The economic impact of physics research in the UK:
Satellite Navigation Case Study

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Executive Summary

- The global market for satellite navigation systems is significant in size and is growing quickly. Based on GPS (Global Positioning System) usage rates by industry and the contribution of those industries to UK GDP, the GPS-sensitive contribution is today worth around 7% of UK GDP, or about £100 billion. The global market of products and services using GNSS-based (Global Navigation Satellite System) positioning and navigation is projected to grow by 10% a year over the next decade.

- The satellite navigation industry is also very important in its own right. The industry is expected to generate a value-added contribution to UK worth £1.45 billion in total (including multiplier impacts) between 2011 and 2020, or around £146 million a year in 2010 prices.

- It can take many years of fundamental research to translate into economic impact. Today’s satellite navigation systems are the result of a century of research. But these technologies would not be possible without accurate time-keeping, which relies on principles inherent in two major theories of modern physics: quantum theory and general relativity. It is only by the combination of the theory of general relativity (1919), atomic clocks (1950s) and the development of satellites (late 1950s) that together made GPS possible.

- The Science and Technology Facilities Council (STFC) is playing a crucial role in two key areas of satellite navigation technologies: determining the impact of space weather on the positioning accuracy of existing satellite navigation systems; and collecting and evaluating the performance of signals from Galileo, the European programme for a global navigation system.

- Most UK citizens have some direct experience with GPS enabled applications, especially in-car guidance. But the UK’s reliance on satellite navigations goes much further. Applications include aviation, fleet management and logistics, and location-based services that in turn lower response times of emergency services.

- With the market for satellite navigation systems growing quickly, and becoming ever-more interlinked with the provision of services on which quality of life, health and safety depend, the need for an independent satellite navigation infrastructure is becoming more important by the day. Galileo will help to guarantee the integrity of provision of such services in the future.

This study was commissioned by STFC and carried out by Oxford Economics. It demonstrates the economic impact of UK fundamental physics research in the area of satellite navigation to the UK and global economy. It updates the previous case study contained in the report “The economic impact of physics research: a case study approach (2009)”, which was carried out by STFC, EPRSC, IOP and RAS.¹

¹ The report is available on request from STFC.
1 The science behind satellite navigation

1.1 Introduction

To navigate to a location accurately, you need to know where you are currently positioned, your speed and direction of travel, and be able to measure time accurately. A satellite navigation system uses specifically coded satellite signals sent to an electronic receiver to precisely determine position (longitude, latitude and altitude), velocity and time.

A satellite navigation system with global coverage is termed a global navigation satellite system or GNSS. There are currently two fully available global navigation systems: The Global Positioning System (GPS) operated by the US Department of Defence; and the Russian satellite navigation system (GLONASS).

1.2 The science

The launch of the first manmade satellite, Sputnik, in 1957 marked the start of a new era in communications technology, not least because US space scientists tracking the satellite noted that the radio signal it was transmitting could be used as a means of navigation. If the satellite’s position is known, the position of the observer can be calculated.

Based on that discovery, US physicist Ivan Getting, working for the US Air Force, soon proposed a system involving many satellites orbiting the Earth that could provide an accurate and reliable positioning system. His idea was put into practise and by the late 1990s GPS has been used to provide precise time, frequency and position co-ordinates world-wide.

Today’s satellite-based navigation and positioning systems such as the United States GPS and Europe’s Galileo are rooted in a range of physics research over the last century including the development of the atomic clock, which is based on an understanding of quantum theory, and Einstein’s general theory of relativity.

Box 1.1 summaries the physics research underpinning satellite navigation and positioning systems used across the globe today. Chapter 5 presents a more detailed a timeline of satellite navigation technologies.

Box 1.1: The science behind satellite navigation

Atomic Clock: Introduction

- To pinpoint location requires measuring the distance between the user and at least three satellites. This is achieved by registering the time taken for a signal sent by the satellite to reach the receiver. The transmission contains the time the signal was sent, along with the exact position of the satellite, which can be compared by the system’s computer with the signals sent by the other satellites.

- Accurate time measurement is central to satellite navigation and positioning because the signal’s transit time is so short (it travels very close to the speed of light) that satellites must carry the most accurate synchronised clocks available. These are atomic clocks, which exploit the fundamental quantum physics of the atom and are accurate to just one-billionth of a second in a day.

- The physicists Louis Essen and Jack Parry built the first reliable atomic clock in 1955 at the UK’s National Physical Laboratory. These clocks are now the gold standard for time – even Big Ben is
checked against one. They are based on the frequency of microwave radiation emitted when an atom (typically of caesium) undergoes a particular quantum energy transition.

