

The economic impact on the UK of a disruption to GNSS

Full Report

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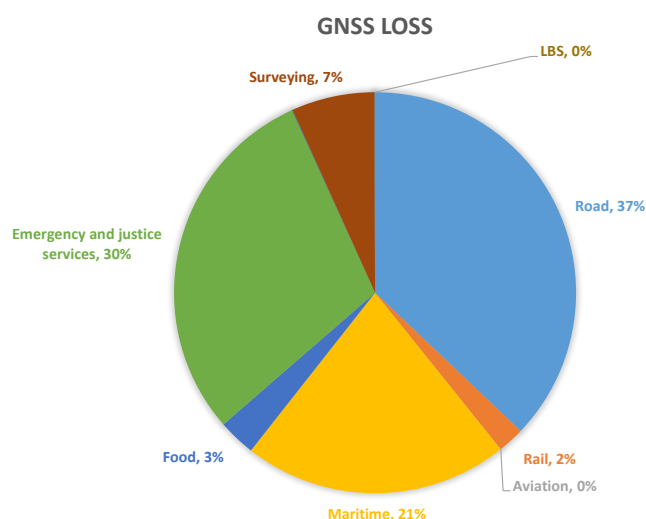
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Key Findings

GNSS – Global Navigation Satellite System(s) – has been described as *the invisible utility*, and the findings of this research suggest that status to be well justified. GNSS is an integral source of timing and positioning information for a very wide range of economic sectors in the UK, enabling and enhancing daily activities for public, commercial and private citizen users. **All critical national infrastructures (CNI)** rely on GNSS to some extent, with Communications, Emergency Services, Finance, Government and Transport identified as particularly intensive users. This reliance has developed over decades, based on assumed availability and continuity of GNSS signals. GNSS is also a primary input for Transport (road, air, maritime, and rail), Agriculture, Surveying, and Legal users. It has been estimated that the UK space industry derived turnover of **£1.7bn** from Position, Navigation and Timing (PNT) services in 2014/15, supporting 4,000 jobs. More broadly, it has been estimated that **sectors generating 11.3% of UK GDP are supported directly by GNSS**, but the primacy of GNSS in CNI means that an even wider range of economic activity is underpinned by GNSS *indirectly*.

Quantified economic benefits to the UK of GNSS have been monetised at £6.7bn per annum, comprised of £1.2bn in Gross Value-Added (GVA) benefits and £5.5bn in utility benefits (efficiency, safety, etc.). These values have been estimated **conservatively** as the incremental benefit of using GNSS rather than the well-functioning next best alternative. Road and Emergency Service applications account for almost 80% of estimated benefits. However, a range of benefits has not been quantified, as GNSS underpins activity for which a global source of accurate timing is a necessity. This includes financial markets, where the internationalisation of the industry has relied on a universally referenceable time source. Accordingly, the total benefits of GNSS estimated in this report may be considered a lower bound, and the true value of GNSS benefits to the UK economy is much higher.

The economic impact to GNSS-reliant present-day UK of a loss of GNSS has been estimated at £5.2bn over a five-day period, comprised of £1.7bn in lost GVA and £3.5bn in lost utility benefits. Applications in road, maritime, and emergency and justice services account for 67% of all impacts. This is limited by the resilience that stakeholders have confirmed are in place for a duration of five days, and the difficulty of robustly estimating the costs associated with loss of certain activities. For maritime shipping, for example, the loss of GNSS would severely disrupt all ports and the loading and unloading of containers for the duration of the outage. The knock-on effects are difficult to estimate in monetary terms, but evidence suggests that factories relying on just-in-time delivery would likely run out of inputs on the first day. Goods imported to the UK by other means would be severely delayed as ports and other transport operations would lose all the efficiencies brought about by GNSS. The telecommunications network, however, would not be affected. The impact on the domestic transport network would be substantial, at £2bn. Congestion would build very quickly, and delivery and minicab drivers would lose their preferred navigation method. This would impact *all* drivers as the increased congestion would mean that even drivers that know their route would see increases in travel time. Similarly, surveying activity – a critical input in all construction activities – would be expected to shut down for the duration of the outage, costing £345m in lost activity.



The UK government has invested almost **£1.2bn (£1.5bn) since 2000** to develop the European GNSS infrastructure, promising **greater performance and resilience**, and to foster the lucrative downstream applications market, which provides **significant benefits to users and the rest of society**. As well as generating significant GVA, high-productivity jobs and taxes for the UK, the contracts have **improved the overall competitiveness** of the UK space sector and helped cement the UK's reputation as a leading partner in European space programmes.

Several mitigation strategies have been discussed in this report. The most applicable mitigation strategies for the largest number of applications are **eLoran** and **Satelles Time and Location (STL)**. These high-availability services could mitigate many of the detriments in the maritime sector, and while the accuracy is insufficient for container stacking and autonomous cranes, the ability to schedule port operations and reduce downtime would help to keep ports open. **The cost of resurrecting (e)Loran to a useful level of three masts would be in the order of £50m over 15 years.** The cost of STL is unclear at this early stage in its development. **Omnisense SP500** and **Locata** may be preferred for localised applications that require high levels of accuracy (e.g. surveying and agriculture). Timing applications have been found to be resilient to a five-day outage of GNSS, but could implement eLoran, STL, Locata or freely-available **Network Time Protocol (NTP)** servers as a source of timing for low accuracy applications. If higher accuracy is required, **Precision Time Protocols (PTP)** or time-over fibre networks, like **NPL-time**, are two alternatives.

Executive Summary

Introduction

GNSS (Global Navigation Satellite Systems) is an umbrella term describing an infrastructure that provides positioning, navigation and timing (PNT) information via satellites orbiting in space. This information allows users with a compatible receiver (e.g. smartphone) to determine their position, velocity and precise universal and local time.

Much of everyday life in the UK, like all modern economies, has become reliant on GNSS – to the extent that it has been called ‘the invisible utility’. Applications leveraging GNSS capabilities are widespread, but the full extent and nature of use, as well as the resilience to a GNSS outage, was previously not well understood. This knowledge gap was concerning, as GNSS is subject to various vulnerabilities to failure. Given the coincidence of widespread use (including safety-critical applications) and vulnerability, the following research question was set:

What would happen if GNSS were not available, even temporarily?

This study aims to provide an answer in terms of estimated economic impact. Using a combination of desk-based research and a programme of 35 expert consultations, the report identifies patterns of current usage, the functional role of GNSS within each system, resilience (if any) to disruption, and estimates the likely impact of a disruption to GNSS signal availability for up to five days across ten application domains in the UK: Road, Rail, Aviation, Maritime, Food, Emergency and Justice Services, Surveying, Location-Based Services (LBS), Other Infrastructure, and Other Applications. More detailed estimates, and a description of the estimation methodologies, are presented in the full report.

Given the highly strategic and economic value of GNSS, the study presents the rationale and a high-level assessment of the impact of UK public funding of GNSS. The cost and effectiveness of possible mitigation strategies are also considered.

Caveats and limitations

The findings are subject to the following high-level limitations and caveats:

- The study is based on codified publicly available information, supplemented by user and expert knowledge – which may potentially add an **optimism bias** to our estimates (loss may be larger), reflecting complacency and/or reticence to acknowledge a vulnerability;
- The report is **agnostic to the actual source of the considered disruption**;
- The disruption to GNSS is considered as a **standalone event**;
- Note that the **impact of a GNSS-reliant present-day UK losing GNSS** functionality unexpectedly (on users plus cascading domino effects on others), is **much greater** than the **incremental benefit to the UK of using GNSS** rather than the well-functioning next best alternative to GNSS;
- **At time of writing**, this report presents up-to-date information gathered. However, as GNSS applications are dynamic and reliance changes over time, the results may have limited shelf-life.

Road

GNSS is prevalent in a number of road applications, both to enhance road infrastructure and provide productivity/efficiency, safety and monitoring benefits to end-users. Applications include:

- GNSS monitoring of infrastructure, particularly bridges, to support timely maintenance and reduce the risk of avoidable closures. The Forth Road Bridge is a notable example;
- In-built, handheld, and smartphone devices which are used to support turn-by-turn road navigation, resulting in a reduction in driver errors, advanced notice of traffic information, convenience and route optimisation;
- GNSS to improve the operational efficiency of logistics companies and businesses that manage vehicle fleets, as well as supporting operators to pre-emptively service their vehicles in advance of breakdown;
- Insurance telematics, where insurance companies offer reduced premiums in exchange for telematics information on driver behaviour;
- Emergency and breakdown call (eCall and bCall) devices that are designed to make an emergency call and provide emergency services with location information if a vehicle is involved in a breakdown or accident.

The total benefits from GNSS are estimated at **£3.3bn per annum**, equivalent to half of all benefits covered in this analysis. This makes road applications the largest beneficiaries of GNSS by some distance. The vast majority of benefits are associated with the improvements to driver performance and reduced congestion that come from professional and mass market applications of turn-by-turn road navigation. The benefits are monetised as time savings, valued at the average UK salary; fuel savings, reductions in emissions, and reduced accident risk. Other notable benefits come from the reduced maintenance costs that are associated with fleet management applications (**£154m**); the reduction in accidents and insurance fraud enabled by insurance telematics (**£16m**), and monetisation of the lives saved and reduction in congestion associated with eCall and bCall (**£15m**).

A five-day loss of GNSS would imply significant disruption to these applications, totalling **£1.9bn** in direct and indirect impacts or 37% of all estimated impacts. For example, devices used to support turn-by-turn navigation would fail soon after the signals were lost. Fixed-mounted smartphones and dedicated navigation devices use inertial sensors and software that would keep the devices in progressively declining use for a short period of time and at most until the car is switched off. An outage would imply costs in excess of the loss of navigation benefits described above. This is because GNSS-dependent drivers – who lose the ability to optimise their route and start making wrong turns – would increase congestion across the entire road network, imposing costs of almost **£1.9bn** on all drivers, regardless of GNSS-dependency. Drivers in rural and intercity areas with limited availability of alternative positioning sources (e.g. Wi-Fi hotspots), would suffer the greatest direct damage as their device would be unable to obtain any position. However, indirect congestion effects would affect urban drivers more because of congestion and the higher accuracy requirement in cities, where the software needs to fix a position on multiple candidate roads.

Since the road network supports a number of other applications indirectly, the impact of congestion would extend far beyond the road domain. For example, emergency vehicles would take longer to reach emergencies; industries operating just-in-time supply chains would face periods of inactivity, and congestion on the roads may impose additional pressure and delays on other modes of transport as some drivers switch away from road use.

Rail

The UK rail network uses GNSS for a wide variety of applications. These include:

- Driver Advisory Systems on high-speed and freight trains which support intelligent driving;
- Plain Line Pattern Recognition (PLPR) systems that use GNSS to detect track faults;
- Power automated doors which use GNSS to open the correct number of doors on the right side of trains at different stations;
- Timing and synchronisation of the rail telecom networks, station clocks and passenger information systems;
- Provision of positioning information to support passenger information systems and traffic management;
- Though not widely used in the UK rail network at present, GNSS-based signalling, could be increasingly used to reduce track infrastructure costs, thereby support the running of low-profit lines for longer.

Benefits are estimated at **£11m per annum**. Almost all of these benefits are accounted for by GNSS-enabled driver advisory systems as a result of better utilisation of existing capacity, and reductions in traction energy and environmental impacts.

A five-day loss of GNSS would imply significant problems for rail infrastructure managers and train and freight operating companies, equivalent to a total of **£110m** in direct and indirect impacts. On the infrastructure side, timing operations would be lost or synchronisation severely disrupted. On the operator side, costs would largely come from the failure of connected advisory systems and power automated doors. The loss of both applications would imply an increase in the length of station stoppage, an increase in rail journey times and subsequently reduced utilisation of rail capacity and foregone productivity.

Aviation

There are a number of aviation applications that are reliant on GNSS. These applications broadly fall under: i) the regulated market – where certified GNSS-enabled equipment is used to achieve safe and efficient operations, and ii) the unregulated market where GNSS is used by recreational pilots. Specific applications include:

- The Automatic Dependent Surveillance – Broadcast (ADS-B) system which automatically reports an aircraft's identity and GNSS-derived location to air traffic control on the ground and other aircraft;
- Smaller airports, including Bristol, Exeter and airports in Scotland use EGNOS landing procedures, with limited ground-based alternative infrastructure;
- GNSS to support the navigation of aircraft that are operating under visual flight rules (VFR);
- Cospas-Sarsat, which is a search-and-rescue (SAR) system that locates emergency beacons activated by aircraft, ships and individuals;
- Mobile satellite Communications (satcoms).

Total benefits from these applications are estimated at **£34m per annum**. Most of these benefits come from the use of satcoms in the aviation industry and accrue to passengers and airlines (**£32m**). This is followed by the value of fatalities that are estimated to have been avoided as a result of the GNSS-enabled Cospas-Sarsat system. This amounts to **£2m** using the average value of preventing a fatality and an assumption that GNSS contributes 20% to these savings. All remaining benefits that

are possible to monetise come from EGNOS landing procedures, which reduce the number of delays, diversions and cancellations (DDC) in adverse weather conditions, and the rate of Controlled Flight Into Terrain (CFIT) procedures.

A five-day loss of GNSS would represent a minor disruption to aviation applications, as reflected in a modest estimate of **<£1m** in direct and indirect impacts. This is because risk-averse air traffic management services and aircraft are set up with multiple redundancy systems that mean they are not reliant on GNSS. Air traffic control is also resilient to a five-day loss of GNSS for timing applications, due to the existence of internal oscillators with sufficient holdover capacity to support continued operations from a few weeks to several months. Loss would, however, come from foregone reductions in DDC and CFIT (**<£0.5m**), and the loss to SAR applications (**<£0.5m**).

Maritime

In the maritime sector, GNSS is used to satisfy the demand for navigation (e.g. in open seas) and positioning of vessels and crews by different stakeholders (e.g. vessel monitoring and traffic management). Specific applications include:

- GNSS is used for communication between the Lighthouse Authority and remote lighthouses; use of AIS base stations to identify nearby vessels, and to support Differential GPS to improve the accuracy of GNSS for the maritime community;
- The use of GNSS to synchronise buoys, thereby supporting navigation within shipping lanes;
- Estimation of speed and location to project journey times and estimate time of arrival;
- Supporting mobile satellite communication between vessels and destination ports;
- RTK-enhanced Portable Pilot Units which help manoeuvre vessels in port;
- The use of GNSS AIS by ports to manage port traffic;
- Augmented GNSS enable automated cranes to load and unload cargo from vessels;
- GNSS-enabled logistics systems which manage the loading of cargo onto transport modes;
- GNSS to support Safety Of Life at Sea (SOLAS) mandated applications;
- GNSS-enabled emergency beacons for Search and Rescue in the maritime domain;
- Fishing vessels which use GNSS to navigate, chart fishing fields, and mitigate risk of capsizing;
- Use of either dedicated or consumer GNSS devices by skippers on recreational vessels.

The total benefits from GNSS are estimated at **£429m per annum** or 7% of all estimated benefits. Of this, an estimated **£350m** is accounted for by the time and fuel savings that GNSS-supported navigation enables, and a further **£70m** in benefits is attributable to the fishing industry. The remainder (**£9m**) is estimated to come from GNSS's contribution to Cospas-Sarsat rescues.

A five-day GNSS loss would impose significant disruption to maritime infrastructure and vessels. These direct and indirect impacts are estimated at **£1.1bn** or 21% of all estimated impacts. Impacts come from the loss of efficiency in port management operations as a result of: the loss of satellite communication and accurate ETA measurement capabilities that enable efficient port planning, and the inoperability of automated cranes for loading and unloading cargo containers for the duration of the outage. Furthermore, while pilots have enough knowledge to dock vessels without GNSS, the process would be less efficient and take longer. The loss of vessel management systems – on top of the disruption to port infrastructure already mentioned – could increase port congestion and create a significant backlog that would last long after the loss of GNSS has passed. Taken together, these direct impacts are estimated to cost the UK **£114m** over five days.

The importance of maritime transport to the supply chains of other UK sectors, particularly manufacturing activities that are reliant on just-in-time warehousing, means that disruptions to shipping would be felt far beyond the maritime industry. In total, secondary impacts are estimated at **£670m** for the manufacturing sector, **£84m** for the shipping and support industries, and a further **£316m** in late delivery penalties for exporters. Additional loss would also come from disruption to satcoms, SAR services and fishing vessels, but monetised estimates are comparatively small.

Emergency and justice services

The emergency services – police, ambulance, fire services and coast guard – and the justice service use GNSS for a number of different applications. These include:

- The public-safety answering point (PSAP) receives emergency calls and sources GNSS location data from the caller's mobile device to pass on to emergency services;
- Fleet management and optimised navigation of emergency service vehicles;
- Synchronisation of Professional Mobile Radios (PMR);
- Offender tracking;
- Time-stamping of the CCTV to support evidence management for criminal investigations.

The monetisable benefits of GNSS for emergency and justice services are **£2.1bn per annum** or 30% of all estimated benefits. The vast majority (**£1.9bn**) comes from the impact of PSAP's location capabilities on emergency service call and search times. Further benefits of **£31m** are attributable to offender tracking, which comes from the difference between the cost of GNSS tagging and a prison place that is avoided. While not monetised, the impact of GNSS on fleet management – in terms of the time, fuel, and cost savings associated with pre-emptive fleet maintenance, reduced downtime of emergency vehicles and more efficient navigation – is likely to be significant.

The loss of GNSS would have a significant impact on emergency and justice services, equal to **£1.5bn** or 30% of all estimated costs. This loss is driven primarily by the increase in emergency response times and the dropping of emergency calls that come from a combination of longer emergency calls, and slower vehicle navigation.

Food

The food sector uses GNSS for agriculture and fishing activities. For agriculture, GNSS enables the reliable positioning of tractors, tools, and other farm assets. Relevant applications include:

- Precision agriculture (PA), which describes the use of GNSS to manage the variability of agricultural production, improving yield and reducing environmental impact (e.g. tractor guidance systems, automatic steering, and variable rate technologies);
- Livestock tracking;
- Assisting monitoring and compliance with the EU's Common Agricultural Policy (CAP) and Common Fisheries Policy (CFP) by enabling more accurate measurements of farmland, and more efficient monitoring of fishing vessels in EU waters.

Total monetisable benefits of GNSS to the food and agriculture sector are estimated at **£285m per annum** or 4% of all estimated benefits. Almost all of these benefits come from the impact of precision agriculture on the efficiency of cultivation (reflecting the value of yield increases and reduced environmental impact from the efficient application of pesticides and fertiliser).

The loss of GNSS would have detrimental effects for the agriculture sector, where all benefits estimated for the period of the outage would be lost because there is no effective alternative. For example, alternatives to PA include manual techniques for mapping land and detecting soil quality. This is time consuming and labour intensive so cannot be done at a frequency that allows it to be an adequate input into the farm management process. This impact would be most keenly felt during the cultivation season, and significantly more limited in other seasons. The average total direct and indirect impact is estimated at **£134m** for an *average* five-day period. Further losses are associated with the food processing (**£22.2m**) and the transportation of food, since both sectors' just-in-time supply chain would be disturbed by the disruptions faced by the road, rail and aviation networks.

Surveying

Surveying is the discipline of accurately determining the position of points and the distances and angles between them. GNSS supports surveying applications, particularly in the construction industry, by assisting operators in both person-based and machinery guidance operations. This offers end-users in the construction sector time, input and capital savings, and higher quality measurements. Example applications include:

- Cadastral surveying which uses GNSS to measure cadastral boundaries and resolve boundary disputes;
- Mapping for cartographic, environmental, and urban planning;
- Yield monitoring of open-pit and surface mines;
- Handheld GNSS-enabled construction devices;
- GNSS-enabled machinery which support more efficient application of construction materials (termed machine control more generally);
- Marine surveying, including hydrographic surveying and off-shore oil and gas exploration;
- Infrastructure monitoring to identify potential faults and allow pre-emptive repair.

Total monetisable benefits from surveying applications amount to **£14m per annum** and materialise in the form of reduced time, labour and construction material costs.

In surveying, all benefits attributable to GNSS and indeed the vast majority of surveying activity would be lost if GNSS suffered an outage. This is because all surveying equipment integrates GNSS, so non-GNSS surveying methods are infeasible. For a five-day period, this direct loss would amount to **£51m**. The civil engineering sector more generally would also suffer reduced activity during this period, implying a total GVA loss of **£294m**.

Location-Based Services

Location-based services (LBS) span a variety of applications, that all rely on location. This location data is accessed through an individual's smartphone or tablet, with a significantly smaller proportion of use coming from dedicated devices, mainly in the tracking domain. Example applications include:

- Smartphone LBS applications which support users to find alternative means of transport, resulting in reductions in fuel consumptions and associated emission and air pollution;
- Smartphone LBS applications for pedestrian navigation (smartphones for car navigation is discussed under the road domain); and
- Fitness tracking applications that are accessed through smartphone applications and dedicated tracking devices.

Total utility benefits from LBS applications of GNSS amount to **£205m per annum** or 3% of all estimated benefits. For navigation devices, these benefits reflect monetised reductions in journey times, fuel consumption, and air pollutants (**£137m**) resulting from modal shift away from private cars. For fitness tracking devices, these benefits reflect the value of the increase in physical activity that is attributable to GNSS (**£10m**).

Loss of GNSS would impact smartphone and tablets users of the wide range of location-based applications. However, the impact of loss depends on the availability of alternative sources of location data, which in turn depends on the user's environment. For this reason, the direct impact is likely to be smaller in dense urban areas where Wi-Fi is abundant. Total LBS losses are therefore **<£1m** due to modal shifts in transportation.

Other infrastructure

A number of the UK's critical national infrastructures (CNI) rely on GNSS for accurate, and widely available timing and synchronisation services, free at the point of use. Relevant applications include:

- Timing and synchronisation of the fixed and cellular telecommunications network;
- Timing and synchronisation of the DVB-T (Terrestrial Digital Video Broadcast) and DAB (Digital Audio Broadcast) broadcasting networks;
- Monitoring of the transport of dangerous goods e.g. chemical and civil nuclear materials;
- Timing and synchronisation of the National Grid's electricity transmission network.

Total monetisable benefits of the above applications amounts to **£41m per annum** and comes from savings to the infrastructure costs of fixed-line and cellular telecommunications (**£37m**) and the National Grid's electricity transmission network (**£4m**). GNSS may be considered an enabler of the current setup of broadcasting of digital audio and video as a free source of accurate and synchronised time. Benefits materialise as the difference between the capital investments that would be required on fixed timing dissemination infrastructure to more than 2,000 sites versus the capital investment required on GNSS equipment. These benefits have not been monetised.

Telecommunications networks (fixed and cellular) have sufficient holdover to maintain timing synchronisation throughout the five-day outage period. There would therefore be no impact on the functionality of the fixed and cellular telecommunications networks, and consequently no economic loss.

Other applications

GNSS is used in a number of other areas in addition to the domains discussed previously, including:

- The financial sector which uses GNSS to timestamp transactions to an accuracy that supports high-frequency trade (1µs), and high street banks (1ms required);
- Weather forecasters, such as the Met Office, which uses GNSS for a number of applications including: radio-occultation; positioning of weather sensors; lightning detection, and the timing and synchronisation of the Met Office's internal network and supercomputer;
- Tracking of vulnerable individuals, including dementia patients and lone workers;
- Satellites (LEO) and ground station infrastructure which use GNSS for position and timing synchronisation, particularly for Earth Observation and GEO satellite communications;
- The legal sector where lawyers need to track timesheets and hours with high precision.

Total estimated benefits from these other applications of GNSS amount to **£350m per annum** or 5% of all estimated benefits. The majority of these benefits (**£248m**) come from the value associated with the number of fatalities that are estimated to have been avoided because of tracking devices. All monetisable remaining benefits are associated with GNSS's contribution to weather forecasting (**£100m**), and the reduced infrastructure costs that come from the use of GNSS in the financial sector (**£0.6m**). For the latter, it is possible to link GNSS with the all the benefits that come from the global synchronisation of timing, but it is beyond the scope of this study to estimate this.

Interviews with stakeholders suggest that the full spectrum of financial services – from traders and stock exchanges with advanced holdover capacity to high street banks with lower grade oscillators – are resilient to a five-day loss of GNSS. The Met Office would also be able to continue forecasting the weather. However, the added uncertainty this implies, suggests some modest loss.

Mitigation technologies and strategies

For positioning and navigation, there are several application-specific alternatives to GNSS. This includes the use of clocks and sextants, and radar systems, to determine position at sea, or the use of paper maps on the road. The aviation sector could also make use of a number of back-up systems such as VHF omnidirectional range (VOR), distance measuring equipment, or instrument landing systems.¹ However, there is currently no *universally applicable* alternative to GNSS for the case of positioning and navigation, and many of the traditional means of navigation might not be readily available or useable by the individuals.

In order to use traditional means of navigation, users need to have the skills and training necessary to operate them. The ability of many people such as delivery and minicab drivers and private drivers, but also current mariners, VFR pilots, farmers and surveyors has been questioned by a number of stakeholders, and the understanding of the severity of the economic impact of loss of GNSS would be further enhanced if such potential skills gaps were investigated further.

Similarly, for timing applications, loss of GNSS can be mitigated by using adequate oscillators in the GNSS clock that can keep timing accuracy for a certain holdover period, ranging from a few minutes to months. Loss of the GNSS signal will affect sectors relying on timing capabilities, and the extent of the impact of this loss will depend on the accuracy requirements of the application, the oscillator's holdover capability, as well as other mitigation strategies that are in place.

One potential mitigation strategy that is applicable to a number of applications is **eLoran**. eLoran is a terrestrial system that, similarly to GNSS, transmits a timing signal and location of the origin of the signal, allowing receivers to compute time (and distance) travelled, and thus location. **The cost of resurrecting (e)Loran would be in the order of £50m over a 15-year period.**²

Positioning and navigation performance of eLoran is similar to GNSS³. However, since it is a ground-based system that operates independently of GNSS, eLoran is not exposed to the same risks faced by satellites. Because of this, eLoran would work well as a backup in case of a loss of GNSS signal⁴ and could also be used in areas where GNSS does not provide sufficient signal strength, for example

¹ Department of Homeland Security (2011). *National Risk estimate: Risks to U.S. Critical Infrastructure from Global Positioning System Disruptions*

² Assuming the U.S. estimate for 28 masts can be linearly transferred to 2 masts in the UK.

³ Cameron A. (2014). *GNSS Backup Delivers 5-Meter Accuracy*. Retrieved 18/11/2016. <http://gpsworld.com/gnss-backup-delivers-5-meter-accuracy/>

⁴ International Loran Association (2007). *Enhanced Loran (eLoran): Definition Document*. Retrieved 01/11/2016, <http://www.loran.org/news/eLoran%20Definition%20Document%200%201%20Released.pdf>

in buildings or underground.⁵ Antennae required to receive eLoran are approximately the size of a frisbee, and a combined GNSS and eLoran receiver could approach cost competitiveness within one year of firm commitment from the government, and from this perspective, eLoran is attractive for timing users, vessels, aircraft, and vehicles.

On the other hand, eLoran's relatively poor accuracy, vulnerability to interference from compact fluorescent light bulbs and antenna requirements mean that it is infeasible for a number of applications. This includes: surveying, agriculture and users of turn-by-turn navigation that require higher accuracy than what is offered by eLoran; road users in cities where interference is likely to be highest, and users of smartphone and tablet applications where there is a need for miniaturised antennas.

The **Satellites Time and Location (STL)** service is in development, and is a payload on Iridium's NEXT satellites. The solution promises position and timing accuracy similar to eLoran, but many aspects such as subscription price and form-factor of the receiver are still unknown. STL offers much higher signal power, and could penetrate indoor environments. The jamming equipment necessary to affect STL would also have to be substantially more powerful than that affecting GNSS. STL appears to be a viable alternative to eLoran and a strong mitigating technology for GNSS.

When high accuracy is required, **Omnisense SP500** and **Locata** may be preferred for localised applications. Similarly, for timing applications where the holdover from oscillators is insufficient, users could implement several different sources of timing information. In addition to the positioning technologies mentioned above, the freely-available **Network Time Protocol** or higher accuracy **Precision Time Protocols** or time-over fibre networks, like **NPL-time** could provide the performance needed for critical national infrastructures and other timing users.

The contribution of UK public funding

GNSS is characterised by a number of market failures that mean that there is a strong economic case for government intervention. This includes large benefits for society that are estimated to be between £4 and £5 per £1 of public investment. In order to capture these benefits, the **UK has made a €1.5bn investment in GNSS since 2000**. Most of this investment (94%) has occurred through EU channels so the **overall impact of the UK's investment in GNSS is strongly tied to the UK's benefits from the European GNSS programmes (EGNOS and Galileo)**.

The benefits associated with the UK's upstream investments since 2000, which account for the vast bulk of the UK's investment to date (94%), are driven by the industrial activities of UK firms that have secured contracts to supply critical parts for the Galileo and EGNOS programmes. As well as generating significant revenue streams, high-productivity jobs and taxes for the UK, these contracts have improved the overall competitiveness of the UK space sector and helped cement the UK's reputation as a leading partner in European space programmes.

The UK's **€94.9m** downstream investments since 2000 have also unlocked significant benefits to end-users and the rest of society that would have been lost without UK funding. These include: the significant commercial opportunity offered by **domestic PRS sales and exports, which is tied directly to the UK's contribution to the Galileo programme**, and **early-stage R&D that support** the development of new GNSS applications that generate revenue for UK companies, productivity benefits for end-users, and environmental benefits for society.

⁵ Divis, D. A. (2014), *Proposal for U.S. eLoran Service Gains Ground*, Retrieved 01/11/2016, <http://www.insidegnss.com/node/3853>

1 Introduction

1.1 What is GNSS?

More commonly known as ‘satellite navigation’ (often abbreviated to ‘satnav’, or more simply ‘GPS’), Global Navigation Satellite Systems (GNSS) is an umbrella term describing an infrastructure that provides positioning, navigation and timing (PNT) information via satellites, supported by a ground segment. This utility allows users with a compatible receiver to determine their position, velocity, and precise local and universal time by processing signals received from satellites in space.

