of life for diabetics, in body glucose sensors could be used to relay information on a patient's blood glucose levels to doctors monitoring that patient remotely. This could reduce the need for check-ups and in turn the need for patients to travel to, wait for and attend medical examination.

In quantifying the economic value of IBGS we assume as our counterfactual scenario in which IBGS are not used. Table A.24 tabulates the costs and benefits which we quantify and Figure A.24 shows our projections of net benefits. Note that:

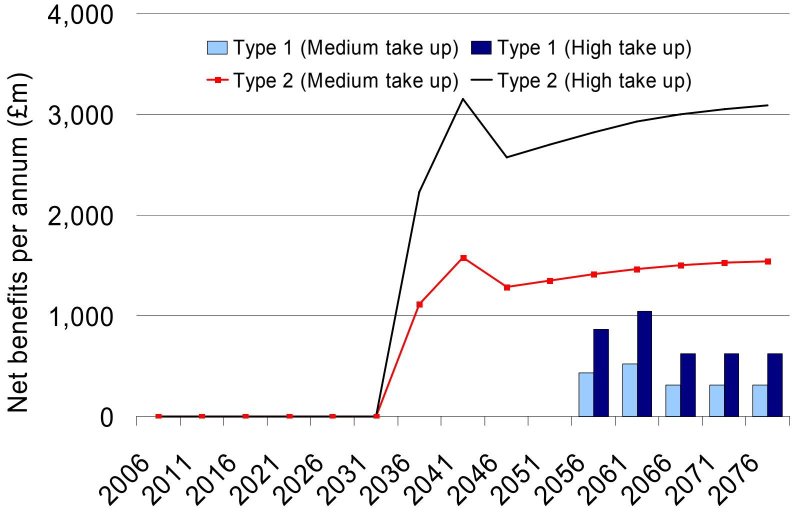
- The benefits are enjoyed a long time after the end of the study period
- There is a peak in net benefit flows. This results from treatment of a backlog of existing patients as well as new patients in the early years of the life of the treatment. As a result we project a peak in downstream benefits – 20 years later for Type II diabetics and 40 years later for Type I diabetics.
- In calculating the NPVs we assume that:
    - IBGS are replaced with some new treatment from 2025 onwards
    - The benefit streams 20 years and more on (Type II) and 40 years and more on (Type I) are reduced by 10% per annum (in addition to the standard discount factor) to account for this obsolescence

Table A.25 – Net present value of using in body glucose sensors

Scenario	Net present value (£m)
Low demand	0
Medium demand	9,297
High demand	18,595

48 See for example $50,000 per QALY, R Braithwaite and MS Roberts, 26th Annual Meeting of the Society for Medical Decision Making, October 2004 and The QALY league table, UK based economic evaluation, 1997 to 2003, published in 2005

Figure A.24 – The net benefits of using IBGS



A.4 Application 4: Radio Frequency Identification (RFID)

A.4.1 Description of the application

What is this application?

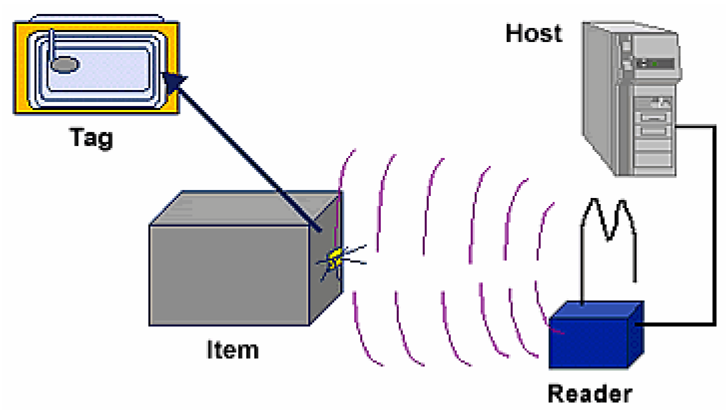
Radio Frequency Identification (RFID) is an established data-carrying technology. RFID systems have three main components:

- The RFID tag with its own data, functions and physical characteristics
- The RFID reader (static or portable) with its own functions and physical characteristics
- The host with its own hardware, functions and predefined tasks

RFIDs emerged in the 1940s as a way of remotely identifying aircraft for military purposes, and has since then been used widely in civil aviation. However, recent technological advances have reduced the cost and the size of the RFID tags, opening up a wider range of uses.

An RFID tag is a small radio device[49] which consists an electronic circuit, which stores data relating an item, and an antenna which communicates the data via radio waves. When an RFID reader broadcasts radio waves, all the tags within range will communicate. Once activated, the tag sends data stored in its memory back to the reader. Software is required to control the reader and to collect and filter the information. This data can then be shared within the organisation and its trading partners in a secure manner.

Figure A.25 – An RFID system



Source: http://www.gs1uk.org/

RFID tags can be active or passive, and they can be read-only or read-write. Passive tags have no internal power and therefore rely on their antenna to capture sufficient power from the radio transmissions of the interrogator to power up the microchip and transmit a response. The tags are small, inexpensive and have an unlimited life. The range over which the interrogator / tag works can be up to a few metres depending on the radio frequency and design. Active tags, on the other hand, have their own internal battery which can last up to 10 years. They are typically more reliable because of their ability to interact with the interrogator at a more sophisticated level and because they can use

[49] Also referred to as a transponder, smart tag, smart label or radio barcode

higher transmit powers. This enables systems to be used in more hostile radio environments and / or over greater distances (more than 100 metres).

Just as important as the tags and the interrogator operating across the air interface is the host, or computerised and networked data management system that allows the captured information to be put to use in making business processes more efficient.

There is a wide range of applications currently in place that use RFID:

- Access control for people including secure access to work place, access to travel on trains and buses, access to leisure facilities, access to a computer or vehicle. Examples include the Octopus system introduced in Hong Kong in 1997, and the Oystercard in London.
- Humans and livestock using embedded RFIDs although in the case of the former privacy issues become even more prominent than they already are. Examples include RFID-based livestock tracking scheme introduced in Australia following the outbreak of BSE across the world.
- Access control for vehicles including road tolls, fuel payment, secure access to a site
- Manufacturing automation including flexible manufacturing through component recognition, recycling of components including
- Logistics and distribution including the tracking of parcels from shipment to end customer, tracking of goods from manufacturer to retail outlet
- Retail including supply chain management and stock taking
- Maintenance including plant / equipment and other fixed assets, for example obtaining information from oil wells where temperatures and pressures are high.
- Product security including evidence of tampering, anti-counterfeiting.

Two of these applications taken together are particularly relevant to the retail sector: the logistics involved in the distribution of goods from the manufacturer to the retail outlet and the supply chain management / stocktaking at the retail outlet itself. This end-to-end (i.e. manufacturer/supplier to retail outlet to consumer) application of RFIDs is the subject of the rest of this profile.

Retail supply chain

There are potential benefits from RFID tagging across the whole retail supply chain, such as:

- Sourcing and manufacturing
  - Upstream quality control by detecting errors prior to departure from the factory, resulting in lower freight costs, fewer invoice deductions etc.
- Warehousing and distribution
  - Pallet tracking facilitates automated tracking systems that reduce manual handling and dwell times and improve asset visibility (for example alert missing items or overdue returns).
  - RFID readers at the dock door can expedite the identification of pallets in an entire shipment and log them into warehouse management or inventory control systems in seconds. At the shipping area, RFID can error-proof shipping operations by ensuring all the items needed to fulfil an order are present and packed before the order is dispatched. Bar coding is effective for shipment verification, but is still prone to errors because it relies on operators to manually scan each item.

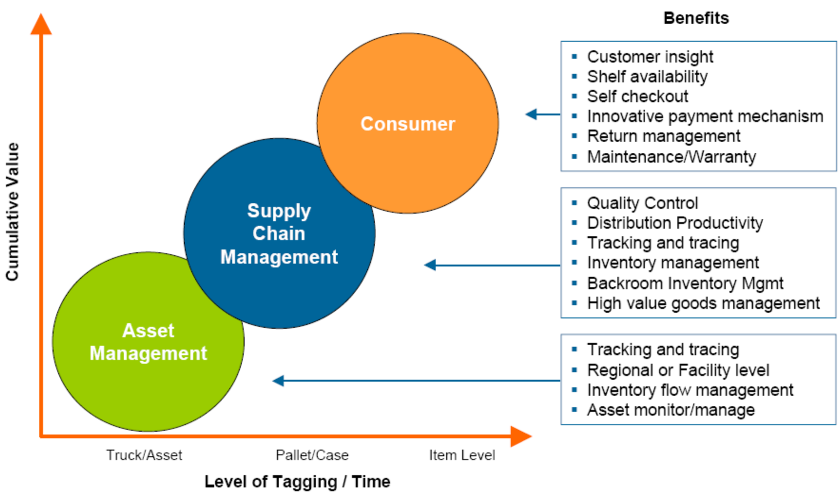
    - Increased flow-through distribution, allowing manufacturers and retailers to process the distribution of the goods from the source to the intermediate distribution points to the store.

- Retail and after sales
    - Using RFID at store level to monitor, prevent or respond to incidents of shelf level out-of-stocks
    - Automated receiving by carriers to stores, and streamlining inbound receiving processes in the back room. This will allow retailers to deploy merchandise more quickly, accurately and with less labour.
    - Rapid inventory counting. According to one study,[50] "*RFID can shave more than 90 per cent off the time needed to track inventory on the sales floor, in holding areas and in the back room*".
    - Rapid check out at point of sale by avoiding the physical handling associated with bar code scanning.

Clearly, companies that adopt effective supply chain management are the ones able to cut the cost of the delivery process and/or increase the value added to the final consumers and therefore improve their competitive advantage. Today, wireless product identification is quickly becoming the basis for enabling efficiency improvements.

It is generally agreed that for the larger retailers RFIDs will initially be introduced on the distribution side at a case / pallet level with identification at an item level coming later. This is reflected in the Figure A.26 below which shows how the use of RFIDs moves closer and closer to the consumer with time. The time axis is not quantified but it can be said that the current situation in the UK still very much concentrates on the asset management part of the schematic with some activity starting in the supply chain management albeit generally on a trial basis.

Figure A.26 – Likely use of RFIDs over time



Source: Accenture, May 2004

[50] Kurt Salmon Associates, "Moving forward with item-level radio frequency identification in apparel/footwear", 2005

A.4.2 Technical characteristics

There are four main RFID spectrum allocations, namely:

- 120 to 148.5 kHz. Low frequency (LF) tags are used in animal tracking, car immobilisers etc. They are commonly used where there are liquids or metals present and when a fast read rate is not required. They provide short range communication of up to 50 cm.
- 13.56 MHz. High frequency (HF) tags are most commonly used for smart cards, and provide a range of 30 to 100 cm.
- 865 to 868 MHz. Ultra high frequency (UHF) tags are mainly used for passive devices but some active, with a range of up to 3 metres. There are 15 x 200 kHz channels of which Channels 4 to 13 may be used for higher power applications up to 2 Watts.
- 2446 to 2454 MHz. This is part of the 2.4 GHz ISM band. Microwave frequency tags are typically used for electronic toll collection. Passive tags have a range of 1 metre whereas active tags have a range of the order of 10 metres. This band is also used by many other systems such as Bluetooth and WiFi systems.

The UHF tags are currently experiencing the most interest. These can be manufactured to cover a 100 MHz operating range (860-960 MHz) so tags can be read in different parts of the world according to the local frequency allocation. For example, in Europe interrogators operate within the 865-868 MHz band, the USA at 902-928 MHz and the Far East at 955-958 MHz.