- The European Laboratory for Particle Physics at CERN\(^2\) was used to calibrate the distance measurements of early versions of GPS when the satellites were first launched in the 1970s. The large Electron Positron (LEP) particle accelerator based at CERN provided the most precise distance measurement between two locations in the world giving millimetre precision measurements over tens of kilometers.\(^3\)

**Atomic Clock: Use in network synchronisation**

- Atomic timing is also widely used in the communications industry for network synchronisation. Telephone companies generally transmit calls digitally and many conversations between the same two cities can be carried down the same wires if computers at both exchanges flick from one conversation to another thousands of times every second. If the clocks controlling the two exchanges get out of step, the calls will become jumbled up. Atomic clocks ensure that this does not happen.

- Mobile telephones, digital television and internet communications use similar technology for network synchronisation. Communications companies often take the time from the clocks on GPS satellites.

- Electric power companies need time-synchronised atomic clocks throughout their power grids to quickly transfer power to parts of the grid where it is needed most. They use such clocks to determine the location of faults along a transmission line and to investigate and analyse abnormalities and incidents that cause loss of system efficiency and effectiveness.

- Atomic clocks are also used for: location and timing-based technologies, spacecraft navigation; monitoring the slowly changing spin of the Earth; and testing physics theories.

**General theory of relativity**

- A further phenomenon predicted by curiosity-driven (i.e. fundamental) physics research has to be taken into account in time measurement. This is the difference in the strength of the Earth’s gravitational field on the ground and in space, which means that a ground-based clock runs a fraction of a second slower than a clock on the orbiting satellite – an effect predicted and explained by Albert Einstein’s general theory of relativity and then verified through experiments by UK scientists, in particular Arthur Eddington. This was critical to establishing the theory as a central pillar in theoretical physics.

- Fortunately, the general theory of relativity also enables physicists to make the essential time corrections. The satellite-based clocks are manufactured to run slightly slower when on Earth, so that they will keep the ‘correct’ time once in orbit. The user’s satellite navigation and positioning equipment can make further corrective calculations as it determines its position. Without these corrections, positioning errors would increase at the rate of around 10 km a day.

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\(^2\) European Organization for Nuclear Research (CERN), based near Geneva.

\(^3\) Beams Department Newsletter, (CERN), Issue 3, December 2011. pp 3-4.
1.3 STFC’s role in satellite navigation

The Science and Technology Facilities Council (STFC) plays a significant role in two key areas of satellite navigation technologies: determining the impact of space weather on the positioning accuracy of existing satellite navigation systems; and collecting and evaluating the performance of signals from the European Union’s Galileo global positioning system.

1.3.1 STFC and space weather

Space weather refers to the changing environmental conditions in outer space and is distinct from the concept of weather within a planetary atmosphere. These conditions include phenomena such as; variations in magnetic fields and radiation, and other matter in space.

For the Earth, space weather effects are dominated by our Sun. Solar eruptions such as solar flares and coronal mass ejections in particular give rise to changes in the solar wind – streams of charged particles ejected from the Sun – and can cause ‘geomagnetic storms’ that can damage Information and Communication Technologies (ICT) systems, especially satellites.

Current research suggests that solar activity follows an approximate 11-year cycle and the next maximum is likely to occur around 2013. Electrical infrastructure and satellite navigation are likely to be affected during the peak period of solar activity and subsequently affect the accuracy and reliability of satellite-based navigation and positioning systems.

STFC, with the support of the Natural Environment Research Council (NERC), has a vibrant research programme in the area of space weather. STFC’s RAL Space has been providing critical space weather expertise and services since the 1980’s. These services include:

- **Monitoring solar wind** – STFC’s RAL Space supplies one-third of the only 24/7 service that monitors the state of the solar wind before it impacts Earth and provides critical input for space weather services around the world.

- **Spectroscopic imaging of the sun** – STEREO (Solar Terrestrial Relation Observatory) is a solar observation mission that performs spectroscopic imaging of the sun via two spacecraft launched in 2006. STEREO is unique because it enables 3-D images of the sun to be produced, which gives scientists a powerful tool for observing and tracking solar phenomena such as coronal mass ejections. The sensitive cameras and detectors on-board the craft were made at RAL Space.

- **Examination of the ionosphere** – Satellite signals suffer variable phase delays when passing through the Earth’s atmosphere, particularly the ionosphere. These generate errors of several tens of metres if not corrected. STFC’s RAL Space has been at the forefront of research to provide ‘ionospheric correction’ to improve the accuracy of satellite navigation systems by providing ionosphere monitoring using an ‘ionosphere sounder’ located at RAL that works by transmitting and then receiving and analyzing short pulses that are reflected at various layers of the ionosphere. The data received provides a picture of ionospheric events that can be used to provide ‘ionospheric correction’ to satellite-based navigation and positioning systems (Box 1.2).

Correcting for the effects of space weather is critical for maintaining the accuracy and reliability of GPS systems and to ensure it remains suitable for safety critical applications.
Box 1.2: The impact of space weather on satellite navigation

- The environment around the Earth has to be taken into account to maintain the accuracy of global satellite navigation and positioning systems such as GPS.

- The signal from a GPS satellite travels through a small amount of ionised material in the upper atmosphere (the ionosphere). This slows the signal to slightly slower than the speed of light, and can therefore generate errors of several tens of metres if not corrected. The error depends on factors such as ‘space weather’ and much effort has been devoted to this ‘ionospheric correction’ as it is a key factor in improving the accuracy of GPS.