Four GNSS constellations provide these signals:

- **GPS** is the original GNSS (fully operational since 1995) developed, maintained and operated by the U.S. Air Force. Except for a few prototypes, all GNSS receivers use the GPS signal, and because it was the first market entrant, the term GPS has become synonymous for GNSS in common parlance;
- **GLONASS** is Russia’s GNSS, managed by the Russian Aerospace Defence Forces. Initially completed in 1995, it has operated at Full Operational Capability since 2011, thanks to restoration following an intervening period of progressive degradation;
- **Galileo**, the European system currently under development, has provided initial services since 2016 and is expected to reach Full Operational Capability in 2020. It is unique in that it is under civilian control in the form of the European Union;
- **BeiDou** is the Chinese GNSS, also under development, set to supersede the COMPASS regional system (operational since 2000) by providing global coverage around 2020. It is managed by the governmental China Satellite Navigation Office.

In addition to the global constellations, there are regional systems (BeiDou-1, QZSS, NAVIC) and regional Satellite-Based Augmentation Systems (SBAS), such as EGNOS (Europe), WAAS (North America), GAGAN (India) and MSAS (Japan) that provide improved accuracy and supplementary information on the reliability of the GNSS signal,⁶ enabling GNSS use for safety critical applications such as aviation.⁷ For the UK case, only EGNOS is relevant.

1.2 Motivation for the study

Applications leveraging GNSS capabilities have become pervasive in today’s modern society, used throughout the economy and society by consumers, public sector users, and commercial users. In fact, most industries in the UK depend on GNSS to some extent. Though it may not be common knowledge, much of everyday life in the UK, as almost all modern economies and societies, has become reliant on GNSS. The full range of GNSS applications used in the UK are outlined in detail later in this report (Chapter 4).

But, GNSS is subject to various vulnerabilities. The Royal Academy of Engineering⁸ classify the vulnerabilities of GNSS into three broad categories:

⁶ European GNSS Agency (2015). *GNSS Market report 2015*.

⁷ European Space Agency (2013). *What is EGNOS?* Retrieved 6/9/2016, http://m.esa.int/Our_Activities/Navigation/EGNOS/What_is_EGNOS

⁸ The Royal Academy of Engineering (2011). *Global Navigation Space Systems: reliance and vulnerabilities*. London: The Royal Academy of Engineering.

- **System-related vulnerabilities** are either due to the satellites themselves (such as a shortage of available satellites or the transmission of bad signals); malfunction and outage of receivers, or problems with the augmentation systems that enhance the GNSS signal (e.g. EGNOS). In particular this includes outages caused by attacks on GNSS systems as well as outages caused by the orbital environment, for example by geomagnetic storms;
- **Propagation channel vulnerabilities** include disruptions to the GNSS signal due to variability in the atmosphere through space weather effects or errors due to signals being reflected off buildings or other objects (multipath);
- Vulnerabilities because of **interferences** could be caused accidentally by signals from other sources such as commercial power transmitters or radars, or deliberately by jamming of receivers, false signals (spoofing) and delayed or rebroadcasted signals (meaconing).

The coincidence of widespread use – including safety-critical applications – and vulnerability of GNSS creates the potential for catastrophic impact scenarios resulting from a loss of GNSS functionality. In the U.S., “GPS has been called ‘a single point of failure’ for much of the U.S. economy and critical infrastructure,”⁹ highlighting the serious fallout that may result from an outage. Closer to home, the outage of the SVN 23 GPS satellite in January 2016^{10,11} was described by Chronos Technology as being “one of the most significant service-affecting issues for GPS timing users”¹².

Furthermore, The Royal Academy of Engineering study (2011) found that “non-GNSS based back-ups are often absent, inadequately exercised or inadequately maintained” and identifying “an increasing number of applications where PNT signals from GNSS are used with little, or no, non-GNSS based back-ups available.”¹³

Thus, given the substantial use of GNSS in the UK, and the vulnerability of the systems to failure, it is important to understand the exposure of the UK economy and society to a disruption of GNSS functionality.

1.3 Research objectives

Accordingly, Innovate UK in collaboration with the UK Space Agency and Royal Institute of Navigation have commissioned London Economics to answer the research question:

What would be the economic impact on the UK through the loss, however caused, of GNSS, for up to five days?

The reason this study takes the five-day loss of GNSS as the input is to align with scenarios within the National Risk Assessment (NRA) for both GNSS and for critical infrastructure. Five days is an alignment point with other service loss planning criteria, e.g. power from the National Grid, as noted in the UK NRA and the business resilience planning assumptions documents. A recommendation in The Royal Academy of Engineering (2011) *Global Navigation Space Systems: reliance and vulnerabilities*¹⁴ was that all services that use GNSS for PNT, directly or indirectly should explain their

⁹ Bartlett, S. et. al. (2015). *Innovation: Enhanced Loran*. Retrieved 6/9/2016, <http://gpsworld.com/innovation-enhanced-loran/>

¹⁰ Baraniuk, C. (2016). *GPS error caused '12 hours of problems' for companies*. Retrieved 6/9/2016, <http://www.bbc.co.uk/news/technology-35491962>

¹¹ Gibbons Media & Research LLC (2016). *BBC, Chronos Report on Lengthy Disruptions Caused by GPS Timing Problem*. Retrieved 6/9/2016, <http://www.insidegnss.com/node/4839>

¹² Chronos Technology (2016), *GPS Anomaly Event – Chronos keeping your networks operational*, Retrieved 01/12/2016. <http://www.chronos.co.uk/files/pdfs/cs-an/26%20January%202016%20GPS%20Event.pdf>

¹³ The Royal Academy of Engineering (2011). p.5.

¹⁴ Available at: <http://www.raeng.org.uk/publications/reports/global-navigation-space-systems>

contingency plans for a five-day outage of GNSS, which can be considered a reasonable worst case scenario.

More specifically, there are five objectives:

- 1) Identify economic sectors and industries supported by GNSS in the UK;
- 2) Quantify the economic benefit that GNSS technology and services bring to the UK;
- 3) Estimate the economic impact to the UK (government and private sector) of a disruption to GNSS functionality of up to five days; and
- 4) Identify the cost and effectiveness of mitigation strategies;
- 5) High-level assessment of the impact of UK public funding of GNSS.

1.3.1 Report structure

This report presents the findings of the study, structured in the following way:

- **Chapter 2** presents a synthesised **review of relevant existing studies and literature** on the range of usage and benefits of GNSS, consequences of a disruption to GNSS, estimates of economic impact resulting from a loss of GNSS, tempered by a discussion of limitations of international experience to the UK case;
- **Chapter 3** outlines the scope, definition and **analytical framework** employed to frame the research, including the ‘impact logic model’, culminating in a list of inputs required for successful implementation of the methodology;
- **Chapter 4** reports on the **current usage and benefits of GNSS in the UK** across three groups of users: critical national infrastructures; professional and industrial uses; and mass market consumer applications;
- **Chapter 5** presents an **analysis of impact of GNSS disruption**, considering the resilience of existing systems across critical national infrastructures; professional and industrial uses; and mass market consumer applications.
- **Chapter 6** considers the role, effectiveness and cost of **alternative and potential future mitigation strategies**, including eLoran, Locata, STL, and more traditional methods;
- **Chapter 7** analyses **the contribution of UK public funding** to the usage, benefits and resilience of GNSS;
- **Chapter 8** closes with a **conclusion** addressing each of the questions answered by this report, and suggests future work in this and related fields.

The annex presents additional supporting material.

1.4 Caveats and limitations

The research has been conducted by a team of independent professional economists with specialist knowledge of GNSS technology and markets, using best practice and best judgement to calculate the most robust and fair estimates. The methodology used and assumptions made are described in this report in a transparent manner, with caveats noted as required. Nonetheless, the reader should bear in mind the following high-level limitations and caveats of this study throughout:

- This **report** portrays information based on codified publicly available information, our own knowledge of downstream GNSS applications, and information gathered through interviews with more than 35 stakeholders in a wide range of domains. Information

gathered from stakeholder interviews is presented at face-value, trusting the contact. This may potentially add an **optimism bias** reflecting complacency and/or reticence to acknowledge a vulnerability.

- Though this report does point to potential sources of a disruption (in order to communicate the vulnerability of GNSS, and the real risk of a disruption), the report is **agnostic to the actual source of the considered disruption**. However, it should be noted that the overall impact of an outage of GNSS is not necessarily independent of the source of the disruption: e.g. a severe natural space weather event causing a loss of GNSS may also cause an outage of other (satellite) services (communications, broadcasting, meteorological, earth observation) and power supply.
- The disruption to GNSS is considered as a **standalone event** – pre-existing redundancy systems are assumed to operate as planned.
- **At time of writing** (spring 2017), this report presents up-to-date information gathered. However, GNSS applications are dynamic and reliance changes over time. The results may therefore not have long shelf-life.
- For the overview of UK public funding in Chapter 7, it should be noted that the analysis is limited to those funding streams for which data was available or provided. Some of the estimated funding levels in this section should therefore be seen as indicative, and subject to further refinement if data can be sourced.
- This study considers **two different counterfactuals**: The benefits of GNSS (**chapter 4**) are estimated against a baseline in which, rather than using GNSS, each application has evolved along a different path to an alternate reality using the next best alternative to GNSS. The loss (**chapter 5**) has been estimated against a baseline in which GNSS is the chosen technology, and considers also degradation in skills associated with increasing reliance on GNSS over time. Thus, **the impact of a GNSS-reliant present-day UK losing GNSS functionality unexpectedly** (on users plus cascading domino effects on others), is not comparable to (and much greater than) the **incremental benefit of using GNSS** rather than the well-functioning next best alternative to GNSS.

2 Review of existing studies

This chapter provides a foundation for the study by reviewing the full range of relevant existing studies and literature relevant to the research objective. The synthetic review is structured around themes: the range of usage and benefits of GNSS; consequences of a disruption to GNSS; estimates of economic impact resulting from a loss of GNSS. The chapter concludes by adding a ‘pinch of salt’ in the form of a statement of limitations of international experience to the UK case.

2.1 Usage and benefits of GNSS

GNSS is used widely around the world. In 2014, there were 3.6 billion GNSS devices in use, and this number is forecasted to grow to over 7 billion by 2019¹⁵. With 3.1 billion smartphones in use in 2014, **Location-Based Services (LBS) is the most dominant application of GNSS.**

Before moving to consider studies on the benefits of GNSS, some caveats apply: **Studies examining the economic benefits of GNSS are few**, and those undertaken **tend to be partial** – each covering only industrial effects or only utility benefits, a single stage in the value chain, limited segments, or only selected economic benefits. The estimates of benefits tend to be based on top-down analysis constructed using subjective assumptions in forward-looking scenarios – accordingly, the values vary widely. Further, **the majority of existing studies focus on the United States**, with studies outside the U.S. being few and far between.

The findings of the studies are summarised in Annex 2. Unless otherwise stated, estimates are annual.

A 2013 report by Oxera¹⁶ estimated the **Gross-Value-Added of ‘Geo Services’** (Location-Based Services + Geographic Mapping) to be **\$113bn globally**, saving users an estimated 1.1 billion hours per year of wasted journey time, and helping to save approximately 150 lives per year in England alone through faster emergency service responses.

A 2011 study undertaken by NDP Consulting¹⁷ analysed the direct economic benefits of GPS on three main sectors of the U.S. economy: **precision agriculture, engineering construction, and commercial surface transportation**. To measure the economic benefits of GPS, the study estimated the GPS adoption rate for each sector based on industry surveys and also extrapolated their results to an adoption rate of 100%.

- To estimate economic benefits in the **agricultural sector** the study focuses on direct benefits due to output gains (estimated to be 10%) and input cost reductions (estimated to be 15% on average) due to GPS equipment. Based on a 10% yield gain, and savings in wages, capital and inputs of 10%, 15% and 15% respectively, their analysis suggests that the economic **benefits** to the U.S. agricultural sector are between **\$19.9bn** (60% adoption rate) **and \$33.2bn** (100% adoption rate) **per year**.
- In a similar manner benefit estimates to the **engineering construction sector** are based on savings to labour, capital, and materials of 59.8%, 30% and 42.5% respectively, which were

¹⁵ European GNSS Agency (2015). *GNSS Market report 2015*.

¹⁶ Oxera Consulting (2013), *What is the economic impact of Geo services?*, Retrieved 18/10/2016 from http://www.oxera.com/Oxera/media/Oxera/downloads/reports/What-is-the-economic-impact-of-Geo-services_1.pdf?ext=.pdf

¹⁷ Pham, D. N. (NDP Consulting) (2011). *The Economic Benefit of Commercial GPS use in the US and the costs of potential disruption*. Retrieved 6/9/2016, http://www.gpsalliance.org/docs/GPS_Report_June_21_2011.pdf

estimated from industry studies, surveys, and testimonials. This analysis yielded an estimate of **annual benefits** to the U.S. Engineering Construction Sector **between \$9.2bn** (40% adoption rate) **and \$23bn per year** (100% adoption rate).

- Benefits to the U.S. **commercial surface transportation sector** are estimated to be **between \$10.3bn** (69.7% adoption rate) **and \$15.1bn per year** (100% adoption rate), based on average savings of labour, fuel and capital equipment of 11.3%, 13.2% and 13.2% respectively.

The study further extrapolates the benefits of these three industries to estimate the direct benefits of GPS on all other commercial GPS users in the U.S., stemming from increased productivity and input cost savings. Their estimates suggest that this would be between \$28.2bn and \$51.1bn per year, and, therefore, that **benefits of GPS to the U.S. economy lie between \$67.6bn and \$122.4bn per year**, or 0.5% to 0.9% of the U.S. economy.

Taking a more industrial perspective, a later (2013) study by NDP Consulting¹⁸ estimated the economic impact of **GNSS-related hardware manufacturing companies** on the U.S. economy in terms of the direct, indirect, and induced effects. To do this, the study uses GNSS revenues (from the GSA's GNSS Market Report) and the manufacturing industry averages (from the U.S. Census Bureau) and then applies the Bureau of Economic Analysis (BEA) wage, value-added and output multipliers. Their estimates suggest that these companies **supported 105,315 jobs, generated \$6.8bn in earnings and \$32bn in outputs in the U.S.**

At the time of writing, there is an ongoing wide-ranging study that aims to estimate the benefits of GPS on the U.S. economy. According to the most recent publicly available update¹⁹, Leveson estimates the **economic benefits of GPS to be \$37.1bn-74.5bn**, or about 0.4% of GDP. The majority of the benefits stem from **Consumer Location-Based Services (\$7.3bn-18.9bn)**, **Precision Agriculture (\$10bn-17.7bn)**, **Surveying (\$9.8bn-13.4bn)** and **Fleet Vehicle Connected Telematics (\$7.6bn-16.3bn)**. However, it is noted that Leveson's estimates are preliminary only, and likely underestimate the economic benefits, as the analysis excludes some sectors as well as a range of indirect and induced benefits.

A 2008 report by the Allen Consulting Group examined the annual economic benefits of GNSS to the **Australian** economy for the agriculture, mining and construction sectors using a computable generalised equilibrium (CGE) model (the *Monash Multi-Regional Forecasting model*), capturing both first round (direct) benefits due to higher output levels and cost savings as well as second round benefits to the upstream and downstream industries. The study estimated the **annual economic benefits of GNSS to the Australian economy** to be **between AUD829m-1486m** (equivalent to 0.06%-0.11% of GDP), **AUD152m-206m** of which stemmed from the **agricultural**, **AUD371m-744m** from the **mining** and **AUD306m-535m** from the **construction** sectors. The study also gives a conservative estimate of the potential **cumulative benefit of GNSS to Australia over the next 20 years of AUD73bn-134bn**.²⁰

ACIL Allen Consulting further tried to quantify the additional economic benefits of augmented GNSS

¹⁸ Pham, N. D. (NDP Consulting) (2013), *The Economic Benefits of Global Navigation Satellite System and its Commercial and Non-Commercial Applications*, Retrieved 18/10/2016 from <https://static1.squarespace.com/static/52850a5ce4b068394a270176/t/52d57f29e4b0dad117c5e3bb/1389723433433/Economic+Impacts+of+GPS+December+2013.pdf>

¹⁹ Leveson, I. (2015). *The Economic Value of GPS: Preliminary Assessment*. National Space-Based Positioning, Navigation and Timing, Advisory Board Meeting, June 11, 2015. Retrieved 6/9/2016, <http://www.gps.gov/governance/advisory/meetings/2015-06/leveson.pdf>

²⁰ The Allen Consulting Group (2008). *Economic benefits of high resolution positioning services: Final Report*. Retrieved 7/9/2016, <http://www.crcsi.com.au/assets/Resources/ffa927a7-55d1-400a-b7d6-9234f4fe4ad2.pdf>

in Australia, relative to a counterfactual where augmented GNSS is not available, by using another CGE model (the *Tasman Global CGE Model*). They find that **by 2012, GDP in Australia was AUD2.3bn-3.7bn higher** than it would have been without augmented GNSS, the majority of which coming from the **Mining Sector (AUD683m-1,085m)**, followed by the **Construction Sector (AUD448m-723m)**, the **Agricultural Sector (AUD298m-466m)** and the **Road Transport and Logistics Sector (AUD154m-213m)**. Moreover, they suggest that this number **may increase to AUD7.8bn-13.7bn by 2020**.²¹

In Europe it has been estimated that the size of economic activities that rely on GNSS is around **€800bn, or 6-7% of EU GDP**.²² Moreover, Europe also benefits from increased economic activity stemming from the implementation of Galileo. In 2005 Arthur *et al.* suggested that these benefits could be in the range of several billion euros over the following ten years, with additional indirect impacts through market externalities of at least twice the direct effects. However, with Galileo now expected to reach full operational capability by 2019/2020²³, this study is outdated and there is a gap concerning detailed, publicly available studies assessing the economic benefits of GNSS in Europe.

In the **United Kingdom**, *The Size & Health of the UK Space Industry 2016* study by London Economics found that companies in the UK Space Industry derive turnover of £1.7bn from Position Navigation and Timing (PNT) services (12% of the UK Space Economy), and employ 4,000 people. More widely, the study also found that GNSS satellite services support industries representing a **total turnover of more than £486bn**, and contributing **£206bn to GDP (11.3%)**.

A summary of the annual benefits of GNSS from the above sources is provided in Annex 2.

2.2 Consequences of a disruption to GNSS

The **degree of disruption** caused by a complete outage of GNSS (all systems) **varies with the degree of dependence** on GNSS. In the case of a complete loss of GNSS, applications that **critically depend** on GNSS will be hit hardest and may be taken out completely. Historical examples of GNSS outage have shown vulnerabilities in telecommunication networks that depend on GNSS for synchronisation purposes and other utilities such as power distribution (as experienced in north-eastern Italy during a GNSS scrambling in the Yugoslavian conflict in the 1990s) or access to cash from SWIFT-based ATMs, and approach and navigation for ports and airports.²⁴ Areas that **do not critically depend** on GNSS, but use it to improve productivity, must find alternative ways to complete their tasks – e.g. farmers can no longer rely on the automated steering and guidance capabilities of their machines, leading to an efficiency loss. Similarly, road vehicles will have to rely on drivers' knowledge and paper maps, which may cause delays and loss of productivity, but also more immediately, a flurry of road incidents owing to driver disorientation as navigation devices lose connection.

The **Department of Homeland Security's (DHS) National Risk Estimate**²⁵ provides an assessment of

²¹ ACIL Allen Consulting (2013). *The value of augmented GNSS in Australia: An overview of the economic and social benefits of the use of augmented GNSS services in Australia*. Retrieved 7/9/2016, http://www.acilallen.com.au/cms_files/ACIL_GNSS_positioning.pdf

²² Georgette Lalis, Director of consumer goods and EU satellite navigation programmes in the European Commission's Directorate General of Enterprises and Industry, quoted in <https://www.gsa.europa.eu/news/support-egnos-and-galileo-crucial-europes-citizens>

²³ European GNSS Service Centre. Retrieved 18/10/2016 from <https://www.gsc-europa.eu/helpdesk/faqs>

²⁴ During a training exercise in 2007 two U.S. Navy ships off the coast of San Diego unintentionally blocked GPS signals to the city for two hours resulting in all these impacts.

²⁵ Department of Homeland Security (2011). *National Risk estimate: Risks to U.S. Critical Infrastructure from Global Positioning System Disruptions*

the risks of an outage of GPS for critical infrastructure sectors (Communications, Emergency Services, Energy, and Transportation Systems) in the U.S. for a range of scenarios such as spoofing and jamming attacks. Risk and impacts of each scenario were judged by a panel of experts. Similarly, the **Lloyd's Space Weather Risk Insight**²⁶ looks at the possible consequences of geomagnetic storms. However, it is important to note that the results of these reports are not directly applicable to the case of a complete outage of all GNSS systems for a period of several days due to the nature of the scenarios considered. Nevertheless, the reports are useful as a broad indication of what might happen in the case of a complete loss of GNSS signals, and so are summarised below.

Impacts on the U.S. **transportation sector** were seen as less severe by industry experts consulted as part of the DHS Risk Estimate, as backups are generally available for this sector. However, experts suggested that a loss of GNSS could reduce both the capacity and the efficiency of the transportation system. For example, the report noted that while **aircraft** could use short-range radio navigation systems (VHF omnidirectional range, VOR) to determine their position, capacity would almost certainly be reduced. Nevertheless, as Volpe²⁷ notes, in the case of a severe outage of GNSS, impacts to aviation could be extensive and would likely include a halt of aircraft take-offs.

Similarly, loss of GNSS is generally not critical for **maritime** navigation because of the presence of backup aids.²⁸ However, operations in constricted waterways such as port approaches, can have severe consequences especially in combination with bad weather. On top of this, current and future maritime communications as well as autopilot systems that use GNSS timing capabilities may also be affected.²⁹ A 2013 experiment jamming GNSS in a conical area of the North Sea (off the coast of Newcastle upon Tyne), involving the Trinity House vessel Galatea, showed that many of these 'future systems' were already in use on this particular vessel. In fact, as the vessel entered the jamming zone, a large number of different alarms went off to alert the captain that something was wrong. As all systems alert at the same time, the prioritisation of actions becomes extremely difficult for the boatmen, and may result in confusion. GNSS is the primary source of navigation information in the maritime world. The only alternative source is (effectively) looking through the window.³⁰

Regarding **road transportation** (fleet management and logistics were not in scope for this source), while loss of GNSS would likely lead to efficiency losses as users have to switch back to alternative navigation methods such as hard-copy maps, safety critical applications are limited. Similarly, while U.S. **railroads** use GNSS for tasks such as fleet tracking or facility mapping, the use in safety-critical applications was found to be limited (this may have changed since by recent Positive Train Control implementation). Hence, while a loss of GNSS would likely lead to efficiency losses, severe safety issues are currently unlikely.³¹ However, it is important to keep the consequences of a potential loss of GNSS in mind when adopting safety critical systems in the future.

Similarly, while the U.S. **emergency services sector** was identified by experts consulted by DHS as not totally dependent on GPS services, an outage could still have major consequences as the communications network depends on GPS timing, and efficient dispatch of emergency vehicles and personnel uses GPS navigation. Moreover, GPS is used for services such as computer-aided dispatch

²⁶ Lloyd's (2010). *Space Weather: Its impact on Earth and implications for business*. 360° Risk Insight.

²⁷ Volpe, J. A., U.S. Department of Transportation (2001). *Vulnerability Assessment of the Transportation Infrastructure Relying on the Global Positioning System: Final Report*.

²⁸ Carrol, J. V. (2003). *Vulnerability Assessment of the U.S. Transportation Infrastructure that Relies on the Global Positioning System*. The Journal of Navigation, vol. 56, pp. 185-193

²⁹ Volpe, J. A., U.S. Department of Transportation (2001). *Vulnerability Assessment of the Transportation Infrastructure Relying on the Global Positioning System: Final Report*.

³⁰ ACCSEAS project, video available at <http://www.accseas.eu/project-information/implementation-of-ship-positioning-test-bed-service/>

³¹ Carrol, J. V. (2003). *Vulnerability Assessment of the U.S. Transportation Infrastructure that Relies on the Global Positioning System*. The Journal of Navigation, vol. 56, pp. 185-193

(CAD), managing fleet vehicles, locating accidents and dispatching emergency personnel. While backup systems are generally available, for example, in the case of a loss of GPS, communications would have to fall back on less sophisticated ways of communication, emergency services would have to find workarounds and service would operate less efficiently.

The U.S. **energy sector** on the other hand could suffer major outages in high consequence scenarios, such as coordinated *spoofing* attacks, due to the use of GPS timing signals for tasks such as network synchronisation. Moreover, Lloyds also points to the risk that critical infrastructure such as transformers may be damaged in high impact scenarios such as geomagnetic storms, which could lead to a possibly severe financial loss as well as longer term consequences with repairs possibly taking months or even years before the grid recovers fully.

Finally, the U.S. **communications sector** also uses GPS timing capabilities for its infrastructure. In the case of a loss of GNSS, networks can continue to operate as internal clocks can hold timing for a certain holdover period. However, higher quality clocks are also more expensive and a continued loss of GPS timing capabilities would almost certainly lead to service degradation and possibly outages in this sector.

Both reports also highlight the **interdependence between the sectors**. For example, Lloyd's points to possible railway disruptions of electric trains caused by power outages. Moreover, as DHS points out, nearly all sectors depend on the communications sector for information exchange.

2.3 Economic impact resulting from a loss of GNSS

A 2013 study by NDP Consulting³² further quantified the direct economic costs of a 50% degradation and a full disruption to GPS in the U.S.. The study focuses exclusively on impacts faced by commercial GPS users (through foregone productivity and cost savings, and investment losses in GPS equipment) and GPS manufacturers (through foregone GPS equipment sales and R&D spending, and opportunity costs of R&D spending).

Based on the lower bound (60% adoption rate) of estimates of the direct economic benefits of GPS in the U.S., it estimates the cost of lost productivity for commercial GPS users to be \$67.6bn. The study further estimates that commercial GPS users would face cost of \$19.6bn³³ through investment losses in GPS equipment; bringing **the total estimated cost of a 100% GPS outage to commercial users alone to \$87.2bn in a year.**

Costs to GPS manufacturers are estimated to be \$8.3bn of foregone GPS equipment sales annually³⁴, \$460m of R&D expenditure to find mitigating technologies³⁵, and \$100m in R&D opportunity costs as a result of the extra R&D expenditure needed to find mitigating technologies³⁶. **This adds a further \$8.8bn to the estimated cost of a 100% GPS outage.**

Hence, the study estimates that the **direct economic cost of a full outage of GPS** to commercial GPS

³² Pham, D. N. (NDP Consulting) (2011). *The Economic Benefit of Commercial GPS use in the US and the costs of potential disruption*. Retrieved 6/9/2016, http://www.gpsalliance.org/docs/GPS_Report_June_21_2011.pdf

³³ This is based on the book value of the current stock of GPS equipment, derived from the purchase value and applying a 5-year straight line average of annual depreciation of 20%, and the assumption that no equipment will be functional in the case of a full outage of GPS.

³⁴ Based on the assumption that in the case of a complete loss of GPS signal, no GPS equipment would work and that users would not buy GPS equipment that does not function.

³⁵ Based on 13% of a total forecasted R&D budget of \$3.6bn (9% of total GPS equipment sales in 2010, which is equivalent to the average of annual R&D expenditures between 2008 and 2010).

³⁶ Based on the assumption that foregone R&D would have produced a 20 % return.

users and manufacturers is **\$96bn per year in the U.S.** (equivalent to 0.7% of the U.S. economy). The study further estimates that the impact of a 50% disruption of GPS would be \$48.3bn per year; \$43.6bn of which would impact commercial GPS users and \$4.7bn would impact GPS manufacturers).

When considering these estimates it is important to note that they are likely to underestimate the real economic impact of an outage of GNSS for several reasons: i) the study focuses exclusively on commercial GPS users and manufacturers and excludes both non-commercial and military users, ii) the study looks only at the direct costs of an outage and does not take spillover effects into account, and iii) since this study has been published, the GNSS market has experienced significant growth, which is forecasted to continue at 8% p.a. through to 2023³⁷. Moreover, the study is limited to the United States. However, it does cover a full year and so considers medium-term effects such as end-user investment losses in GPS equipment and foregone sales of GPS equipment manufacturers.

In addition to this, the U.S. Department of Transportation³⁸ estimates the loss stemming from a GNSS outage in 2020 - affecting a maximum of 5 impact regions, with a radius of 200 miles per region, for one month to **be \$1bn to maritime logistics and \$1.13bn to the telecommunications sector**³⁹.

2.4 Limitations on relevance to the UK case

It should be re-iterated however that the information and estimates in Sections 2.2 and 2.3 are specific to U.S. infrastructure and will therefore only have limited relevance to the UK case. The pattern of GNSS utilisation, vulnerabilities and resilience in the UK may differ significantly – hence the need for the current study.

For example, the UK **power grid network** uses a more resilient design for its transformers and has a lot of redundancy built in. The National Grid has also developed contingency plans for the case of severe space weather events, including the availability of spare transformers in the case of damage. Specifically, the *Space Weather Preparedness Strategy*⁴⁰ suggests that there are 13 transformers, which could be permanently damaged in the case of powerful geomagnetic storms on the scale of the Carrington Event. However, the strategy estimates that only two of the 13 could be damaged to an extent that would lead to disruptions to power supplies and disconnections. In this case, disruptions would continue for around two to four months while transformers are replaced. The strategy also suggests that voltage instability as a result of an event could lead to possible short-term blackouts in the region of a few hours.

Similarly, the UK's **telecommunication sector** is able to continue to supply customers with mobile services even if GNSS timing capabilities are lost.⁴¹ Specifically, in the UK most core telecom networks use rubidium oscillators that continue to provide accurate timing information for *three days* in the event of a loss of GNSS timing capabilities. Moreover, with the exception TD-LTE, which uses GNSS synchronisation as a backup system, almost all public mobile systems were specifically

³⁷ European GNSS Agency (2015). *GNSS Market report 2015*.

³⁸ Volpe, J. A., U.S. Department of Transportation (2009), *The Use of eLORAN to Mitigate GPS Vulnerability for Positioning, Navigation, and Timing Services: Benefit-Cost Assessment Refresh*, Retrieved 01/11/2016, <https://rntfnd.org/wp-content/uploads/Benefit-Cost-of-eLoran-Volpe-Center-2009.pdf>

³⁹ Both losses in 2009 prices.

⁴⁰ Department for Business, Innovation and Skills (2015). *Space Weather Preparedness Strategy*.