In the short to medium term, the industry view is that existing RFID spectrum is probably adequate, as technology enhancements such as Listen Before Talk (LBT) and Adaptive Frequency Agility (AFA) enable the spectrum to be used very intensively. However there is a concern that congestion will arise in the longer term if the technology becomes ubiquitous.

A number of standards (ISO and ETSI) have been developed relating to RFID systems. On the air interface side the ones of greatest current interest relate to the UHF band 860-960 MHz. There is clearly a strong link between the physical detection of identification data as achieved through the air interface and the structure of the data itself. This has led to EPCglobal, a joint venture between EAN International (now called GS1) and the Uniform Code Council (UCC), producing a standard that also addresses Electronic Product Codes (EPC). This standard, often referred to as Gen2, is in the process of being added to the ISO family of standards, although recent interventions from Japan have lead to uncertainty as to the outcome.

Other properties of a given RFID system also depend on other key parameters:

- ***Range***. The range of a RFID system depends on the frequency, power of the reader, and the material between the tag and the reader. The range can be up to a few metres for passive systems but in excess of 100 metres for active systems due to the onboard battery that facilitates increased radio transmitter power.
- ***Size***. A larger antenna is needed to transmit at lower frequencies and therefore the tag size increases.
- ***Read rate***. As the frequency increases, so does the read rate, and therefore the amount of data that can be transferred in a given time. This is important when many tagged goods need to be read in a short time.
- ***Cost of tags***. The cost of tags tends to decrease as the frequency increases, although active tags cost must more than passive tags irrespective of frequency. Also, the longer the range required and the more information stored, the more costly the tag.

A.4.3 Evolution of demand

Growth in retail usage of RFID

The developments in RFID technology have attracted considerable attention from a number of retailers. In June 2003, Wal-Mart, the world's largest retailer, instructed its top 100 suppliers to replace RFID tags on all its pallets and cases by January 2005, and a year later announced this requirement would be extended to a further 200 suppliers by January 2006. METRO, Germany's biggest retail group, upgraded its entire process chain beginning in November 2004. Approximately 100 of their suppliers will initially affix RFID tags to their pallets and transport packages for delivery to ten central warehouses and around 250 METRO stores. Other implementations that have been reported include:

- Tesco[51] has stated that there is no business case for Tesco undertaking item level tagging. It has focused on pallet-level tagging through a pilot scheme for tagging and tracking milk deliveries from Robert Wiseman Dairies to distribution plants and two Tesco stores. More recently[52] it has been reported that Tesco's plans for their nationwide roll-out has been delayed by several years because of low tag quality and slow read speeds due to interference between high concentrations of readers in the warehouse.
- Marks & Spencer[53] is expanding their RFID trial from 9 to 53 stores. Currently it has 17 million RFID tagged garments on sale using UHF and has already tagged 61% of the plastic pallets used for food distribution using 13.56 MHz tags.
- Northern Foods[54] supplies £1.4 billion of convenience food a year to UK supermarkets, of which more than 30 per cent goes to Marks & Spencer. M&S mandated pallet-level tagging in 2004. Northern is redesigning its supply chain to better use the information it has gathered from deploying RFIDs in the hope of recovering the costs arising from M&S's mandate.
- Following its US parent Wal-Mart, Asda[55] intends to carry out internal trials with no suppliers involved which will involve the tracking of returnable RFID-enabled cages used to distribute goods in warehouses and stores.

A number of challenges are brought about by the introduction of RFID[56] that will impact on the take up adoption of RFID in the future by retailers. These include:

- A need for industry awareness of RFID and a fundamental strategic review of business processes and relationships between retailers and suppliers, as seen in the case of Tesco's and Northern Foods.
- The total costs of introducing RFID will have to be reviewed and weighed against the anticipated benefits. At current costs of tags, item-level tagging could prove to be too expensive although prices have fallen dramatically in the last two or three years. The Parliamentary Office of Science and Technology[57] notes that in 2004 tags cost around 20p each, and item-level tagging will not be widely cost effective until tags are less than a few pence per tag.

[51] Computer Weekly, "No business case for item-level RFID tags unless done by suppliers, Tesco trial finds", 19 April 2006

[52] Computing, "Tesco closes tills to PIN fraud", 29 June 2006

[53] Computer Weekly, "Marks & Spencer expands RFID trial as it moves closer to decision over full roll-out", 4 April 2006

[54] Computer Weekly, "Northern rejigs its supply chain to optimise RFID", 6 June 2006

[55] Computing, "Asda confirms plans for trials of RFID", 23 February 2006

[56] P. Jones, C. Clarke-Hill, D. Hiller and D. Comfort, 2005, "The benefits, challenges and impacts of radio frequency identification technology (RFID) for retailers in the UK", Marketing Intelligence & Planning, Vol. 23, No. 4.

[57] Parliamentary Office of Science and Technology, "Radio frequency identification (RFID)", postnote, July 2004

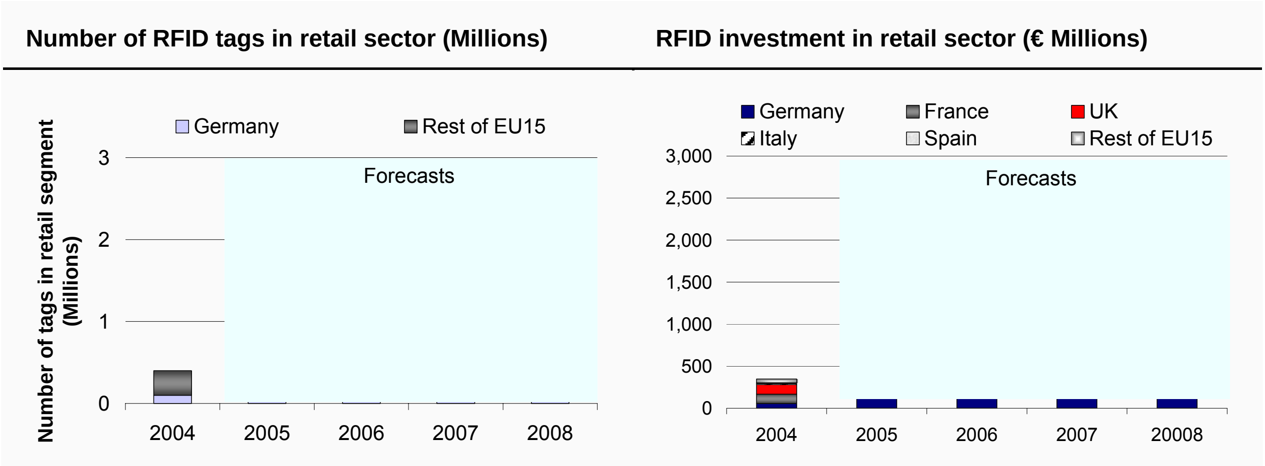
- Lack of internationally agreed RFID standards and numbering system (like the one for bar codes), although EPCGlobal has developed some common standards for RFID equipment in June 2004.
- Integrated data management systems for the massive and continuous stream of data received from tagged products. This will involve significant staff retraining to use the new systems and master new job functions.

Finally, just as RFID can be used to aid security, a handheld RFID reader can comprise a company's business when used by the wrong person. Related to this are data privacy concerns relating to the use of data by a third party, an increase in targeted direct marketing and the ability to track individuals. However, if RFID tags are used to link items to personal data, then they are subject to the Data Protection Act, as in the case with bar codes. To collect these data, retailers must obtain written consent from the consumer. The Information Commissioner's Office (ICO) is keeping "a watching brief" and is collaborating with colleagues in the European data protection and privacy fields. At the same time, retailers will have to address the drawbacks as a result of the negative feeling towards RFIDs amongst some consumers and civil liberty groups, and potential liability risks associated with this.[58]

Investment in RFID

Deutsche Bank Research estimates that RFID systems will rapidly continue to gain significance[59] and that RFID projects hold out enormous potential for efficiency gains in process management and warehousing. Between 2004 and 2010 the number of RFID tags used in the retail sector will grow 0.2 million to 2.6 million across the EU15 countries. The total costs of RFID investment over this period will grow from €0.4 billion to €4 billion, an annual growth of 47 per cent per annum. This is made up of software costs (44%), installation (17%), RFID readers (17%) and other costs (22%). Figure A.27 shows that in the UK RFID investment is expected to grow from less than €100 million in 2004 to €500 million in 2008.

Figure A.27 – Forecasts of RFID investment in the retail sector



Source: Deutsche Bank Research, February 2006

[58] In the US, a family in Washington managed to sue a grocer who sold them beef infected with mad cow disease. They argued that their loyalty card for the store should have informed the grocer of all those that had bought the infected meat, and therefore he had ignored his responsibility to get in touch with customers and tell them.

[59] Deutsche Bank Research, "RFID chips", 20 February 2006

Juniper Research[60] forecasts revenues in the RFID market from different sectors including retail. These figures are lower than the Deutsche Bank forecasts because they do not include the costs of the software and other installation costs, which amount to around 60 per cent of the total investment costs.

Assuming that the total revenue from the supply chain is associated with retail activity, the proportion of the total revenue in the retail sector is around 60 per cent in 2004, falling to 48 per cent in 2009.

Table A.26 – Total Western Europe RFID revenue by sector forecast 2004 – 2009 (USD Millions)

Sector	2004	2005	2006	2007	2008	2009
Retail	92.9	125.4	169.3	217.1	267.4	315.6
Pharmaceutical	32.5	62.7	127	194.2	282.2	408.5
Mass Transportation	83.6	112.9	169.3	228.5	297.1	371.3
Supply Chain	185.8	250.8	296.2	388.5	490.2	575.6
Other	69.7	75.2	84.6	114.3	148.5	185.7
Total	464.4	626.9	846.4	1,142.6	1,485.4	1,856.7
Retail + supply chain	60%	60%	55%	53%	51%	48%

Source: Juniper Research

The European Commission PT43 report[61] provides market predictions for logistic applications for UHF passive tags to 2012 within CEPT zones.

Figure A.28 –UHF RFID tags, 2006 to 2012

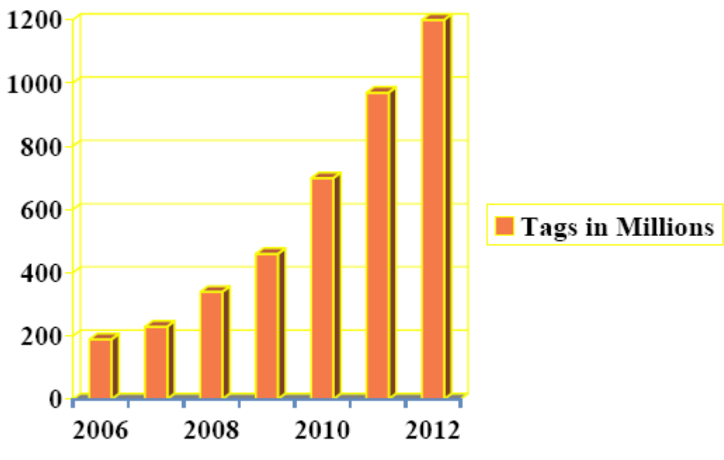


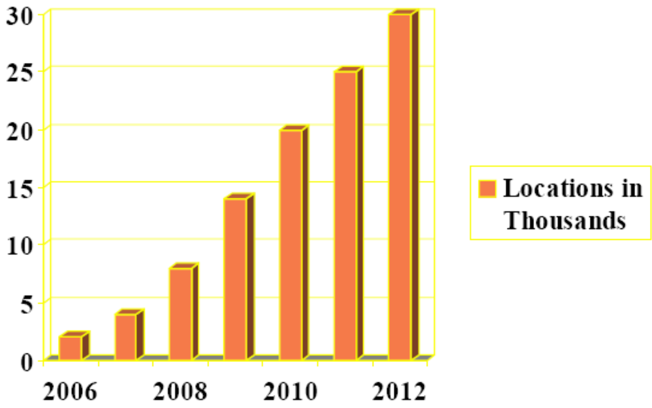
Figure A.29 shows the market predictions for the growth of sites to be installed with RFID tag/interrogator systems. We note that the Figure A.28 and Figure A.29 refer to logistic applications, and we assume that this covers a number of industry sectors of which the retail sector is just one.