- The US and Europe have deployed networks of instruments to determine the local correction and feed this to GPS receivers. RAL Space provides the local correction for South England and the Falklands.

- Space weather remains an active area of STFC’s physics research because of the strong interest in improving GPS accuracy and reliability.

1.3.2 STFC and Galileo

The Galileo project (Galileo) is the European programme for a global navigation system. A joint initiative of the European Union (EU) and the European Space Agency (ESA), it is the first satellite navigation and positioning system specifically designed for civil purposes. Crucially it offers a more advanced, more efficient and more reliable platform than the current US GPS system.

Galileo is being implemented in three phases:

1. The definition phase, completed in 2003, providing the basic specification for the system.
2. The deployment and in-orbit validation phase, which is currently underway.
3. The deployment phase which will commence with the launch of the final satellite to complete the constellation in about 2020.

STFC and predecessors managed the ESA subscription until April 2011 when it was taken over by the then newly formed UK Space Agency. During this time, two test satellites, GIOVE-A and GIOVE-B, were launched in 2006 and 2008 respectively. The objectives of these satellites were to:

- Make satellite transmission frequency measurements;
- Validate key technologies such as the rubidium (atomic) clocks on the satellites;
- Test and evaluate the reception of signals from the satellites.

Two parts of STFC played a crucial role in the successful GIOVE-A mission, the Chilbolton Observatory in Hampshire and the Rutherford Appleton Laboratory (RAL) in Oxfordshire (Box 1.3).
Box 1.3: STFC and GIOVE-A

**Chilbolton Observatory’s role**

- The first signals from the GIOVE-A were detected on Thursday 12th January 2006 using a purpose-built receiver at the Chilbolton Observatory, designed and built by STFC’s engineers.
- To meet international telecommunication standards, extensive calibration procedures and tracking tests were made at Chilbolton in the run-up to the launch of GIOVE-A. This resulted in the Chilbolton staff developing a sensitive, flexible and well-calibrated receiving and signal analysis system to allow high quality data to be collected.
- The initial phase of the operational measurement phase of the project lasted for around two months, during which many overpasses were tracked and recorded by Chilbolton Observatory and RAL Space staff.

**Rutherford Appleton Laboratory (RAL) role**

- It was the 12 metre antenna of the RAL Ground Station that was used to communicate with the GIOVE-A satellite, sending commands to control the satellite and receive telemetry data.

### 1.4 Conclusions

It can take many years before fundamental research translates into economic impact. Today’s satellite navigation systems such as the American GPS are rooted in a range of physics research over the last century including the development of the **atomic clock**, which is based on an understanding of quantum theory, and Einstein’s **general theory of relativity**. It is only by the combination of the theory of general relativity (1919), atomic clocks (1950s) and satellite development (late 1950s) that together made GPS possible.

Research carried out by STFC played a major role in enabling the on-going development of satellite navigation, most notably in the area of space weather to improve the accuracy and reliability of existing systems, but also in testing and evaluating the performance of signals from Europe’s Galileo global positioning system that will eventually offer a more advanced, more efficient and more reliable platform than the current US GPS system.
2 Economic impact of satellite navigation

2.1 Introduction

Global navigation satellite systems (GNSS) are a significant enabling technology that has many applications that generate economic and social benefits for the UK and the wider global economy.

Box 2.1 summaries some of the key industrial sectors most exposed to satellite navigation technologies that benefit from the timing and positioning functionality it provides.

Box 2.1: Key areas of application for satellite navigation technologies by industry

- **Road transport**: - a wide range of applications including navigation devices to automatic toll systems, safety applications and pay-per-use insurance.
- **Air transport**: - improved accuracy and integrity of navigation systems to optimize flight planning and so lower fuel use, time and emissions.
- **Maritime**: - Vessel tracking and tracing inland water transport. Port approaches.
- **Rail transport**: - signaling and train location systems. Improved safety of speed control and operating systems.
- **Agriculture**: - Optimize crop control, reduce fertilizer and pesticide inputs, and ensure effective use of land and water.
- **Search and rescue**: - allowing near real-time reception of distress messages from anywhere on Earth with precise location information between rescue centres and people in distress.
- **Location-based services**: - Customers will be able to access specific ‘vicinity’ information through their mobile phone (e.g. the nearest restaurant or cash point machine, the best way to the nearest hospital).
- **Oil and gas**: - Exploration and exploitation of oil and gas fields.

It is not easy to reliably assess the size of the benefits for the UK from the applications enabled by GNSS. Various studies have been conducted but data sources and methodology are far from fully comparable. However, what is clear from all the studies is that the benefits are likely to be very significant indeed.