⁴¹ Department for Business, Innovation and Skills (2015). *Space Weather Preparedness Strategy*.

designed in such a way that they do not need GNSS timing capabilities for synchronisation.⁴² Hence, the effects of an outage of GNSS on the UK energy and telecommunications sectors are likely to be less severe than the U.S. studies suggest. However, the *Space Weather Preparedness Strategy*⁴³ notes reliance of telecommunications on power supply – i.e. service degradation or outages as a result of a power loss. Chronos Technology further notes that new Single Frequency Networks (SFN) and future 4G services are much more sensitive to timing errors and, hence, that future outages on the scale of the SVN 23 GPS satellite outage, may lead to major problems for critical infrastructure unless dissimilar backup timing technology is implemented⁴⁴.

Emergency services in the UK rely on Airwave's Terrestrial Trunked Radio (TETRA) network. This network uses GNSS for timing and synchronisation purposes at each base station. A loss of GNSS in the absence of backup systems could thus disable Airwave's network.⁴⁵ Hence, emergency services would have to fall back on other ways to communicate, resulting in a loss of efficiency and potentially increased response time to emergencies.⁴⁶ However, it is important to note the presence of holdover oscillators built into the system allowing the Airwave network to remain functional in the case of a loss of GNSS for a limited period of time.⁴⁷ Whether the service can withstand a five-day outage of GNSS or not will thus depend on the quality of the oscillators in use (considered in section 5.1).

⁴² The Royal Academy of Engineering (2013). *Space Weather: Full Report* and Curry, C. (2010). *Dependency of Communications Systems on PNT Technology*. Chronos Technology

⁴³ Department for Business, Innovation and Skills (2015). *Space Weather Preparedness Strategy*.

⁴⁴ Chronos Technology (2016), *GPS Anomaly Event – Chronos keeping your networks operational*, Retrieved 01/12/2016. <http://www.chronos.co.uk/files/pdfs/cs-an/26%20January%202016%20GPS%20Event.pdf>

⁴⁵ The Royal Academy of Engineering (2013). *Space Weather: Full Report*

⁴⁶ Locata Corporation (2015). *Locata Positioning will Underpin Future Unmanned Aerial System Research at NASA's Famed Langley Research Center*. Retrieved 18/10/2016 from <http://www.locata.com/2015/09/locata-positioning-will-underpin-future-unmanned-aerial-system-research-at-nasas-famed-langley-research-center>

⁴⁷ Department for Business, Innovation and Skills (2015). *Space Weather Preparedness Strategy*.

3 Analytical framework

This chapter sets out the framework used to structure the analysis to provide answers to the research questions, covering the scope, definitions counterfactual, and an ‘impact logic model’, culminating in a list of inputs required for successful implementation of the methodology.

A list of the definitions used in this analytical framework are provided in Annex 1.

3.1 Scope

The scope of the research and analysis is limited by the following:

- The disruption event is a single instance of a five-day disruption to all GNSS (GPS, GLONASS, Galileo, BeiDou, and SBAS) following which all services are restored to full capacity;
- The analysis is agnostic to the cause of the disruption event;
- The disruption occurs in the ‘present’ characterised by current usage/reliance – no forecasting of future adoption/reliance is undertaken;
- The disruption period is a ‘typical’ five days in the year; no seasonal effects are considered;
- Military/defence applications are excluded from scope, but civil law enforcement, emergency response and judicial applications (e.g. offender tracking) are in scope;
- Benefits and losses are converted to monetary values (‘monetised’) whenever possible, and only benefits and losses that can be monetised are considered;
- Benefits lost are considered against a baseline where GNSS is fully functional; mitigating efforts through ‘traditional’ means (e.g. by using paper maps) is considered.

3.2 Counterfactual

This study considers **two different counterfactuals**:

- The benefits of GNSS (**chapter 4**) are estimated against a baseline in which, rather than using GNSS, each application has evolved along a different path to an alternate reality using the next best alternative to GNSS.
- The loss (**chapter 5**) has been estimated against a baseline in which GNSS is the chosen technology and in the absence of a disruption, the GNSS systems continue to operate as usual and that all users continue to use and derive benefit from the continuing operation of GNSS signals. Given the brevity of the period of analysis (five days), no additional investments are foreseen at the system or user level. The impact estimation does consider degradation in skills associated with increasing reliance on GNSS over time. For a wide range of applications, GNSS has become the sole provider of PNT information over the last decade or two. The skill level that prevailed before GNSS cannot be expected to remain readily available after all this time, so reverting to traditional methods is not always an option, and if it is, the performance would be worse than what GNSS replaced.⁴⁸ The ability

⁴⁸ To illustrate this point, consider the answers to the somewhat analogous questions: What is the value of electronic telephone books? Vs. What would be the impact of loss of electronic telephone books? The value of electronic telephone books is positive and incremental on the situation in which individuals remembered the most important telephone numbers in their lives by heart, and wrote down the others. On the other hand, if we all lost our electronic telephone book tomorrow, the majority would remember a handful of numbers (at best) and have no source of the remaining numbers, so the impact of loss would be substantially greater than the original benefits.

of professionals and drivers in general to operate without GNSS has not been tested and is therefore unknown.

Note that the impact of a GNSS-reliant present-day UK losing GNSS functionality unexpectedly (on users plus cascading domino effects on others), is much greater than the incremental benefit to the UK of using GNSS rather than the well-functioning next best alternative to GNSS.

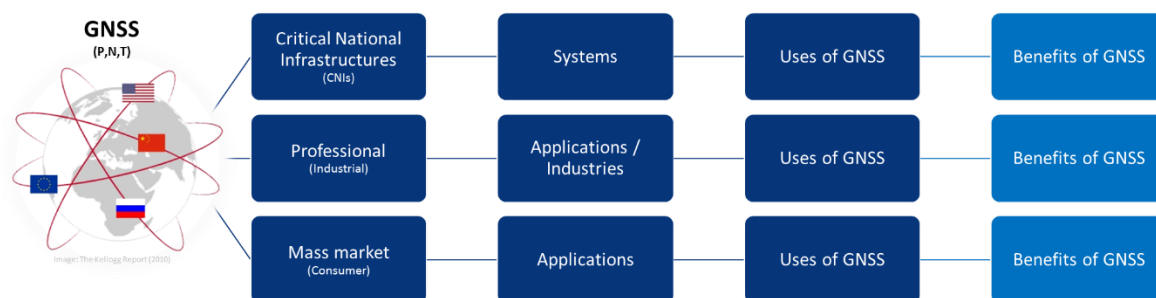
3.3 Impact logic model

GNSS delivers value to the UK economy and society via a value chain. To better understand the potential impact of a GNSS outage, it is informative to first identify and map the logical relationship between inputs, processes, outputs and impacts of GNSS signals. This is done in two steps, which is reflected in the structure of the report:

- Identification of the current usage and benefits of GNSS in the UK (Chapter 4); and
- Identification of the impacts of a disruption to GNSS (Chapter 5).

The first step is to identify and map the pattern and extent of GNSS use across all types of user in the UK, and to understand the benefits that users enjoy – as these benefits are at risk to disruption.

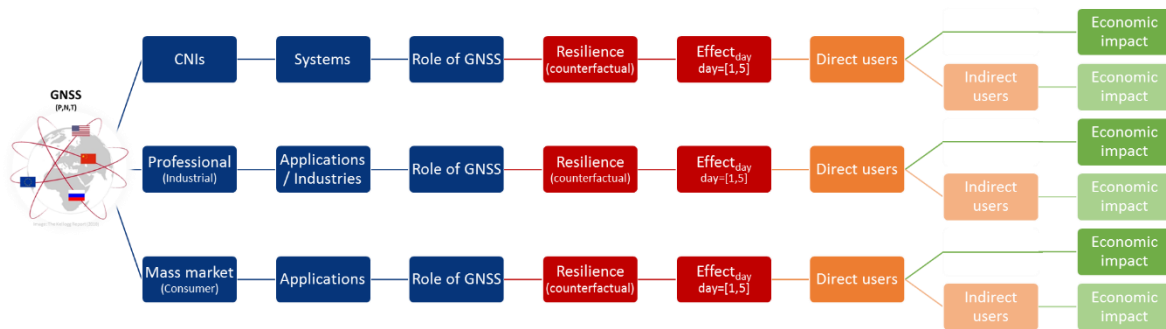
Figure 1 Identification of the current usage and benefits of GNSS in the UK



Source: London Economics

Taking this further, the next step is to track the economic impact 'domino effect' that would be experienced in the instance of a disruption event to GNSS signal availability.

Figure 2 Identification of the impacts of a disruption to GNSS



Source: London Economics

3.4 Inputs required for successful implementation

In order to successfully implement this framework, the following information is required:

- Identification of users;
- Identification of applications and uses;
- For every use:
 - Clear understanding of the full range of user benefits and socio-economic impacts;
 - Monetisation of user benefits and socio-economic impacts;
 - Clear understanding of the role of GNSS within a system, including resilience (e.g. holdover performance, etc.);
 - Clear understanding of the effect (potentially progressive) of a disruption to GNSS signals;
 - Appropriate parameters to inform estimation of the economic impact of a disruption to GNSS signals.

4 Current usage and benefits of GNSS in the UK

This chapter addresses two of the five research objectives, namely:

- Identify economic sectors and industries supported by GNSS in the UK; and
- Quantify the economic benefit that GNSS technology and services bring to the UK.

Use of GNSS is identified and described across three broad groups. These are: **Critical National Infrastructures (CNI)** in section 4.1, **Professional applications** in 4.2 and **Mass-market applications** in section 4.3 to ensure full coverage. In some cases, e.g. rail applications, the infrastructure aspects (tracks) are considered in 4.1 while operations are considered in 4.2.

Benefits associated with the use of GNSS are discussed for each application against a baseline in which GNSS is not the chosen source of PNT, and reported whenever monetised values are available.

It is important to note that GNSS usage in some instances has developed over decades, which means that the appropriate counterfactual against which the benefits should be assessed is very difficult to establish. In some instances the reliance of GNSS for certain solutions has rendered historical non-GNSS-reliant practices infeasible. Reasons include a current lack of skills (i.e. forgotten); unavailability of equipment (how many drivers carry a paper map in their car?); or that the application of GNSS has developed after GNSS became widely available, so no alternative solution has ever been used. This results in the absence of a counterfactual against which to assess the additional benefits of GNSS and makes it very difficult to report credible benefits of GNSS because it is unreasonable to attribute all the benefits of an application to GNSS merely because no alternative PNT source has been developed for the application.

4.1 Critical National Infrastructures

The UK government has identified 13 Critical National Infrastructures (CNI). In the words of the Centre for the Protection of National Infrastructure (CPNI), below, an infrastructure is critical if its unavailability would result in severe economic or social consequences or loss of lives.

“Critical elements of national infrastructure where loss or compromise would result in major detrimental impact on the availability, delivery or integrity of essential services, leading to severe economic or social consequences or to loss of life.”⁴⁹

This section discusses the use of GNSS for each of the CNIs, and estimates the economic benefits arising from the use of GNSS in each infrastructure when data permits. The section displays current best available knowledge on the use of GNSS in each infrastructure, informed by consultation with stakeholders. However, not all operators in each application have been consulted. This means that certain statements based on consultation with one stakeholder might not reflect the status for the entire infrastructure.

It is beyond the scope of this study to define the CNIs in detail and it is assumed that the infrastructure’s title is sufficient to allow the reader to follow the argument. For more detail on the

⁴⁹ Centre for the Protection of National Infrastructure (CPNI). Available at: <https://www.cpni.gov.uk/about-cpni> [accessed 05/12/16]

delimitation on each CNI, the reader is recommended to consult the Cabinet Office's (2016) *Summary of the 2015-16 Sector Resilience Plans*.⁵⁰

This section is structured by CNI, with one sub-section for each.

4.1.1 Chemicals

Benefits cannot be monetised without using unfounded assumptions.

The Chemicals CNI is considered to use GNSS to a very limited extent. This is because its primary operations are limited to a few sites whose primary focus is on resilience against theft and chemical releases on-site. However, one important aspect of the chemicals sector is reliant on GNSS. This is the **monitoring of transport of dangerous goods**.

Transport of dangerous goods straddles the transport and chemicals (and other) CNIs. No regulation on the tracking or monitoring of the transport of dangerous goods have been sourced, but a 2014 consultation by the European Commission's Directorate-General for Enterprise and Industry suggests the possibility of introduction of a future mandate on the use of EGNSS for tracking of dangerous goods.⁵¹ Benefits have not been monetised.

4.1.2 Civil Nuclear

Benefits cannot be monetised without using unfounded assumptions.

Civil nuclear is considered to be similar to Chemicals. GNSS use is limited to the tracking of goods, and despite invitations for interviews, the community has not engaged with this study. Benefits are therefore not monetised. Please note for the purposes of this study, energy generation (including from nuclear sources) is contained in the Energy CNI.

4.1.3 Communications

The communications CNI comprises multiple distinct sub-sectors that are discussed in turn below.

Fixed-line telecommunications (including internet)⁵²

Estimated annual GVA contributing benefits from GNSS: £32.0m

Estimated annual utility benefits from GNSS: £0m

Fixed-line telecommunications use GNSS as a source of **timing** information. Following Chronos (2011) three distinct aspects of timing may be considered. These are: i) Traffic Timing (Frequency); ii) Common epoch (usually UTC) time slot alignment (Phase) and iii) Time of day (Time).

Digital telecommunications consists of data packets that flow around the network at a constant rate defined by the bandwidth of the network. In order to ensure the correct packet is 'unpacked' in the

⁵⁰ Available at

https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/526351/2015_16_summary_of_the_srp.pdf

⁵¹ European Commission's Directorate-General for Enterprise and Industry (2014) *Public Consultation Document: Applications of EU satellite navigation programmes (Galileo and EGNOS)*. Available at:

<http://ec.europa.eu/DocsRoom/documents/10843/attachments/2/translations/en/renditions/native> [accessed 05/12/16]

⁵² This section draws on Chronos Technology Ltd (2010) *Dependency of Communications Systems on PNT Technology*. Available at: http://www.chronos.co.uk/files/pdfs/wps/Dependency_of_Comms_on_PNT_Technology.pdf [accessed 05/12/16]

correct location, it is necessary to ensure all ‘(un)packing stations’ or switches operate a mutually referenceable time, thereby ensuring that the packets arrive at the correct destination.

The errors that may occur in the telecoms networks are constant traffic speed errors and varying traffic speed errors (wander). Constant traffic speed errors imply that data arrives at the switch either too early or too late compared with expectation. If the problem becomes too large, and the buffer at the switch fills up, the buffer must be emptied, and data is lost. Wander has a similar effect, but differs from constant traffic speed errors as the error may cancel out over time.

To reduce the risk of errors, the devices at opposite ends of the network must be synchronised to the same clock.

Telecommunication timing devices have holdover capability whose precision depends on the exact oscillator in use. The use of GNSS enables network operators to calibrate local timing devices using GNSS, and thus save money compared to a setup using atomic clocks conditioned by alternative sources.

Since telecommunications is particularly critical, the core network derives timing information from three independent sources to ensure resilience against outage of one source. Limited evidence suggests switches at the edge of the networks may rely on GNSS to greater extent.

Benefits have been estimated in the order of **£5.8m** per year from reduced infrastructure costs on atomic clocks (assuming prices are comparable, the savings derive from the longer lifetime of GNSS devices).

Additional benefits are achieved as the GNSS-based solution removes the need for the telecoms company to provide alternative sources of timing in a setup where atomic clocks are used. Basestations are connected by cable or satellite backhaul, so there is an alternative means of distributing timing information, but the required precision of time means that this would require a complicated setup, which is avoided when using GNSS. The UK fixed-line telecommunications networks consists of approximately 100,000 nodes spread all over the UK. Delivering synchronised time to those nodes would involve significant additional effort. Using the same ratio of atomic clock-benefits to capital investment reduction-benefits as derived for Energy (see section 4.1.6), the savings are estimated at **£26.1m**.

Cellular telecommunications⁵³

*Estimated annual GVA contributing benefits from GNSS: **£5.0m***

*Estimated annual utility benefits from GNSS: **£0m***

In addition to the application of GNSS in fixed-line telecommunications, a further layer of complexity is introduced as base station timing for radio frequency stability and call hand-over management are required. Benefits have been estimated in the order of **£0.9m** per year from reduced infrastructure costs on atomic clocks (assuming prices are comparable, the savings are derived from the longer lifetime of GNSS devices).

⁵³ This section draws on Chronos Technology Ltd (2011) *Dependency of Communications Systems on PNT Technology*. Available at: http://www.chronos.co.uk/files/pdfs/wps/Dependency_of_Comms_on_PNT_Technology.pdf [accessed 05/12/16]

Much greater benefits are achieved as the GNSS-based solution removes the need for telecoms companies to provide alternative sources of timing in an alternative setup where atomic clocks are used. Not all cellular basestations are cabled, so it is necessary for the operator to provide an alternative delivery mechanism of precise time (e.g. using synchronised Ethernet) to the estimated 50,000 basestations in the network. Using the same ratio of atomic clock-benefits to capital investment-benefits as derived for Energy (see section 4.1.6), the savings are estimated at **£4.1m**.

Broadcast – DVB

Benefits cannot be monetised without using unfounded assumptions.

The terrestrial digital video broadcast (**DVB-T**) network uses different frequencies for different regions of the country, coinciding with BBC news regions and advertising regions for commercial stations. GNSS is used on all 1,154 DVB-T transmitters in the UK as it is the cheapest source of accurate time and reference frequency.

The network uses a master signal which is delivered to the main transmitters via fibre. This signal is then converted by a local transmitter to achieve the correct frequency. The benefits of GNSS cannot be reasonably monetised, but it has been stated that alternative sources of time must be accessed via wireless rather than fibre, as the cost of laying out the required infrastructure would be prohibitively high. Given this current setup, GNSS may be considered an enabler of DVB-T.

Broadcast – DAB

Benefits cannot be monetised without using unfounded assumptions.

Digital Audio Broadcast (DAB) uses GNSS to synchronise the transmission so that signals received from different transmitters are not delayed beyond the tolerance (guard interval) that ensures all receivers in an area receive the same signal. Digital radio stations operate on the same frequency across the whole of the UK, so synchronising the broadcast needs a national source of timing and base frequency.

UK DAB transmitters relied on GNSS at the time of the SVN 23 anomaly event (January 2016).⁵⁴ This resulted in timing issues on a small number of transmitters and minor, short duration impacts on coverage in some areas. Stakeholders confirm the DAB network has subsequently been made more resilient to GPS outage.

Benefits of GNSS materialise because costs are limited to a capital investment, with no operating costs once installed. The DAB national and local networks consist of approximately 800 transmitters, of which many are in remote areas, and the broadcast signal to be transmitted is distributed via fibre, shortwave and satellite. The cost of installing alternative sources of timing information would be great and would involve laying cable to all the transmitters, thereby ensuring that an alternative (e.g. fibre-based) time solution could be delivered instead. The ease and convenience of GNSS as a source of timing makes it a cost-effective solution compared to fibre based alternatives. Whilst the recent anomaly did lead to some timing issues on a small number of sites, GNSS has been shown over many years to provide an effective source of timing information and methods to improve its reliability and resilience are now under investigation.

⁵⁴ Charles Curry (2016) A2.3 – SVN 23 (aka UTC Anomaly Event') International Navigation Conference 2016 presentation. Available at: http://www.chronos.co.uk/files/pdfs/pres/2016/INC_SVN23%20What%20Happened.pdf

TETRA

Estimated annual GVA contributing benefits from GNSS: £4.3m

Estimated annual utility benefits from GNSS: £0m

Professional Mobile Radios (PMR) in the UK use the TETRA⁵⁵ standard for communication between emergency responders. GNSS is used to synchronise the network, and for synchronisation and positioning of handheld TETRA radios (e.g. for distress calls). Benefits have been monetised using EU-level information for the network (not handheld radios) and then calibrated to the UK context. Monetised benefits in 2016 are estimated to be **£4.3m**.

The UK's emergency services will migrate to a different network as of 2020, when EE's 4G network is scheduled to replace TETRA. As part of the contract award, EE committed to extend coverage of its 4G network in rural areas of the UK and the London Underground. The rural base stations will rely on GNSS for timing and synchronisation, similar to 'cellular telecommunication', above.

Internet data centres

Benefits cannot be monetised without using unfounded assumptions.

Synchronisation of internet data centres is of great importance to heavyweight internet-based companies such as Google, Facebook, and Amazon. As users access data, they may draw on a variety of data centres across the globe. It is of crucial importance that the information is synchronised so that the user receives the correct response to their inquiry, and in the right order. Timestamping a user's request and the response of each data centre means that the programme can order the responses correctly, and ensure data is not corrupted. In abnormal situations where individual data centres are taken out for maintenance or because temperatures exceed normal operating conditions, the synchronisation of data requests ensures that users are minimally impacted.

In 2012, Google published a research paper,⁵⁶ which explains how its data centres are synchronised using the TrueTime API, which relies on timing information from GPS and atomic clocks, and recognises the vulnerabilities of each. Google have no data centres in the UK, but UK-based users are dependent on the TrueTime API to be able to use Google and other internet services.

The importance of accurate synchronisation was further evidenced by the crash of Reddit in 2012, caused by a leap second discrepancy between different applications on its Linux-based servers.⁵⁷

It is beyond the scope of this paper to estimate the economic benefits of cloud-based internet services. However, it should be recognised that the fact that they developed after GNSS became proliferated means that no alternative source of global, synchronised time is available.

⁵⁵ Terrestrial Truncated Radio

⁵⁶ Google Inc. (2012) *Spanner: Google's Globally-Distributed Database*. Available at: <http://static.googleusercontent.com/media/research.google.com/en/archive/spanner-osdi2012.pdf>

⁵⁷ Wired (2012) *The Inside Story of the Extra Second That Crashed the Web*. Available at: <https://www.wired.com/2012/07/leap-second-glitch-explained/>

4.1.4 Defence

Defence is beyond the scope of this study. However, GNSS – born as a U.S. defence utility – is used in multiple military applications.

4.1.5 Emergency Services (Police, Ambulance, Fire Services, Coast Guard)

Emergency services use GNSS from two sides. Firstly, the **public-safety answering point (PSAP)** receives emergency calls, approximately 70% of which now originate from mobile phones, some of which share the caller's location information. Secondly, after a call has been made, emergency services rely on GNSS to navigate to the emergency, and use GNSS-based fleet management systems to optimise vehicle routing.

Public-Safety Answering Point (PSAP)

Estimated annual GVA contributing benefits from GNSS: £0

Estimated annual utility benefits from GNSS: £1,921.0m

As of 25th July 2016, smartphones that run the Android operating system in the UK send their location when an emergency call is made.⁵⁸ This solution uses the phone's multi-sensor derived location which comes from GNSS and non-GNSS sources. As a side note, the incorporation of GPS in mobile phones improved the accuracy of location to a degree that allowed positioning and mapping, and therefore encouraged developments towards increased accuracy from Wi-Fi. For this reason, and the fact that the absence of GNSS would likely mean the use of Cell-ID location, it is reasonable to attribute all the benefits of improved location to GNSS.

Data from the London Ambulance Service⁵⁹ compares call length between landline and mobile emergency calls.⁶⁰ On average, calls made from landlines are shorter than calls from mobile, with 'Location and Chief Complaint' (T1-T3) achieved 27 seconds faster from landline. The total duration of the call is also shorter for landline calls, by 42 seconds. It is reasonable to assume that precise location information reduces the difference between mobiles and landlines, but owing to other differences between the technologies (notably 'signal strength' and sound quality on calls); it is likely that calls from landlines will remain shorter than from mobiles.

Beyond the 'normal' cases above, where information is eventually given, and the rest of the emergency response process is similar for both types of calls, the London Ambulance Service states that approximately 36,000 annual 'confirmed' critical incidents, reported from mobile phones, result in searches on location for at least 30 minutes.

As of 2014, 67% of emergency calls in the UK were made from mobile phones, and the benefits from GNSS are estimated as the reduction in time spent in the two sets of cases, namely the 'normal' calls where time is reduced only at the actual call, and the 'special' case where time is reduced because

⁵⁸ Google Blog (2016) *Helping emergency services find you when you need it the most*. Available at: <https://blog.google/topics/google-europe/helping-emergency-services-find-you/> [accessed 06/12/16]

⁵⁹ Included in European Emergency Number Association (EENA) (2014) *112 Caller Location & GNSS* available at: <http://ec.europa.eu/DocsRoom/documents/5372/attachments/1/translations/en/renditions/native> [accessed 06/12/16]

⁶⁰ The location of a landline is known, so the PSAP immediately knows where the call originates. However, signal strength and call quality are non GNSS-related factors that also affect the duration of an emergency call.

of reduced search times. Following the London Ambulance Service's approach, the valuation of time saved draws on a Swedish study,⁶¹ which finds that the cost of 1 minute lost was €1,300 in 2004.

Benefits have been estimated in the order of **£1,921.0m** per year from time saved on emergency calls and searches.

Police, Ambulance and Fire services

*Estimated annual GVA contributing benefits from GNSS: **£96.5m***

*Estimated annual utility benefits from GNSS: **£0***

Benefits of GNSS for the operations of emergency services follow the same logic as those for fleet management in road transport. Benefits therefore materialise in the form of **reduced maintenance costs**, where accurate information on vehicle use allows operators to service the vehicles pre-emptively and in advance of a breakdown. In particular, vehicles in the emergency services' fleet will be required to operate at different intensities. Long periods of high speed on motorways will take a different toll on a car than many starts and stops in an urban area. Accurate knowledge of vehicle use therefore enables better maintenance programmes.

Additional benefits arise from constant monitoring of the fleet of vehicles, which allows dispatchers to **optimise the use of the fleet** and reduce downtime or 'return trips'. Without GNSS monitoring, drivers of emergency vehicles would be required to report and return to base much more frequently. The Command and Control system for emergency services is very lean, and few staff members are required to be able to monitor the location, destination, and status of all vehicles. This has represented a substantial improvement in efficiency over traditional means, where individual police officers or ambulance drivers reported the information by radio, for it to be pinned to a map.

Further benefits are derived from the use of **navigation** equipment in emergency vehicles, where drivers no longer need to be familiar with the local area, or spend large parts of the journey navigating by map. This allows more flexibility of emergency services as ambulances and police vehicles (and to lesser extent fire engines) are able to efficiently cover a larger area than previously.

The use of GNSS in control centres for emergency services, on average is assumed to have saved six staff members when comparing to the traditional method of pinning vehicles to a map and maintaining overview in that way. The benefits are therefore approximated by the labour costs of six staff members around the clock per control centre (of which there are 204 in the UK), assuming minimum wage +20% reflecting the skills required for operation, the estimated benefits per year are: **£96.5m**.

4.1.6 Energy

*Estimated annual GVA contributing benefits from GNSS: **£4.4m***

*Estimated annual utility benefits from GNSS: **£0***

⁶¹ Jaldell, Henrik (2004) *Cost-benefit analysis and life-saving operations*, University of Karlstad. Based on data from the Swedish Rescue Services statistical unit.

The National Grid is the UK's electricity transmission and distribution company. GNSS is not used for distribution, but it is a very important input in transmission.

National Grid's substations monitor the voltage and load on the network, and adjacent substations communicate with each other to identify disturbances. The communication between substations is timestamped using GNSS-time to ensure that the information is identified in the correct order. If there is a fault in the communication link between substations, the information is rerouted, so the time it takes for the information to be received may increase. Without the timestamp, incorrect inferences may be drawn from the information.

In case of disturbance, National Grid are required to shift the load from a disturbed power line to a functioning line within 120ms. This relies on the layout of the transmission grid, which is fully meshed. Benefits of GNSS materialise as GNSS equipment has longer lifetime than atomic clocks, which would be the alternative. Additional benefits are derived because GNSS clocks are synchronised as part of operations, whereas atomic clocks would need to be conditioned periodically.

The benefits arising from longer **device lifetime** are monetised at **£0.8m** per year based on 337 substations, each using 8 GNSS receivers/clocks on average, at a cost of £2,000 and lifetime of 20 years for GNSS and 5 years for atomic clocks.

The removal of the need to condition atomic clocks through non-GNSS sources brings great benefits, as transportation of accurate time to each substation is a challenging endeavour. Indeed, owing to the remoteness of the network, it is questionable whether a fibre-based time transportation system could be created at all. The National Grid's transmission network is approximately 8,000 km long,⁶² and the price of fibre-optic cable ranges from £0.81 to £4.49 per metre.⁶³ Assuming £3 per metre, and the need for three times the network to ensure resilience, the capital cost for National Grid would be £72m, in addition to which the accurate timescale would come at a cost. Assuming the lifetime of fibre optic cable is 20 years, this would imply annualised replacement cost of **£3.6m**. With GNSS, these costs have not materialised.

Additional benefits of using GNSS are derived from convenience. Suppliers of equipment offer a complete solution incorporating GNSS. This removes an obligation on National Grid to offer its own timing solution.

4.1.7 Finance

*Estimated annual GVA contributing benefits from GNSS: **£0.6m***

*Estimated annual utility benefits from GNSS: **£0***

The financial sector requires timestamping of transactions to ensure the prevailing price at the time of the transaction is charged. This is true of stock exchanges and financial trading centres in banks. The European MiFID⁶⁴ 2 defines accuracies of timing with respect to UTC⁶⁵ that are required for an entity to be allowed to continue operating. High street banks are required to be able to timestamp activities with an accuracy of at least 1ms with respect to UTC, while high-frequency traders need

⁶² National Grid (2017) *UK Transmission*. Available at: <http://www2.nationalgrid.com/Contact-us/UK-Transmission/> [accessed 20/03/2017]

⁶³ CableNet (2017) *Fibre Optic Cable*. Available at: <http://www.cablenet.co.uk/catalogue/fibre-cable.htm> [accessed 20/03/2017]

⁶⁴ Markets in Financial Instruments Directive

⁶⁵ Universal Coordinated Time

accuracy of 1µs. In high-frequency trade, the accuracy with which a transaction can be timestamped has significant impact on the amount of money a trader can earn from a transaction. Therefore, the equipment used by high-frequency traders has sophisticated oscillators for holdover, ensuring that trade can continue long after an external timing source is lost. Similar equipment is present in stock exchanges.

GNSS has been used as the external source for timing and synchronisation of financial applications for decades, and has the added advantage of being a global resource, ensuring that all trade undertaken by different sites across the globe are traceable to the same reference time. As a result, an alternative scenario in which a different, global source of UTC traceability were to be used is difficult to imagine, and the incremental benefits of GNSS are therefore likely underestimated. Estimating the benefits of the internationalisation of the banking sector (and associated flow of capital) is beyond the scope of this study so modest benefits have been estimated in the order of **£0.1m** per year from reduced infrastructure costs on atomic clocks (assuming prices are comparable, the savings derive from the longer lifetime of a GNSS device).