[60] Juniper Research, “RFID futures in western Europe”, January 2005

[61] European Commission, “Interim report from CEPT in response to the Second EC Mandate to CEPT to develop a strategy to improve the effectiveness and flexibility of spectrum availability for Short Range Devices (SRDs)”, Brussels 21 November 2005

These forecasts are not comparable to the Deutsche Bank forecasts as the former includes all types of RFID tags, although only in the retail sector.

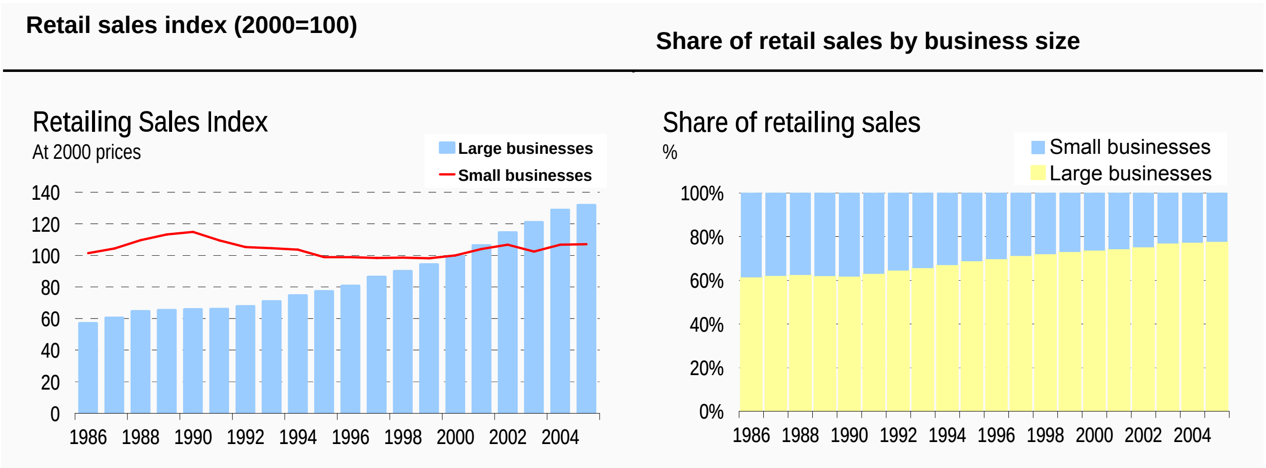
Figure A.29 – Sites to be installed with UHF RFID tag/interrogator systems, 2006 to 2012.



Demand scenarios

There is no doubt that the use of RFID in the retail sector is going to grow significantly over the next few years, by supermarkets as well as predominantly non-food businesses. Overall retail sales have grown significantly over the last 20 years, and there has been a growing trend in recent years of larger retailers[62] dominating the total sales value in the UK as shown in Figure A.30. These retailers are ones that have the funds available to carry out RFID trials. We assume that they will lead the take up, which will then diffuse rapidly into other segments of the market as the technology becomes more ubiquitous.

Figure A.30 – Retail sales in the UK



Source: ONS, Retail Sales statistics

The key assumptions for our three scenarios are set out in Table A.27. We assume that current trials are insignificant compared to the rest of the sector. Once the suppliers implement item-level or even

[62] Defined as those businesses with 100 or more employees.

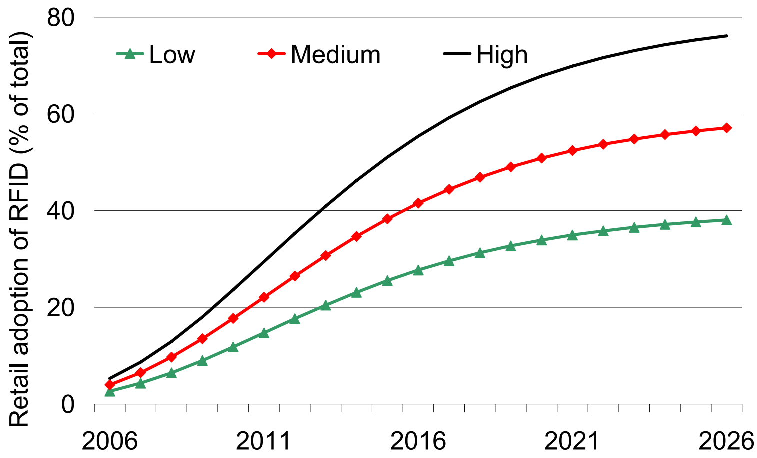
pallet-level RFID tags and the price of the tags fall, smaller and independent retailers may begin to adopt this, so that RFID becomes integrated into the retail business concept across the value chain.

Table A.27 – Summary of model assumptions for adoption of RFID in the retail sector

	Low	Medium	High
% retailers that adopt RFID			
2006	0%	0%	0%
2026	40%	60%	80%
Average growth rate at inflexion point	20%	20%	20%
Time of maximum growth relative to 2006	2011	2011	2011

The resulting take up of RFID under the three scenarios are illustrated in Figure A.31.

Figure A.31 – Forecasts of take up of RFID systems in the retail sector



A.4.4 Ofcom Cost Benefit Analysis

Ofcom conducted a cost benefit analysis of using RFIDs in the UK supermarket sector.[63] It made the following assumptions and calculations:

Reduction of goods being out of stock

Ofcom assumed that the costs to a retailer from stocks being out of stock are around 4 to 8 per cent of sales. These costs are due to "*lost sales and profits arising from an inability to meet consumer demand*". Based on a US study, Ofcom assumed that RFID can reduce stock outs by 50 per cent, resulting in a 2 to 4 per cent increase in sales revenues worth a total of £2 to 4 billion in net present value terms.

[63] Ofcom, "Ofcom's decision to exempt the use of radio frequency identification equipment in the 865-868MHz band from Wireless Telegraphy Licensing", 2005

Reduction of overstocked goods
The costs of overstocked goods include higher working capital costs and storage costs, and these are assumed to be 7.5 per cent on an on-going basis. However, these costs were not quantified in Ofcom's analysis.

Reduction in inventory shrinkage
Ofcom assumed that 50 per cent of the shrinkage due to theft and wastage would be avoided by better inventory management, amounting to 0.85 per cent increase in additional sales revenues, or about £1 billion in net present value terms.

Costs of RFID investment
Ofcom estimated that the costs of RFID investment represent approximately two thirds of the value of improved efficiency generated through its implementation.

Total benefits of RFID
The total additional sales revenue from the use of RFID was estimated to be between £3 and 5 billion in net present value terms. To estimate the total economic benefit, Ofcom assumed that producer surplus was around 6 per cent of the additional sales, reflecting the profit margin on each unit sold. Consumer surplus was estimated to be of the same magnitude by assuming that the responsiveness of demand and supply are similar. Therefore, total economic benefits were between £300 and 600 million in net present value terms. Deducting from this the costs of RFID investment gives net economic benefits of £100 to £200 million.

Ofcom also considered other potential benefits at a qualitative level:

- Internal efficiencies (e.g. M&S reported reduction in receiving times of 29 seconds to 5 seconds per dolly) – possible staff reduction.
- More accurate stocking (less overstock or out-of-stock), but some argue that current systems based on barcodes should prevent this happening. Improved data management systems rather than RFIDs themselves could offer the necessary improvements.
- Asset management. Appropriate when the supply chain is based on supporting items of value and/or requiring maintenance
- Warranty and returns management
- Improved product traceability – increasingly required by legislation
- Higher gains expected for high value goods (small shipments / high profits) and perishable goods (especially with regard to overstock for the latter).

A.4.5 Economic value

To estimate economic value we use as our counterfactual the scenario in which RFIDs are not used in the UK retail sector.

There is general acceptance that the ability to track goods can enhance business processes and therefore bring about economic benefits. Table A.28 summarises the costs and benefits from using RFIDs that are quantified in our analysis.

Table A.28 – List of quantified costs and benefits

Benefits	Quantified?	Costs	Quantified?
Reduction of goods being out of stock	Yes	Costs of RFID tags and readers	Yes, in combination
Reduction of overstocked goods	Yes	Software and data management system upgrades	
Reduction of inventory shrinkage	Yes	Installation costs	
Greater speed and efficiency in stock operations and inventory control	No	Staff retraining and other costs	
Better tracking of goods throughout supply chain	No	Reduction in competition between large retail organisations and smaller independent retailers	No
Clearer tracking of customers and the tracking of purchasing behaviour leading to improved customer service	No		

We seek to quantify this for the retail sector, which includes the whole supply chain. We note that there is a growing trend of sales being carried out over the internet, where the impact of RFID systems are more limited since the delivery of the goods to the consumers is not time critical. Nonetheless, we assume that once RFID tags are implemented by the suppliers, the same goods would be shipped to all retailers whether they are predominantly online or in-store. As such, the benefits will eventually diffuse to the whole the retail sector.

Benefits from RFID

Reduction of goods being out of stock

In the retail sector, stock-outs results in a loss of consumer surplus for consumers who cannot purchase the good and does not buy an alternative at that time. In aggregate, the impact on consumer surplus from buying a product from a second-choice retailer is the difference in willingness to pay less than the difference in price. The University of Arkansas[64] has undertaken research that aims to quantify the benefit of reducing out-of-stock items in the retail sector with RFID. Their research showed that when faced with an out of stock item, 24 per cent of consumers choose not to go for an alternative (i.e. buy a different brand, product or from a different retailer). We assume that those who substitute their purchase do not suffer a loss in consumer surplus.

Studies have quantified the level of stock-outs amongst different retailers. Ofcom assumed this to be between 4 and 8 per cent of total sales. Another study estimates[65] that stock-outs "*can account for as much as 4% of the total sales and up to 11% of the high selling items*". Another estimated that "*in typical supermarket out-of-stock situations cause a 3 per cent loss of revenue through lost sales*"[66] and that 53 per cent of stock-outs are due to store ordering processes and a further 8 per cent due to unshelved inventory. In the United Sates, "*across the retail industry, stock-out levels remain near 8% and represent a key issue that retailers hope to reduce with RFID*".[67]

[64] B. Hardgrave, M. Waller, R. Miller, "Does RFID reduce out of stocks? A preliminary analysis", RFID Research Centre, University of Arkansas, November 2005

[65] RFID Gazette, "RFID and price reduction in retail", 30 September 2005

[66] M. Karkkainen & J. Holmstrom, (2002), "Wireless product identification: enabler for handling efficiency, customisation and information sharing", Supply Chain Management: An International Journal, Vol. 7, No. 4

[67] RFID Product News, "Marketing Benefits Tops in RFID Adoption, Says Study"

The Arkansas research also showed that RFID reduced out of stocks by 16 per cent during the study period, significantly smaller than the 50 per cent assumed by Ofcom.

Assuming constant elasticity of demand ε of -1[68] for general consumer goods, total economic benefit is given by $-p/2\varepsilon$, where *p* is the price. We estimate the benefits the benefits arising from reducing out of stock goods that result in non purchase using total retail sales foregone as a proxy for the total price paid by consumers for goods they would otherwise consume in any given year.