2.2 Summary impact of GPS

A recent study by the European Commission stated that the European dependence on the satellite radio navigation provided by the USA’s Global Satellite Positioning System (GPS) is estimated to represent 6% to 7% of the GDP of EU-27, i.e. € 800 billion in the European Union. This assessment is based on several US studies and in particular one by the Space Policy Institute of George Washington University, which identified the most satellite navigation exposed industries. A further assessment then established the actual share of these sectors’ contribution to GDP for EU-27 countries. This showed that:

Delivery services – 100% reliance. Fleet management and parcel tracking by satellite navigation is used by freight forwarders and express delivery companies in all countries.

Utilities – 60% exposure. The transmission and distribution networks such as electricity grids rely on satellite navigation timing for synchronisation (see Box 1.1).

Banking and finance – 35% exposure. This relates to money transactions that are stamped with GPS time using satellite based synchronisation technology.

Agriculture – 10% exposure. This relates to precision agriculture whereby field management (e.g. spraying) on the bigger farms in the EU is done by GPS assistance in the tractor or combine.

Communications – 40% exposure. Mobile phone turnover accounts for 40% of telecom turnover in the EU. Around 400 million smartphones containing a GPS chip were shipped globally in 2010, around 15% of them in the EU.

Based on these EU-27 satellite navigation penetration rates, and the contribution of these industries to UK GDP, we estimate that the GPS sensitive contribution is around 7% of UK GDP, or about £100 billion in 2010 prices.

2.3 The need for Galileo

The UK and the rest of Europe is currently reliant on the American GPS system, with no viable alternative if that system faced a security breach, or worse still, if the system was to become inaccessible even for just a few moments. As shown in Box 2.1, the reliance of users on GPS is spread across many key industries that have become central to the UK economy and on which our quality of life, health and safety depend. It is against this backdrop that the EU is developing an independent satellite navigation infrastructure to guarantee the provision of services.

The remainder of this Chapter sets out the direct economic impact to the UK of the UK’s involvement in Galileo. In particular, it focuses on what that involvement means for the UK satellite navigation industry and the subsequent impact on GDP.

2.4 Definition of the satellite navigation industry

The satellite navigation industry is not well defined in standard government industry classifications (SIC) and hence data are not available from sources such as the Office for National Statistics. The key sources of information on the economic importance of the satellite navigation industry are the Department for Business Innovation and Skills (BIS) paper ‘The Space Economy in the UK: An economic analysis of

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6 http://www.gartner.com/it/page.jsp?id=1466313
7 The closest Standard Industrial Classification (SIC 2007) codes for the activities of the satellite navigation industry in National Statistics are 61.30: Satellite telecommunication activities, and 61.90: Other telecommunication industries. Both these codes also include the radio and television.
the sector and the role of policy (2010), and the 2010 report ‘The Size and Health of the UK Space Industry’ published by the UK Space Agency (UKSA). The estimates presented here draw heavily on these statistics but have been supplemented by our own research including our report ‘The Case for Space’, published in 2009.

The satellite navigation industry consists of companies that provide the satellite technology (the upstream sector), as well as companies that exploit the technologies (the downstream sector). The distinction between the upstream and the downstream segment is not always completely clear, for that there could be companies whose activities could be included in both the upstream and downstream. As a general rule, the following definitions are used:

**Upstream segment**: the ‘Provision of satellite navigation technology’. For this, our upstream analysis focuses on the impact of the UK’s involvement with Galileo, Europe’s satellite navigation system. In particular, we consider the role of Surrey Satellite Technology Ltd, based in Guildford, and who are now part of Astrium, Europe’s largest upstream space company, and Logica, one of the UK’s prominent suppliers to the Galileo project who provide the ground technology that transmits and processes the data.

**Downstream segment**: the ‘Exploitation of satellite navigation technology’. The downstream segment includes the manufacture of the navigation device, as well as the provision of services to the end user.

Where possible we quantify the economic impact in the UK and globally, both now and in the future.

2.5 Methodological approach

There are many channels through which the UK satellite navigation industry makes a contribution to the UK economy. This contribution includes:

- **Direct impacts**: employment and activity in the satellite navigation industry itself. As discussed above, this includes the upstream provision of technology by UK companies as well as the downstream exploitation of the technologies by UK-based downstream companies (e.g. manufacturers of the navigation device for the end user).

- **Indirect impacts**: employment and activity supported down the supply-chain to the UK satellite navigation industry as a result of UK companies purchasing goods and services from UK suppliers. By way of example, jobs supported by the manufacture of computers sold to satellite navigation companies, or the manufacture of metal used in satellites would be classed as an indirect supply-chain impact.

- **Induced impacts**: employment and activity supported by those directly or indirectly employed by the UK satellite navigation industry spending their incomes on goods and services in the wider UK economy. This helps to support jobs in supplying industries such as jobs in retail outlets and business service providers.