The geographic concentration of the financial sector data centres means the saved capital investments in an alternative non-GNSS-reliant timing source for finance is relatively small compared with the decentralised energy and telecommunications sectors considered above (see sections 4.1.3 and 4.1.6). Nevertheless, the benefits associated with the ability to access precise time through pre-fabricated devices utilising GNSS does bring significant benefits, as the banks and stock exchanges are exempt from finding alternative sources of timing. Considering that 250 collocated data centres⁶⁶ and 280 trading centres⁶⁷ would need to be connected to reliable alternative sources of synchronised time, the avoided costs are estimated in the order of **£0.5m**.

ATMs do not receive timing information from GNSS, but certain payment services, such as Apple pay, rely on GNSS as an input in a risk assessment that ultimately decides whether a transaction is approved by card issuing companies. Such payment services remain of limited importance in the UK, and do not feature in the Fraud The Facts 2016 report by Financial Fraud Action UK. In future, the practice of linking the location of a card owner's mobile to the use of the card could reduce the £187.7m worth of 'card fraud abroad' committed in 2016, describing situations where criminals obtain payment card data and then clone the card in order to use it abroad.⁶⁸ The economic benefit of GNSS-based localisation are considered negligible at this point.

4.1.8 Food

The food CNI does not directly incorporate agriculture or fisheries, so benefits of GNSS in these applications are treated separately (see section 4.2.3 and 4.2.5). The food sector itself does not use GNSS directly, but relies on it through the transport sector (in addition to agriculture and fisheries). This is primarily because the food sector operates a just-in-time supply chain. Logistics companies which serve the food sector must therefore be as efficient and effective as possible.⁶⁹

⁶⁶ www.datacentermap.com showing 250 sites in the UK.

⁶⁷ Based on Orbis Bank Focus (<https://www.bvdinfo.com/en-gb/our-products/company-information/international-products/orbis-banks>)

⁶⁸ Financial Fraud Action UK (2017) *Fraud The Facts 2016*. Available at: <https://www.financialfraudaction.org.uk/fraudfacts16/> [accessed 16/3/2017].

⁶⁹ Cabinet Office (2016) *Summary of the 2015-16 Sector Resilience Plans*. Available at https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/526351/2015_16_summary_of_the_srp.pdf

4.1.9 Government

The Government CNI encompasses a wide range of activities, some of which rely on GNSS. The majority of Government activity does not currently rely on GNSS to any notable degree. The objective of the UK Space Agency's Space for Smarter Government Programme is to identify new applications of space technologies, including GNSS.⁷⁰

Weather forecasting

*Estimated annual GVA contributing benefits from GNSS: **£75m***

*Estimated annual utility benefits from GNSS: **£25m***

The Met Office is the UK's National Meteorological Service and is a Trading Fund within the Department for Business, Energy and Industrial Strategy (BEIS). The Met Office uses GNSS for a wide array of applications including:

- **Radio-occultation:** a technique where the refraction of GNSS signals across the atmosphere is measured by high-quality GNSS receivers on board meteorological satellites hundreds of times per day. This process refines estimates of water vapour in the atmosphere and contributes a couple of % to total weather forecasting accuracy. A similar activity is undertaken a few times per day by ground-based receivers. Using GNSS signals, the Met Office also maps the ionosphere, where LEO satellites operate, to inform satellite operators of any anomalies.
- **Positioning of sensors:** The Met Office sources many data points from moving sensors including weather balloons, marine networks (including buoys, Argo floats, and ships), and aircraft with in-built weather sensors. Many of the sensors use GNSS as the only source of position information. In addition, the JASON satellites (measuring sea level) are GNSS-enabled as the technique requires extremely accurate information on the location of the satellites.
- **Lightning detection network:** Using the time of detection of the radio pulse of lightning strikes at different sites in the network it is possible to accurately estimate the location of lightning strikes. This approach requires very accurate timing and location information, which is sourced from GNSS.
- **Timing and synchronisation:** The Met Office's internal network and supercomputer are synchronised using GNSS clocks on-site. The supercomputer requires timing accuracy of approximately 1s.

A recent study⁷¹ of the UK Met Office estimates its economic impact at £30bn over 10 years. It has been found that 50% of this value is attributable to observations, where the location of sensors makes a key contribution to the accuracy of the forecasts. This suggests GNSS benefits in weather forecasting upwards of £100m per year, of which **£25m** are utility benefits to the public and climate change information benefits, and the remaining **£75m** are benefits to businesses.

⁷⁰ Please see <http://www.spaceforsmartergovernment.uk/> for more information.

⁷¹ London Economics (2016) *General Review* available at: <http://londoneconomics.co.uk/blog/publication/met-office-general-review-march-2016/>

Offender tracking

*Estimated annual GVA contributing benefits from GNSS: **£30.8m***

*Estimated annual utility benefits from GNSS: **£0***

One area that Government actively uses and seeks to expand its use of GNSS is for offender tracking. At present, over 255,000 offenders are subject to electronic tagging in the UK. Tagging is available for offenders that are on bail or community orders as well as those released on license. The prevalent technology for tagging is RFID,⁷² which requires a home monitoring unit at the offender's home, and an ankle tag that communicates with the home unit and constantly verifies the offender is near. GNSS can be used to allow the offender more flexibility, and enable them to be in a larger geo-fenced area, for example including the offender's place of work, local shops and so on. It could also be used to enforce restraining order and anti-social behaviour orders, ensuring the offender stays away from particular areas.

The cost of a prison place in the UK is approx. £96.40 per day, while the cost of operating the tracking infrastructure would be around £12 per day per tag. Currently, 1,000 offenders participate in a pilot scheme for GNSS tracking, implying current benefits in the order of **£30.8m**.

Offender tracking is particularly vulnerable to jamming and spoofing because this would liberate the offender, and allow them to leave the fenced area that they may legally occupy. OS (or CS, PRS) Authentication to be provided by Galileo by 2020 is one of the European system's clear differentiators, and could result in significant take-up of GNSS tagging in the UK and elsewhere.

Evidence management

Benefits cannot be monetised without using unfounded assumptions.

The UK's vast network of CCTV makes an important contribution to the prosecution of offenders as it enables accurate determination of an offender's location at a specific point in time. The timestamps on the images therefore play an important role in conviction. CCTV vendors offer GNSS-sourced NTP servers as complementary products to the camera network itself, indicating that the timing information for at least some CCTV networks is GNSS-based.

Without accurate time information available, the value of CCTV camera imagery is severely reduced (if useful at all), and additional circumstantial evidence is required to get a conviction. Benefits of GNSS have not been quantified as it is extremely difficult to access data, and it is beyond the scope of this study to speculate about the economic value of a conviction, and the probability that certain camera systems would be able to source alternative timing information (either cabled or from signals of opportunity).

CAP and CFP compliance monitoring

*Estimated annual GVA contributing benefits from GNSS: **£0.8m***

*Estimated annual utility benefits from GNSS: **£0***

⁷² Scottish Government (2013) *Development of Electronic Monitoring in Scotland*. Available at: <http://www.gov.scot/Publications/2013/09/7937/3>

Compliance with the European Union's common agricultural policy and common fisheries policy can be assisted by GNSS. Farmers are paid compensation depending on the acreage of 'greening' and GNSS can be used to improve efficiency of measurements of fields that comply.

All fishing vessels over 12m in EU waters need to be fitted with a VMS transponder that derives GNSS-based location, and communicates this information to the authorities, who are then able to verify the whereabouts of vessels. There is no EC Impact Assessment that monetises the benefits of compliance with either the CAP or the CFP.

One benefit of the CFP is that the GNSS-based infrastructure required to operate a fishing vessel (longer than 12m) offers convenience for the fisherman and allows them to keep an electronic log rather than a physical one (which was previously a requirement). In 2015,⁷³ the UK fishing fleet comprised 1,324 vessels greater than 10m, and 4,863 shorter than 10m. Assuming the 10.01-15m band is evenly distributed, the number of UK fishing vessels monitored by VMS is 921. Assuming the same distribution holds for the number of days at sea (total for vessels longer than 10m: 183,191), and that manual population of the log would require 15 minutes per day, the amount of time saved by using the VMS-based system is 2 million minutes or 16FTEs. GVA per worker in the fishing industry is £53k, implying productivity improvements of **£0.8m**.

4.1.10 Health

Estimated annual GVA contributing benefits from GNSS: £0

Estimated annual utility benefits from GNSS: £247.6m

The Health CNI does not rely on GNSS at its core. However, social carers and district nurses, midwives, etc. that drive from location to location are considered to use GNSS for navigation purposes. Similar to emergency services (considered in section 4.1.5), these non-stationary activities are expected to rely on GNSS-based fleet management solutions to respond to urgent requirements as and when they arise. In the simplest form, ambulance services transport patients to hospitals to allow treatment of ailments, and in some cases, transport patients back home, thereby freeing hospital beds for other patients. GNSS use in ambulance services is extensive, and as a result, the Health CNI has secondary reliance on GNSS.

One primary health application of GNSS is in tracking devices, which has the potential to offer benefits to people with dementia and their carers. The use of this technology can alert carers that an individual has moved outside a set boundary, as well as assisting in locating a person at any time or in any place where GNSS is accessible. This is likely to be associated with significant benefits in terms of reduced search costs. Additionally, the freedom to move more freely provides physical and psychological benefits for people with dementia. However, there remain concerns over the ethical and practical use of tracking devices for such patients.

The UK Alzheimer's Society reports that 850,000 patients are diagnosed with dementia with a total economic cost of £26.3bn in 2015. Approximately, one-third live in residential care and the remaining two-third at home. McShane et al. (1998) found that 40% of people with dementia get lost outside their home. Therefore, there are approximately 227,800 annual search events.

⁷³ Data in this section are based on: Marine Management Organisation (2016) *UK Sea Fisheries Statistics 2015*. Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/598208/UK_Sea_Fisheries_Statistics_2015_full_report.pdf [accessed 27/03/2017]

A Danish study⁷⁴ estimates that GNSS can reduce the number of search events by half. Moreover, the use of a tracking device is likely to allow dementia patients to stay at home for six additional months, reducing the cost burden faced by the NHS.⁷⁵

The number of dementia patients that are tracked using GNSS is not known, therefore benefits have not been monetised for the UK.

Other forms of trackers include those used by **lone workers**, whose superiors are able to respond to emergency signals from lone workers and direct search teams to their location. UK company Skyguard provides lone worker tracking devices and management solutions to more than 100 NHS trusts to allow district nurses and other personnel to trigger alarms if they face physical or verbal abuse. The company cites a Royal College of Nursing report that states that more than 60% of nurses have been subjected to abuse in a two-year period, with 10% having experienced physical assault.⁷⁶ The company also supplies solutions to more than 50% of police forces to be used by people under police protection, witness protection and anyone worried about their safety. Timely response in cases of domestic abuse can make a world of difference to the victim. Other applications of lone worker tracking are in hospitality, where lone hotel workers frequently face troublesome guests; housing associations, council and care workers.

The benefits of the GNSS-based solution are both in terms of peace of mind for the individual equipped with an alarm, and for companies who are able to prove that they take the safety of their staff members seriously. The Health and Safety Executive estimates that it costs £17,000-£19,000 to investigate a physical assault, costs that would be payable by the employer if found negligent.

Another UK company, trackaphone and the TecSOS project track approximately 15,000 subscribers, with strong growth foreseen over the coming years. The estimated number of lives saved in a year from tracking 15,000 people is 18-20, estimated based on actual alerts and the situations faced. The value of a statistical life is £1.7m according to the Department for Transport,⁷⁷ implying benefits of £32.3m. Assuming similar rates for Skyguard's 100,000 users, the total benefits are monetised at **£247.6m**.

4.1.11 Space

LEO satellites

Benefits cannot be monetised without using unfounded assumptions.

Satellites in Low Earth Orbit increasingly use GNSS for positioning and timing information. The benefit is of convenience, as the satellite has an unobstructed view of a large number of GNSS satellites and has no problems with multipath or other disruptions. EO satellites use stars to determine the appropriate attitude of the cameras, but require location information to translate the star field into accurate attitude information. The required accuracy of location depends on the resolution and swath width of the system as higher resolution, narrow swath satellites need greater accuracy to ensure they capture the target area. Position information is available from the U.S.

⁷⁴ INCA Vidensformidling & InnovationsHus Syd (2011) *Demonstrationsprojekt med brug af GPS system i eget hjem*, available (in Danish) at: <http://www.safecall.dk/mediafiles/safelink/PDFfiler/Slutevaluering-GPS-til-demente.pdf> [accessed 09/12/2016]

⁷⁵ An estimated 25 percent of hospital beds are occupied by people with dementia (Source: Counting the cost – caring for people with dementia on hospital wards, Alzheimer's Society, 2009)

⁷⁶ Skyguard (undated) *Why more than 100 NHS trusts use Skyguard to protect their lone workers?*. Available at: <http://skyguard.co.uk/nhs/>

⁷⁷ Department for Transport (2016) *Accident and casualty costs (RAS60)*. Available at: <https://www.gov.uk/government/statistical-data-sets/ras60-average-value-of-preventing-road-accidents> [accessed 17/03/2017]

Department of Defense Two-Line Element set, which is published every two days. Satellites travel in deterministic orbits, so knowledge of position even at two-day intervals is sufficient to compute future locations with sufficient accuracy for operations.

Ground stations

Benefits cannot be monetised without using unfounded assumptions.

EO ground stations use 2 GNSS receivers to derive timing information and have local oscillators in place to keep time. The accuracy of timing information is kept at a few 10s of milliseconds, but the system would continue to function up to 1s accuracy. This is to ensure that ground station dishes are pointed at the satellite as it travels overhead and that the frequency of communication is consistent between satellite and ground segment.

For GEO satellite communications, GNSS is used in the ground station to source a reference frequency which ensures the space and ground segment communicate on the same frequency and align frequency in the up- and down-converters. The ground segment uses two GNSS receivers and two oscillators to maintain frequency accuracy in the event GNSS was lost. As is the case for many other applications, benefits of GNSS are primarily of convenience as access to accurate time and frequency information is easily available. Alternative sources of reference frequency are available, so the incremental benefits of GNSS are limited.

Satcoms

*Estimated annual GVA contributing benefits from GNSS: **£31.7m***

*Estimated annual utility benefits from GNSS: **£0***

High-throughput mobile satellite communication devices require a GNSS fix in order to complete a 'handshake' with the communication satellite, which allows acquisition of the appropriate focused spot beam. FAQs from Inmarsat suggest that GNSS location information is required,⁷⁸ and that no alternative means of inputting location information is available on the communication devices. This implies that mobile satcoms (certainly from GEO satellites) is critically reliant on GNSS. It is beyond the scope of this study to comprehensively estimate the benefits of mobile satcoms

However, a recent study estimates annual global benefits of satcoms in aviation of \$480m.⁷⁹ Benefits mainly accrue to passengers and airlines so the UK share of global benefits is approximated based on the registered country of aircraft. The UK's share of the global fleet is 6.61%,⁸⁰ so the annual UK benefits of satcoms in aviation is estimated at **£31.7m**.

Satellite communications from non-GEO orbits (e.g. Iridium's LEO constellation) do not rely on GNSS for functionality, but rather offer so-called bread-crumbs services, where users can set a frequency of position fix and report to allow family members to track their movements, for example when hiking in the wilderness.

Users of fixed satellite communications do not rely on GNSS.

⁷⁸ <http://www.inmarsat.com/support/faq/>

⁷⁹ Helios (2017) *The benefits of satcom to airlines*. Available at: <https://www.inmarsataviation.com/dam/jcr:08c077ff-e783-4460-88a9-ee77cd4969fc/Airline%20Benefits%20of%20Satcom%20-%20A%20Report%20for%20Inmarsat.pdf>

⁸⁰ Based on Flightglobal: <https://www.flightglobal.com/>

4.1.12 Transport

Benefits of GNSS in the transport domain are discussed in section 4.2 with the exception of the transport infrastructure itself, which is considered here.

Road transport infrastructure

Benefits cannot be monetised without using unfounded assumptions (but monetisation of benefits to drivers available in sections 4.2.2 and 4.3.2).

GNSS is used for monitoring infrastructure, mainly bridges. The Forth Road Bridge for example is monitored using GNSS⁸¹. Following closure of the bridge over Christmas 2015 for emergency repairs, the intensity of GNSS-based monitoring was increased tenfold from three sensors to thirty, as the owners and operators of the bridge realised that better monitoring could have allowed earlier intervention and limited the closure of the bridge.⁸² The Forth Road Bridge remains the only UK bridge that advertises its use of GNSS. Benefits of GNSS monitoring are related to the probability that the bridge will need to be closed. Indeed, reducing capacity on the Forth Road Bridge to one lane in each direction can cost the operator upwards of £650,000 per day.⁸³ Estimating the probability that the bridge will be closed and GNSS-derived impact on this probability are substantial undertakings, and the associated benefits are not anticipated to justify the effort required.

Rail transport infrastructure

Benefits cannot be monetised without using unfounded assumptions (but monetisation of benefits to train operating companies is available in section 4.2.7).

The UK railway network is owned and maintained by Network Rail. Its Plain Line Pattern Recognition (PLPR) system uses GNSS to geo-tag high resolution, high frequency 3D and thermal imagery obtained from sensors on four dedicated trains that cover the whole of the track every fortnight. The images are then analysed to identify potential faults on the track, so they can be remedied. Given that 33,000 potential faults were detected in the single month of September 2014,⁸⁴ the efficiency gains from enabling track-side workers to focus their attention on identified faults are vast. Benefits are discussed qualitatively in *The Case for Space 2015*.⁸⁵

Network Rail uses GNSS for a wide variety of additional applications, including:

- **Timing:** Timing and Synchronisation of the Network Rail Telecoms network, station clocks and passenger information systems, logger and recorder system timing;
- **Positioning:** Passenger information systems, traffic management, and train describers. In future, GNSS positioning will be an integral part of the European Rail Traffic Management System (ERTMS) level 3.

⁸¹ European Space Agency (2015) *Monitoring Bridges from Space*. Available at: <https://artes-apps.esa.int/projects/showcases/monitoring-bridges-space> [accessed 07/12/2016]

⁸² European Space Agency (2016) *Monitoring Bridges Opens Vast Markets*. Available at: <https://artes-apps.esa.int/projects/showcases/structural-health-monitor-vast-markets> [accessed 09/12/2016]

⁸³ European Space Agency (2015) *Monitoring Bridges from Space*. Available at: <https://artes-apps.esa.int/projects/showcases/monitoring-bridges-space> [accessed 16/03/2017].

⁸⁴ Andrew Taratola (2014) *This "Flying Banana" Keeps Britain's Trains from Running off the Rails*. Available at: <http://gizmodo.com/this-flying-banana-keeps-britains-trains-from-running-1656940177> [accessed 27/03/2017]

⁸⁵ London Economics (2015) *The Case for Space 2015 (iii) Case Studies*

The Rail Standards and Safety Board (RSSB),⁸⁶ provides guidance on the most efficient way to access and use GNSS information across a wide array of applications. The document asserts that many GNSS applications in the rail domain source satellite data from isolated antennae and receivers. It offers guidance on how a single GNSS receiver should be specified to ensure multiple applications can utilise the same processed signal.

GNSS-based signalling on low density lines will enable reduced infrastructure costs and thus allow low-profit lines to remain open. GNSS-based signalling has not yet been rolled out in the UK, and therefore no benefits of GNSS have been estimated for the application.

Maritime transport infrastructure

Benefits cannot be monetised without using unfounded assumptions (but monetisation of benefits to skippers is available in section 4.2.3).

Maritime transport infrastructure comprises navigation aids such as lighthouses and buoys as well as ports and associated operations including pilotage.

Lighthouses rely on GNSS for the communication link that allows the Lighthouse Authority to control and monitor the lighthouse remotely. Lighthouses are also used as AIS⁸⁷ base stations (receiving the location and identity of nearby vessels) which is used for monitoring of UK waters and compliance with the Common Fisheries Policy. The Lighthouse Authority also offers a Differential GPS service to the maritime community, which improves accuracy of GNSS and is available across UK waters.

Buoys marking the edges of shipping lanes use GNSS for synchronisation purposes to ensure the light on each pair of buoys flash at the same time, resembling the lights on a runway. This helps captains or pilots on very large vessels to navigate and ensure they remain within the confines of the shipping lane.

The benefits associated with the availability of lighthouses and buoys have not been quantified. However, the benefits associated with those and Differential GPS (DGPS) as an integrated element in the successful and safe navigation at sea are expected to be large.

From the perspective of port operations, GNSS is used across a wide variety of applications that could be considered from different starting points. The process of berthing, unloading, loading and launch of transport vessels uses GNSS as a tool to assist the following activities:

- On board the ship, GNSS is used as it is by far the superior source of over-ground speed and accurate location information. These data are used by the on board electronics to project journey times and estimate time of arrival in the destination port. The information is then sent to the destination port using satcoms (with GNSS⁸⁸) to allow the port operator to schedule arrival.
- As vessels approach ports, pilots are deployed on the vessel to safely berth it in the designated location. Pilots use RTK⁸⁹-enhanced Portable Pilot Units as a key input in the manoeuvring of the vessel within the port area.

⁸⁶ Rail Safety and Standards Board (2015) *Guidance on the Use of On-Train Satellite Positioning Technology Based Locator for Railway Applications*

⁸⁷ Automatic Identification System, a broadcasting system on vessels that computes position from GNSS and shares location and identity of the vessel.

⁸⁸ See section 4.1.11 above.

⁸⁹ Real Time Kinematic

- Ports use vessel tracking systems based on GNSS (AIS) to be able to manage traffic.
- Following safe docking of the vessel, unloading of cargo containers commences using large automated cranes relying on augmented GNSS to ascertain their own position, the position of the cargo that needs to be moved, and the position that it needs to be moved to, which is logged for future reference.
- The cargo can then be moved out of the port on lorries managed by GNSS-enabled logistics systems, and the vessel may be reloaded and finally launched from the port area by a pilot.

Qualitatively, the benefits of GNSS to port infrastructure operations may be considered strongly related to the societal benefits of container shipping and just-in-time inventory strategies across the economy. The efficiency in current port operations can only be achieved because GNSS enables accurate timetabling and container stacking as well as communications links. This reduces the demands on land and staff for warehousing activities, freeing up resources for other purposes.

Efficiencies offered by GNSS have helped UK ports process 307 million tonnes of inward cargo through ports in 2015. Table 1 shows a breakdown of the weight of selected inward cargo by type and the market share of the three largest import ports for each type of cargo.

Table 1 UK imports of selected cargo types through ports, 2015

Cargo type	Description	Weight (thousand tonnes)	Market share of top 3 ports
Liquid bulk	Subtotal	112,139	42%
Liquid bulk	Liquefied gas	11,794	92%
Liquid bulk	Crude oil	51,275	47%
Liquid bulk	Oil products	43,178	46%
Liquid bulk	Other liquid bulk products	5,892	47%
Dry bulk	Subtotal	80,800	39%
Dry bulk	Ores	12,932	96%
Dry bulk	Coal	23,411	63%
Dry bulk	Agricultural products	8,849	50%
Dry bulk	Other dry bulk	35,608	23%
Container and roll-on/roll-off	Subtotal	100,090	46%
Container and roll-on/roll-off	Container traffic	38,705	68%
Container and roll-on/roll-off	Roll-on/roll-off	61,385	36%
Other general cargo	Subtotal	13,897	33%
Other general cargo	Forestry products	5,614	56%
Other general cargo	Iron and steel products	4,983	38%
Other general cargo	General cargo & containers <20'	3,300	39%
Total	Total	306,925	36%

Source: Department for Transport Statistics [port0104 & port0400]

The market shares show that certain types of cargo (notably liquefied gas, ores, containers and coal) are concentrated in a few ports that process the majority of imports. Maritime shipping is the cheapest way of transporting cargo over long distances, and many intermediate inputs for production are therefore shipped this way. GNSS in ports and logistics operations related to berthing slots enable the efficiencies that allow UK retailers and manufacturers to operate with limited warehousing facilities using 'just-in-time'.

The Society of Motor Manufacturers and Traders (SMMT) recently commented that: "Many manufacturers carry stock to last them no more than four hours, so they are utterly dependent on

*rapid, fast-flowing [imports].*⁹⁰ In fact, Jaguar Land Rover and Nissan, the two largest car makers in the UK, hold two hours' of stock of some items. This has previously caused Nissan to procure RAF aircraft to collect parts that could leapfrog those stranded on a ship.⁹¹

Air transport infrastructure

Benefits cannot be monetised without using unfounded assumptions (but monetisation of benefits to airlines and passengers is available in section 4.2.4)

Air traffic control at large UK airports does not use GNSS for operations that are critical for navigation and landing of aircraft. However, GNSS is a crucial input for ADS-B,⁹² which is a system that broadcasts an aircraft's identity and GNSS-derived location to ground infrastructure. ADS-B could not function without GNSS. However, the UK airspace is managed using radar and other systems, and ADS-B is not a critical input in the process. In future, the UK will adopt space-based ADS-B (through the SESAR⁹³ process), and the reliance on GNSS will therefore increase significantly.

Smaller airports including Bristol, Exeter and airports in Scotland and the Channel Islands use EGNOS landing procedures (LPV 200, covering approximately 15 airports in the UK), and in many cases have limited ground-based landing systems in place.

Similar to maritime infrastructure, air traffic also uses satcoms to receive updates from aircraft, but unlike maritime, aircraft have an HF radio system in place as backup in case satcoms are lost.

Air Traffic Control uses GNSS extensively for timing and synchronisation purposes between control centres and ground infrastructure across airports and between airports. Applications include the IT systems that compute predicted paths and landing times for aircraft, nav aids, communications sites and data links.

4.1.13 Water & Sewerage

Actual GNSS use in Water & Sewerage is considered to be insignificant.

The water and sewerage networks are underground and therefore not prime candidates for the use of GNSS. Monitoring the integrity of a water distribution network uses audio that allows identification of leaks and breakages. A noise logging system relying on fixed-location noise loggers that are able to transmit two weeks' worth of logged data wirelessly to a mobile receiver unit is able to incorporate an external GNSS device in the receiver. This means significant efficiencies in monitoring of water networks, as a single operator can cover 220km-350km of network per day, and easily transfer all the data to a geo-tagged database. This ensures any problems can be addressed effectively.⁹⁴ Actual usage of GNSS in water & sewerage has not been identified, but is assumed to be limited.

⁹⁰ Jamie Robertson (2017) *Why carmakers have the most to fear from protectionism*, BBC News. Available at: <http://www.bbc.co.uk/news/business-38570387>

⁹¹ Financial Times (2016) *UK car industry fears effects of Brexit tariffs on supply chain*. Available at: <https://www.ft.com/content/c397f174-9205-11e6-a72e-b428cb934b78> [accessed 15/03/2017]

⁹² Automatic Dependent Surveillance – Broadcast

⁹³ Single European Sky ATM (Air Traffic Management) Research

⁹⁴ Radiodetection (2011) *Water leak detection products*.

Repair teams attending broken water pipes most likely rely on GNSS to navigate to the broken pipe as has been reported.

4.2 Professional (industrial activity)

Benefits estimated in this section rely on the information London Economics has collected over many years of work at the EU-level. Benefits have been converted to the UK setting based on the bottom-up inputs used in our previous work whenever possible and supplemented with stakeholder consultations and bespoke estimates.

4.2.1 Industrial activity in the UK

In the UK, 220 space organisations derive revenue from activities in the Position, Navigation and Timing-domain (PNT).⁹⁵ These companies turn over £1.7bn from PNT activities (12% of total space economy turnover), and employ approximately 4,000 people. The companies range from small start-ups to large multinationals with significant UK presence.

The main impact of GNSS on the UK, however, is in the activities it supports. In fact, PNT services from satellite have been found to support sectors in the UK that generate **11.3% of UK GDP**, showing a wide proliferation of the use of GNSS.⁹⁶

This section presents the use of GNSS by professional sector in the UK, and values the economic benefits derived by the operators in the sectors.

4.2.2 Road

Road vehicles benefit from navigation services through portable (incl. smartphones) or in-vehicle systems while on board units help with performance monitoring and general fleet management. In addition to this, GNSS services can be used for a range of other road applications including the monitoring of traffic, which helps drivers avoid congestion.

This section covers the use of GNSS in road applications by professional users (from logistics companies to travelling sales people). Benefits are grouped into distinct applications.

Navigation

Estimated annual GVA contributing benefits from GNSS: £0

Estimated annual utility benefits from GNSS: £1,921.3m

Navigation, the original driver of proliferation of GNSS in the wider population, is the use of an in-built or handheld device that offers turn-by-turn navigation. Increasingly, smartphones have replaced dedicated devices for navigation purposes. The benefits arise as drivers are able to follow the instructions given by navigation devices, and therefore no longer need to use a map. Further benefits accrue as fewer errors are made and the driver therefore gets lost on fewer occasions. Additional benefits are possible when navigation equipment is connected, and therefore prompts

⁹⁵ London Economics (2016) *The Size and Health of the UK Space Industry 2016*

⁹⁶ London Economics (2016) *The Size and Health of the UK Space Industry 2016*

the driver to select a preferred route, based on simplicity, distance, expected journey time and traffic information (Advanced Driver Advisory Systems - ADAS).

Benefits are monetised as time savings valued conservatively at the average UK salary, fuel savings and associated reductions in pollutants and CO₂ emissions. Further benefits from ADAS have been estimated based on the reduction in congestion and the resulting reduced number of accidents. The aggregate annual value of navigation benefits to the UK have been estimated at: **£1,921.3m**.

Logistics and fleet management

*Estimated annual GVA contributing benefits from GNSS: **£154.2m***

*Estimated annual utility benefits from GNSS: **£0***

Logistics companies and other businesses that possess a fleet of vehicles use GNSS to improve the efficiency of their operations. Benefits materialise in the shape of **reduced maintenance costs**, where accurate information on use of vehicles allows operators to undertake pre-emptive vehicle service in advance of a breakdown. In particular, wear and tear of vehicles will be different depending on the environment in which they operate, where some primarily travel intercity while others are restricted to start-stopping in cities.

Additional benefits arise from constant monitoring of the fleet of vehicles, which allows head office to respond to urgent orders, **optimise the use of the fleet**, and reduce downtime or 'return trips'.

Benefits are estimated in terms of maintenance cost reduction and time and fuel savings arising from better routing of vehicles, and the associated impacts on the environment and pollutants. Benefits from navigation are considered in the sub-section above. The aggregate annual value of logistics and fleet management benefits to the UK have been estimated at: **£154.2m**.