Reduction of shrinkage

Retail shrinkage is the difference between book stock and actual stock. It is the unaccounted loss of retail goods. Its main causes are theft by employees, administrative errors, shoplifting by customers, vendor fraud, and expired perishables. RFID can offer solutions to track sell-by dates of each product on the shelf. The collection and utilisation of this information can help retailers maintain a better inventory management system that can react to demand much more quickly than with current systems. The RFID Product News report suggests that the implementation of RFID would reduce by as much as 20% the cost of inventory write-offs that occur when goods are no longer fit for consumption. It also reports estimates that shrinkage via customer theft, employee theft, and inaccurate inventory counts represents 1.69% in lost sales for retailers. RFID technology has the potential to alert staff when items are being removed illegally, or when they have been misplaced within the store, and could reduce lost sales to just 0.78%. In their trial, Marks and Spencer reported a lower impact of RFIDs, which reduced shrinkage by 15 per cent.[69]

A reduction in shrinkage through use of RFIDs is a cost saving for the retailer which, in a competitive market, is all passed to the consumer as an economic benefit. We quantify this effect in our model.

Other reductions in operating costs

RFIDs reduce other operating costs in addition to shrinkage. For example overstocking of goods creates costs to retailers because of the extra floor space required to store them, additional labour to deal with the inventory (counting and stocking) and eventually the loss in revenue due to the need to write-off or offer discounts to these products. Some estimates of the reduction in operating costs due to RFID are in the region of around 7.5 per cent per annum[70] through reduced labour, administration and storage costs associated with the additional stock holding. This reduction includes the front of store applications of RFIDs, which will be realised once the use of RFIDs moves towards item-level tagging in the future.

We assume that for a given level inventory, better management leads to a 7.5 per cent reduction of operating costs. Since operating costs account for around 31 per cent of total costs for a typical retailer[71] this translates into a reduction of 2.33 per cent in total costs. This has two impacts on economic benefits:

- Producer surplus for those retailers that have implemented RFID. We assumed that 10 per cent of the reduction in costs is retained as profit.[72]

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[68] For most consumer goods and services, price elasticity tends to be between .5 and 1.5. As the price elasticity for most products clusters around 1.0, it is a commonly used rule of thumb. See, for example, Pindyck and Rubenfeld, Econometric Models and Economic Forecasts, 2d ed.. New York: McGraw Hill, 1981, chapter 13.

[69] S. Li, J. Visich, B. Khumawala and C. Zhang, (2006), “Radio frequency identification technology: applications, technical challenges and strategies”, Sensor Review

[70] http://retailindustry.about.com/cs/it_rfid/a/bl_atk111003.htm

[71] Indepen, “The economic costs and benefits of easing Sunday shopping restrictions on large stores in England and Wales. A report for the DTi”, May 2006

[72] See discussion in Indepen (2006)

- Through competition, 90 per cent of the cost reductions will be passed onto consumers in the form of lower prices. This increases the competitive edge of the retailers that have adopted RFID tagging and further justifies the adoption. With no change in the willingness to pay by consumers, this amounts to an increase in consumer surplus.

The total economic benefit is then the sum of the producer surplus and the consumer surplus.

Other estimated efficiency gains

Some studies have considered the impact of RFID solutions on inventory-related costs. RFID Product News quote a study that estimated reductions of a wide array of costs: 50-65% in receiving, 22-30% in stocking, 22-30% in checkout, 40-60% in cycle counting, and 90-100% in physical counting. However, these are particular to the type of retailer, and the inclusion in this analysis would require detailed cost breakdowns.

On another level, several trials have shown that RFID systems enable retailers to remove inefficiencies by using real-time inventory information. This enables retailers to provide a greater level of service and sales support. Sales associates will be able to see when and where stock will be delivered to a particular store, thus avoiding the request that customers check back to see if an item has been brought into the store. In effect, these act like marketing tools and enhance the experience faced by consumers.

Costs of RFID implementation

Investment costs of RFID systems

Based on the Deutsche Bank research, RFID investment in the UK will to grow from £308 million in 2006 to £330 million in 2008. In the trials carried out by Marks and Spencer, RFID tags were used to track 3.5 million reusable trays, dollies and cages throughout the store's refrigerated food supply chain.[73] They noted that the RFID tags are reusable and their fixed costs can be spread over time, therefore the capital cost of an RFID system would be less than 10 per cent of the annual cost of using bar codes (since each bar code can only be used once). In Sainsbury's trial of RFID, they estimated that the payback period of the system would be between two and three years.[74]

Based on a two to three year payback period assumption, we can calculate the proportion of annual costs of RFID implementation as a proportion of the estimated annual benefits, shown in Table A.29.[75]

Table A.29 – Annual costs of RFID implementation as a proportion of annual benefits (%)

Initial RFID implementation costs as a proportion of annual running costs of RFID systems (%)	Payback period (Years)		
	2	2.5	3
200%	50%	56%	60%
300%	40%	45%	50%
400%	33%	38%	43%

73 Jones et al (2005), op cit.

74 M. Karkkainen, (2003), "Increasing efficiency in the supply chain for short shelf life goods", International Journal of Retail & Distribution Management, Vol. 31, No. 10

75 Assuming constant annual benefits B arising from RFID implementation, the costs of doing so would be initial costs CC and annual operating costs OC. A payback period of 2 years means that at the end of year 2, 2B=CC+2OC. If initial costs are three times annual operating costs, then annual operating costs would be 2/(2+3)=40% of annual benefits.

We therefore assume that the implementation costs are between 35 to 65 per cent of the total benefits based on the lower bound of the two year payback period, and the assumption adopted in Ofcom's impact assessment.

Reduction in competition

There have been concerns regarding the position of small independent retailers in the UK in the face of more aggressive strategy by the larger organisations to capture greater shares of the total market, particularly in the supermarket segment. As expressed by Jones et al (2005) RFID systems will require financial resources to enable the investment in computer hardware and software, as well as analytical capacity and personnel in order to derive the benefits from the information generated by RFID. This may increase the competitive advantage of large retailers over their smaller counterparts and make it increasingly difficult for them to survive in the market place. This may in turn increase the spatial and structure concentration of retail outlets, and have secondary impacts on the economy as a whole. We do not quantify this impact.

Valuation scenarios

We assume that RFID systems will be implemented across the retail sector, and that future retail sales will grow at 1.5 per cent per annum, based on the historic relationship between overall growth in GDP and growth in retail sales.

Table A.30 – Summary of model assumptions for the impact of RFID in the retail sector

	Low	Medium	High
Total retail sales			
Growth in retail sales 2006-2026	1.5%	1.5%	1.5%
Elasticity of demand	-1.0	-1.0	-1.0
Reduction of goods being out of stock			
Proportion of stock-outs (% total retail sales)	4%	6%	8%
Proportion of stock-outs that does not lead to purchase of substitute	25%	25%	25%
Reduction due to RFID	15%	25%	50%
Reduction of overstocked goods			
Reduction in costs due to RFID (% of operating and capital costs)	5%	7.5%	10%
Reduction of shrinkage			
Proportion of shrinkage (% total retail sales)	1.0%	1.5%	2.0%
Reduction due to RFID	15%	25%	50%

Termination value

We assume that beyond 2026, the benefits accrued will continue, although they are discounted by the probability that future technologies will allow further integration and streamlining of retail business processes. We assume this probability to be 10 per cent per annum.

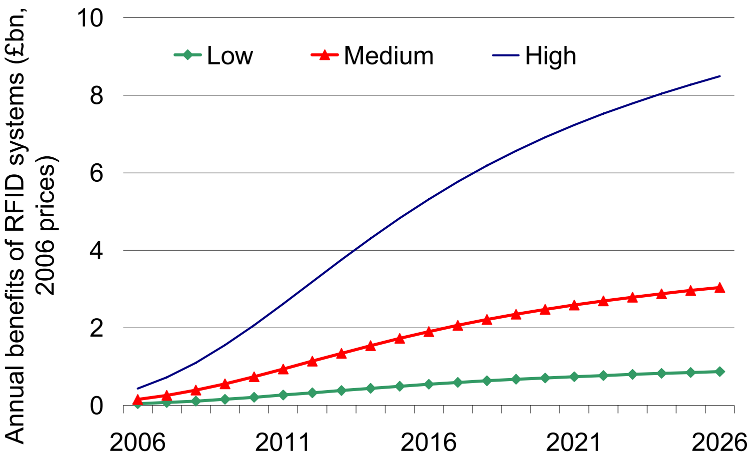
A.4.6 Demand valuation projections

Based on the medium case scenario, the total net present value of adopting RFID systems in the retail sector is just over £1 billion in 2006 prices.

Table A.31 – Summary of net present value of benefits from using RFID systems (£m, 2006 prices)

	NPV of net benefits from use of RFIDs in retail (£m)
Low	10,061
Medium	35,106
High	97,966

Figure A.32 – Annual benefits from RFID (£m, 2006 prices)



Detailed forecasts for each of the scenarios are summarised as follows.

Table A.32 – Annual benefits of RFID – Low demand scenario (2006 prices)

Low scenario	2006	2011	2016	2021	2026
Households in the UK (Millions)	25.1	26.5	28.0	29.6	31.3
Total broadband households (Millions)	11.5	19.9	23.8	26.6	28.8
Households that use broadband because of existence of wireless home networks (000)	351	883	1,448	1,857	2,178
Annual installations of wireless home networks in such households (000s)	83	98	75	61	69
Costs of wireless routers (£)	-100	-85	-70	-55	-40
Additional installation costs of wireless home networks in these households (£m)	-8	-8	-5	-3	-3
Consumer surplus from having broadband (£ per year)	124	124	124	124	124
Total consumer surplus from having broadband (£m)	44	110	180	231	270
Net benefits from having wireless home networks (£m)	35	101	174	227	268
Households that replace wired networks with wireless (000s)	1,402	3,532	5,792	7,428	8,711
Annual installations of wireless networks (000s)	332	392	302	243	278
Additional costs of wireless routers (£)	-50	-43	-35	-28	-20
Avoided cost of wiring a home (£)	200	200	200	200	200
Cost savings from installing wireless home networks (£m)	50	62	50	42	50
Total benefits (£m)	85	163	224	269	318

Table A.33 – Annual benefits of RFID – Medium demand scenario (2006 prices)

Medium scenario	2006	2011	2016	2021	2026
Households in the UK (Millions)	25.1	26.5	28.0	29.6	31.3
Total broadband households (Millions)	11.5	19.9	23.8	26.6	28.8
Households that use broadband because of existence of wireless home networks (000)	351	1,177	1,905	2,582	3,191
Annual installations of wireless home networks in such households (000s)	119	127	123	114	134
Costs of wireless routers (£)	-100	-85	-70	-55	-40
Additional installation costs of wireless home networks in these households (£m)	-12	-11	-9	-6	-5
Consumer surplus from having broadband (£ per year)	124	124	124	124	124
Total consumer surplus from having broadband (£m)	44	146	237	320	396
Net benefits from having wireless home networks (£m)	32	135	228	314	391
Households that replace wired networks with wireless (000s)	1,402	4,710	7,621	10,327	12,762
Annual installations of wireless networks (000s)	475	507	493	457	534
Additional costs of wireless routers (£)	-50	-43	-35	-28	-20
Avoided cost of wiring a home (£)	200	200	200	200	200
Cost savings from installing wireless home networks (£m)	71	80	81	79	96
Total benefits (£m)	103	215	309	393	487

Table A.34 – Annual benefits of RFID – High demand scenario (2006 prices)

High scenario	2006	2011	2016	2021	2026
Households in the UK (Millions)	25.1	26.5	28.0	29.6	31.3
Total broadband households (Millions)	11.5	19.9	23.8	26.6	28.8
Households that use broadband because of existence of wireless home networks (000)	351	1,472	2,401	3,170	3,798
Annual installations of wireless home networks in such households (000s)	154	161	141	118	137
Costs of wireless routers (£)	-100	-85	-70	-55	-40
Additional installation costs of wireless home networks in these households (£m)	-15	-14	-10	-7	-5
Consumer surplus from having broadband (£ per year)	124	124	124	124	124
Total consumer surplus from having broadband (£m)	44	183	298	394	472
Net benefits from having wireless home networks (£m)	28	169	288	387	466
Households that replace wired networks with wireless (000s)	1,402	5,887	9,603	12,682	15,193
Annual installations of wireless networks (000s)	617	646	564	473	547
Additional costs of wireless routers (£)	-50	-43	-35	-28	-20
Avoided cost of wiring a home (£)	200	200	200	200	200
Cost savings from installing wireless home networks (£m)	93	102	93	82	98
Total benefits (£m)	121	271	381	469	565

A.5 Application 5: Public access broadband services

A.5.1 Description of the application

What is the application

This profile describes the provision of public access broadband services which use wireless technologies based on unlicensed spectrum. Specifically the profile covers the provision of broadband public services in the home, office, and public hotspots using WiFi technologies.