But the impact of satellite navigation technologies goes much further than the narrowly defined upstream and downstream industry segments. Satellite navigation systems are very much an enabling technology for a wide range of applications, predominantly in transport and personal location-based services. These generate benefits from which the government, consumers, society and other industries can derive economic activity. These are known as the ‘catalytic’ or ‘wider’ economic impacts of satellite navigation systems, and are derived from such applications as road vehicle navigation, road user charging, fleet vehicle management, and vehicle tracking. These are considered in Chapter 3 of this report.
2.6 Upstream direct impacts

To estimate the impact of the upstream segment of the satellite navigation industry (i.e. the provision of satellite navigation technologies) we consider the value of Galileo-based contracts awarded to UK companies since the beginning of the Galileo project.

The project itself has two main phases, with UK companies very much at the heart of both phases, which can be summarised as follows:

**In-orbit validation (IOV) phase** – is aimed to assess the effectiveness of the Galileo space, ground and user segments through extensive in-orbit/on-ground tests and operations. During this phase, four operational satellites will complement the two experimental satellites, Giove-A built by Surrey Satellite Technology Ltd, and Giove-B, whose payload was developed by EADS Astrium in the UK.

**Full Operational Capability (FOC) phase** - consists of the deployment of the remaining ground and space infrastructure, including an intermediate initial operational capability phase with 18 satellites in operation (the four IOV satellites plus 14 others). By 2015, 18 satellites should be in place, followed by the rest in 2020. The full system will consist of 30 satellites, control centres located in Europe and a network of sensor stations and uplink stations installed around the globe.

The value of Galileo-based contracts awarded to UK companies to 2010 was £210 million. This was split between £150 million awarded for the UK development of Giove-A and Giove-B, plus £60 million to LogicaCMG UK for software supplies for the system’s in-orbit validation phase.

The value of Galileo-based contracts awarded to UK companies for the FOC phase between 2010 and 2020 is £584 million. Surrey Satellite Technology Ltd won a contract to build the payloads for the next 14 Galileo satellites worth £475 million\(^8\), while Astrium (£62 million)\(^9\) and Logica (£47 million)\(^10\) have secured other major Galileo contracts for the ground control segment and the ground mission segment respectively.

Putting these together shows the UK has been awarded £794 million worth of contracts associated with the validation and operational phases of the Galileo project. Equating the contract awarded figures to represent the impact on the turnover of these companies we can provide estimates of the direct impact of the Galileo project to the UK in the period 2003-2010, and 2011-2020\(^{11}\).

\(^8\) http://blog.sstl.co.uk/archives/274-Green-light-for-Galileo-satellites.html


\(^10\) www.logica.co.uk/we-are-logica/media-centre/news/2011/logica-to-secure-the-galileo-satellite-navigation-programme/

\(^11\) Given both Giove-A and Giove-B are already in space, we assume that the value of those contracts has already impacted on the UK economy. With the IOV phase active until 2015, we assume that 75% of the software support budget has already been provided to Logica, with the remaining 25% budget delivered over the next 5 years.
While turnover in the upstream satellite navigation industry provides a good indication of the size of the direct impact of the Galileo project, the value-added (defined as turnover less all input costs) an industry generates provides an indication of the impact on the UK economy. Estimates from the UKSA show the upstream space industry to have a value-added to turnover ratio of 1.47 (i.e. for every 1 million of turnover, the value-added contribution to UK GDP will increase by £470,000).

By assuming that the upstream satellite navigation industry has the same value-added to turnover ratio as the broader space industry, the upstream industry made a value-added contribution to UK worth £100 million in total between 2003 and 2010, and an estimated **upstream value-added contribution to UK GDP of around £11 million in 2010**.

Over the next decade, the **upstream satellite navigation industry is expected to generate a direct value-added contribution to UK worth £250 million in total between 2011 and 2020, or around £25 million a year in 2010 prices**.

### 2.7 Downstream direct impacts


Turnover in the UK downstream space sector reached £7.6 billion in 2010, up from £7.2 billion in 2009. The bulk of the downstream space sector is derived from satellite broadcast services (59%) and satellite communication providers (17%). Around 1% of this turnover (£76 million) was derived from satellite navigation service providers.

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12 This estimated multiplier is lower than the 1.75 multiplier used in the previous study ‘The economic impact of physics research: a case study approach’, but represents a more accurate estimate as it is based on more up-to-date information and more detailed supplier-purchases information from firms operating in the UK space industry.
Applying the space industry value-added to turnover ratio of 0.47 to the turnover of satellite navigation service providers leads to an estimated **downstream value-added contribution to UK GDP of around £36 million in 2010**.

In terms of prospects for industry in the UK, projections by Oxford Economics constructed as part of the study ‘The Case for Space’ (2009), show expected real growth in the UK space industry of 4.8% a year in real terms over the next decade. The projections are based on short-term projections reported by the space industry in the BNSC study ‘The Size and Health of the Space Industry’ in 2008, adjusted to take account of the recent global recession and using growth forecasts for broad sectors comparable with the UK space industry (e.g. telecommunication and aerospace).

Assuming that satellite navigation providers retain their current 1% share of the UK’s downstream space sector turnover, **the downstream satellite navigation sector will make a £470 million value-added contribution to UK GDP in the period 2011-2020, or around £47 million a year**.