4.2.3 Maritime

*Estimated annual GVA contributing benefits from GNSS: **£420.0m***

*Estimated annual utility benefits from GNSS: **£8.8m***

Use of GNSS in maritime applications is primarily driven by the **Safety Of Life At Sea (SOLAS)** convention from the International Maritime Organization under the United Nations. Vessels larger than 500 gross tonnes (or 300 gross tonnes if in international transit) are required to carry GNSS devices for general navigation purposes. Other maritime applications of GNSS are in port approaches, or high-precision and augmented devices used by pilots (discussed in section 4.1.12). GNSS also provides information to the systems that monitor vessels (e.g. AIS or VMS), both for merchant and fishing vessels.

For positioning and navigation purposes, GNSS is the only technological option to derive accurate information on location and speed over ground. In seas with strong currents, the only alternative indicator of speed is using landmarks with known distance and measuring the time it takes to travel the distance. Far from land, this option is no longer viable, and average speed derived from the position at sunrise and sunset, for example, is the main alternative to GNSS. Other applications on board the vessel rely on GNSS to operate. Satcoms from GEO satellites (discussed in section 4.1.11) cannot function without accurate location information, and GNSS is therefore integral to the provision of communications at sea. Depending on the configuration of the vessel, GNSS may also

be used to provide information used by the ship's clock, radar, and compass. Although all vessels must carry a magnetic compass, and radar works without it, the integration of GNSS in all of these functions on a vessel shows how reliant many maritime activities are on the service.

GNSS is mandated by the SOLAS convention on large vessels, but the penetration of GNSS on all vessels (including non-SOLAS) is high, which suggests that real benefits materialise. Among those benefits are the ability to map better routes that minimise the time and fuel used to travel from A to B, but also the ability re-trace known routes and therefore reduce the time spent on planning.

Benefits of GNSS are measured against the counterfactual that GNSS replaces. In maritime, this means that only performance over and above what can be achieved by mariners should be considered. Traditionally, it has been asserted that good mariners can achieve navigation performance that is very similar to that of a GNSS-based solution, and the benefits are therefore of limited magnitude. Indeed statements such as, 'a good mariner will manage just as well without GNSS' has often been encountered. From this perspective, the benefits of GNSS are negligible.

However, this traditional view is changing. As GNSS has become more proliferated in the maritime world over recent decades, the quality of the average mariner is considered by multiple stakeholders to be in decline, and new mariners are not trained in navigating without electronics. In addition, the unavailability of alternative e-navigation tools on the vessel, makes GNSS an enabler for the shipping industry as it currently operates.

A micro-level, bottom-up assessment of the benefits of GNSS in maritime shipping is a large undertaking, and beyond the scope of this study, but a recent report on the economic impact of the shipping industry in the UK (including ferries) estimates direct contribution to GDP of £2.9bn in 2013 and more than 200,000 jobs supported across the economy.⁹⁷ As an enabler of the activity, one possibility is to attribute the whole activity to GNSS, but in reality, shipping has occurred for many years, and such an estimate would not be considered robust. Using instead the same assumption of travel time and fuel reduction employed for road transport (12%), an estimate of **£350m** per year is derived.

Another key application for GNSS in the maritime domain is for **Search and Rescue** where a large number of emergency beacons are GNSS-enabled and thereby share the location of a person in distress with emergency services. Three types of emergency beacons are used in the maritime domain, namely Personal Locator Beacons (PLB), emergency position-indicating radiobeacon (EPIRB), and AIS-SART, which uses the AIS system to transmit emergency signals to nearby vessels. Cospas-Sarsat is the international organisation that operates the emergency beacon system. They report that 907,000 GNSS-enabled beacons were deployed worldwide in 2015 (54.2% of all 1,673,000 beacons).⁹⁸ Once operational, Galileo will provide a 'return link', acknowledging receipt of the distress message.

In the UK, Cospas-Sarsat estimate that a total of 130,000 beacons were in use in December 2015.⁹⁹ The UK average GNSS penetration in beacons probably exceeds the global value, so it is reasonable to assume that at least 70,000 location enabled emergency beacons are used by UK vessels and aircraft. In 2015, 22 maritime rescue operations monitored by Cospas-Sarsat related to the UK in one of two ways, either the beacon activation was picked up by the UKMCC (Mission Control

⁹⁷ Oxford Economics (2015), *The economic impact of the UK Maritime Services Sector: Shipping*

⁹⁸ Cospas-Sarsat (2016) *Preliminary Results of the 2016 Beacon Manufacturers Survey*. Available at: http://www.sarsat.noaa.gov/BMW%202016_files/BMW%20Presentation%20Beacon%20Manufacturers%20Survey%20-%200003.pdf

⁹⁹ Cospas-Sarsat (2016), *Cospas-Sarsat report on system status and operations C/S R.007 No.32: January – December 2015*

Centre), or the beacon was registered to a UK owner. From nine beacon activations in the UK, North Sea or Atlantic, 20 people were saved and in two instances (six people), Cospas-Sarsat's was the only distress information to reach emergency services. Further afield, thirteen UK-registered maritime beacons were activated from Australia to Bahamas and Madagascar to Norway and 32 people were rescued.

The Cospas-Sarsat report does not distinguish GNSS and non-GNSS beacons, but assuming the overall percentage of location enabled beacons holds for those of relevance to the UK, approximately 26 people have been saved faster and more efficiently as a result of GNSS in beacons. The average value of preventing a fatality is £1.7m according to the DfT,¹⁰⁰ indicating GNSS-assisted savings of £44.2m and assuming 20% GNSS contribution to the rescue, **£8.8m** of GNSS benefits.

Fishing vessels use GNSS as an integral part of their operations. GNSS is used for navigation and positioning and to chart good areas. Fishing vessels also use GNSS to estimate heading, pitch and roll. With 3-4 antennae on the vessel, it is possible to use GNSS to identify whether the vessel is tilting or at danger of capsizing. Trawlers are the main users of this GNSS application, as their nets can generate enough drag to risk capsizing, especially in rough seas. A recent jamming event instigated by North Korea highlights the usage of GNSS as 70 of 332 South Korean fishing vessels returned to port following the disruption of their systems.¹⁰¹ Assuming GNSS increases catches by 10% for UK fishing vessels (£775m worth in 2014),¹⁰² the benefits of GNSS in fishing are **£70m**.

4.2.4 Aviation

*Estimated annual GVA contributing benefits from GNSS: **£0.5m***

*Estimated annual utility benefits from GNSS: **£2.0m***

In **aviation**, commercial and private aircraft use GNSS for navigation and surveillance purposes, with aircraft being able to report position automatically to air traffic control through the ADS-B surveillance system. Benefits of GNSS are primarily driven by an ability to reduce **DDC** (Delay, Diversion and Cancellation) as GNSS-assisted (specifically EGNOS) landing procedures enable airport operations in adverse weather conditions. The associated benefits are monetised as avoided fuel burn, delays, diversions and cancellations using standardised inputs from Eurocontrol.¹⁰³ Further benefits are realised through reduced CFIT (Controlled Flight Into Terrain), as additional instruments are available to the pilot. Additional benefits are monetised in terms of environmental impacts owing to reduced fuel burn. UK benefits in 2016 have been estimated at **£0.5m**.

Cospas-Sarsat also monitors the use and triggering of Emergency Locator Transmitters (ELTs) that are mounted on the tail of aircraft and activate on impact. In 2015, UK registered beacons were triggered six times (one outside the UK) and a further six foreign registered beacons were activated in the UK. In addition, one beacon registered to Ireland was triggered in Kosovo, but registered by the UKMCC. In most cases, the Cospas-Sarsat data were not used for search and rescue activities, but for six people (in Greece and the UK), rescue was aided or enabled by Cospas-Sarsat data. The

¹⁰⁰ Department for Transport (2007), *Highways Economics Note No. 1 2005 Valuation of the Benefits of Prevention of Road Accidents and Casualties*. Inflated using the GDP deflator (sourced from the ONS)

¹⁰¹ Reuters (01 April 2016), *South Korea fishing boats turn back after North 'disrupts GPS'*. Available at: <http://af.reuters.com/article/worldNews/idAFKCN0WY315>

¹⁰² The Marine Management Organisation (MMO) (2016) *Fishing industry in 2015 statistics published*. Available at: <https://www.gov.uk/government/news/fishing-industry-in-2015-statistics-published> [accessed 16/03/2017].

¹⁰³ Eurocontrol (2015) *Standard Inputs for EUROCONTROL Cost Benefit Analysis Ed. 7*. Available at: <http://www.eurocontrol.int/documents/standard-inputs-eurocontrol-cost-benefit-analyses>

benefits of saving those six individuals are approximately £10.2m using the average value of preventing a fatality, and GNSS contribution to the savings is assumed to be 20%, equivalent to **£2.0m**.

4.2.5 Agriculture

*Estimated annual GVA contributing benefits from GNSS: **£132.5m***

*Estimated annual utility benefits from GNSS: **£151.9m***

GNSS users in agriculture generally rely on more sophisticated equipment than many other user groups. GNSS devices for agriculture are more expensive than for other sectors, and track more signals and constellations, many including EGNOS and commercial augmentation services such as Real Time Kinematic (RTK) or Precise Point Positioning (PPP) for improved accuracy.

Fundamentally, GNSS is used for two purposes within cultivation. The first purpose is to navigate the tractor, either through a **tractor guidance** system where the driver is constantly told whether to steer left or right or by using an **automatic steering** system that autonomously steers the tractor. Using GNSS for tractor navigation increases the efficiency of farm operations as it is possible to reduce pass-to-pass overlap. This means that the working of the field (e.g. ploughing, sowing, fertilising, etc.) can be completed faster and using fewer inputs. The monetised benefits estimate the value of saved inputs (labour, fuel and other products), and associated environmental benefits.

The second purpose is for **Variable Rate Technology (VRT)**, which requires more detailed field information. Software packages on offer from leading equipment manufacturers (and other sources) integrate agronomy (information that may be gathered using GNSS in the first place) and remote sensing data on the health of the field to determine which sections require more or less fertiliser (or pesticides, and so on) than the average. This information is stored by the equipment, and the spray is adjusted according to needs. Benefits of this technology are primarily in the form of yield increases because pesticides can be applied to infested plants, crops that are too small can receive a fertiliser boost, and crops that are so large they are at risk of falling over can be prescribed a reduced amount of fertiliser.

The benefits of use of GNSS in cultivation in the UK have been estimated at **£284.4m** in 2016.

GNSS is also used for tracking of livestock to know where the herd is, and monitor health by tracking animals. Further benefits can be realised in hunting, where GNSS collars for hunting dogs alert the huntsman that the dog (and therefore game) is coming their way. Other benefits can be realised in silviculture, where GNSS is used to execute decisions made in the office, based on remote sensing imagery. This too relies on sophisticated software packages, often supplied by manufacturers. Further benefits still derive from GNSS-based asset tracking of farm equipment.

4.2.6 Surveying

*Estimated annual GVA contributing benefits from GNSS: **£13.9m***

*Estimated annual utility benefits from GNSS: **£0***

Similar to agriculture, the devices used in the surveying profession are generally more sophisticated than average, and may incorporate commercial augmentation systems including RTK and PPP to improve accuracy. GNSS has fundamentally changed the surveying profession as the traditional requirement of clear line of sight between the point of measurement and a known reference point

is no longer required. Surveying was also an early adopter of GNSS and despite the high prices (especially in the early years), penetration quickly reached high levels. The benefits of GNSS in surveying are assessed against a counterfactual where GNSS would not have taken the role it has and an alternative remained. Data from Eurostat (special extract request) suggests there are approximately 50,000 surveyors in the UK.

Users can broadly be classified into three categories, users of handheld devices, machine control and marine surveying. Handheld surveying includes **cadastral surveying**, which deals in the measurement of cadastral boundaries and the resolution of boundary disputes. The benefits therefore materialise in the form of labour cost reductions. Benefits have been monetised at **£4.0m** in the UK in 2016.

Mapping is a discipline that charts specific points of interest for cartographic, environmental and urban planning. Generally, the devices used in mapping are the simplest in the surveying domain as the required accuracy is lower than for other applications. Here too, benefits accrue thanks to reduced labour costs. Benefits have been monetised at **£1.0m** in the UK in 2016.

Mining is a surveying application that measures mines, and can be used to monitor yield. Generally limited to open-pit and surface mining, benefits have been monetised at **<£1m** in the UK in 2016.

Construction surveying is split between person-based and machine-based applications. GNSS in **person-based construction** saves labour inputs for the same efficiency reasons as the other handheld applications. **Machine control** is similar in essence to the applications in agriculture, and manufacturers of equipment report significant benefits. Benefits accrue because an automatic construction machine can apply new concrete or asphalt more precisely than humans, which saves inputs, ensures the newly paved road is accurately located, and meets the other junction point where it is intended. GNSS is primarily used for Civil Engineering projects such as road or rail construction. Benefits have been monetised at **£7.5m** in the UK in 2016.

Marine surveying includes hydrographic surveying, which is the charting of the seabed, and a key input in off-shore oil and gas exploration, which both require highly accurate location information. Benefits have been monetised at **£1.4m** in the UK in 2016.

Additional applications in the surveying domain include **infrastructure monitoring**, which is the study of movements in infrastructure to identify beginning faults and allow faster repair. The Shard is a prime candidate for GNSS based infrastructure monitoring and the construction of Crossrail may also use GNSS to monitor the buildings above the construction sites. However, benefits are extremely difficult to monetise.

4.2.7 Rail

*Estimated annual GVA contributing benefits from GNSS: **£10.9m***

*Estimated annual utility benefits from GNSS: **£0***

The use of GNSS from a rail infrastructure perspective by Network Rail is discussed briefly in section 4.1.12. This section instead considers the use of GNSS by the users of the infrastructure, Train Operating Companies (TOCs), Freight Operating Companies (FOCs), and train manufacturers.

Current applications of GNSS in the UK rail sector include **asset management**, where train manufacturers fit rolling stock with GNSS to monitor the performance of trains, and call them in for

maintenance as soon as performance degrades. This marginally reduces the risk of train derailments, which have substantial impacts when they occur. Annual benefits to the UK have been estimated at **£114,000**. The modest size of the estimate owes to a conservative assumption on the probability of derailments as such events were rare before GNSS was used.¹⁰⁴

Another application of GNSS that is in use today is **passenger information**, where GNSS-monitoring of trains enables departure time information and informs passengers waiting on the platform when their train is expected.

A mature application of GNSS in rail is **automatic power-operated external doors**, where GNSS location is used to search a database of stations, and open the appropriate number of doors on the correct side of the train. The benefits are of efficiency as the driver is relieved from the task of searching the databases and manually opening the doors. If GNSS is not available in the station, the system has to be restarted and doors opened manually. Benefits have not been monetised.

Another mature rail application of GNSS in the UK is **driver advisory systems**, which are fully implemented on UK high-speed and freight trains. Driver advisory systems are used by drivers for intelligent driving, which reduces traction energy consumption and wear and tear of brakes. Connected driver advisory systems (implemented in the UK) also allow a higher throughput of trains and thus better utilisation of existing capacity. Benefits of **£10.8m** are estimated to the UK in 2016. Benefits are monetised based on the cost of traction energy, reduced environmental impacts from energy savings, and reduced wear and tear of brakes as a result of a smoother drive. Further benefits come from capacity improvements.

4.2.8 Legal profession

A nascent user of GNSS is the legal sector, where lawyers need to track timesheets and billable hours with high precision. They also require accurate timestamps of files and communications in the event that the chain of events leading to their creation is ever questioned. GNSS-based NTP-servers in the offices of law firms provide the necessary accuracy and availability of traceable timestamps. The benefit of using GNSS as opposed to other services is the ease of reference and the fact that the system is globally available on a consistent basis.

4.3 Mass market (consumer applications)

In general, consumers access GNSS signals using smartphones or consumer-grade devices dedicated to applications ranging from fitness and personal trackers to navigation devices for cars, leisure aircraft and recreational vessels.

4.3.1 Location-Based Services (LBS)

Estimated annual GVA contributing benefits from GNSS: £0

Estimated annual utility benefits from GNSS: £204.8m

Location-based services span a variety of applications, that all rely on location. The main means of accessing location is through an individual's smartphone or tablet, with a significantly smaller

¹⁰⁴ The recent derailment of a tram in Croydon was found to have travelled 3.5 times the speed limit, which has been found to be the main cause of the accident. See Rail Accident Investigation Branch (2017), *Fatal accident involving the derailment of a tram at Sandilands Junction, Croydon 9 November 2016*.

proportion of use coming from dedicated devices, mainly in the tracking domain (fitness, luggage, and so on). GNSS is the most accurate source of location information outdoors, but the location calculation algorithm within smartphones uses supplementary information from Wi-Fi networks, Bluetooth, cell-ID, and other signals of opportunity to calculate the location.

For smartphones and tablets, the accessibility of GNSS means that many people use the technology. In 2014, for example, global downloads of apps that rely on positioning data reached 2.8 billion.¹⁰⁵

Monetised benefits of GNSS in location-based services include those that are driven by the ability of users to identify alternative means of travel and thus reduce the amount driven in personal cars. The market leading map applications for smartphones all include a 'public transport'-option, which induces a small proportion of users to switch means of transport. Benefits are monetised as fuel consumption reductions and associated reductions in air pollution and CO₂ emissions. Benefits have been monetised at **£57.4m** in the UK in 2016.

Additional benefits are realised for navigation. The use of smartphones for car navigation is included in section 4.3.2, so this section only considers time savings benefits from **pedestrian navigation** where GNSS helps people navigate through unknown areas and avoid getting lost. Benefits have been monetised at **£137.4m** in the UK in 2016.

Benefits from other applications such as Augmented Reality gaming (such as Pokémon Go) that need GNSS to function, location-aware social media and location-based advertisements have not been monetised.

Fitness tracking is accessible through both smartphone applications and dedicated devices. GNSS enables the user to track their progress and chart their route when running or cycling. The total annual economic costs to the NHS due to physical inactivity were estimated to be €14.2bn.¹⁰⁶ The cost savings due to increased physical activity as a direct result of GNSS in fitness tracking devices are calculated to monetise these benefits. Benefits have been monetised at **£10.0m** in the UK in 2016 using input assumptions that attribute a modest proportion of the increased activity to GNSS.

Beyond location, the time on smartphones is calibrated by derivations from GNSS or networks that have been synchronised using GNSS.

4.3.2 Road

Navigation

Estimated annual GVA contributing benefits from GNSS: £0

Estimated annual utility benefits from GNSS: £1,217.4

Navigation, the original driver of proliferation of GNSS in the wider population, is the use of an in-built or handheld device that offers turn-by-turn navigation. Increasingly, smartphones have replaced dedicated devices for navigation purposes. The benefits arise as drivers are able to follow the instructions given by navigation devices, and no longer need to use a map. Further benefits accrue as fewer errors are made and the driver therefore gets lost on fewer occasions. Additional benefits are possible when navigation equipment is connected, and therefore prompts the driver to

¹⁰⁵ European GNSS Agency (2015) *GNSS Market Report Issue 4*

¹⁰⁶ Centre for Economics and Business Research (2015) *The economic costs of physical inactivity in Europe - An ISCA and Cebr report*

select a preferred route, based on simplicity, distance, expected journey time and traffic information (Advanced Driver Advisory Systems - ADAS).

Benefits are monetised as time savings valued conservatively at one-third of the average UK salary (consistent with UN guidelines), fuel savings and associated reductions in pollutants and CO₂ emissions. Further benefits from ADAS have been estimated based on the reduction in congestion and the resulting reduced number of accidents. The aggregate annual value of navigation benefits to the UK have been estimated at: **£1,217.4m**.

Insurance telematics

*Estimated annual GVA contributing benefits from GNSS: **£16.1m***

*Estimated annual utility benefits from GNSS: **£0***

The UK is a European leader in the uptake of insurance telematics, where insurance companies offer a reduced premium in exchange for telematics information on the driver's behaviour. Bearing the counterfactual for estimating benefits in mind (the situation without GNSS) benefits are somewhat limited relative to the size of the market (455,000 active policies as of March 2016¹⁰⁷). Vehicles on telematics-based insurance policies would for the most part be insured regardless of the technology, and the reduction in premium, which is a benefit to the insured driver, is offset by the reduction in income for the insurance company.

Two types of benefits are monetised, namely accident reduction, and insurance fraud reduction.

The British Insurance Brokers' Association assert that telematics-based insurance is the preferred option for young drivers, and that the crash risk for new drivers with an insurance telematics policy is 40% lower.¹⁰⁸ The Department for Transport estimates the average value of preventing a road accident at £6,715 and the number of accidents involving a young driver of approximately 9,000 per million drivers.¹⁰⁹ Assuming 350,000 of the telematics-based policies are held by young drivers, the reduction in accidents equates to 2,100 per year, at an average value of **£14.1m**.

Benefits have also been monetised in terms of a **reduction in insurance fraud**, where precise information on a vehicle's location at all times makes the practice of damaging vehicles for insurance pay-outs less likely. One insurer, *Insure The Box*, uncovered a fraud ring using telematics data and saved claims worth £0.5m for a five month period in 2016. This leads to a conservative estimate of **£2m** of benefits in 2016 for all providers.¹¹⁰

At more than £1,000 per year, the savings offered to drivers who take a telematics-based insurance policy are significant, and for some people, particularly young drivers, is the difference between

¹⁰⁷ The British Insurance Brokers' Association (2016) *40% increase in telematics motor policies in a year*. Available at: <https://www.biba.org.uk/press-releases/40-increase-in-telematics-motor-policies-in-a-year/>, [accessed 17/03/2017]

¹⁰⁸ The British Insurance Brokers' Association (2016) *40% increase in telematics motor policies in a year*. Available at: <https://www.biba.org.uk/press-releases/40-increase-in-telematics-motor-policies-in-a-year/>, [accessed 17/03/2017]

¹⁰⁹ Department for Transport (2016) *Accident and casualty costs (RAS60)*. Available at: <https://www.gov.uk/government/statistical-data-sets/ras60-average-value-of-preventing-road-accidents> [accessed 17/03/2017]

¹¹⁰ Financial Times (2016) *Insurers test the limits of telematics' big data*. Available at: <https://www.ft.com/content/86e62742-21d9-11e6-9d4d-c11776a5124d> [accessed 17/03/2017]

being able to afford to run a car or not.¹¹¹ The net economic benefits of car ownership for the group of young people on this margin have not been monetised as the required inputs are unavailable.

Emergency and breakdown calls (eCall and bCall)

Estimated annual GVA contributing benefits from GNSS: £0

Estimated annual utility benefits from GNSS: £15.0m

In Europe, **eCall** is synonymous with the EU regulation that requires all new car models to be fitted with an emergency call devices as of April 2018.¹¹² The system is designed to make a call to emergency services if the car's airbag is triggered. The call will contain information on the car's exact location (derived by GNSS), and allow emergency services to respond. The system also allows manual triggering of an emergency call, and there are provisions for the driver to be able to speak with emergency services. However, many commercial systems are already available in the market that allow similar functionality, and many of those also include a breakdown call (**bCall**) system, which routes the call to a help centre that can then send for the AA or similar breakdown assistance. In this report, benefits of eCall and bCall are considered in parallel.

The benefits of eCall (and bCall) are in terms of lives saved and reduced congestion (as accidents are located faster and therefore cleaned up faster). Benefits need to be estimated, considering the proliferation of commercial eCall systems in the UK in particular. The companies that offer such systems include BMW, General Motors (mainly Vauxhall in the UK), Ford and Volvo. Statista¹¹³ estimate that in 2016, 1.8m UK cars were 'connected' (approximately 5% of total), meaning they were able to make an emergency or breakdown call. eCall aims to reduce fatalities on the road by 10% owing to faster response times. If proprietary systems can achieve the same, and fatalities are equally likely in cars with and without the system,¹¹⁴ and based on 1,730 road fatalities in 2015, the lives saved may amount to 9 lives in 2016, which would imply monetised benefits of **£15.0m**.¹¹⁵ These benefits are expected to increase substantially as the share of equipped vehicles in the UK will increase in future years because of the regulation.

4.3.3 Non-road transport

Consumer use of GNSS beyond the applications covered above include the use of GNSS for flying under visual flight rules (VFR) and leisure boating.

Pilots operating under visual flight rules are required to fly their aircraft based on waypoints that are visible from the cockpit, but given the availability of apps for smartphones, tablets and dedicated navigation devices that are available for less than £1,000, many pilots take advantage of GNSS for navigation purposes.

¹¹¹ The British Insurance Brokers' Association (2016) *40% increase in telematics motor policies in a year*. Available at: <https://www.biba.org.uk/press-releases/40-increase-in-telematics-motor-policies-in-a-year/>, [accessed 17/03/2017]

¹¹² European Commission (2015) *eCall in all new cars from April 2018*. Available at: <https://ec.europa.eu/digital-single-market/en/news/ecall-all-new-cars-april-2018> [accessed 08/12/2016]

¹¹³ Statista (2016) *Number of connected cars in the United Kingdom (UK) from 2014 to 2020 (in millions)*. Available at: <https://www.statista.com/statistics/523800/digital-market-outlook-total-number-of-connected-cars-in-the-uk-statistic/> [accessed 03/03/2017].

¹¹⁴ Probably a strong assumption as proprietary systems are found in newer and typically more expensive vehicles that may also be heavier and safer.

¹¹⁵ Valuing prevented fatalities at £1.7m following Department for Transport (2007), *Highways Economics Note No. 1 2005 Valuation of the Benefits of Prevention of Road Accidents and Casualties*. Inflated using the GDP deflator (sourced from the ONS)

The benefits of satellite navigation for VFR pilots are multiple, and if used correctly,¹¹⁶ the devices help pilots improve their skills and experience. As many devices can be updated to contain up-to-date information on notified airspace, and can warn the pilot of impending infringements, the UK's Future Airspace Strategy VFR Implementation Group indicate that infringements of notified airspace are much less likely for VFR pilots using GNSS. Pilots that use satellite navigation devices are able to plan and simulate a route in advance of the flight, and can add waypoints to the device electronically. They are then notified of the waypoint and its likely direction during flight. Estimated time of arrival at waypoints is also often available, allowing the pilot to communicate this information to Air Traffic Control if required. However, GNSS devices create the greatest benefits when something does not go to plan. Changes in weather that imply greater fuel consumption can leave a VFR aircraft stranded, so the capability of many devices to assist diversion and suggest nearby aerodromes that are suitable for the aircraft can be very beneficial. It is also possible to reverse the route and fly back to the origin using the same route (if fuel allows). After flight, the route flown and decisions made by the pilot can be extracted from the device and help the pilot improve their skills.

Similar benefit streams are available to recreational boaters using more than half a million recreational vessels in the UK¹¹⁷ and either dedicated GNSS devices or applications for smartphones and tablets. However, similar to guidance for VFR pilots, GNSS chart plotters should not be used as the primary navigation source.¹¹⁸

Benefits have not been monetised as other systems must be in place in both cases. Additionally, for leisure travellers, time savings is not necessarily a relevant measure of benefits, as the people in question, by assumption, enjoy flying under VFR or sailing in recreational vessels. No data exist on accidents avoided as a positive result of using GNSS.

4.4 Summary of benefits

The direct benefits of GNSS estimated against a counterfactual scenario in which GNSS had not been developed or chosen as the source of PNT amounts to **£6.6bn per annum**.

Infrastructure	Benefit label	GVA benefits	Utility benefits
Chemical	Transport of dangerous goods	<i>Not monetised</i>	<i>Not monetised</i>
Civil nuclear	Tracking of classified goods	<i>Not monetised</i>	<i>Not monetised</i>
Communications	Fixed-line telecommunications	£31.9m	
	Cellular telecommunications	£5m	
	Broadcast – DVB	<i>Not monetised</i>	
	Broadcast – DAB	<i>Not monetised</i>	
	TETRA	£4.3m	
	Internet data centres	<i>Not monetised</i>	<i>Not monetised</i>
Defence	<i>Not in scope of study</i>		
Emergency services	Public-safety answering point		£1,921m
	Emergency vehicles	£96.5m	
Energy	Infrastructure costs	£4.4m	
Finance	Banking and stock exchanges	£0.6m	

¹¹⁶ This section draws on The Royal Institute of Navigation (2016) *SATNAV Use in VFR Navigation*. Available at: <https://liveicomgrshot.blob.core.windows.net/rinfiles/Uploadedpdfs/StaticPages/GPS%202017RIN.docx.pdf>

¹¹⁷ ICOMIA (2016) *Recreational Boating Statistics 2015*

¹¹⁸ Royal Yachting Association (RYA) (undated) *Chart plotter – friend or foe?*. Available at: <http://www.rya.org.uk/knowledge-advice/cruising-tips/navigation/Pages/chart-plotter-friend-or-foe.aspx> [accessed: 27/03/2017]

Food	<i>Scope of sector does not include GNSS</i>		
Government	Weather forecasting	£75m	£25m
	Offender tracking	£30.8m	
	Evidence management	<i>Not monetised</i>	
	CAP and CFP compliance monitoring	£0.8m	
Health	Dementia tracking	<i>Not monetised</i>	<i>Not monetised</i>
	Lone worker tracking	£0m	£247.6m
Space	LEO satellites	<i>Not monetised</i>	<i>Not monetised</i>
	Ground stations	<i>Not monetised</i>	<i>Not monetised</i>
	Satcoms	£31.7m	
Transport	Road transport infrastructure	<i>Not monetised</i>	<i>Not monetised</i>
	Rail transport infrastructure	<i>Not monetised</i>	<i>Not monetised</i>
	Maritime transport infrastructure	<i>Not monetised</i>	<i>Not monetised</i>
	Air transport infrastructure	<i>Not monetised</i>	<i>Not monetised</i>
Water & Sewerage	Fixed-location noise loggers	<i>Not monetised</i>	<i>Not monetised</i>
Professional application	Benefit label	GVA benefits	Utility benefits
Road	Road navigation/Advanced Driver Advisory Systems		£1,921.3m
	Logistics and fleet management	£154.2m	
Maritime	Navigation and shipping	£350m	
	Search and rescue applications		£8.8m
	Fishing	£70m	
Aviation	Reduction in DDC and CFIT	£0.5m	
	ELTs and PLBs		£2m
Agriculture	Cultivation	£284.4m	
	Livestock tracking, hunting and silviculture	<i>Not monetised</i>	
Surveying	Cadastral surveying	£4m	
	Mapping	£0.96m	
	Mining	£0.04m	
	Construction (person and machine-based)	£7.5m	
	Marine surveying	£1.4m	
	Infrastructure monitoring	<i>Not monetised</i>	
Rail	Asset management	£0.1m	
	Driver advisory systems	£10.8m	
Legal	Timesheets and billable hours	<i>Not monetised</i>	
Mass Market application	Benefit label	GVA benefits	Utility benefits
Location-based services	Smartphones		£57.4m
	Pedestrian navigation		£137.4m
	Fitness tracking		£10m
Road	Navigation/Advanced driver advisory systems		£1,217.4m
	Insurance telematics	£16.1m	
	Emergency and breakdown calls		£15m
Non-road transport	Recreational boating	<i>Not monetised</i>	
	VFR aviation	<i>Not monetised</i>	

5 Analysis of impact of five-day GNSS disruption

It has been established that the use of GNSS in the UK is widespread, yielding a range of valuable socio-economic benefits. This chapter considers, and estimates the economic loss to the UK of the hypothetical situation where GNSS would be unavailable for a period of five days.