There are two main technologies which could use LE spectrum to provide such services:

- WiFi technologies based on IEEE 802.11 specifications
- WiMAX technologies based on IEEE 802.16 specifications

WiFi is a brand originally licensed by the WiFi Alliance to describe the underlying technology of WLAN based on the IEEE 802.11 specifications. WiFi is now so pervasive, and the term so generic, that the brand is no longer protected and it appears in Webster's dictionary.[76]

WiFi was intended to be used for mobile computing devices, such as laptops, in local area networks (LANs) but is now used for more applications, including Internet access, gaming, and basic connectivity of consumer electronics such as televisions and DVD players. There are more standards in development (IEEE 802.11p) that will allow WiFi to be used by cars on highways in support of an Intelligent Transportation System to increase safety, gather statistics, and enable mobile commerce.

A person with a WiFi device, such as a computer, telephone, or PDA can connect to the Internet when near an access point. The region covered by one or several access points is called a "hotspot". Hotspots can range from a single room to many square miles of overlapping hotspots. WiFi can also be used to create a Wireless mesh network. Both architectures are used in wireless community network and municipal wireless networks. WiFi also allows connectivity in peer-to-peer mode, which enables devices to connect directly with each other. This connectivity mode is useful in consumer electronics and gaming applications.

When the technology was first commercialised there were many problems because consumers could not be sure that products from different vendors would work together. The WiFi Alliance began as a community to solve this issue so as to address the needs of the end user and allow the technology to mature. The Alliance created another brand "*WiFi Certified*" to denote products are interoperable with other products displaying this brand.

WiMAX stands for Worldwide Interoperability for Microwave Access. The WiMAX Forum, formed in April 2001 promotes conformance and interoperability of products which use the standard IEEE 802.16. The Forum describes WiMAX as "*a standards-based technology enabling the delivery of last mile wireless broadband access as an alternative to cable and DSL*".[77]

The WiMAX Forum is "*the exclusive organisation dedicated to certifying the interoperability of BWA products, the WiMAX Forum defines and conducts conformance and interoperability testing to ensure that different vendor systems work seamlessly with one another*." Those that pass conformance and interoperability testing achieve the "WiMAX Forum Certified" designation and can display this mark on their products and marketing materials. According to the Forum, vendors claiming their equipment is "WiMAX-ready," "WiMAX-compliant," "pre-WiMAX," are not WiMAX Forum Certified.

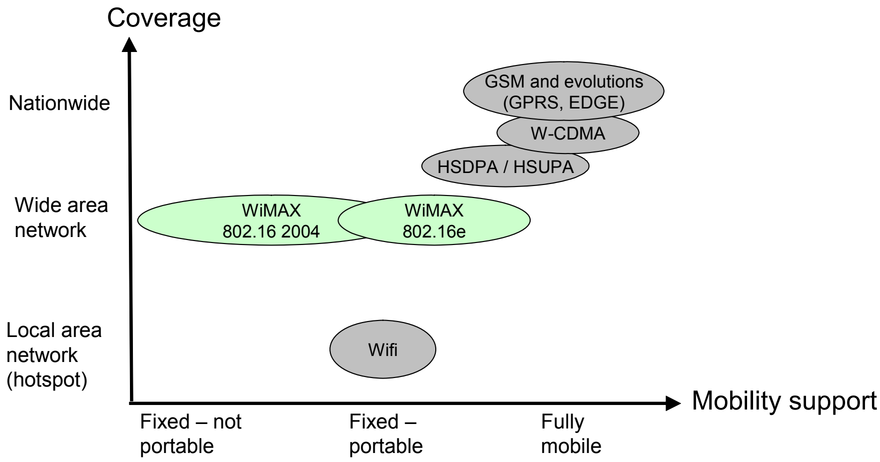
[76] http://www.m-w.com/dictionary/wi-fi

[77] http://www.wimaxforum.org/about

WiFi vs. WiMAX. vs 3G mobile technologies

Figure A.33 shows how these two technologies are positioned in terms of geographic coverage and mobility in relationship to each other and to key 3G mobile technologies.

Figure A.33 – Coverage and mobility provided by WiFi, WiMAX and 3G mobile technologies



Source: Ovum

How does WiFi work?

The typical WiFi setup contains one or more Access Points (APs) and one or more clients. An AP broadcasts its Service Set Identifier (SSID) network name via packets that are called beacons. The beacons are transmitted at 1 Mbps. They are relatively short and therefore do not influence performance. Since 1 Mbps is the lowest WiFi transmission rate there is a guarantee that the client who receives the beacon can communicate at a rate of at least 1 Mbps. Based on the settings (e.g. the SSID), the client may decide whether to connect to an AP. The firmware running on the client WiFi card is also of influence. If two APs of the same SSID are in range of the client, the firmware may decide based on signal strength to which of the two APs it will connect. The WiFi standard leaves connection criteria and roaming open to the client. This is a strength of WiFi, but also means that one wireless adapter may perform substantially better than another.

Examples of WiFi Devices include:

- ***Wireless Access Point (WAP)***: A wireless access point (AP) connects a group of wireless stations to an adjacent wired LAN. An AP is similar to an Ethernet hub, but instead of relaying LAN data only to other LAN stations, an AP can relay wireless data to all other compatible wireless devices as well as LAN stations connected by wire.
- ***Wireless Routers***: A wireless router connects a group of WiFi enabled devices (i.e. PDAs, laptops, etc.) to an adjacent wired network (such as a cable modem or DSL modem). A wireless router is a wireless AP combined with an Ethernet hub. A wireless router forwards IP packets between a wireless subnet and any other subnet.
- ***Wireless Ethernet Bridge***: A wireless Ethernet bridge connects two separate networks.
- ***Range Extender***: A wireless range extender can increase the range of an existing wireless network by being strategically placed in locations where the wireless router or access point signal is degraded or out of range.

Table A.35 summarises the main advantages and disadvantages of WiFi technology

Table A.35 – Advantages and disadvantages of WiFi technology

Advantages	Disadvantages
Allows LANs to be deployed without cabling, potentially reducing the costs of network deployment and expansion.	Spectrum assignments and operational limitations are not consistent worldwide; most of Europe allows for an additional 2 channels beyond those permitted in the US
WiFi silicon pricing continues to come down, making WiFi a very economical networking option	Power consumption is fairly high compared to some other standards, making battery life and overheating are a concern
WiFi products are widely available in the market. Different brands of access points and client network interfaces are interoperable at a basic level of service	The most common wireless encryption standard, Wired Equivalent Privacy or WEP, has been shown to be breakable even when correctly configured. Novice users benefit from a zero configuration device that works out of the box but are unaware they are allowing unsecured wireless access to their LAN
WiFi networks support roaming, in which a mobile client station such as a laptop computer can move from one access point to another	WiFi networks have limited range. A typical WiFi home router using 802.11b or 802.11g with a stock antenna might have a range of 45m indoors and 90m outdoors. Outdoor range with improved antennas can be several kilometres or more with line-of-sight.
WiFi is a global set of standards. Unlike cellular carriers, the same WiFi client works in different countries around the world	WiFi networks can be monitored and used to read and copy data (including personal information) transmitted over the network when encryption is not enabled
Widely available in more than 100 thousand public hot spots and millions of homes and corporate campuses worldwide	Interoperability issues between brands or deviations from the standard can disrupt connections or lower throughput speeds on other user's devices within range.
New protocols for Quality of Service (WMM) and power saving mechanisms (WMM Power Save) make WiFi even more suitable for latency-sensitive applications (such as voice and video) and small form-factor devices	

Source: Ovum

How does WiMAX work?

The IEEE 802.16 media access controller (MAC) is significantly different from that of the WiFi MAC. In WiFi, the MAC uses contention access—all subscriber stations wishing to pass data through an access point are competing for the AP's attention on a random basis. This can cause distant nodes from the AP to be repeatedly interrupted by less sensitive, closer nodes, greatly reducing their throughput. And this makes services, such as VoIP or IPTV which depend on a determined level of quality of service (QoS) difficult to maintain for large numbers of users.

In contrast, the 802.16 MAC is a scheduling MAC where the subscriber station only has to compete once (for initial entry into the network). After that it is allocated a time slot by the base station. The time slot can enlarge and contract, but it remains assigned to the subscriber station, and means that other subscribers are not supposed to use it but take their turn. This scheduling algorithm is stable under overload and over-subscription conditions (unlike IEE 802.11). It is also much more bandwidth efficient. The scheduling algorithm also allows the base station to control Quality of Service by balancing the assignments among the needs of the subscriber stations.

A recent addition to the WiMAX standard is underway which will add full mesh networking capability by enabling WiMAX nodes to simultaneously operate in "subscriber station" and "base station" mode. This will blur that initial distinction and allow for widespread adoption of WiMAX based mesh networks and promises widespread WiMAX adoption. WiMAX/802.16's use of OFDMA and scheduled MAC allows wireless mesh networks to be much more robust and reliable.

In 2002, The Institute of Electrical and Electronics Engineers Standards Association (IEEE-SA) ratified the IEEE 802.16 standard – a point-to-multipoint broadband wireless access standard for systems in the 10-66GHz and 2-11GHz frequency ranges. Table A.36 provides an overview of the main IEEE 802.16 standards and amendments.

Table A.36 – IEEE 802.16 standards

	802.16	802.16a	806.16-2004	802.16e
Data rates	Up to 132Mbits/s (28 MHz channel)	Up to 75Mbits/s (20MHz channel)	Up to 75Mbits/s (20MHz channel)	Up to 15Mbits/s (5MHz channel)
Frequency band	10-66GHz	2-11GHz	2-11GHz	2-6GHz
Channel size	1.5-20MHz	1.5-20MHz	1.5-20MHz	1.5-5MHz
Sub-channelisation	No	No	Yes (BPSK, QPSK, 16QAM, 64QAM)	Yes (BPSK, QPSK, 16QAM, 64QAM)
Environment	Line-of-sight	Line-of-sight, non-line-of-sight	Line-of-sight, non-line-of-sight	Non-line-of-sight
Mobility	Fixed	Fixed	Fixed/nomadic	Mobile, up to 120km/h

In terms of standard development, the IEEE 802.16 Working Group has completed the ratification of 802.16e as of December 2005, while 802.16-2004 was ratified in July 2004.