### 2.8 Upstream and downstream multiplier impacts

The 2010 Size and Health of the UK Space Industry Survey, conducted by UKSA, included detailed questions on company spending on non-space UK inputs, which enable accurate indirect value-added multipliers to be calculated. Using the survey responses, the space industry’s **value-added multiplier is estimated to be 1.91**. This is slightly higher than the estimated 1.75 multiplier impact for the satellite navigation industry in the previous case study, which was based on historical data contained in the Input-Output table for the UK published by the ONS. We believe the new estimate to be a more reliable reflection of the likely multiplier impact as it is based on the latest available purchasing habits of 260 companies activity involved in the UK space industry.

Estimates based on Oxford Economics’ detailed econometric model of the UK suggest the **induced impact multiplier is around 1.25**. This means that for every £1 million of value-added output generated by the UK satellite navigation industry and its supply-chain, a further £0.25 million of output is generated in the UK economy as workers spend their earnings on other goods and services.

This means that the satellite navigations industry’s (upstream and downstream) direct value-added contribution to GDP £47 million results in an additional GDP contribution of £66 million through the multiplier impact. In total, **the industry’s value-added impact contribution to UK GDP in 2010 was estimated to be £113 million**. Around one-quarter of the total impact is via the upstream impacts, and the remaining 75% via the downstream impacts (Figure 2.2).

**Figure 2.2: Total upstream and downstream GDP impact in 2010**
Over the next decade, the upstream and downstream satellite navigation industry is expected to generate a value-added contribution to UK worth £1.45 billion in total (including multiplier impacts) between 2011 and 2020, or around £146 million a year in 2010 prices.

Figure 2.3: Total cumulative upstream and downstream GDP impact in 2011-2020

2.9 Conclusions

Global navigation satellite systems (GNSS) are a significant enabling technology that has many applications that generate economic and social benefits for the UK and the wider global economy.

Based on these EU-27 satellite navigation penetration rates, and the contribution of these industries to UK GDP, the GPS-sensitive contribution is around 7% of UK GDP, or about £100 billion in 2010 prices.

The reliance of users on GPS covers many key industries that have become central European economies and on which quality of life, health and safety depend. With no viable alternative to GPS, the EU is now developing Galileo, an independent satellite navigation infrastructure to guarantee the provision of global satellite navigation services for the years ahead.

The UK’s ongoing involvement in Galileo has generated significant benefits for firms involved in the upstream (provision of satellite navigation technology) and downstream (companies that exploit satellite navigation technology) stages of the satellite navigation industry.

In total the upstream and downstream satellite navigation industry is expected to generate a value-added contribution to UK worth £1.45 billion in total (including multiplier impacts) between 2011 and 2020, or around £146 million a year in 2010 prices.
3 Catalytic impacts of Satellite Navigation

3.1 Introduction

This chapter considers some of the key findings of a study by the European GNSS Supervisory Authority (GSA) published in late 2010. The study estimates the current and predicted market of four discrete products and services using existing GNSS based positioning (i.e. the American GPS), both globally and in the EU. These estimates have been supplemented by our own research to highlight the possible UK impacts.

To put the findings of the study in context, the core global market of products and services using GNSS-based positioning and navigation over the period 2011-2020 is projected to grow by 10% a year and so generate a cumulative total of £970 billion, with around 30% generated from European Union originated companies.

Figure 3.1: Core global GNSS market by segment (cumulative revenues 2011-2020)

3.2 Road navigation

The use of satellite navigation in road vehicles is growing fast and is expected to be installed in most vehicles in 10 years time. Satellite navigation benefits road users in terms of time saved and reductions in accidents, vehicle theft and emissions.

3.2.1 Vehicle navigation

Car navigation is currently the main application of GNSS. GNSS data combined with electronic maps allow positioning and guidance of the road user. Personal navigation device (PND) sales have grown

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13 This case study considers three of these sectors in detail – road, aviation and location-based services.

14 The core market includes only the parts of the retail value chain of the products and services that are attributable to GNSS (e.g. chipset, maps, and navigation software).
strongly over the last 4 years: 76% per year worldwide, 55% in the EU. Today around 28% of road vehicles in use have a GNSS device.

Independent research by Dutch research institute TNO\textsuperscript{15} that was based on a range of research methods including test drives by test subjects, surveys, and a literature review, concluded that if a vehicle driver was driving in an unfamiliar location and driving to an unfamiliar destination, then a satellite navigation device:

- Reduced vehicle mileage by as much as 16%;
- Reduced time spent travelling by as much as 18%;
- Lowered insurance claims - those drivers of lease cars who do not have a satellite navigation device made 12 percent more damage claims than those who use satellite aided navigation devices.