Before commencing with the impact analysis, it is useful to draw an important distinction between the **value of economic activity supported by GNSS**, and the **economic impact (loss) of a disruption to GNSS**, as explained below – conflating the two would do a disservice to the economic value that GNSS provides to the UK economy:

- **Value of economic activity supported by GNSS:** In previous research,¹¹⁹ London Economics estimated that GNSS (positioning, navigation and timing) satellite services support industries contributing a total Gross Value-Added of £206bn to the UK economy (11.3% of UK GDP). This figure indicates the value of economic activity throughout the year that is supported (in a broad sense) by GNSS use. It does not make any consideration of reliance, resilience, or alternative means of operating (i.e. counterfactual deadweight).
- **Economic impact (loss) of a disruption to GNSS:** Whereas, the estimates provided in this chapter only cover a period of five days and are limited to the causal impact of a GNSS outage (in a specific sense) in particular economic activities that do not have sufficient holdover resilience in place and the economic output that depends on inputs from those activities.

The impact of a disruption to GNSS in each of the applications discussed in Chapter 4 depends on the degree to which GNSS is required for the operation of the activity. In addition, existing fall back mechanisms that would come into force in the event of GNSS loss determine the severity of the impacts. In other words, despite presenting positive estimates of the economic benefits of GNSS in Chapter 4, the economic impact is nil if the application is resilient to loss of GNSS for five days.

Note: Spoofing and localised jamming events are out of scope. This chapter discusses the impact of loss of GNSS from a **clean-cut outage**, i.e. GNSS signals instantly transition from full availability to non-availability, without a gradual degradation of service that may occur from a spoofing attack. Stakeholder consultations suggest that slow degradation would have more severe impacts as they could take the form of ‘hazardously misleading information’ and become comparable to a spoofing event on a global scale, where all receivers gradually lose accuracy before finally ceasing function. Such outage would result in immediate impacts, as devices would appear to function correctly and users (e.g. drivers) would receive progressively less reliable information that would lead to stress and potentially bad decision-making. For this reason, this is recommended for further study.

The estimates in this chapter fundamentally differ from those in chapter 4, as the counterfactual used in the estimation is different. In chapter 4, the counterfactual baseline against which the benefits of GNSS has been derived, is a situation in which use of GNSS within the application had not been implemented. Implicitly, the benefits are therefore estimated using assumptions on the availability of alternative solutions, and the ability of individuals to use those. In this chapter, the impact is estimated from a loss of GNSS for five days, and the impact can be considered the difference between **economic value-added and public utility in five normal days versus five days without GNSS**. The current use of GNSS means that alternative solutions (assumed available in

¹¹⁹ London Economics (2016). *The Size and Health of the UK Space Industry 2016*

chapter 4), do not necessarily exist, and the ability of operators in the application to use traditional and/or alternative means may be lower relative to the chapter 4 baseline.

The quantification of the impact of loss of GNSS follows a staged approach, where the first stage is to assume that 5/365 of the annual benefits estimated in section 4 would be lost (these benefits have been estimated as GNSS-attributable benefits for each application against a counterfactual in which GNSS would not be the source of PNT information). The second step is to adjust the estimate in each application to take into account which mechanisms are in place or could be activated to mitigate the impact of loss of GNSS. The third step discusses and seeks to quantify the additional impact felt as a result of interactions between different applications and activities that do not directly use GNSS.

5.1 Critical National Infrastructures

With some exceptions, Critical National Infrastructures (CNI) rely primarily on GNSS for timing purposes. For this reason, the main objective of the consultations undertaken for this study has been to understand the quality of the holdover capability currently in place in the UK infrastructures. The first sub-section therefore discusses the relative performance of oscillators in timing equipment, and benchmarks this against the (regulated) requirements that prevail in each sector. Subsequent sub-sections discuss the impact of GNSS loss with reference to each CNI.

Sufficiency of existing mitigating strategies

GNSS devices used for timing applications may have holdover capability to safeguard against a temporary loss of the GNSS signal. The duration of holdover depends on the type and quality of oscillator used.

Higher quality oscillators provide longer holdover times, but are also more expensive. On the low end, a Temperature Compensated Crystal Oscillator (TCXO) is available for a few pence. A TCXO tracks the GNSS signal but does not provide any meaningful holdover in the event of a signal loss. A more expensive Oven Controlled Crystal Oscillator (OCXO) can cost anywhere from £10s to £100s, depending on the quality and length of holdover period required. An OCXO has a holdover period in the magnitude of hours, depending on the quality of oscillator. On the high end, Rubidium XPRO Atomic Oscillator (£10,000+) provide holdover periods in the magnitude of days or even months, which all depends on the specific requirements in the application.¹²⁰

The table in Annex 3 compares the time error for oscillators of varying quality and cost following a loss of GNSS signal for three and five days against the requirements of various applications.

5.1.1 Chemicals

The impact is: Low risk, but potentially significant impact.

Consistent with the discussion provided in section 4, the impact of loss of GNSS is limited to transport of dangerous goods, where loss of GNSS would mean such transport would no longer be monitored. The impact of loss of GNSS for this particular type of transport is primarily linked with

¹²⁰ Curry, C. (2010). *Dependency of Communications Systems on PNT Technology*. Chronos Technology, pp. 5-6

adverse impacts that may occur if a vehicle were to be involved in an accident or theft. Evidence of such accidents has not been available.

5.1.2 Civil nuclear

The impact is: Low risk, but potentially significant impact.

Consistent with the discussion provided in section 4, the impact of loss of GNSS is limited to the transport of dangerous goods, where loss of GNSS would mean such transport would no longer be monitored. Stakeholders differ on the actual process of transporting nuclear waste as some suggest a convoy of security personnel would accompany such transport (in which case tracking could be achieved by radio), while others suggest nuclear waste is transported ‘by stealth’ so as not to attract attention. The impact of loss of GNSS for this particular type of transport is primarily linked with adverse impacts that may occur if a vehicle were to be involved in an accident or theft. Public Health England report that no such events occurred in 2012 (latest data).¹²¹

5.1.3 Communications

The loss of GVA is found to be: Low risk and low impact

The loss of utility benefits is found to be: Low risk and low impact

The impact of loss of GNSS in **telecommunications** (fixed and cellular) hinges on the quality of the holdover technology that is in place to maintain synchronisation. If holdover were sufficient to continue operations, there would be no impact. The impact of loss of synchronisation would be that calls would break up, and information would not be transmitted.¹²²

Indirect effects of loss of telecommunications would be a loss of access to the internet as well as telephony, which would severely impact the productivity of the UK and be further exacerbated by the anticipated increase in the number of people trying to work from home to avoid the expected increased road congestion also resulting from the GNSS outage.

Fixed-line telecommunications (including internet)

Stakeholder consultation suggests that fixed-line telecommunications operators in the UK are aware of the vulnerabilities and limitations of GNSS, and have the necessary holdover in place to maintain operations throughout the time period. As a result, there would be no impact on functionality, and consequently no economic loss.

Cellular telecommunications

Stakeholder consultation confirms that sufficient holdover is in place to avoid calling out emergency repair teams at weekends and bank holidays, meaning the system can maintain operations for at least four days. It is suggested that the system would be sufficiently resilient to cope with a fifth day as well. The mobile telecommunications infrastructure uses Caesium (Cs) clocks in core nodes to maintain the time information between calibrations (from GNSS). A Cs clock can easily maintain the

¹²¹ Public Health England (2014) *Radiological Consequences Resulting from Accidents and Incidents Involving the Transport of Radioactive Materials in the UK – 2012 Review*

¹²² Curry, C. (2010). *Dependency of Communications Systems on PNT Technology*. Chronos Technology

necessary accuracy for five days, and timing information can be pushed through the network using fixed line signals or even fixed satellite backhaul if required (mobile services would be affected).

Broadcast – Digital Video Broadcasting (DVB)

GNSS is used at all terrestrial broadcast transmitters. However, the network would be able to continue operation in the event of loss of GNSS due to the quality of the antenna on the roof of buildings.

Broadcast – Digital Audio Broadcasting (DAB)

For **digital audio broadcasting (DAB)**, the impact of loss of GNSS as of January 2016 is well-known, as the anomaly of SVN 23 acted as a real-life experiment. On that occasion, the loss of GNSS resulted in timing issues on a small number of transmitters and minor, short duration impacts on coverage in some areas. The UK DAB operators are aware of the risks associated with GNSS and have increased resilience.

TETRA (Professional Mobile Radio, PMR)

For **TETRA (Professional Mobile Radio, PMR)** the impact of loss of GNSS is unknown. If the implication were that the TETRA network would cease to function, then communication for emergency responders would be lost, and the efficiency of response would be severely degraded. As TETRA is designed for emergencies, it is unlikely that the TETRA *network* is vulnerable to a loss of GNSS. On the other hand, the award of future emergency service communication to EE from 2020 means the incentive to increase resilience of the network in recent years has been limited. In case TETRA were disrupted, emergency responders could use personal mobile phones (that would continue to function) or, in the worst case, borrow a phone from a member of the public.

Internet data centres

The holdover capability in data centres has not been confirmed in stakeholder consultations, but based on Google's paper¹²³, that organisation appears fully aware of the risks and limitation of GNSS, and reports the use of atomic clocks for holdover. However, a five-day loss of GNSS is generally considered to be a very low probability event and therefore may be beyond the scope of planning. The paper reports implemented accuracy of 10ms, suggesting even a mid-range OCXO oscillator could maintain the required holdover for the duration of the time period (assuming the timing at the last point of calibration is accurate to less than 4ms).

5.1.4 Defence

Defence is beyond the scope of this study.

5.1.5 Emergency services

The loss of GVA is found to be: £0m

The loss of utility benefits is found to be: £1,531.5m

¹²³ Google Inc. (2012) *Spanner: Google's Globally-Distributed Database*. Available at: <http://static.googleusercontent.com/media/research.google.com/en/archive/spanner-osdi2012.pdf>

Public-Safety Answering Point (PSAP)

The impact of loss of GNSS would be to remove all the benefits estimated to PSAPs as they would all revert back to the less accurate Cell-ID and therefore spend more time on the phone with callers.

The five-day equivalent (pro rata) of estimated annual benefits of £1,921.0m (see Chapter 4 for estimation) that would be lost for the duration of the outage: **£26.3m over the five days**.

As the PSAP operator would need to spend more time with each caller, and given the significant pressure on PSAPs in normal times, it is likely that some marginal callers would fail to get through to the operator, which in turn may result in greater damages. In addition, the anticipated increase in emergency calls resulting from heavier congestion and accidents on the roads would exacerbate the problems.

Loss of efficiency in the PSAP is proxied by an assumption that 3% of the call volume in normal times would fail to be attended to (the reduced time spent on calls with GNSS-enabled mobile users is approximately 20%, which accounts for 35% of calls), and consequently that approximately 6,300 calls across emergency services would go unanswered. The UK Department for Transport estimates the value of preventing an accident between £2,142 and £2,005,664 depending on severity. Using the weighted average value for all severities of £76,466,¹²⁴ the value of dropping 6,300 emergency calls (i.e. those that require action from emergency services, see next section for a breakdown) is estimated at **£481.7m**.

Police, Ambulance and Fire services

The logistics and fleet management-type benefits enjoyed by police, ambulance and fire services would also be lost, but an additional problem would arise as first responders would need to spend more time charting and following routes to emergencies and even additional time going slowly to ensure the correct house number is identified before stopping the vehicle. This would increase the response time and result in significant, detrimental impacts.

Additional effects are expected from increases in accidents owing to stressed drivers trying to navigate without GNSS and potentially behavioural changes brought about by lack of access to food in shops or from online shopping. Congestion would also lead to longer response times (beyond the impact of navigation itself) as emergency response units would be held up in traffic despite the ability to use blue lights.

The positive impact of GNSS-based fleet management operations on the efficiency of dispatch points would be lost, and substantial effort would be needed to keep track of all units (position, destination and status) to ensure the most appropriate units were assigned to incidents.

There are approximately 31 million calls to emergency services each year, of which 40% are filtered out at the first PSAP and 60% go through to the 204 Stage 2 PSAPs (92 police, 59 fire, 34 ambulance, 19 coastguard).¹²⁵ In 2015-16, 10.68m calls were transferred to NHS Ambulance Trusts, of which 38.1% were handled by the operator without requiring emergency ambulance support.¹²⁶ Fire

¹²⁴ Department for Transport Statistics (2015) *Average value of prevention per reported casualty and per reported road accident [RAS60001]*

¹²⁵ BT (2011), *UK Emergency calls*. Available at: http://www.eena.org/ressource/static/files/112_in_uk.pdf

¹²⁶ Association of Ambulance Chief Executives (2016), *Annual Report 2015-2016*. Available at: <http://aace.org.uk/wp-content/uploads/2016/10/AACE-A4-ANNUAL-REPORT-2015-2016-W.pdf>

services attended 496,000 fires in 2014/15¹²⁷, and police forces took 8.2m calls in 2013/14¹²⁸. Ambulance services therefore manage approximately 90,000 calls, police 110,000 emergency calls and fire services 10,000 calls over the five-day period.

Fire services rely on GNSS only to a limited extent as fire engines return to the station when no fire is reported and originate from there if a fire breaks out, covering a smaller area than the other services. Assuming the loss of GNSS would add 2 minutes to the average response time for fire engines, the cost would be **£53m**.¹²⁹

Assuming the outage occurred at an 'average time of year', police forces would need to handle an average of 200 emergency calls per control centre per day without access to the system that allows dispatch operators to monitor and manage vehicles in the field. In addition, police forces receive between 3 and 6 times as many additional calls on 101 and other telephone numbers.¹³⁰ This would absorb significant additional resources that would either be provided by active police officers, volunteers or any other available staff. It is assumed that each control centre would require six additional staff on average to maintain operations. If such staff could be sourced quickly and paid minimum wage, this would imply additional costs of **£0.5m**. In reality, this should be considered a lower bound estimate as if new staff are not available, existing officers would most likely be required to fill the gaps at higher pay rate and overtime.

Efficiency of operations would also be reduced, which is assumed to add 2 minutes to the response time to incidents, on average. A Swedish study values response time at £8,364¹³¹ per five-minute interval for traffic accidents. It is assumed that traffic accidents form a reasonable average of the types of emergency calls police forces receive. Assuming an average delay of two minutes, 110,000 calls and approx. £8,364 per five-minute delay yields economic costs of **£368m** from loss of life, injuries, damage to property and delays to motorists.

For ambulance services, the loss of GNSS would have severe impacts, as the system is highly dependent. In general, ambulances do not carry paper maps, and while they carry personal smartphones that could help navigation (assuming the passenger is free to navigate, which might be true on the way to the emergency, but not on the way to the hospital), some mitigation of the impact is possible. Ambulance drivers cover a large area and are therefore not able to rely on local knowledge for navigation. There is very limited capacity in the ambulance system, so any increase in response time translates to reduction in patients transported. Assuming response time on average increases by 4 minutes (50% of target response time), and valuing the impact at the same as traffic accidents, £8,364 per five minutes, the estimated impact is **£602m**.

¹²⁷ Home Office (2016) *Fire Statistics England, 2014/15*. Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/532364/fire-statistics-england-1415-hosb0816.pdf

¹²⁸ College of Policing (2015) *College of Policing analysis: Estimating demand on the police service*. Available at: http://www.college.police.uk/News/College-news/Documents/Demand%20Report%2023_1_15_noBleed.pdf

¹²⁹ The valuation of response time relies on Jaldell, H. (2004) *The importance of the time factor in fire and rescue service operations in Sweden*. Available at: <http://www.eena.org/ressource/static/files/6.-henrik-jaldell.pdf> using 2003 exchange rate to convert estimate and UK CPI.

¹³⁰ E.g. Greater Manchester Police Force: 433,646 on 999; 1,311,046 on 101; and West Midlands Police: 700,000 on 999 and 4,000,000 on 101 and other numbers. See: <http://www.gmp.police.uk/content/section.html?readform&s=5C4B8FC3793EC0D98025796000487503> and <https://www.west-midlands.police.uk/contact-us/response-times/index.aspx>

¹³¹ Actually, SEK86,200, but converted at 2003 exchange rate and grown using UK CPI inflation. Jaldell, H. (2004) *The importance of the time factor in fire and rescue service operations in Sweden*. Available at: <http://www.eena.org/ressource/static/files/6.-henrik-jaldell.pdf>

5.1.6 Energy

The impact is: Low risk, but potentially significant impact.

If GNSS were lost, the clocks based on the systems would go into holdover, but would drift relatively quickly, at 2ms in a couple of hours. As the drift cannot be assumed to be symmetric across devices, the redundancy in the ability to detect disturbances would begin to deteriorate. The electricity transmission system employs different disturbance (protection) detection equipment with considerable overlap normally comprising two different types of fast acting main protections (isolating the fault in 100msec) and slightly slower back-up protections (typically 500msec- 1 sec), e.g. main protection devices would be able to detect 90% of faults each, and two devices would cover the full set with back-up protection providing greater resilience. Depending on the specification of individual protection devices, loss of GNSS might remove one protection device from the service, and particular faults within only that protection device's remit could go un-isolated until back-up protection operated in slightly longer timescales.

In the event of loss of GNSS, National Grid manually staff affected substations, and considerable effort would need to be expended to ensure that equipment and power system health are monitored locally by staff. A nationwide GNSS outage would make it difficult for National Grid to staff all substations and would take several hours to get in place at key sites.

National Grid estimate that on average, one transmission system disturbance/fault occurs in any five-day window, and the impact of such an event would be determined by the specific fault type, and the correct operation of protection equipment supplemented by individual staff members.

If GNSS was lost, and a disturbance occurred, and it went undetected until back-up protection operated, then impacts on the system range from reduced network resilience to loss of supply (which for transmission could impact 100,000s of customers), or loss of generating plants. This latter loss would require more expensive generators needing to be run, and possibly further impacts on customers supplies if large volumes of generation were tripped.

Loss of power could have significant knock-on effects on all critical infrastructures relying on GNSS timing, as devices in holdover (without backup electricity generation) would lose time and be unable to reacquire it. As reported in section 2.4, the Space Weather Preparedness Strategy suggests the energy system could fall victim to short-term blackouts because of voltage instability associated with a geomagnetic storm (which is a possible source of GNSS loss). If this were to occur, the loss of power for a short period of time could reset all the GNSS clocks in holdover, and impacts may be much more severe.

It is not possible to estimate the economic impact of loss of GNSS in energy as a wide range of concurrent events are needed for impacts to materialise. For example, one disturbance over the period is an estimated annual average, but if the GNSS outage were to coincide with particularly bad weather involving strong winds and lightning strikes, many more disturbances often occur.

However, it can be stated that it is possible to imagine a scenario in which loss of GNSS and other concurrent events would result in loss of power in parts of the country, which would have severely detrimental impacts on critical infrastructures and other applications using GNSS time, as holdover capability would be lost until GNSS re-emerges.

5.1.7 Finance

The loss of GVA is found to be: £0

The loss of utility benefits is found to be: £0

The implications of loss of GNSS have been ‘tested’ on a small scale using a jamming detector at the London Stock Exchange, which identified more than 1,000 events of at least 30 seconds in the year to March 2016. The longest such event was 42 minutes.¹³² This proves the London Stock Exchange has holdover capability that is sufficient for that length of disruption. Given the concentration of banks nearby and the paucity of public news concerning any disruptions to trade, it can be inferred that banks have similar holdover capacity.

Indeed, one stakeholder confirmed that computer-automated traders and stock exchanges are fully equipped to withstand a five-day loss of GNSS and continue trading (i.e. remain referenceable to UTC within 1µs). High street banks face less stringent obligations and therefore tend to use lower-grade oscillators. However, these oscillators are correctly specified and able to continue operations (referenceable to UTC within 1ms) without GNSS access for five days.

Payment systems and ATMs are not vulnerable to loss of GNSS as the holdover capability that is in place is sufficient to ensure continued operation.

5.1.8 Food

The scope of the sector does not include GNSS so no detriments would be suffered directly (see sections 5.2.2 and 5.2.4 for impact on fisheries and agriculture, respectively).

5.1.9 Government

The loss of GVA is found to be: £1.5m

The loss of utility benefits is found to be: £0.4m

Weather forecasting

Loss of GNSS would deprive the Met Office from using GNSS radio-occultation to inform itself on the composition of the atmosphere. Many of the Met Office’s moving terrestrial sensors would also lose their position information, and the lightning detection network would cease functioning.

The Met Office would be able to continue forecasting the weather, although with some added uncertainty, so the impact of loss is limited. This is because its supercomputer would remain synchronised. Based on the conservative attribution of £100m of Met Office annual benefits to GNSS, the loss of GNSS for five days would account for **£1.5m**.

Offender tracking

If GNSS fails, the offender tracking application will no longer work, and offenders would be able to escape custody even if they continue to wear the tag. A tagged offender remains under arrest, so if the positioning information is lost, the police forces are obliged to apprehend tagged offenders. This

¹³² Charles Curry (2016) *eLoran – The Future of Resilient PNT*, conference presentation at ITSF, 1-3 November 2016

would absorb resources that could be used elsewhere. Offenders suited for tagging are not the most dangerous of criminals, but they may nevertheless reoffend at a cost to society.

The loss of benefits would amount to approximately **£0.4m** over a five-day period with current usage, but greater impact can be expected from the use of police resources required to apprehend 1,000 tagged offenders. However, monetising the impact on police forces when apprehending offenders cannot meaningfully be undertaken as it would require information to substantiate assumptions related to the behaviour of offenders, e.g. what proportion would realise they could escape? What proportion would 'escape' to their local pub, which may be expected to be the first place to search? What proportion would genuinely try to run away? Such information is not available and the loss cannot be monetised.

Evidence management

The economic impact of loss of GNSS on the applicability of evidence may be very large depending on the holdover capability of the timing server for CCTV. In 2009, the Daily Telegraph reported that more than 70% of murders in London were solved as a result of CCTV to capture the movements of the perpetrator or the murder itself, and that CCTV contributed to almost all investigations (95%). Losing accurate timing of CCTV footage would seriously undermine its usefulness for investigation as tracking of movement from one camera's coverage area to another would be severely impaired. Furthermore, the loss of accurate timing would complicate the use of disparate CCTV systems – covering a range of different data formats and standards¹³³ – as GNSS-referenced time can be used to support their harmonisation for investigative purposes.

The economic loss associated with inability to track and convict offenders during a five-day period is beyond the scope of this study.

CAP and CFP compliance monitoring

The loss of GNSS would have widely different impacts on CAP and CFP. For farmers, the loss of GNSS would be one of inconvenience (and potential delay if a sale was occurring), but no lasting impacts would be expected – farmers would not be expected to relocate their farms, for example. For the CFP on the other hand, the loss of GNSS would shut down both AIS and VMS-based fishing vessel monitoring systems. Depending on the risk aversion of fishermen, this could either induce them to catch fish outside their quotas or not fish at all as failing to provide positions would be in breach of regulation. Fishermen who choose to breach regulations may dent the efforts to maintain fish stocks (the purpose of the CFP), and therefore have lasting impacts on the business for many years. The loss has not been monetised, and it is not reasonable to speculate how people would react. It is expected that the regulator would choose not to revert to manual logbooks, as this would alert the fishermen to the GNSS outage and potentially induce unregulated fishing.

5.1.10 Health

*The loss of GVA is found to be: **£0m***

*The loss of utility benefits is found to be: **£0.7m***

¹³³ E.g. Surveillance Camera Commissioner and Tony Porter (2015) *Benefits of sharing CCTV and networks*. Available at: <https://www.gov.uk/government/speeches/benefits-of-sharing-cctv-and-networks>

The impact on tracking of lone workers could be mitigated depending on the type of device in use. For smartphone applications, the loss of GNSS would be less critical than dedicated devices, as smartphones can derive position information for Wi-Fi and other signals of opportunity. Assuming 20% of devices would lose position information and assuming lone workers are equally likely to be in distress irrespective of the system in use, less than one incident would go unanswered, on average.

Benefits from fleet management operations for carers would be lost, and additional detriment may arise as a result of increased congestion and reduced ability to navigate between sites.

5.1.11 Space

The loss of GVA is found to be: £22.5m

The loss of utility benefits is found to be: £0

LEO satellites

A loss of GNSS would reduce the precision of satellite routing and therefore the success of navigation. This is especially relevant for high-resolution satellites, Stereo SAR missions and disaster monitoring, where the necessary accuracy of images is high. The U.S. Department of Defense's Two-Line Element set provides sufficiently accurate information to track the satellite and ensure ground stations are pointed in the correct direction to steer the satellite. In cases of space debris, where the satellite needs to take evasive action, GNSS offers fast information to ascertain whether the action has been successful. Two-Line Elements may be used for the same purpose, but would add significant uncertainty to the operation.

Ground stations

For EO satellites, the accuracy required to communicate with the satellite is low (approximately 1s), and holdover capability in the ground station GNSS receiver is considered to be sufficient. However, even if it is not, alternative sources could be found over the five-day period.

For GEO satellite communications, GNSS is primarily used as a reference frequency that ensures communication with the satellite is aligned. The holdover capacity of the two separate GNSS receivers in use is sufficient to continue operations for five days.

Satellite communications

Mobile satcoms would be severely impacted by loss of GNSS, as the devices would lose the location information that allows them to acquire the appropriate spot beam from satellites. Inmarsat's FAQ¹³⁴ is clear that only GNSS-derived location can be used to acquire the satellite and it therefore follows that mobile satcoms from GEO satellites would be lost if GNSS were lost.

The benefits of mobile satcoms are beyond the scope of this study, but applications include maritime and aviation as well as research expeditions and reporters operating in areas of poor cellular coverage (e.g. conflict areas). Inmarsat's LEO competitor, Iridium, is less forthcoming with information on the GNSS usage of their devices, and choose to promote tracking applications instead, where a user can send a 'breadcrumb trail' of recent locations to selected recipients. The

¹³⁴ <http://www.inmarsat.com/support/faq/>

Iridium constellation is fundamentally different to Inmarsat as overlapping spot beams constantly change position, meaning multiple satellites are required for a conversation. It therefore appears that the core functionality of the Iridium solution could be maintained following GNSS loss.

The degree to which benefits of mobile satcoms would be lost when GNSS is lost therefore depends on the relative market shares of LEO and GEO solutions. While market data are not forthcoming, various sources suggest the majority of mobile satcoms currently rely on GEO services.¹³⁵

Inmarsat is the largest UK satellite communications company, and its service is entirely mobile. If GNSS were to be lost for five days, Inmarsat's revenue of \$1.3bn per year would be lost for the duration of the outage. Detriment to the company and users is therefore estimated at **£22.1m**.

The five-day equivalent loss of the benefits of satcoms in aviation estimated in section 4.1.11 of £31.7m is **£0.4m**, which would all be lost.

The largest user of mobile satcoms is the maritime shipping sector, where mobile satcoms enable accurate scheduling of port operations and allow access to weather forecasts and communication for crew. The impact of the loss of satcoms is nested within the wider impact of loss of GNSS for maritime shipping and considered under maritime transport infrastructure in section 5.1.12, below).

5.1.12 Transport

*The loss of GVA is found to be: **£1,069.3m***

*The loss of utility benefits is found to be: **£0***

Road transport infrastructure

Monitoring of bridges that uses GNSS would no longer work, and the added level of information resulting from the system would be lost. The impact would not be significant if the bridge continues to operate normally, but in cases of high wind or other sources of damage, the lack of GNSS-derived information would increase the effort required to monitor the bridge through other measures, and could cause a severe issue in the worst instance or precautionary closure of the bridge. The loss has not been monetised.

Rail transport infrastructure

All benefits to Network Rail from PLPR would be lost as the system could not function. The implication might be that the railway would not be maintained for the duration of the outage. If there is no substantial damage on the track, the impact is nil, but if any damages were not identified on time, the result might be derailments and loss of life. Network Rail's ambition with PLPR was to reduce monitoring by trackside maintenance crew by 80%. If they have succeeded in doing so, it is likely the company has no fall-back option.

However, the PLPR system would most likely continue to crawl the track and identify damages, and while the location information embedded in the imagery would be missing, faults on the track would still be identified and remedial measures could be taken. For example, the sequence of images

¹³⁵ See e.g. ASF 2015: Jose del Rosario of NSR on satellite mobility markets. Available at: <https://www.slideshare.net/CommsDay/asf-2015-jose-del-rosario-of-nsr-on-satellite-mobility-markets>

would remain chronological, so knowing an approximate starting time of the vehicle and the number of images per minute would allow an approximation of the location of the fault.

Without access to GNSS, the timing operations that rely on it would most likely be lost or synchronisation severely disrupted. Impacts of disruption in rail have been monetised in section 5.2.6, which considers train and freight operations rather than the infrastructure itself.

Maritime transport infrastructure

Among the infrastructures to be hit the hardest, maritime transport is strongly reliant on GNSS with no suitable alternative for many of the applications currently in use. The impacts range from nuisance/inconvenience brought about by buoys that are no longer synchronised (making navigating a large vessel in narrow shipping lanes more challenging) to severely detrimental effects from the loss of accurate measures of speed and consequent unavailability of accurate ETA at ports. This effect is further compounded for users of mobile satellite communications from GEO satellites as the loss of GNSS means a loss of communication capabilities and therefore the loss of ability to reschedule port timeslots and even access weather forecasts. The loss of navigation, speed information and AIS would also most likely cause vessels to slow down, reducing the likelihood that they make the designated timeslot. The impact of loss of GNSS would be particularly high in adverse weather conditions with reduced visibility as vessels would need to reduce speed to ensure they remain in shipping lanes and do not run aground.