In terms of product availability, several 802.16-2004 chipsets have been available since early 2005, following announcements by Intel and Fujitsu. There have also been several pre-WiMAX technologies (base station and CPE) available on the market since early 2005.

Regarding 802.16e,[78] the WiMAX Forum is targeting the second half of 2006 to launch the certification testing for 802.16e equipment. This means that the first commercially available, certified products based on 802.16e can be expected in 2007.

78 The standard which allows mobile terminals to use WiMAX at speeds of up to 120 kph

What spectrum is used for WiMAX?

The 802.16 specification can use a wide range of frequencies. Table A.37 shows current deployment in the EU. There is already use in the 2.4, 3.5, and 5.8 GHz bands. However, it is clear from talking to UK industry that it is interested in using WiMAX technology in the 2.5 GHz band on a license basis for any major deployment. Only at this frequency can operators build a business case which supports the major investment required. In addition there are technology issues. At 5.8 GHz for example WiMAX will not support handover of calls or sessions between WiMAX cells. Yet mobility is important for the viability of the WiMAX business case.

Table A.37 – WiMAX deployments in Europe

Country	Operator	Type	Spectrum	Nature of licence	Vendor	Target	Coverage	Public funding
Belgium	Clearwire Belgium	New entrant	3.5GHz	Nationwide	NextNet	Enterprises Consumers	Brussels	No
Denmark	Danske Telecom	Alternative operator	3.5GHz	Nationwide	Cambridge Broadband	Enterprises Consumers	Areas around Copenhagen	No
France	Altitude Telecom	WLL player	3.5GHz	Nationwide	Alvarion	Enterprises Consumers	Orne, Vendée & Calvados	Yes
Ireland	Irish Broadband	WLL player	3.5GHz	Local licences in 23 cities	Alvarion Navini	Enterprises Consumers	Dublin, Cork	No
Ireland	Clearwire Ireland	New entrant	3.5GHz	Local licences	NextNet	Business consumers	N/A	No
Netherlands	IntroWeb	ISP	2.4-2.6 GHz	Unlicensed	Navini	Consumers	Twente, Hengelo, Enschede, Almedo & Oldenzaal	No
Netherlands	Enertel	Alternative provider	3.5GHz	Nationwide	Aperto	Enterprises	Rotterdam, Amsterdam, The Hague, Utrecht & Eindhoven	No
Spain	berbanda	WLL player	3.5GHz	Nationwide	Alvarion Aperto	Enterprises Consumers	Andalusia	Yes
UK	Libera	New entrant	5.8GHz	Light regime licence	Aperto	Enterprises	Bristol	No

Source: Ovum

For the purposes of this study, we assume that WiMAX technology (whether the fixed or mobile version) will operate in the UK using only licensed spectrum. We therefore make projections of demand and economic value for WiFi based services only, although we consider the likely impact of WiMAX on these projections.

A.5.2 Technical characteristics of WiFi

Overview of 802.1 standard family (WiFi)79

802.11
In 1997, the Institute of Electrical and Electronics Engineers (IEEE) created the first WLAN standard. They called it 802.11 after the name of the group formed to oversee its development. 802.11 only supported a maximum bandwidth of 2 Mbps - too slow for most applications. For this reason, ordinary 802.11 wireless products are no longer being manufactured.

802.11b
IEEE expanded on the original 802.11 standard in July 1999, creating the 802.11b specification. 802.11b supports bandwidth up to 11 Mbps, comparable to traditional Ethernet. 802.11b uses the same radio signalling frequency (2.4 GHz) as the original 802.11 standard. Being an unregulated frequency, 802.11b gear can be affected by interference from microwave ovens, cordless phones, and other appliances using the same 2.4 GHz range. However, by installing 802.11b gear a reasonable distance from other appliances, interference can easily be avoided. Vendors often prefer using unregulated frequencies to lower their production costs.

- Pros of 802.11b - lowest cost; signal range is best and is not easily obstructed
- Cons of 802.11b - slowest maximum speed; supports fewer simultaneous users; appliances may interfere on the unregulated frequency band

802.11a
When 802.11b was developed, IEEE created a second extension to the original 802.11 standard called 802.11a. Because 802.11b gained in popularity much faster than did 802.11a, some believe that 802.11a was created after 802.11b. In fact, 802.11a was created at the same time. Due to its higher cost, 802.11a is usually found on business networks whereas 802.11b better serves the home market.

802.11a supports bandwidth up to 54 Mbps and signals in a licensed 5GHz range. This higher frequency limits the range of 802.11a and signals have more difficulty penetrating walls and other obstructions. Because 802.11a and 802.11b utilise different frequencies, the two technologies are incompatible with each other. Some vendors offer hybrid 802.11a/b network equipment, but these products simply implement the two standards side by side.

- Pros of 802.11a - fastest maximum speed; supports more simultaneous users; regulated frequencies prevent signal interference from other devices
- Cons of 802.11a - highest cost; shorter range signal that is more easily obstructed

802.11g
In 2002 and 2003, WLAN products supporting a new standard called 802.11g began to appear on the scene. 802.11g attempts to combine the best of both 802.11a and 802.11b. 802.11g supports bandwidth up to 54 Mbps, and it uses the 2.4 GHz frequency for greater range. 802.11g is backwards compatible with 802.11b, meaning that 802.11g access points will work with 802.11b wireless network adapters and vice versa.

[79] http://en.wikipedia.org/wiki/Main_Page

- Pros of 802.11g - fastest maximum speed; supports more simultaneous users; signal range is best and is not easily obstructed
- Cons of 802.11g - costs more than 802.11b; appliances may interfere on the unregulated signal frequency

Table A.38 summarises the technical characteristics of IEEE 802.11 standard family.

Table A.38 – Technical characteristics of 802.11 standard family

Issue	IEEE 802.11a	IEEE 802.11b	IEEE 802.11g
Standard Ratified	Sep-99	Sep-99	05-Mar
Raw Data Rates	54 Mbps	11 Mbps	54 Mbps
Average Actual Throughput	4-5 Mbps	27 Mbps	20-25 Mbps
Frequency	5 GHz	2.4 GHz	2.4 GHz
Available spectrum	300 MHz	83.5 MHz	83.5 MHz
Modulation / Encoding	Orthogonal Frequency Division Multiplexing (OFDM)	Direct Sequence Spread Spectrum (DSSS) / Complementary Code Keying (CCK)	Direct Sequence Spread Spectrum (DSSS) / Packet Binary Convolutional Code (PBCC)
No. Channels / non-overlapping	12/8	11/3	11/3

Source: IEEE

WiFi and “polite protocols”

WiFi has been designed to be a “polite protocol”. The original standard defines Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) as the medium access method. A significant percentage of the available raw channel capacity is sacrificed (via the CSMA/CA mechanisms) in order to improve the reliability of data transmissions under diverse and adverse environmental conditions.

CSMA/CA avoids the collisions by using a polling method, the sender asking for a request to send (RTS) and the receiver (usually the Access Point) sending a clear to send (CTS) message when channel is ready to use. The access to the support is controlled by the use of interframe spaces (IFS), which corresponds to the interval of time between the transmission of two frames. The IFS intervals are idle periods when channel is not used by anyone. The length of IFS depends on the characteristics of the environment, the more noise, the longer the ISM, therefore making data rate slower when transmission is bad. During transmission between two pieces of equipment, the destination station checks the error control (CRC) of the frame and returns an Acknowledgment of Delivery (ACK) to the transmitter. If the transmitting station does not receive this ACK in time, it is assumed that a collision occurred, the frame is retransmitted after another CTS message has been received. Protocol CSMA/CA makes it possible to manage the collisions while also managing the constraints of radio transmissions (shared channel for all stations). On the other hand the mechanisms of CSMA/CA increases overhead (signalling frames necessary for the network but containing no user data) therefore making the performances of WiFi not as good as an equivalent bandwidth switched wired network.

WiFi uses an algorithm of "listen before talk". If there is some other non-WiFi device transmitting nearby, WiFi will wait for that other transmission to finish. So WiFi always goes second i.e. it is a polite protocol. Indeed, WiFi may listen and then start to transmit data only to find that one of these other devices, like a cordless phone or a microwave oven, which doesn't follow the same protocol, start to transmit in the middle of the transmission of WiFi packets. A collision is then experienced and the packets get lost and have to be retransmitted.

As a result WiFi users may experience fluctuations in the data rates especially when in public hotspots. Relative good quality of service can be guaranteed through packet re-transmission. However, this might not be suitable for real-time applications (such as voice) since any delays degrade the service quality severely.

A.5.3 Existing WiFi-based services

We examine the current level of WiFi-based public telecoms services in the UK. We can divide these services into two types:

- Use of the BT Fusion service (and those of any rival products). So far BT has sold around 30,000 phones for this service.[80] Initially using Bluetooth for its local wireless interface, BT plans to migrate to WiFi for this interface in 2006 and intends to have 3 terminals available by the end of 2006. BT plans for its Fusion customers to be able to use their hybrid mobiles/WiFi phones from the home, office and public hotspots which offer its OpenZone service. Given BT's strong market position this could have a significant impact, both from a demand side and the supply side perspective, on the take up of public WiFi services in the UK.
- Use of public WiFi hotspots by PCs and PDAs. In June 2006, there were 13,000 public hotspots in the UK.[81] This is split between The Cloud (7,350), BT OpenZone (1,500) and T-Mobile (1,000). The rest is made up of smaller players, e.g. coffee shops and hotels etc offering hotspots in public spaces. Apart from the agreements presented above, The Cloud also operates hotspots in all major UK airports, First Great Western train stations, Coffee Republic outlets, Little Chef cafes and Swallow Hotels, as well as over 4,000 pubs and regional hotels across the country. It expects its own hotspot count to increase to 10,000 by the end of 2006.

In January 2006,[82] the UK Government also unveiled plans for city centre WiFi networks that will give users in nine city centres high-speed wireless Internet access from laptops, PDAs and mobile phones. The first phase of the project, due to be completed by 2006, will see city centre "umbrellas" of wide WiFi hot spots rolled out in Birmingham, Cambridge, Edinburgh, Leeds, Liverpool, Manchester, Nottingham and Oxford, along with the London boroughs of Westminster, Kensington and Chelsea, Camden and Islington as well as the City of London. Many of these networks are being built by European wireless provider The Cloud. The firm already runs several WiFi hotspots in London, such as at Canary Wharf, the British Library and it has very recently won the WiFi blanket coverage network contract for the City of London They will be open to any Internet service provider that wants to offer services. Blanket wireless coverage will be provided in the city centres through WiFi equipment fitted on lampposts and street signs. People who want to use the wireless network will pay one of the ISPs for access, and revenues will be split between The Cloud, the local council and the ISPs. When this project is completed it is expected to give significant boost to WiFi usage and demand since WiFi networks' availability will move from the local to citywide level.