This reduction in time and distance would mean that less fuel is consumed. This saves businesses and consumers money. It also helps to lower harmful emission since less fuel is consumed. Overall vehicle traffic was around 318 billion vehicle miles in the UK in 2010. Using information on fuel costs and average vehicle mileage per litre, and assuming an illustrative 1% reduction in vehicle mileage for all vehicle drivers due to the use satellite navigation devices, we estimate that without satellite navigation devices:

- UK vehicle traffic would have increased by 520 million miles and cost consumers and businesses an additional £520 million in fuel costs.
- UK vehicle emissions would have been around 1 million tonnes of carbon dioxide equivalent (MtCO\textsubscript{2}e) higher than the reported 120 MtCO\textsubscript{2}e.

3.2.2 Fleet management and logistics

Satellite navigation systems support fleet management and are used to locate and track vehicles (e.g. trucks, buses, taxis) in order to maximise resource management, reduce travel time, increase security and reduce fuel consumption. Around 5 million vehicles in the EU were equipped with fleet management and vehicle tracking systems in 2009.

Such satellite navigation systems enable the global express industry to function – a key feature of express services is that each delivered item is tracked throughout its journey and so offers the possibility of changing the destination of the addressee in transit. Research by Oxford Economics shows that:

- The Global Express Industry is a £125 billion global business directly creating 1.3 million jobs and supporting 2.75 million jobs in total.
- The UK Express Industry contributed £2.3 billion to GDP in UK in 2010, and directly supported 38,000 full-time jobs and a further 43,000 full-time jobs in other sectors of the economy through its supply-chain impacts.

3.3 Aviation

Traditionally, radio navigation systems near airports, combined with on-board guidance systems which keep track of the plane’s location are used. GNSS-based navigation has the potential to greatly complement these systems for en-route navigation at all altitudes and for airport approaches.

\textsuperscript{15} www.tomtom.com/lib/img/pr/32324%20TNO\_ES-UK.PDF
The aviation market requires the highest possible robustness and integrity in its navigation systems. Satellite based augmentation systems (SBAS) help overcome many of the deficiencies in today’s air traffic infrastructure thanks to its accurate, continuous, all-weather positioning (see Box 2.3 on the impact of the ionosphere on the accuracy of satellite signal). This is particularly important for general aviation that covers a wide range of activities such as leisure, business, surveillance, etc. and usually involves smaller sized aircraft.

In Europe the European Geostationary Navigation Overlay Service (EGNOS) was certified for civil aviation in 2011 (See Box 3.1). This satellite augmentation system improves the accuracy and integrity of GNSS via a network of ground stations that take measurements of GNSS and broadcast information messages to users via satellite. Its enhanced vertical precision and integrity will improve safety, efficiency and accessibility. According to the ESA, EGNOS enables:

- Reduced occurrence of Controlled Flight into Terrain by 75%.
- Curved approaches and continuous descent paths, which can reduce noise and emissions.

Box 3.1: EGNOS

EGNOS is Europe’s first venture into satellite navigation. It increases the accuracy of the GPS position and provides information on its reliability, making it suitable for safety-critical applications. Consisting of three geostationary satellites and a network of ground stations, EGNOS achieves its aim by transmitting a signal containing information on the reliability and accuracy of the positioning signals sent out by GPS. It allows users in Europe and beyond to determine their position to within about 1 metre.

Oxford Economics quantified the impacts of the use of satellite navigation in aviation in the study ‘The Case for Space: The Impact of Space Derived Services and Data’, Oxford Economics, November 2006. Updating those estimates implies that the satellite navigation systems saved the UK aviation industry £1.6 billion in 2010, with benefits from:

- commercial benefit from reduced delays – £1 billion;
- time saved by passengers – £544 million;
- lower emissions from more efficient network planning – £91 million per year.

3.4 Location-based services

Location-based services offer information to a user based on their current location to provide an enhanced service or experience. Such services delivered through mobile phones include:

- **Information** – location of shops, bars, restaurants, cash machines and petrol stations;
- **Advertising** – enticing travellers with special offers as they walk past a bar or restaurant;
- **Emergency** – every emergency call must have location information attached to it in order to enable the emergency services to get to the scene of an incident more quickly;
Security – permission based tracking of friends and family, including children, the elderly and lone workers.

More and more mobile phones now include GNSS functionality. GNSS penetration in mobile phones worldwide increased from below 5% in 2005 to 15% in 2009 and is expected to increase very quickly over the next decade. Although penetration within the EU and the UK is lower than average at present, by 2020 penetration of GNSS in mobile phones is expected to reach 97% (See Figure 3.2). This development will help enable UK GNSS market size for location-based services accounting for the full price of GNSS mobile phones to reach around £4 billion by 2020\(^\text{16}\).

Figure 3.2: GNSS penetration in mobile phones EU (%) and UK GNSS market size, 2010-2020

![Bar chart showing GNSS penetration in mobile phones EU (%) and UK GNSS market size, 2010-2020.](image)

Source: Oxford Economics based on GSA data

3.5 Conclusion

Most UK citizens have some direct experience with GPS enabled applications, especially in-car guidance. But the UK’s reliance on satellite navigations goes much farther. Applications include aviation, fleet management and logistics, and location-based services that in turn lower response times of emergency services.