Pilots have local knowledge and are therefore able to navigate the vessel into ports without GNSS, but the process would take significantly longer and require twice as many pilots to ensure all visual information is taken into account. The implications are that vessels that arrive on time for their port slot are likely to be forced to wait for available pilots. The loss of vessel management systems and disruption to normal flows would likely cause the ports to prioritise known vessels where personnel are known to be competent and it is likely that most vessels would require pilotage. Vessels carrying critical cargo such as medicine may also be prioritised by the port.

Depending on the local tide, timeslots for the largest vessels may be restricted to just 2-3 hours either side of high tide, meaning that reduced velocity, increased congestion in the port, and limited availability of pilots could delay docking by many hours.

When container ships eventually make it to port, the automated cranes operating in the largest ports would no longer be operational, and it is likely that no alternative exists, and loading and unloading of containers would be terminated for the duration of the outage.

For non-container cargo, unloading would be able to continue as normal, but only if there were vehicles to unload the cargo onto. Depending on the impact of GNSS disruption on road transport and congestion, this is likely to be an increasingly binding constraint as the five-day period elapses.

The loss of GNSS would therefore have profound effects on shipping throughout the five-day period, and substantially afterwards to clear an increasing backlog.

The UK water transportation sector contributed £2.7bn to UK GDP in 2015.¹³⁶ Some water transportation activities could remain if GNSS was lost so the reduced efficiency of ports and vessels

¹³⁶ ONS (2017) *Annual Business Survey* for 2015.

is assumed to reduce activity by 60% on average over the five days of outage **plus the following five days** when the backlog is cleared. The loss of value-added is therefore estimated at **£44.6m**.

In addition to water transportation itself, further detriment would be felt in the 'warehousing and support activities for transportation' sector, which contributed £26.7bn to GDP in 2014. Assuming the turnover of water transportation as share of all transportation is a reasonable approximation for its share of warehousing and support activities, and that the impact is as strong (60%) over the same time period (10 days), the economic loss has been estimated at **£38.9m**.

Secondary impact

Information on the reliance on just-in-time warehousing in the UK is not available. However, the automotive manufacturing industry is known to be a heavy user of just-in-time. As discussed in section 4.1.12, the Society of Motor Manufacturers and Traders (SMMT) have stated their stocks would allow a four-hour delivery delay and for some inputs only two hours.

Of the 43 UK manufacturing sectors included in the ONS analytical input-output tables,¹³⁷ 10 sectors that directly contribute £31.8bn to GDP import more than 30% of intermediate inputs (by value). 'Manufacture of motor vehicles, trailers and semi-trailers' imports 35% of inputs to generate £10bn of GVA.

It is assumed that all sectors that import more than 30% of intermediate inputs are highly vulnerable to a delay, and therefore need to stop production during the five-day GNSS outage. Depending on the cargo type, sectors are affected to different extent. Container traffic would stop completely, while bulk cargo and roll-on/roll-off (RoRo – i.e. lorries) would 'only' be severely delayed and disrupted. Motor vehicle manufacturing is the only sector among the top 10 importers that has been deemed to rely on container traffic. As most of the other sectors are petroleum, metal or chemical processing sectors, the vast majority of imports are expected to be bulk or RoRo. For this reason, the impact on the motor vehicle manufacturing sector is considered separate from the others.

It is assumed that automotive manufacturing factories will shut down after four hours on the first day, workers will be sent home after another four hours. Supplies are assumed to arrive overnight (these are mostly stuck in traffic rather than in ports), and production would continue on the second day. Having spent the inputs by the end of the second day, the delays return, and the factory is idle on the third. Some inputs arrive on the fourth day (via RoRo), and partial production is possible, assume 25%. On the fifth day, no more inputs remain and the factory is shut again. In total, the factory runs at less than 30% capacity over the five days, and substantial overtime will be required from the sector's 150,000 employees to make up the delay (assume 50% of the estimated loss during the period). It is, however, worth pointing out that the sector is more than the process of manufacturing, and the R&D, marketing and management activities undertaken in the companies could continue. Assume 20% of all activities (by value-added) could continue despite the lack of inputs. The economic loss from a five-day outage of GNSS in automotive manufacturing is therefore estimated at: **£117.0m**.

The other sectors that have been assessed to rely on bulk imports rather than containers, and for which no evidence of strong reliance on just-in-time has been found, would not be as badly affected as automotive. Specifically, the assumption of stoppage on the first day would be delayed, and the fourth day would have full production rather than partial. Factories in the remaining 9 sectors

¹³⁷ ONS (2017) *UK input-output analytical tables*. Available at: <https://www.ons.gov.uk/economy/nationalaccounts/supplyandusetales/datasets/ukinputoutputanalyticaltablesdownload>

(generating £21.7bn of GVA) would therefore run at 47% of capacity over the five days. It is assumed they too would be able to continue 20% of all activities that do not rely on frequent inputs, and that required overtime to make up the delay amounts to 25% of estimated direct loss. The monetised loss to these sectors is therefore **£163.6m**.

Accounting for the rest of the manufacturing sector, it is assumed that sectors that import 20%-30% of inputs would lose manufacturing activities worth 0.4% of annual GVA (compared with 1.1% for automotive and 0.7% for the other high import sectors). 14 sectors generating £73.7bn of GVA fall in this category, yielding a loss of **£294.6m** over five days. The remaining manufacturing sectors that import less than 20% of inputs are assumed to lose activities worth 0.2% of annual GVA (£47.5bn). This loss amounts to **£95m**.

In total, the adverse effect of disruption to shipping has been estimated at **£670.2m** for the *manufacturing* sector in the UK.

Export

The value of UK exports via ports was £277bn in 2014.¹³⁸ The seven largest ports account for £175bn worth of exports. As discussed above, although all would be affected, the severity of the impact of loss of GNSS would depend on the type of cargo shipped. Container ports would no longer be able to use autonomous cranes, and are therefore expected to cease operations for the duration of the outage, while bulk and roll-on/roll-off (Ro-Ro) cargo handling ports would be less adversely hit.

Assuming the weight of cargo handled in the ports is a reasonable approximation of the value (i.e. that the value of one tonne of dry bulk is equivalent to one tonne of container *content* and one tonne of Ro-Ro content, the indicative value of exports via **containers** from the seven main export ports per year is £55.4bn. The five-day equivalent of lost export due to loss of GNSS amounts to £758.8m.

Table 2 summarises the value of exports and breaks down the weight of exports in the seven most important export ports.

Table 2 Export value by port and cargo type

Port	Value (£bn)	Cargo type (by weight)
Southampton	40.1	Bulk: 53.1%; Containers: 37.3%; Ro-Ro: 9.6%
Dover	32.8	Ro-Ro: 99.8%
Felixstowe	30.0	Containers: 88.4%; Ro-Ro: 11.5%
Grimsby & Immingham	22.5	Bulk: 55.4%; Ro-Ro: 40.3%; Containers: 2.3%
Liverpool	19.1	Ro-Ro: 47.1%; Containers: 26.6%; Bulk: 24.7%
London	17.8	Containers: 42.7%; Ro-Ro: 26.9%; Bulk: 24.6%
Forth	12.4	Bulk: 92.7%; Containers: 5.8%

Note: Ro-Ro: roll-on/roll-off

Source: Department for Transport Statistics [port0104 & port0400] and MDS Transmodal (2016) *The value of goods passing through UK ports*. Available at: <http://www.abports.co.uk/content/files/downloads/The%20Value%20of%20Goods%20Report.pdf>

The loss of GNSS would also have detrimental effects on exports of non-containerised cargo. Assuming the disruption over five days would reduce the throughput of vessels by 50% (reflecting

¹³⁸ MDS Transmodal (2016) *The value of goods passing through UK ports*. Available at: <http://www.abports.co.uk/content/files/downloads/The%20Value%20of%20Goods%20Report.pdf>

the increased requirement for pilots), an estimate of a further loss of exports is derived at £59.8bn or £819.2m over five days.

Loss of GNSS would thus affect £1,578.0m, but it should be noted that the economic impact (i.e. the associated cost) depends on the service-level agreements in place between the exporting company, port, shipping company and buyer, which is not known. Assuming an average 20% penalty for late delivery, a total loss of **£315.6m** is estimated.

Air transport infrastructure

*The loss of GVA is found to be: **£0***

*The loss of utility benefits is found to be: **£0***

The cautious nature of air traffic management means that GNSS, a resource beyond their control, is not relied upon to the degree that non-availability can disrupt the system. Any impact that may affect the travel time of individual aircraft can be managed as there is always a plane queuing to land at major airports. Therefore the risk of a knock-on from missed landing slots is extremely low.

For timing applications, air traffic control is also resilient, with internal oscillators in place with holdover capacity ranging from a few weeks to months, depending on the system. Generally, the accuracy required is not very high, and MSF¹³⁹ time is considered a suitable alternative if GNSS fails.

5.1.13 Water and Sewerage

The impact is: Negligible.

The use of GNSS in water is not clearly identified, cf. section 4.1.13. If noise loggers are the extent of use, then detriment would be felt only in the cases where GNSS-enabled noise logging would identify a broken pipe that could be fixed. If no pipes break, there would be no impact. GNSS is not expected to be a key input in water maintenance beyond navigation for repair teams.

5.2 Professional (industrial activity)

5.2.1 Road

*The loss of GVA is found to be: **£24.2m***

*The loss of utility benefits is found to be: **£26.3m***

Professional road applications include all activities related to transport on the road network for business purposes, but exclude commuting. This specifically includes logistics and delivery services, long-haul trucking and travelling sales people. The impact of loss of GNSS is inherently uncertain as there is no information on the ability of people to navigate using traditional paper maps, and even less information on the availability of such resources in vehicles.

Long-haul drivers are expected to be able to proceed without GNSS until they approach their destination, but would be expected to be able to navigate the majority of the route by street signs, especially if they are following known routes. On the other hand, delivery and minicab vehicles are

¹³⁹ A radio time signal transmitted from Anthorn by the National Physical Laboratory on 60kHz.

thought to be very heavily reliant on GNSS for routing and turn-by-turn navigation, and are not necessarily aware of the whole route, but instead focus on the next drop or pickup point. The impact is estimated separately for navigation applications and fleet management in the sections below and the effect of increased congestion is considered in section 5.3.2.

Navigation

Devices used in the sector would start to fail very soon after GNSS signals were lost. However, for fixed-mounted smartphones (i.e. not held by a passenger) and dedicated navigation devices, simple dead reckoning from inertial sensors in combination with snap-to-map software solutions would be able to keep devices in progressively declining service for a limited period, and until the car is turned off at the latest. Handheld smartphones would continue to derive position from all available sources, so a position would continue to be available. The impact of loss of GNSS on handheld smartphone-users depends on the availability of alternative sources of positioning. On a country road, the blue circle indicating uncertainty could increase to Cell-ID levels (radius of more than 2km), while a driver on a residential street could experience accuracy almost to the level of GNSS thanks to an abundance of Wi-Fi hotspots in the vicinity.

Given the short holdover capability of devices used in the sector, it is reasonable to assume all benefits generated by GNSS would be lost for the duration of the outage. However, because of this holdover capability, the likelihood of a sudden spike in accidents when all drivers lose GNSS simultaneously is limited.

The time savings made possible by GNSS would all be lost as a result of an outage. The value is estimated at **£26.3m** for a five-day period, and is based on conservative assumptions on the contribution of GNSS to navigation (see section 4.2.2 for more details).

A compounding effect of the loss of GNSS is that congestion will increase because more drivers need to spend more time navigating their route and therefore spend more time on the roads going back on wrong turns. Drivers would also need to make additional stops for waypoint navigation because users of electronic maps on their smartphone are prohibited from moving the map by hand.

The economic cost of GNSS loss would not be limited to the loss of benefits faced by individual users of navigation for professional road applications. This is because of network effects, whereby GNSS-reliant drivers that are unfamiliar with their route move more slowly, impacting the entire flow of the network and imposing congestion costs on all drivers, regardless of their GNSS dependency.

The estimated economic impact of congestion induced by the GNSS loss for professional applications cannot be disentangled from mass market road applications, so both professional and mass market impacts are estimated together and presented in section 5.3.2 below.

Beyond the effects on the navigation and congestion sides of road transport, it is very likely that drivers would get increasingly frustrated and confused at the loss of GNSS. This might result in additional low impact accidents and road-rage events and could be exacerbated by drivers choosing to ignore the law prohibiting them from moving electronic maps by hand as they would be less attentive than required. Additional accidents would result in even further delays and an additional strain on emergency services.

Logistics and fleet management

The loss of efficiencies in the logistics sector will most likely result in delayed delivery of products (parcels, supermarket orders and shop supplies). This could in turn result in shortages of products on the shelves of stores, and further lead to volatile behaviour in the population. The business model of many companies in the so-called ‘sharing economy’ relies on GNSS to a great extent. *Uber* recently changed its terms and conditions to gain access to the location of all the users of its app,¹⁴⁰ and apps of companies in related industries such as minicabs and black cabs rely on GNSS to ensure the location of the customer is known. *Deliveroo* also relies on GNSS to deliver food orders to users.

Benefits from fleet management systems of **£2.1m** for a five-day period would be lost, but the impact on control centres may be much greater as discussed below. The fleet management system (like emergency service dispatch) have become much more efficient through use of GNSS, and it is not clear that the skills required to track all vehicles’ location, destination, and status are available at the control centre for a paper map-based alternative solution. In addition, the loss of GNSS-derived ETAs (the last known of which would most likely have been inaccurate given the expected increase in congestion) means that just-in-time operations for road haulage would be lost, and delays and stacking may be required.

The UK *freight transport by road sector* comprises 44,565 enterprises, employs 245,000 staff, and contributes £11.9bn to GDP.¹⁴¹ On average, the enterprises in the industry have a fleet of 4.5 vehicles,¹⁴² and it is reasonable to assume that many small operators would be affected to a limited extent as a result of loss of fleet management and logistics systems. However, 61% of the vehicles in the haulage industry are part of fleets with more than 11 vehicles, registered on approximately 6,000 licenses.¹⁴³ Assuming the 6,000 license holders would require additional staff to manage their fleets, 3 people on average, in two shifts, to track the location of the vehicles and manually derive the information that is normally gathered automatically, 36,000 person-days would be required. Assuming eight hour days and minimum wage, the additional cost to monitor and manage the fleet would be **£2.2m**, but this assumes such staff numbers would be readily available, which is highly unlikely.

Additional effects are likely if the loss of logistics reduces efficiency to the degree that deliveries or collections would be missed completely. The GVA of the largest operators is approximated by share of vehicles in large fleets, and is estimated at £99.4m over five days. Assuming economic loss of 20% of this GVA, this would result in an additional loss of **£19.9m**. In reality, this is likely to be an underestimate of the full economic impact, as it does not include impacts further down the supply chain – for example, stock shortages and reduced sales in the retail sector.

If ports are able to continue to function for some goods (notably roll-on/roll-off) at reduced capacity, then lorries for international transit would continue to drive to Dover and other ports, but it is likely that much time would be lost to congestion and stacking operations in the process.

¹⁴⁰ Wired (2016) *Uber can now track your location even when you're not on a ride. Here's how to turn it off*. Available at: <http://www.wired.co.uk/article/uber-track-location-data-update-turn-off> [accessed 09/12/2016]

¹⁴¹ ONS (2017) *Annual Business Survey for 2015*.

¹⁴² DFT (2016) *Domestic Road Freight Statistics 2015*

¹⁴³ Traffic Commissioners for Great Britain (2016) *Traffic Commissioners' Annual Reports 2015-16*. Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/567036/tc-annual-report-2015-2016.pdf

5.2.2 Maritime

*The loss of GVA is found to be: **£11.9m***

*The loss of utility benefits is found to be: **£0.1m***

All the monetised benefits in Search and Rescue would be lost if GNSS was lost,¹⁴⁴ equivalent to loss of **£0.1m**. This amount is based on the fundamental assumption of the study that the five-day GNSS outage occurs in an 'average' period.

Loss of GNSS would imply loss of the five-day equivalent of the £350m benefits estimated for the maritime shipping industry, **£4.8m**. The secondary economic impact of loss of GNSS for merchant shipping cannot be disentangled from the impact on ports operations and have therefore been considered under maritime transport infrastructure in section 5.1.12, above.

The loss of GNSS for fishing vessels would require the fisherman to be able to navigate to destination waters using conventional methods. However, the greater impact on fishing vessels is likely to the VMS requirements to report position information based on GNSS. The requirements stipulate that the VMS device must transmit positional fixes every hour and that the position is accurately timestamped with respect to UTC. It is not possible to manually insert position information. The regulation does not consider the event where GNSS is lost,¹⁴⁵ but cautious fishermen may choose to return to port until the VMS is back in operation. Assuming the UK fishermen would be at least as cautious as the South Koreans, it is anticipated that more than 20% of fish landings would be lost every day for the duration of the outage, which could imply shortage of fish products in processing plants and shops.

In 2014, UK vessels landed £775m worth of catches on UK and foreign shores.¹⁴⁶ Assuming 20% of catches during the five-day period of outage would be lost due to fishing vessels returning to port,¹⁴⁷ the equivalent loss is **£2.1m**.

Further loss would be expected from the 80% of vessels that would not choose to return to port. 10% loss of efficiency is assumed, yielding additional loss of **£0.8m**.

Further losses still can be expected in the export markets and in the fish processing and retail industries, which rely on UK and imported fish to support the market. The UK processing and preserving of fish, crustaceans and molluscs industry contributes £553m to UK GDP per year.¹⁴⁸ The sector is presented alongside the larger processing and preserving of fruit and vegetables in the input-output tables, which accounts for approximately 70% of the combined output. The combined import share is 10%.¹⁴⁹ The effect of loss of import for the sector is considered in section 5.1.12, so this section instead considers the impact of the loss of domestic catch. Considering a strong delimitation between fish-related inputs into the combined sector (£305m) and fruit and vegetable-related inputs (£766m), it is assumed that all fish-related inputs are relevant for the sector. Of the

¹⁴⁴ Derived from improved accuracy and reduced search time for Search and Rescue operations that is attributable to GNSS.

¹⁴⁵ The Marine Management Organisation (2016) *VMS 5: UK fishing boats satellite tracking device specification*. Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/498453/vms5.pdf

¹⁴⁶ The Marine Management Organisation (MMO) (2016) *Fishing industry in 2015 statistics published*. Available at: <https://www.gov.uk/government/news/fishing-industry-in-2015-statistics-published> [accessed 16/03/2017].

¹⁴⁷ Similar to the South Korean fishing vessels subjected to jamming, sourced from: Reuters (01 April 2016), *South Korea fishing boats turn back after North 'disrupts GPS'*. Available at: <http://af.reuters.com/article/worldNews/idAFKCNOWY3I5>

¹⁴⁸ ONS (2017) *Annual Business Survey for 2015*.

¹⁴⁹ ONS (2017) *UK input-output analytical tables*. Available at: <https://www.ons.gov.uk/economy/nationalaccounts/supplyandusetable/datasets/ukinputoutputanalyticaltablesdownload>

inputs, it is assumed that 22% are derived from aquaculture and the remaining are catches from seagoing vessels.¹⁵⁰

Assuming the loss of fish from vessels that return to port (20%) and reduced catches for the remaining vessels (10%), the combined loss of GVA in the sector and of the processing industry has been monetised at £1.3m for the five-day period. However, the impact of the additional detriment suffered from inability to charge a 100% mark-up (assumed) on the inputs in the restaurant and retail sectors has been monetised at £2.9m. The total loss to the processing, retail and restaurant sectors is therefore estimated at **£4.2m**.

5.2.3 Aviation

*The loss of GVA is found to be: **£0.1m***

*The loss of utility benefits is found to be: **£0.3m***

The benefits of GNSS estimated for Search and Rescue and for EGNOS landing procedures would all be lost for the duration of the outage as these are all additional to existing systems. The impact is estimated at **£0.1m** from DDC and CFIT reduction foregone (see section 4.2.4).

The GNSS benefits estimated for Search and Rescue applications using ELT would also be lost. The five-day equivalent of the £2.0m benefits estimated in section 4.2.4 is **£0.3m**.

Aircraft are setup with multiple redundancy systems, and no additional impact is expected.

5.2.4 Agriculture

*The loss of GVA is found to be: **£151.6m***

*The loss of utility benefits is found to be: **£4.2m***

The loss of GNSS would have detrimental effects for the agriculture sector, where all benefits estimated for the period of the outage would be lost. Cultivation activities change with the seasons, so the simplifying assumption of a 'representative five-day period' has particular importance in agriculture.¹⁵¹ By the same token, the impact of loss of GNSS on agriculture might be substantially greater (if the loss coincides with a particularly busy period for cultivation), or reduced if the outage coincided with activities that do not involve working the field. Agriculture equipment only source position from GNSS directly, and indirectly using satellite-based augmentation systems (SBAS – EGNOS), differential GNSS (DGNSS) or Real Time Kinematic (RTK).

Benefits of GNSS for an average five-day period have been estimated at £3.9m, which would all be lost. However, benefits have been estimated against a baseline in which farmers achieve the best possible results absent GNSS, i.e. a pass-to-pass overlap of 30cm which has been reduced to 4cm by GNSS. It is reasonable to assume that a farmer who has relied on GNSS for a decade would be unable to achieve the same pass-to-pass overlap as the baseline, and therefore that further detriment would be felt. No experiments on the degradation of traditional skills have been undertaken (including for farmers). Therefore, further detriment is estimated based on an assumption that pass-

¹⁵⁰ Based on Eurostat (2016) *Fishery statistics*. Available at: http://ec.europa.eu/eurostat/statistics-explained/index.php/Fishery_statistics

¹⁵¹ Please see Section 3 for the analytical framework, scope and limitations.

to-pass overlap for a current farmer would be double what a traditional farmer could achieve. The detriment is therefore twice as high as the benefit estimated, **£7.8m**.

Fundamentally, cultivation applications in precision agriculture generate benefits because the precision of the operations makes fields more productive. One such operation relates to the use of the same tyre tracks on the field for the duration of the year, ensuring that the minimum amount of field is compressed. Soil is more productive when it has not supported the weight of a tractor, so beyond the loss of benefits for the five-day period of outage, further loss would be incurred, as the loss of GNSS would make it harder for the driver to stay on the same track. The additional detriment would materialise as reduced yield and consequent increases in grain and other prices, which could materialise several months after the outage.

Yield increases from precision agriculture range in estimates depending on the size and type of field and crop. Assuming 15% yield increase from GNSS,¹⁵² the detriment suffered from its loss would be a reduction of domestically-produced cereal of 13%. In 2015, the value of cereals produced in the UK was £2.9bn.¹⁵³ The loss in yield would reduce self-sufficiency of the UK in terms of cereal production, and supplies would be needed from elsewhere. A five-day outage of GNSS could affect the yield of the crop season by 13%, so assuming three seasons, the loss is estimated at **£125.7m**

Further losses of **£22.2m** in lost GVA over the five-day period can be expected in the food processing industries that rely on UK and imported agricultural inputs. This is because the 13% reduction in agricultural productivity will reduce the total domestic inputs available to the sector – by £54.3m¹⁵⁴ over the five-day period – and therefore the total value add. The effect of loss of import for the sector is considered separately in section 5.1.12.

GNSS benefits of livestock tracking and hunting have not been monetised, but are considered to be of limited importance as the market remains immature.

Similarly for silviculture, benefits have not been monetised, but given a fairly limited market with users of forestry software solutions estimated at 1,000 in Europe,¹⁵⁵ the benefits to the UK (and therefore losses incurred from outage) are expected to be of limited magnitude.

5.2.5 Surveying

*The loss of GVA is found to be: **£344.8m***

*The loss of utility benefits is found to be: **£0***

In surveying, benefits attributable to GNSS would be lost if GNSS suffered an outage. As all relevant surveying equipment integrates GNSS, reversal to non-GNSS methods is infeasible. Loss would therefore extend far beyond the loss of efficiency benefits, as all economic activity in the sector would most likely cease during the period of the outage. In total, surveying benefits for the average five-day period have been estimated at **£0.2m**.

Detriment beyond those losses (estimated against a GNSS-free baseline) would be felt as the surveying sector would be unable to function. Surveying is contained in the Engineering activities

¹⁵² Low end of the 9%-35% range in Ingenia Online (2015) *Precision farming*. Available at: <http://www.ingenia.org.uk/Ingenia/Articles/972> [accessed 12/04/2017]

¹⁵³ DEFRA (2016) *Agriculture in the United Kingdom*

¹⁵⁴ ONS (2017) *UK input-output analytical tables*

¹⁵⁵ GSA (2017) *GNSS Market Report Issue 5*, forthcoming

and related technical consultancy, which employed 372,000 people and contributed £25.8bn to GDP in 2015.¹⁵⁶ In 2014, the UK had approximately 53,000 surveyors.¹⁵⁷ Assuming surveyors have the same productivity as the rest of the sector, loss of all activity for five days would imply loss of GVA of **£50.5m**.

However, the sector itself generates economic activity of much greater magnitude still. Construction activities, for example require inputs from surveyors, and civil engineering projects such as road and rail construction would not be able to continue without inputs from the surveying profession, indicating the loss to society will vastly exceed the modest monetised loss.

In the UK, Civil Engineering contributes £15.7bn to GDP.¹⁵⁸ A loss of GNSS-based surveying inputs is assumed to reduce activity on the first day by 75%, and for the rest of the five-day period, only 5% of activities can be continued. The required effort to rectify the delay imposed on construction projects is assumed to add 50% to costs. The estimated economic impact of loss of GNSS in civil engineering is therefore **£294.1m**. The majority of other construction activity uses GNSS to very limited extent, and the loss has not been monetised.

In addition to this monetised loss, the oil and gas sector could be affected by loss of GNSS through the loss of marine surveying vessels used for exploration. The impact depends on whether any prospecting activities coincide with the loss, and have not been monetised. However, stakeholders have commented that it costs approximately £200,000 per day to run a survey vessel, so cost could accumulate fast.

5.2.6 Rail

*The loss of GVA is found to be: **£94.9m***

*The loss of utility benefits is found to be: **£15.5m***

Benefit in Connected Driver Advisory Systems over the five-day period would all be lost, as there are no back-up systems. The monetised benefits from a five-day period that would be lost have been estimated at **£0.1m**.

Greater impact would be felt through the application that uses GNSS to open the appropriate doors at the right side of the train (depending on the station layout), which is highly mature. Trains without a guard use GNSS to open the doors (otherwise it is the guard's job). The system uses GNSS to figure out which station the train is at, and extract relevant properties of the station. Originally, if GNSS was not available, the procedure was for the train to continue until it received a positional fix, causing severe disruption to commuters. The system has since been updated such that the driver is able to open the train doors, but only after a system restart, and manual input of the station name into the system. The additional time required at each station has been estimated to be 0.5-1 minute.

The 2,621 stations on the UK's 15,799 km railway network suggest there is a station every 6km, on average. The concentration of stations is greater in London and the South East, where the majority of rail journey start and or finish. The average rail passenger journey is 37.4km, indicating the average train journey would pass 4 intermediate stations (plus origin and destination).

¹⁵⁶ ONS (2017) *Annual Business Survey* for 2015.

¹⁵⁷ Special extract from Eurostat, occupation code, ISCO-08: 2165

¹⁵⁸ ONS (2017) *Annual Business Survey* for 2015

At 1.72bn rail passenger journeys per year, the proportion of track that is served by driver-only operations (30%) and assuming an average five-day period, five (relevant) stations per passenger journey, 1 minute delay per station and no further congestion-based effects, the loss of time over a five-day period amounts to 0.7m passenger-hours, which – valued at the average hourly wage and conservatively assuming it is all leisure travel and therefore worth a third of business time – yields a conservative estimate of **£2.8m**.¹⁵⁹

Additional to the passenger time lost, a sizeable indirect impact is monetised for the loss of productivity resulting from people's inability to get to the places they desire. The equivalent FTE of 0.7m passenger hours is 341, and using the average UK labour productivity of £50,000,¹⁶⁰ the equivalent GVA lost is **£17.1m**.

However, the loss of Connected Driver Advisory Systems and increased time spent at platforms is very likely to have a strongly detrimental effect on the utilisation of the network. UK railways run close to capacity and therefore need to be used in the most efficient way. Short delays at all stations and to all trains will most likely not be synchronous, which will imply start-stop travel on the network. This would require additional spacing between trains and therefore reduced efficiency. Cancellations of trains are also expected (indicating much greater magnitude of delay to certain passengers) and subsequent impacts through missed or delayed meetings, which would affect not only the passenger, but all the people scheduled for the same meeting.

The average price of a single UK train ticket is £5.46,¹⁶¹ implying total fares paid over five days of £127m. If a train is cancelled, the operator is obliged to compensate passengers the full amount.¹⁶² Assuming the reduced efficiency caused by loss of Driver Advisory Systems and the automatic doors described above materialise as cancellation of 10% of trains, the operators would be hit with a loss of **£12.7m** over the five days, on average.

Additional detriment from lost production from workers stuck on platforms waiting for cancelled trains is estimated at **£77.7m** using the same ratio of lost GDP to passenger detriment as derived above (6.1).

5.2.7 Legal profession

The impact is: Negligible.

The timing accuracy required to track timesheets and billable hours for lawyers is not regulated, and therefore depends on the firm's internal practices. Loss of GNSS would most likely result in drift, but all NTP-servers have built-in holdover capability. The drift would most likely be of relatively limited magnitude and strongly correlated between start and end-times, so the actual time spent would most likely still be reasonably accurately measured. As seen in Annex 3, even the cheapest oscillators would maintain accuracy with UTC of approximately 2 minutes, which would most likely mean the

¹⁵⁹ These two paragraphs use statistics from ORR (http://orr.gov.uk/data/assets/pdf_file/0015/22056/passenger-rail-usage-2015-16-q4.pdf, <http://orr.gov.uk/statistics/published-stats/station-usage-estimates>, http://www.orr.gov.uk/data/assets/pdf_file/0015/22056/passenger-rail-usage-2015-16-q4.pdf), RSSB (<https://www.rssb.co.uk/hot-topics/driver-only-operation>), ONS (<https://www.ons.gov.uk/employmentandlabourmarket/peopleinwork/earningsandworkinghours/bulletins/annualsurveyofhoursandearnings/2016provisionalresults>)

¹⁶⁰ London Economics (2016) *Size and Health of the UK Space Industry 2016*, grown using ONS labour productivity index at: <https://www.ons.gov.uk/employmentandlabourmarket/peopleinwork/labourproductivity/timeseries/a4ym/prdy>

¹⁶¹ National Rail (2017) *About your rail fare*. Available at: http://www.nationalrail.co.uk/times_fares/ticket_types/83871.aspx [accessed 16/03/17]

¹⁶² Office of Rail Regulation (2014) *Passenger compensation and refund rights for delays and cancellations*

chain of events leading to email communication would be preserved. Stakeholder consultation suggests the oscillators used by lawyers are better than TCXO.