[80] BT announcement for 31 March 2006

[81] The Cloud, June 2006

[82] http://news.com.com/U.K.+cities+to+get+blanket+WiFi+coverage/2100-7351_3-6016122.html

We note that different operators (such as The Cloud, BT OpenZone, and T-Mobile) deploy WiFi networks in different areas or regions in the UK based on contracts won. However all of them have, to date, signed roaming agreements based on commercial negotiations for the bilateral use of their WiFi networks respectively. In other cases, operators that own significant number of hotspots offer wholesale services to smaller ones. For example, BT Open Zone customers can get online in hotspots managed by The Cloud and those hotspots provided by T-Mobile if they have an ongoing monthly account with BT Open Zone

WiFi based public services will also complement WiMAX solutions. For example BT plans to offer a combined WiFi-WiMAX[83] proposition in 12 UK cities, and it has already signed up 8 cities including Westminster, Leeds, Liverpool and Edinburgh. BT predicts that demand for (fixed) WiMAX will grow at 400% per annum in the early years. The main application for WiMAX deployment until 2010 will be connectivity to laptops, and WiMAX-enabled laptops availability will follow the penetration curve of WiFi. Mobile WiMAX is more likely from 2010 on, but it will still have limited coverage. WiMAX providers will still need to become Mobile virtual network operators (MVNOs) using 3G providers to provide service outside cities.

At the same time it is clear that WiFi and/or WiMAX will substitute for 2G and 3G mobile services – with relatively plentiful WiFi spectrum being used for sessions (voice or data) established in the home, office or public hotspot rather than the relatively scarce 2G and 3G spectrum.[84] For example Table A.39 sets out the advantages and disadvantages of WiFi based public services when compared with 3G mobile services.

Table A.39 – Advantages and disadvantages of WiFi compared to 3G mobile

Advantages	Disadvantages
For the average travelling business user, WiFi is still convenient and inexpensive. Availability is widespread and in just the locations most business users are likely to need it: corporate offices, airports, hotels, and coffee bars	WiFi service is decentralised and chaotic where in the case of 3G coverage is significantly better offering true mobility
The hardware is essentially free, as it's built into just about every notebook manufactured in the past three years	WiFi hotspots performance is not always warranted: dead spots, slow performance, and frequently dropped connections due to interference and overloaded access points
The monthly subscription cost of WiFi is roughly half that of a 3G account, and in a growing number of hotels and in some localities building municipal WiFi, connectivity is virtually free	If not a monthly WiFi subscription is used and charge is based on 'pay as you use', WiFi service can be more expensive than the 3G one
In 3G, uplink rates can be a fraction of downlink ones where in the case of WiFi they are basically the same (bi-directional services enabled)	Stand alone WiFi or dual/triple mode 2G/3G/WiFi devices not yet widely available in the market (price considerations as well)

Source: Ovum

Availability of appropriate handsets

Nowadays, embedded wireless network cards are more the rule than the exception in laptops; however cost is still a major issue for WiFi devices which will be used in both the public domain and

[83] Using licensed spectrum for WiMAX

[84] Such sessions represent over 70% of all sessions involving mobile phones according to one recent study

the home. Neither Motorola nor Nokia released retail prices of their WiFi enabled devices launched at 3GSM in 2006. However we believe that operators such as BT, bent on subsidising fixed-mobile convergence (FMC) devices, will drive down the end user price. BT Fusion handsets are free or are supplied at minimal cost with the BT Fusion package.[85] This is consistent with the pricing policy for 2G and 3G phones in the UK where mobile phones vary in price from free to over £200 depending on the type and size of contract signed by the user. As with 3G, the availability of volumes of reasonably priced devices will be key in driving mass market take up in the UK.

One indicator on the timeline for the availability of WiMAX devices comes from Markku Hollstrom, Nokia's GM of broadband wireless for radio networks. Speaking at WiMAX World Europe in June 2006, he said that Nokia is developing WiMAX base technology for use in its terminals from 2008 with the Nokia 770 as the platform for WiMAX. This will prove a huge driver for the market post 2008.

Coverage of WiFi hotspots

A mobile telephony service allows users to make and receive calls at any location, and allows the user to around while on the phone. Currently, WiFi allows users to make and receive calls near a hotspot, but confines the users to that hotspot's coverage range during the call. WiFi and future implementations such as Voice over IP (VoIP) over WiFi fall well short of being a mobile service. As such, WiFi is a technology for local access, not wide-area access. Whilst this maybe less of an issue for a nomadic laptop user, it means that WiFi will have limited usefulness as a bearer for voice communications unless it can be integrated with mobile services as BT Fusion is attempting to do. Once city centre WiFi networks are in place the WiFi coverage will improve.

Pricing trends

Many end-users complain about the high costs of usage of WiFi when around a hotspot. Prices for WiFi offering vary from £5 to £6 per hour to £13 to £16 per 24 hours. WiFi service prices in hotspots are currently quite expensive but as citywide WiFi networks are deployed and competition intensifies service prices are expected to reduce. Even at current levels, monthly subscription to WiFi services is significant lower than the price of high data speed mobile services offered for example by 2.5G/3G data cards. Table A.40 summarises the cost of ownership of a mobile data card.

[85] Motorola RAZR V3B has a £19.99 one-off charge with BT Fusion 100 call plan. Up to 5 phones can be connected to this plan at a cost of £9.99 each per month

Table A.40 – Cost of ownership of a mobile data card

		Vodafone	Orange	O2	T-Mobile
Lowest entry package	Cost of datacard	£199	£299	£176	£179
	Monthly fee	£11.75	£2.35 per MB	£9.40	£12.93
	MB included per month	5	0	5	7
'Typical' package	Cost of datacard	£149	£149	£176	£129
	Monthly fee	£23.50	£23.50	£17.04	£25.85
	MB included per month	75	65	36	100
Largest package	Cost of datacard	Free	£99	£88	£29
	Monthly fee	£53	£88	£88	£90.48
	MB included per month	1,024	1,024	1,024	1,024

Source: Enders Analysis; company data

Table A.40 suggests that for mobile data cards the price per MB sent varies roughly from £4 (lowest entry package) to £0.20 (largest package).[86] According to an experiment in Dartmouth College average daily traffic per active WiFi card in a typical WiFi hotspot located in the University Campus is 64.2 MB.[87] According to another study by Pronto Networks, daily download volumes in a WiFi hotspot vary significantly by location, type and pricing structure. Wherever a flat 24-hour rate exist, users average more than 20 MB in cafes and more than 50 MB in hotels.[88] By considering a daily average traffic for a typical public hotspot of 40 to 50MB per user and a 24-hour flat WiFi subscription of £15, we can then calculate the average price per MB per user to be roughly £0.30. These prices are comparable with those of the largest packages offered by 3G technology as shown above. As competition intensifies and WiFi coverage improves these prices are expected to reduce to a point where they are significantly cheaper than 3G data cards while offering higher data rates.

As far as WiMAX is concerned, pre-WiMAX prices will be relatively high, but the launch of volume production of the first generation chipsets by Intel and Fujitsu will contribute to lower the prices, in particular for CPE. Intel expects its chipset will go into consumer or business onsite devices priced from £150-300 ($250-550). As early as April 2005, Redline Communications unveiled its RedMax line of CPE using Intel's chip, that combined an outdoor antenna and an indoor box around the £250 ($500) for end users. The compares favourably with the £800 ($1,500) for outdoor antenna used for LMDS, but is still too high if the WiMAX service is expected to target residential users and compete in areas where DSL or cable is available.

86 Assuming the average user uses 50% of his monthly allowance

87 http://www.cs.dartmouth.edu/~tristan/pubs/witmemo05-hotspot.pdf

88 http://www.wi-fitechnology.com/displayarticle1299.html

A.5.4 Evolution of demand

According to analyst firm GfK[89] the growing demand for WiFi technology in the UK led to a dramatic rise in sales of WiFi equipment in 2005. Sales of wireless routers totalled £24m or an increase of 108% from the first quarter of 2005 to the same period in 2006. Similar growth is expected for coming years regarding usage of WiFi with lower device costs and improved coverage (also enabled through roaming deals). However much of this market growth comes from private rather than public service use of WiFi.

Given the analysis set out in this profile we conclude that:

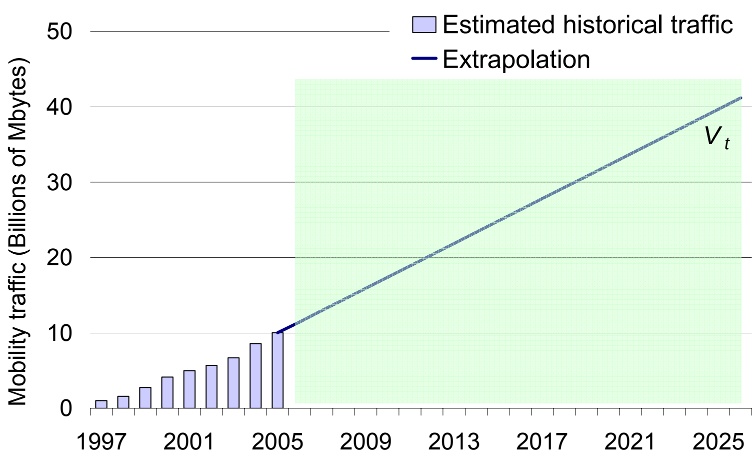
- WiFi coverage in main cities across the UK will improve as city centre WiFi networks are deployed and WiFi service coverage is significantly enhanced
- WiFi monthly subscription (or price per Mbyte) will reduce significantly when compared to similar services offered by other competing wireless technologies
- WiMAX services, whether based on the fixed or mobile version of WiMAX, will be offered only in licensed spectrum

Baseline demand for mobility traffic

We estimate a baseline demand for mobility traffic (V_t) in absence of WiFi, measured in terms of Mbytes carried each year. This is a linear extrapolation of historic growth in UK mobility traffic from 1997 to 2005 in which we assume that:

- Each minute of voice traffic generates 0.11 Mbytes of data (60 seconds x 14.4 kbit/s / 8 bits per byte)
- Each text message (SMS) generates 0.0001 Mbytes of data
- Each 3G data user generates 20 Mbytes of data each week

Figure A.34 – Baseline demand for mobility traffic



Demand scenarios

Measure of demand: Mbytes carried each year.

89 http://www.netstumbler.com/2006/05/25/uk-sales-of-wi-fi-equipment-soar/

We propose three possible scenarios of how demand for public access WiFi services in the UK might evolve over the next 20 years. We

- consider the role of WiFi as one of several competing mobility technologies
- assume that WiFi will be offered both on a stand alone basis and as a hybrid service using dual mode (WiFi/3G) and triple mode (WiFi/3G/WiMAX) terminals which offer comprehensive geographic coverage
- consider the use of WiFi to offer services which substitute for other mobility services. Thus we exclude private use of WiFi in the home[90] and office except where it is integrated into a public access service such as that offered by BT Fusion.

We then project WiFi demand based on this. The three scenarios are:

- ***High demand scenario***. WiFi and WiMAX are successful: BT and other main operators aggressively support WiFi and WiMAX technologies (FMC solution: BT Fusion); in parallel citywide WiFi 'umbrellas' are deployed in all main cities in the UK in the coming 3 years. Overall wireless traffic (voice and data) increases over time and significant migration of traffic from 3G and other wireless technologies to WiFi/WiMAX is experienced
- ***Medium demand scenario***. WiFi succeeds but WiMAX does not: BT and other main operators aggressively support WiFi technology; in parallel citywide WiFi 'umbrellas' are deployed in all main cities in the UK in the coming 3-4 years. However, significant delays in standards' ratification and products' availability for WiMAX 802.16e (mobile version) is experienced which affects overall uptake of WiFi as well. Overall wireless traffic (voice and data) increases over time but with limited migration of traffic from 3G and other wireless technologies to WiFi because of the limited coverage offered by WiFi when compared to 3G
- ***Low demand scenario***. WiFi remains a niche product and WiMAX fails: Attempts by BT and other operators to fully support and lobby for WiFi and WiMAX do not prove successful. WiFi citywide 'umbrellas' are deployed but demand is low. Moreover, significant problems regarding WiMAX 802.16e standards' ratification further postpone WiMAX's availability providing 3G technology with a significant advantage. Overall wireless traffic (voice and data) increases over time but there is almost no migration of traffic from 3G and other wireless technologies to WiFi.