With the market for satellite navigation systems being both sizeable and growing, and becoming ever-more interlinked with the provision of services on which quality of life, health and safety depend, the need for an independent satellite navigation infrastructure is becoming more important by the day. Galileo will help to guarantee the provision of such services in the future.

All the benefits set out above are underpinned by a range of physics conducted over the last century. The following Chapter provides a timeline of the key milestones over that period starting from the initial fundamental research through to today’s applications that are enabled by satellite navigation systems.

\(^{16}\) Oxford Economics estimate based on EU and global data from GSA GNSS market report allocated to UK using GDP shares.
4 Timeline of satellite navigation systems

It can take many years before fundamental research translates into economic impact. And those impacts are impossible to predict at the outset of the research. Today’s satellite navigation systems such as the American GPS are rooted in a range of physics research conducted over the past century.

1916 Albert Einstein publishes his general theory of relativity, which describes how time is affected by gravity.

1919 British physicist, Arthur Eddington, leads an expedition to Principe Island in West Africa to observe the total solar eclipse, in which the bending of light rays was predicted by general relativity. He was the first to appreciate the importance of Einstein’s theories of special and general relativity, and published a treatise on the subject.

1955 The first reliable atomic clock is built by physicists at the UK’s National Physical Laboratory.

1957 Sputnik is launched and people realise that this ‘artificial star’ could be used for navigation.

1960 The first navigation satellite is launched for the use of the US Navy.

1960 Physicist Ivan Getting proposes the idea of a space-based multi-satellite positioning system for land forces.

1967 The second is redefined as an exact measure of time in terms of atomic clocks.

1978 The first GPS satellite is launched equipped with an atomic clock.

1990 The first GPS in-car navigation system is launched by the Pioneer Corporation.

1993 The GPS is fully operational, giving worldwide coverage.

2004 A GPS navigation system costs less than £100.

2005 GNSS penetration in mobile phones worldwide reaches 5%.

2005 The first Galileo satellite, GIOVE-A, built by Surrey Satellite Technology Limited, a spin-out company from the University of Surrey, is launched. First signals received at Chilbolton Observatory by a purpose-built receiver designed and built by RAL engineers.

2008 The second Galileo satellite, GIOVE-B, built by the UK-based aerospace company Astrium, is launched.

2008 GPS-enabled mobile phones come onto the market.

2009 GNSS penetration in mobile phones worldwide reaches 15%.

2011 Launch of the first two of four operational satellites designed to validate the Galileo concept in both space and on Earth. Two more will follow in 2012.

2020 GNSS penetration in mobile phones worldwide expected to reach 65%.

2020 Full operational capability of Galileo.
Annex  Methodological approach

The case study approach to demonstrate the economic impact of UK physics research utilized in this study follows the same approach used in our previous study\textsuperscript{17}.

As before, the economic benefits for the UK economy arising from UK fundamental research in physics have been disaggregated as follows:

- **Direct benefits** from the commercialisation of physics research in the Satellite Navigation industry, measured in terms of company sales, contracts awarded to UK companies related to the Galileo project, and value-added contribution to UK GDP;

- **Multiplier effects** that arise from further economic activity associated with additional supplier and income purchases; and

- **Wider or ‘Catalytic’ benefits** that are a result of research that delivered positive benefits to society as a whole (e.g. reduced travel time, reduction in traffic accidents, fuel and release of harmful emissions).

Estimates of the number of jobs supported by the Satellite Navigation industry use companies’ accounts data to estimate the direct number of jobs, while UK productivity is used to translate the indirect and induced estimates of GDP into jobs supported by that indirect and induced activity.

The approach provides a valuable snap-shot of impact for a particular year, but also considers how the cumulative impacts build-up over time and where possible we also present projections of likely future impact over the next decade. Though the focus of the analysis is on UK-level benefits, it is clear that the impact of UK-based physics research extends globally and generates significant international benefits. These benefits are reflected in the global estimates of economic impact presented in this paper.

In demonstrating the impact of UK-based fundamental physics research and technology development the following key points should be noted:

- The case study provides lower bound estimates which demonstrate the economic impact of Satellite Navigation systems. The ‘true’ economic value both to the UK and globally of Satellite navigation systems will be significantly higher than set out in this report. However, by adopting a lower bound estimate it is highly unlikely that UK physics research has contributed less than the estimates in this report.

- The demonstrated benefits are purely indicative. The outputs of each case study cover only some of the many applications cited in the underpinning research and provide only an illustration of the economic contribution of physics research to the UK economy. The ‘\textit{true economic}’ value to the UK will be significantly greater than specified in this study. Note that this is not a cost-benefit analysis but an economic assessment. The study focused on demonstrating achieved gross economic benefits to the UK based on empirical evidence and stakeholder consultations, without consideration of the costs of providing that benefit.

\textsuperscript{17} For full details of the methodological approach please refer to the report “The economic impact of physics research: a case study approach”, available from STFC.