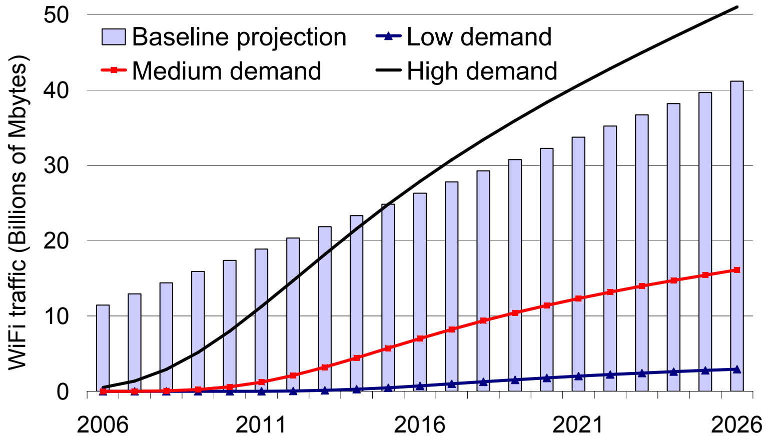
Table A.41 tabulates the key assumptions and Figure A.35 the resulting projections of demand for WiFi traffic. We also include in Figure A.35 our projections of baseline mobility traffic (in the absence of WiFi services) from Figure A.34.

Table A.41 – Demand scenarios assumptions

	Low	**Medium**	**High**
% of mobility traffic which migrates to WiFi by 2025	5%	20%	50%
Year of maximum growth of this %	2016	2013	2010
New mobility traffic stimulated by WiFi as a % of migration traffic	50%	100%	150%

[90] Application 6 looks at WiFi for home data networking

Figure A.35 – Demand projections for public WiFi access services



A.5.5 Economic value

Counterfactual: there are no public access broadband services based on WiFi and end users must rely on other technologies such as 3G mobile services

In considering the economic value of using LE spectrum for public telecoms services we need to differentiate between the economic value generated by mobility attributed to wireless technologies as a whole and the economic value generated by the specific use of WiFi.

Table A.42 – List of quantified costs and benefits

Benefits	Quantified?	Costs	Quantified?
Where WiFi based services substitute for mobile			
Reduced cost of using WiFi rather than mobile	Yes	Benefit is cost difference	N/a
Where WiFi based services stimulate mobility use			
Increased productivity of end user Better and faster decision making Improved logistics Social benefits	In combination through willingness to pay estimate	Cost of supply of WiFi service	Yes
Where WiFi based services substitute for fixed line service			
		Stress caused by expectation that worker will always be available	No

Economic value attached to the mobility factor

The economic value of mobility in general includes the following components:

- ***Increased productivity***. Mobility services turn dead time (e.g. in airport lounges, railway stations etc) into productive time, especially if connectivity allows access to office systems and other information sources. For knowledge-based professionals who charge in excess of £100 per hour, this enhances their revenue generating potential.
- ***Better and faster decision making***. The ability to communicate on the move allows relevant people to be involved more, and more quickly, in decision making processes. Access to information on the move also improves decision making, often for basic operational processes eg field engineers retrieving important data to enable diagnosis and repair
- ***Improved logistics***. Greater convenience and fast access to information enable better travel planning, so avoiding public transport and road congestion delays.
- ***Reduced set up time and capital expenditure***. Computers can access networks without requiring the purchase, installation, maintenance and repositioning of cables and network connections during office set ups and moves.

Mobility also generates costs in terms of the burden of expectation it places on individuals to be constantly available. Whilst the technology undoubtedly allows individuals to "work smarter", the work load and volumes increase to fill all available time. This can encroach on time previously spent in recreation, relaxation or sleeping. This then has a detrimental effect on social well-being and mental and physical health which may create other burdens on the economy in the long term e.g. NHS, healthcare and leisure industry.

Economic value of WiFi based public services

There are two specific examples of economic value attached with the use of WiFi as compared to other available wireless technologies:

- ***Lower cost of delivery of mobility services***. The limited evidence available suggests that WiFi offers a substantially lower cost method of communications than 3G mobile (or WiMAX) for sessions established in the home, office, or at a public hotspot. Moreover for the bulk of these sessions the user does not require cell handover since s/he completes the session whilst within the home cell offered by the WiFi interface. We expect these lower costs to be reflected in the prices of WiFi and 3G mobile services and for end-users to substitute WiFi voice and data successions for 3G mobile sessions in future. This costs reductions represent a clear economic benefit.
- ***Increased use of mobility services***. If, as we expect, public WiFi based services are significantly cheaper than 3G mobile services then this will lead to greater use of mobility services, the users making voice and data calls which they would not make in a mobile services only environment. These additional calls will generate additional consumer (and producer) surplus.

Quantifying these benefits is challenging. WiFi will both substitute for mobile traffic and stimulate mobility traffic to some extent because it is a lower unit cost technology if demand is high enough. We need to assume

- how the relative prices of WiFi, WiMAX and 3G mobile will evolve over the study period, and
- what the take up of WiFi for services which substitute for mobile and WiMAX will be

We propose the following model. Historic data is available from Ofcom statistics on:

p_{mt} = Price per Mbyte of mobile network traffic

R_t = revenue from mobility traffic

Based on Ofcom statistics on historical mobility traffic, we estimate:

V_t = Baseline mobility traffic in year *t* in absence of WiFi

The assumptions in Table A.41 provides estimates of

N_t = New mobility traffic from successful WiFi

S_t = Traffic which moves from mobile network to WiFi

We know that:

$$R_t = [V_t - S_t] \cdot p_{mt} + [S_t + N_t] \cdot p_{nt}$$

We can use this equation to calculate p_{nt}, the Price per Mbyte of WiFi network traffic

Then the economic benefits of WiFi/WiMAX are

- Benefits of lower prices for WiFi for the people who would use this service even if there is no public access broadband service based on WiFi
- Consumer surplus generated from new traffic

That is,

$$\text{Economic benefits} = [p_{mt} - p_{nt}] \cdot S_t + \frac{N_t \cdot p_{nt}}{2\varepsilon}$$

where ε = price elasticity of demand for new traffic

To estimate the economic benefits under the three demand scenarios we assume that:

- ε = -0.33. This is consistent both with price elasticities for mobile services estimated during the Competition Commission inquiry into mobile termination rates in 2002 and with elasticities implied by estimates of mobile consumer surplus made by Hausman[91] and the UK Radio Communications Agency[92]
- Spend on mobility services continues to grow but at a reducing rate, starting at 12 per cent per annum in real terms[93] in 2004 and reducing to 2 per cent[94] by 2012.

A.5.6 Economic valuation projections

Based on our assumptions we estimate the net benefit streams for WiFi public services as shown in Figure A.36. and the NPV of these streams as shown in Table A.43.

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[91] See Shann Lecture, March 2003

[92] The UK's Radio Communications Agency also estimated a consumer surplus for UK cellular services, there, using a willingness to pay survey. In 1999 cellular services generated revenues of £4.8 billion while the consumer surplus was estimated at £7.2 billion for the year

[93] The average rate observed from 1997 to 2004 in the UK

[94] To reflect expected real GDP growth rate

Figure A.36 – Annual benefits from using public WiFi access services

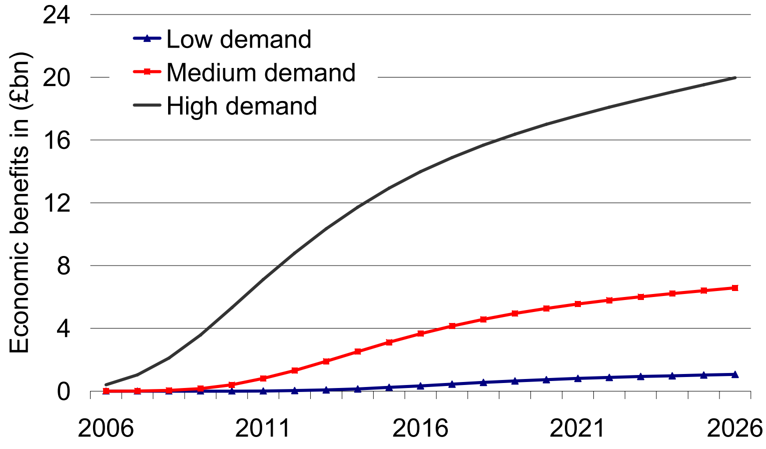

Table A.43 – Net present value of the net benefits from public WiFi services – 2006 to 2025

Scenario	Net present value (£ billion)
Low demand	9
Medium demand	68
High demand	239

Table A.44 – Annual benefits from using public WiFi services – Low demand scenario

	2006	2011	2016	2021	2026
Baseline traffic without WiFi (Billions of Mbytes)	11.5	18.9	26.3	33.7	41.2
Price per Mbyte (pence)	129	105	83	72	65
WiFi traffic substituted from baseline mobility traffic (Billions of Mbytes)	0.0	0.0	0.5	1.3	2.0
Price reduction per Mbyte from using WiFi (pence)	43	35	28	24	22
Benefits from substituted traffic (£bn)	0.0	0.0	0.1	0.3	0.4
New WiFi traffic (Billions of Mbytes)	0.0	0.0	0.2	0.7	1.0
Price per Mbyte of WiFi traffic (pence)	86	70	55	48	43
Benefits from new traffic (£bn)	0.0	0.0	0.2	0.5	0.6
Total net benefits from broadband services using WiFi (£bn)	0.0	0.0	0.3	0.8	1.1

Table A.45 – Annual benefits from using public WiFi services – Medium demand scenario

	2006	2011	2016	2021	2026
Baseline traffic without WiFi (Billions of Mbytes)	11.5	18.9	26.3	33.7	41.2
Price per Mbyte (pence)	129	105	83	72	65
WiFi traffic substituted from baseline mobility traffic (Billions of Mbytes)	0.0	0.6	3.5	6.2	8.1
Price reduction per Mbyte from using WiFi (pence)	65	52	42	36	32
Benefits from substituted traffic (£bn)	0.0	0.3	1.5	2.2	2.6
New WiFi traffic (Billions of Mbytes)	0.0	0.6	3.5	6.2	8.1
Price per Mbyte of WiFi traffic (pence)	65	52	42	36	32
Benefits from new traffic (£bn)	0.0	0.5	2.2	3.3	4.0
Total net benefits from broadband services using WiFi (£bn)	0.0	0.8	3.7	5.5	6.6

Table A.46 – Annual benefits from using public WiFi services – High demand scenario

	2006	2011	2016	2021	2026
Baseline traffic without WiFi (Billions of Mbytes)	11.5	18.9	26.3	33.7	41.2
Price per Mbyte (pence)	129	105	83	72	65
WiFi traffic substituted from baseline mobility traffic (Billions of Mbytes)	0.2	4.5	11.2	16.3	20.4
Price reduction per Mbyte from using WiFi (pence)	78	63	50	43	39
Benefits from substituted traffic (£bn)	0.2	2.8	5.6	7.0	7.9
New WiFi traffic (Billions of Mbytes)	0.3	6.8	16.7	24.4	30.6
Price per Mbyte of WiFi traffic (pence)	52	42	33	29	26
Benefits from new traffic (£bn)	0.2	4.3	8.4	10.6	12.0
Total net benefits from broadband services using WiFi (£bn)	0.4	7.1	14.0	17.6	20.0