5.3 Mass market (consumer applications)

5.3.1 Location-Based Services

The loss of GVA is found to be: £0

The loss of utility benefits is found to be: £0.8m

Loss of GNSS would impact smartphone and tablet users of the wide range of location-based applications. However, depending on the user's environment, the impact may be vastly reduced by the availability of alternative positioning sources, notably Wi-Fi. For fitness trackers, no alternative location source is known. As the benefits from fitness trackers are driven by the inducement of more activity, it could be argued that a certain 'mental holdover' would be present, so the benefits would probably not be lost.

Benefits from inducement to use public transport rather than personal cars may be considered resilient to loss of GNSS as the primary geographical area for such effects is in cities where Wi-Fi is available in abundance. On the other hand, the strain to rail operations (discussed above) might reduce the desirability of rail solutions significantly. The anticipated increase in congestion on the roads may also make the use of buses less appealing and therefore bring people back to cars. On balance, the five-day benefits of the modal shift of **£0.8m** would therefore most likely be lost.

Benefits of pedestrian navigation would most likely be kept as the majority of pedestrian navigation is in cities, where alternative location sources are available. In fact, the benefits of such navigation solutions (based on all sources) may ultimately increase as a result of the congestion that will make people walk rather than drive. However, such benefits have not been monetised.

The paragraph above fundamentally assumes that, faced with an electronic map on a smartphone, individuals will be able to ascertain their position 'within the light blue circle', and navigate streets based on visual aids, street names and the local environment. This assumption is considered valid certainly for the adult population, but could be questioned among 'millennials' or 'the smartphone generation' whose ability to use conventional navigation techniques relies on personal interest rather than ever having had to learn it. Indeed, a recent study published in the journal *Nature Communications*¹⁶³ suggests that individuals who navigate by satnav switch off the brain's navigation centres and therefore lose track of where they are and the ability to identify the most suitable route. The study analyses individuals with a better-than-average sense of direction, so the results can be expected to apply to most road users.

It is beyond the scope of this study to test the assumption on people's ability to navigate, but future work to ascertain these skills in the population is encouraged.

5.3.2 Road

The loss of GVA is found to be: £0

¹⁶³ Javadi, A-H; Emo, B; Howard, L R; Zisch, F E; Yu, Y; Knight, R; Pinelo Silva, J; Spiers, H J (2017) *Hippocampal and prefrontal processing of network topology to simulate the future*

*The loss of utility benefits is found to be: **£1,869.7m***

Navigation

Devices used for turn-by-turn navigation would fail very soon after the signals were lost. However, for fixed-mounted smartphones (i.e. not held by a passenger) and dedicated **navigation** devices, dead reckoning from inertial sensors in combination with positioning software solutions would be able to keep devices in progressively declining service for a limited period, and until the car is turned off at the very latest.¹⁶⁴ Handheld smartphones would continue to derive position from all available sources, so a position would continue to be available (although the accuracy is not known). The impact of loss of GNSS on handheld smartphone users depends on the availability of alternative sources of positioning. On a country road, the blue circle indicating uncertainty could increase to Cell-ID levels (radius of more than 2km), while a driver on a residential street could experience accuracy almost to the level of GNSS thanks to an abundance of Wi-Fi hotspots in the vicinity.

Given the short holdover capability of devices in this sector, it can be assumed that all benefits generated by GNSS would be lost during the outage. The estimated loss would be **£16.7m**.

This loss of benefit will be compounded by the effects on congestion as GNSS-dependent drivers lose the ability to optimise their route, spending more time navigating and going back on wrong turns. Together with second order network effects that consider the impact of slower moving GNSS-dependent drivers on the entire road network (i.e. on all drivers), the estimated cost of increased congestion during the outage for all professional¹⁶⁵ and mass market users is **£1,853m**

This figure is based on a monetised estimate of the additional time spent by road users in increasingly congested traffic (£1,668 m) and the associated loss of fuel due to idling (£185 m).

To arrive at an estimate for the value of driver time lost to congestion, it is assumed that users of motorways and 'A' roads see their travel time increase by 18%¹⁶⁶ (or about 10.6 million more road-user hours over five days, based on 2016 road usage data and average car occupancy¹⁶⁷) and users of 87 city networks for which data are available will see their travel time increase by a total of 86 million additional road-user hours¹⁶⁸, ranging from an initial day 1 journey time increase of about 60%¹⁶⁹ (57 minutes per driver) for London and 20% (19 minutes per driver) for smaller UK cities. This reduces after subsequent days to reflect some driver substitution away from the road network). The resulting total travel time increase is about 97 million hours over five days. This is then monetised using the average UK value of time estimate of £17.31 per hour from the Department for Transport¹⁷⁰.

¹⁶⁴ Consultation with maker of GNSS modules used for road navigation and comment made by representative of Google at International Navigation Conference 2016.

¹⁶⁵ As described in section 5.2.1, professional and mass market road applications cannot be disentangled, so this figure presents the combined loss faced by both types of users.

¹⁶⁶ This is the percentage of travel time reduction estimated to come from GNSS, based on NAVTEQ traffic figures. Available here: http://filecache.drivetheweb.com/mr5str_navteq/61738/download/Media_Fact_Sheet_NAVTEQ_Traffic_Europe+MAH_BW.pdf

¹⁶⁷ Based on the Department for Transport's Road Traffic Statistics, available here: www.gov.uk/government/organisations/department-for-transport/series/road-traffic-statistics

¹⁶⁸ These estimates are based on driver and congestion figures from Inrix's Global Traffic Scorecard. Available here: <http://inrix.com/scorecard/>

¹⁶⁹ For reference the 2009 and 2010 London tube strikes saw travel times increase by 74% during the evening period and 35% during the morning period, based on statistics from Tsapakis, I., et al. (2011). *Effects of Tube Strikes on Journey Times in the Transport Network of London*. Transportation Research Record.

¹⁷⁰ Department for Transport (2015). Values of travel time savings and reliability: final reports

To estimate the loss of fuel to congestion, this study uses an estimate of 1.8 litres of fuel consumed per hour¹⁷¹ of congestion, which is then valued at the national average 2016 price of fuel which factors in the split between diesel and petrol cars in the UK (£1.09/litre).

Reflecting the higher road density, incident sensitivity and GNSS-dependence (among private cabs, delivery drivers and other professional users) in cities, the approach suggests that the vast majority of impact (89%) is accounted for by increased congestion in the 87 cities for which data are available, and the rest (11%) is accounted for by the increased congestion on motorways and 'A' roads.

A further detrimental effect is related to the precise moment in which GNSS is lost. If this happens to be at rush hour, the vast majority of drivers will lose their precise location, and the speed gauge and other applications on the satnav may present rather confusing values. This is likely to perplex drivers, and could result in low impact accidents, or worse. However, because of the holdover capability, the likelihood of a sudden spike in accidents is reduced.

As mobile telecommunications and internet data centres have been found to be resilient to loss of GNSS (see section 5.1.3), drivers would have access to electronic maps from their smartphones, but would not be allowed to move the map while driving. Therefore, paper maps would be required for drivers who regularly travel unknown routes. Neither the availability of paper maps nor the ability of people to use them efficiently has been verified for this study.

Insurance telematics

The estimated benefits of **insurance telematics** are derived as a result of behavioural changes in drivers who take up the policy compared with other drivers. The technology has been shown to reduce accident risk for young drivers by 40%. The response to loss of GNSS in insurance telematics depends on whether the system has ingrained the safer behaviour in drivers or they see it as a free pass to drive recklessly. There is no meaningful way to estimate such a behavioural response.

Emergency and breakdown calls (eCall and bCall)

All benefits estimated for **eCall and bCall** would be lost for the duration of the outage as location information would no longer be available in the emergency message. This would likely result in serious confusion in the case of an automatic call from a crashed vehicle as no information would be forthcoming. As the proliferation of the application remains marginal in the UK, the loss is unlikely to be of great magnitude.

5.3.3 Non-road transport

The loss of GNSS might cause difficulty for skippers of recreational vessels and pilots of small aircraft flying under visual flight rules (VFR). Both groups of people are required to be able to navigate without the use of GNSS, but these skills are considered in decline, helped by the availability of cheap GNSS-based solutions for at least a decade. It is likely that skippers of recreational vessels would get lost if GNSS were disrupted, which could easily result in emergency calls and actions for the coastguard. Similarly for VFR aviation, the loss of GNSS may result in pilots making the wrong decision if conditions worsen (e.g. infringing notified airspace or aiming for an airfield outside its reach). The impact could be severe in bad weather, but it is likely that skippers or pilots would refrain from instigating their leisure activity if GNSS were lost. The loss has not been monetised.

¹⁷¹ Texas Transportation Institute (2012). *Urban Mobility Report*. Available here <https://mobility.tamu.edu/ums/archive/#umr2012>

5.4 Summary of impacts

Total economic loss to the UK estimated as a result of loss of GNSS is **£5.2bn over the five-day period**, composed of £1.7bn of lost GVA and £3.5bn of utility loss.

The impact is estimated against the counterfactual in which GNSS (the preferred source of PNT across a wide variety of applications) functions normally. The estimate therefore reflects that some applications rely on GNSS with no suitable backup system in place, meaning that loss of GNSS cripples the activity, and has cascading effect on sectors and industries for which inputs from such activities are critical.

The impact by application is summarised in the table below, with a RAG (red/amber/green) rating summarising the overall impact on the application (capturing non-monetised impacts).

Infrastructure	Aspect	RAG	Loss of GVA (direct+secondary) (five days)	Loss of utility benefits (five days)
Chemicals	Transport of dangerous goods	Amber	Low risk, but potentially significant impact	Low risk, but potentially significant impact
Civil nuclear	Tracking of classified goods	Amber	Low risk, but potentially significant impact	Low risk, but potentially significant impact
Communications	Fixed-line telecommunications	Green	£-	£-
	Cellular telecommunications	Green	£-	£-
	Broadcast – DVB	Amber	Negligible	Negligible
	Broadcast – DAB	Amber	Negligible	Negligible
	TETRA (PMR)	Grey	Unknown	Unknown
	Internet data centres	Green	£-	£-
Defence	Out of scope	Grey	Out of scope	Out of scope
Emergency services	Public-Safety Answering Points	Amber		£508.0m
	Emergency vehicle logistics	Amber		£1,023.5m
Energy	Electricity transmission	Amber	Low risk, but potentially significant impact	Low risk, but potentially significant impact
Finance	Bank trading centres	Green	£-	£-
	ATMs and payment networks	Green	£-	£-
Food	Food security	Grey	See Agriculture & Fishing usage applications	See Agriculture & Fishing usage applications
Government	Weather forecasting	Amber	£1.5m	£0.4m
	Offender tracking	Amber	£0.4m	Low risk, but potentially significant impact
	Evidence management	Amber	Negligible	Low risk, but potentially significant impact
	CAP and CFP compliance monitoring	Grey	Unknown	Unknown
Health	Dementia tracking	Grey	Unknown	Unknown
	Lone worker tracking	Grey	Unknown	£0.7m
Space	LEO satellites	Green	£-	£-

	Ground stations		£-	£-
	Satellite communications		£22.5m	See Maritime transport infrastructure
Transport infrastructure	Road transport infrastructure		Negligible	See Road: Navigation usage applications
	Rail transport infrastructure		Negligible	See Rail usage applications
	Maritime transport infrastructure		£1,069.3m	See Maritime usage applications
	Air transport infrastructure		£-	£-
Water & Sewerage	Fixed-location noise loggers		Negligible	Negligible
Professional application	Aspect	RAG	Loss of GVA (direct+secondary) (five days)	Loss of utility benefits (five days)
Road	Navigation			£26.3m
	Logistics and fleet management		£24.2m	
Maritime	Navigation		£4.8m	
	Search and rescue applications			£0.1m
	Fishing		£7.1m	
Aviation	Reduction in DDC and CFIT		£0.1m	
	Search and rescue (ELTs and PLBs)			£0.3m
Agriculture	Cultivation		£151.6m	£4.2m
	Livestock tracking, hunting and silviculture		Negligible	Negligible
Surveying	All applications		£344.8m	£-
Rail	Driver advisory systems		£17.2m	
	Automatic train doors			£2.8m
	Train cancellations		£77.7m	£12.7m
Legal	Timesheets and billable hours		Negligible	Negligible
Mass Market application	Aspect	RAG	Loss of GVA (direct+secondary) (five days)	Loss of utility benefits (five days)
Location-based services	Public transport modal shift		£-	£0.8m
	Pedestrian navigation		£-	Negligible
Road	Navigation		£-	£1,869.7m
	Insurance telematics		£-	Low risk, but potentially significant impact
	Emergency and breakdown calls		£-	Negligible
Non-road transport	Recreational boating		Negligible	Low risk, but potentially significant impact
	VFR aviation		Negligible	Low risk, but potentially significant impact

5.4.1 Severely-affected applications

Loss of GNSS would imply severe disruption to a handful of industries and applications, and the dominoes triggered by the loss in those industries and applications would be wide-ranging, and affect the majority of society. The table below restates those particular uses of GNSS.

Infrastructure	Aspect	RAG	Loss of GVA (direct+secondary) (five days)	Loss of utility benefits (five days)
Space	Satellite communications		£22.5m	<i>See Maritime transport infrastructure</i>
Transport infrastructure	Maritime transport infrastructure		£1,069.3m	<i>See Maritime usage applications</i>
Application	Aspect	RAG	Loss of GVA (direct+secondary) (five days)	Loss of utility benefits (five days)
Surveying	All applications		£344.8m	£-
Rail	Automatic train doors			£2.8m
	Train cancellations		£77.7m	£12.7m
Road	Navigation		£-	£1,869.7m

6 Alternative and potential future mitigation strategies

This chapter addresses the final research objective, namely:

- Identify the **cost** and **effectiveness** of mitigation strategies

This task aims to identify the options available to GNSS users who wish to mitigate their reliance on GNSS for everyday operations. Three services are available from GNSS: Position, Navigation and Timing (PNT), and it is useful to consider available options for users of each service. Many users will rely on two or more services depending on environment of use, but some generalisation is feasible:

- Users of **positioning** range from *consumer electronics* (smartphones, fitness trackers), insurance telematics, and non-safety critical rail and maritime applications; over *safety and Search and Rescue* applications (such as emergency beacons under the Cospas-Sarsat programme); to *high-accuracy applications* including precision agriculture (variable rate technology) and construction applications.
- Similarly, for **navigation**, users of GNSS range from consumers and transport professionals for road transport over transport operations and approaches, to automatic steering for agriculture and unmanned navigation for RPAS (Remotely Piloted Aerial Systems).
- **Timing** users have significant overlap with the critical national infrastructures and include communication, power distribution and financial operations.

Mitigation strategies range from traditional methods and current and future technologies, discussed in the sections below.

6.1 Traditional/current methods

For positioning and navigation, application-specific alternatives to GNSS could be used. This includes the use of clocks and sextants, or radar systems, to determine position at sea, and the use of paper maps on the road. The aviation sector could also make use of a number of back-up systems such as *VHF omnidirectional range (VOR)*, *distance measuring equipment*, or *instrument landing systems*.¹⁷² However, there is currently no *universally applicable* alternative to GNSS for the case of positioning and navigation, and many of the traditional means of navigation might not be readily available or useable by the individuals in question.

For example, for **pedestrian and road navigation**, it is unknown whether delivery drivers carry maps in their vehicles. More fundamentally, the ability of drivers to actually navigate successfully based on maps is also not clear, and the number of maps that would be required, most likely exceeds what is in stock (e.g. London A-Zs). The skills-based considerations do not stop at drivers as many stakeholders have expressed concern at the ability of mariners to revert to traditional means. This concern extends to leisure boating and VFR flight. For other industries, e.g. **agriculture** and **surveying**, no comparable traditional mitigation strategies exist. The development of automated container ports also means that GNSS-based systems have replaced manual labourers, and large ports would not be able to revert to barcode-based identification of containers.

¹⁷² Department of Homeland Security (2011). *National Risk estimate: Risks to U.S. Critical Infrastructure from Global Positioning System Disruptions*

Loss of the timing capabilities of GNSS can be mitigated by using adequate oscillators in the GNSS timing receiver that can hold time for a certain holdover period, ranging from a few minutes to months (see Annex 3), or through the use of caesium or rubidium clocks.¹⁷³ However, higher quality equipment with longer holdover periods is more expensive. Hence, loss of GNSS signal will still affect sectors relying on timing capabilities, and the extent of the impact of this loss will depend on the quality of the oscillator used as well as other mitigation strategies that are in place.¹⁷⁴

6.2 Current and future technologies

This section summarises the current and future technological solutions to mitigate the risks associated with loss of GNSS, and considers the costs and effectiveness of mitigation against the loss estimated in section 5.

The section is organised by technology and discusses each in turn. Four of the technologies have been identified as relevant for position and navigation. Coverage, dimension and accuracy of each are summarised in Table 3 below, with the discussion to follow in the relevant sections.

Table 3 Accuracy and coverage of positioning (and navigation) mitigation technologies

Technology	Potential Coverage	2D/3D Positioning	Accuracy
eLoran	National / Global	2D	10-20m – improving to 5m with eDLoran
Locata	Local / Regional	3D	< 1cm
Omnisense S500	Local	3D	20cm-2m
Iridium STL service	Global	3D	Horizontal: 20m-50m unassisted and 10m in augmentation scenarios (1σ)

Source: London Economics research based on sources referenced in this section.

In addition to the four positioning and navigation-relevant technologies, four additional technologies have been identified specifically for the Timing property of GNSS. Table 4 summarises the findings for all eight technologies that are discussed in turn in this section.

Table 4 Timing accuracy of mitigation technologies

Technology	Accuracy
NTP timing servers (NPL)	≤ 1ms – 30ms
NPL MSF 60 kHz radio signal	10ms
PTP	10ns (1×10^{-5} ms) - 100ns (0.0001ms) – but dependent on network setup and clock used as a timing source
NPL-Time	100ns (0.0001ms)
eLoran	100ns (0.0001ms)
Locata	2.5ns (2.5×10^{-6} ms) – potentially much better
Omnisense S500	100μs (0.1 ms) – possibly up to 10ns (1×10^{-5} ms) in the future
Iridium STL service	Compatible with IEEE-1588 standards: 10ns-100ns

Source: London Economics research based on sources referenced in this section.

¹⁷³ The Royal Academy of Engineering (2011). *Global Navigation Space Systems: reliance and vulnerabilities*.

¹⁷⁴ See Curry, C. (2010). *Dependency of Communications Systems on PNT Technology*. Chronos Technology and Annex 3 for a thorough analysis of how long different oscillators can keep accurate timing information in the case of a loss of GPS.

6.2.1 eLoran

One potential mitigation strategy that is applicable to a number of applications is **eLoran**. eLoran is a terrestrial system that, similar to GNSS (in layman's terms), transmits a timing signal and location of the origin of the signal, allowing receivers to compute time (and distance) travelled, and thus location. **The cost of resurrecting (e)Loran would be in the order of £50m over a 15-year period.**¹⁷⁵

Positioning and navigation performance of eLoran is similar to GNSS¹⁷⁶. However, since it is a ground-based system that operates independently of GNSS, eLoran is not exposed to the same risks as GNSS. Because of this, eLoran could work as a complementary source of PNT and mitigate the risks associated with loss of the GNSS signal.¹⁷⁷ Properties of the eLoran signal mean it could be used in areas where GNSS does not provide sufficient signal strength, for example in buildings or underground.¹⁷⁸ eLoran's transmitted timing signals allow easy translation to Coordinated Universal Time (UTC) with measured timing errors of less than 100 nanoseconds in a 2014 test.¹⁷⁹ This is better than the current timing accuracy requirements of major timing applications.

On the other hand, eLoran is only able to provide 2D positioning information, and its frequency is susceptible to interference from compact fluorescent lamps (also known as low-energy lightbulbs) which operate on 40-80kHz and therefore potentially interfere with eLoran receivers attempting to decode the signal on 90-110kHz.¹⁸⁰ In addition, the accuracy of eLoran makes it unsuitable for certain GNSS applications. The antennae required to receive eLoran are approximately the size of a Frisbee making eLoran a viable option for infrastructure timing users, vessels, and aircraft. Road vehicles are not considered likely to incorporate eLoran as the interference is likely stronger in the environment where navigation is required, namely cities, and the form factor of the antenna is unappealing.

The future status on eLoran is unclear as only one mast remains in operation in Europe (at Anthorn). With one mast available, eLoran is not an option as mitigation for navigation and positioning.

The user cost of an eLoran solution is currently higher than GNSS, but leading manufacturers have confirmed that receiver prices would reach a competitive level within one year of firm Government commitment to continuing the eLoran service. Additional costs of a combined eLoran and GNSS solution at that point in time will therefore be the additional antenna.

6.2.2 Satellites Time and Location Service (STL)

Iridium Communications has recently introduced its Satellite Time and Location (STL) service. This service will provide positioning, navigation and timing information through Iridium's satellites at much greater signal strength than GNSS (300-2400 times the power), offering a resilient back-up to GNSS for critical national infrastructure. Satellite Time and Location is compatible with IEEE-1588 standards and can achieve timing accuracy of 10ns-100ns and horizontal position accuracy of 20m-

¹⁷⁵ Assuming the US estimate for 28 masts can be linearly transferred to 2 masts in the UK.

¹⁷⁶ Cameron A. (2014). *GNSS Backup Delivers 5-Meter Accuracy*. Retrieved 18/11/2016. <http://gpsworld.com/gnss-backup-delivers-5-meter-accuracy/>

¹⁷⁷ International Loran Association (2007). *Enhanced Loran (eLoran): Definition Document*. Retrieved 01/11/2016, <https://www.loran.org/otherarchives/2007%20eLoran%20Definition%20Document-1.0.pdf>

¹⁷⁸ Divis, D. A. (2014), *Proposal for U.S. eLoran Service Gains Ground*, Retrieved 01/11/2016, <http://www.insidegnss.com/node/3853>

¹⁷⁹ Curry, C. (2014). *Delivering a National Timescale using eLoran*. <https://rntfnd.org/wp-content/uploads/Delivering-a-National-Timescale-Using-eLoran-Ver1-0.pdf>

¹⁸⁰ For more information, please see Annex 4.

50m (10m with augmentation). Such performance would make STL attractive for critical infrastructures and transport applications.

STL is a private enterprise including Iridium, Spectracom, McMurdo, and Orolia (three leading GNSS companies). The system costs are therefore covered by the companies, so the costs of the solution needs to be considered from a user perspective. No information on user cost is available, but the STL signal is transmitted in L-band (1626MHz) on a frequency near GPS Coarse Acquisition signal (1575.42MHz), so it appears possible that combined receivers could emerge in the future. These would not only be attractive from a risk mitigation perspective, given the greater signal strength, but would be interesting for seamless indoor and outdoor navigation. As user equipment is not yet available, form-factor considerations are premature and the applicability of the solution is therefore expected to be at least similar to eLoran. Device prices and subscription fees to access the service (if any) are not yet known.

6.2.3 Locata

Locata is another potential alternative to GNSS that could be used at a local level. Locata provides accurate positioning information, and has achieved accuracy at sub-centimetre level.¹⁸¹ Instead of using satellites, Locata works by creating local hotspots on the ground transmitting radio-positioning signals. Several Locata hotspots form a local network of transmitters called *LocataNet*.¹⁸² **Locata's** time synchronisation capability is promising, achieving a synchronisation accuracy of 2.5 nanoseconds over a 35-mile distance in tests by the University of New South Wales in 2013.¹⁸³

Locata works in a similar way to GNSS and, like eLoran and STL, can work both as a standalone alternative to GNSS – in case of an outage of GNSS – or as a complimentary extension to GPS. Locata receivers can track both GNSS satellite signals and terrestrial Locata signals offering seamless integration of the two systems.

However, unlike eLoran and STL, Locata could not act as a large-scale alternative to GNSS, but is specifically designed for localised applications.

Locata is still in the early stages of development. Nevertheless, it has already had successes in military applications, e.g. in the U.S. Military White Sands Missile Range¹⁸⁴. In addition to this, NASA has also announced the installation of a LocataNet at the Langley Research Center as the core PNT technology for their safety-critical Unmanned Aerial System (UAS) research.

6.2.4 Omnisense SP500 System

A further potential GNSS alternative at a local level is the **Omnisense S500 Cluster geolocation system**. The Omnisense system is a full 3D positioning system that, similarly to Locata, works by deploying a number of mobile beacons that periodically broadcast navigation signals, forming a wireless network of beacons.

¹⁸¹ Barnes J. et. al. (2004). *Structural Deformation Monitoring Using Locata*. Retrieved 09/12/2016 from https://www.fig.net/resources/proceedings/2004/nottingham/proc/ts_04_4_barnes_et.al.pdf

¹⁸² Locata Corporation (2015). *Locata Positioning will Underpin Future Unmanned Aerial System Research at NASA's Famed Langley Research Center*. Retrieved 18/10/2016 from <http://www.locata.com/2015/09/locata-positioning-will-underpin-future-unmanned-aerial-system-research-at-nasas-famed-langley-research-center>

¹⁸³ Locata Corporation (2013). *Superb performance demonstrated in world-first paper on Locata's time synchronization*. Retrieved 08/12/2016 from <http://www.locata.com/article/locatas-time-synchronization-capability/>

¹⁸⁴ Connolly, P., and Bonte, D. (2016), *Low-Cost Precision GNSS Receivers*, ABLresearch

According to Omnisense, their system is portable (no fixed infrastructure requirement), easy to install and competitively priced and can be used in industrial settings for tasks such as site logistics, yard management, construction, fleet management, etc.; agriculture for cow tracking/monitoring and environmental monitoring; emergency services for firefighters, first responders, police, etc.; healthcare for dementia tracking, sports and fitness training, etc.; and defence for soldier training, GPS-denied situations, etc.¹⁸⁵ The Omnisense system could thus be a viable GNSS backup solution for very localised tasks that require a rapid and easy deployment.

Omnisense is market ready and a system can be acquired from Omnisense. In terms of coverage, it is targeted towards local applications such as the use on a farm for tracking of cows. Given this, the system would not act as a large-scale backup of GNSS PNT information, but rather as a local alternative / backup. Omnisense uses ultra-wide band and 'Wi-Fi' frequencies to deliver its solution.

This section contains additional sensitive information that has been redacted for public dissemination.

6.2.5 Low accuracy timing methods

Another option to access time is to use a free timing service provided by **NTP (Network Time Protocol) servers** – many of which are freely-available on the internet. Unfortunately, the accuracy of these services is limited by, and highly dependent on, the speed of the network path between the client and the server with accuracies ranging from ≤ 1 millisecond to 30 milliseconds. Such NTP servers may also themselves be based on GNSS.

Applications that do not need a very accurate timing signal may also use the **MSF 60 kHz** radio signal provided by the National Physical Laboratory. However, at 10ms, the degree to which this timing source is suitable as a backup depends on the accuracy requirement of the application.

6.2.6 Precision Time Protocol (PTP)

If a higher accuracy is required, the **Precision Time Protocol (PTP)** can be used for synchronisation. Similarly to NTP, PTP is a network based timing protocol. However, unlike NTP implementations that generally perform timestamping on the software level, PTP implementations use dedicated hardware for timestamping in order to minimise network path issues. PTP can be used within local area networks using a local grandmaster clock as a timing input.¹⁸⁶ The use of dedicated hardware allows PTP to achieve accuracies of 10 to 100 nanoseconds^{187, 188}, although the accuracy depends on the type of clock used as a timing source and the setup of the network. It is crucial that the timing source used as an input to the PTP network does not depend on GNSS or provides sufficient holdover capabilities in the case of a loss of GNSS.

¹⁸⁵ See Omnisense Market Sectors / Applications for more details: <http://www.omnisense.co.uk/markets.html> [accessed 13/12/2016]

¹⁸⁶ It should be noted that PTP can also be used without dedicated hardware using software timestamping. However, in this case accuracies are lower, typically around 10 to 100 microseconds. For more information see: EndRun Technologies. *PTP/IEEE-1588 Frequently Asked Questions*. Available at <https://www.endruntechnologies.com/ptp-ieee-1588-faq.htm> [accessed 13/12/2016]

¹⁸⁷ EndRun Technologies. *PTP/IEEE-1588 Frequently Asked Questions*. Retrieved 13/12/2016 from <https://www.endruntechnologies.com/ptp-ieee-1588-faq.htm>

¹⁸⁸ Symmetricom (2010). *NTP and PTP (IEEE 1588) - A Brief Comparison*. Retrieved 13/12/2016 from <http://www.en4tel.com/pdfs/NTPandPTP-A-Brief-Comparison.pdf>

Similarly to NTP, the Precision Time Protocol can also be used as a synchronisation protocol over longer distances. However, performance is dependent on the network configuration¹⁸⁹.

6.2.7 NPL Time

For finance applications, the National Physical Laboratory is now offering a paid for timing service that is delivered entirely over fibre, **NPL Time**, which is certified to meet regulatory requirements that is independent of GNSS. As the service is relatively new it is not yet widely used. In addition to this provision of this service depends on the coverage of current fibre networks and the access NPL has to these. Nevertheless, NPL has already signed agreements to provide NPL Time to both UBS and TMX Atrium.¹⁹⁰

In addition to this, a recent Government Office for Science report¹⁹¹ recommends that NPL explores the feasibility of creating a fully optical fibre network for timing and frequency distribution that links key locations around the UK. The applicability of this and other cabled solutions depends on the application as it is infeasible to roll out fibre-optic networks to all sites in some applications.

6.3 Summary of mitigating strategies

This section summarises the mitigation strategies discussed in this chapter, and identifies useful candidates for mitigation of problems, where ‘traditional methods’ is considered a default mitigation and not mentioned in the tables.

The mitigations assume that all users (NTP-servers, buildings, vehicles, etc.) that may reasonably be expected to equip with the mitigation technologies would do so.

The total estimated loss is **£5.2bn** (see section 5) and mitigation technologies can reduce this loss by up to £4.2bn if all users implement the solution that would precisely meet their requirements with very relaxed conditions for physical and practical implementation.

In reality, these conditions are not likely to hold, so a more realistic estimate, where form factor is considered to be a constraint for applications and local networks (Locata and Omnisense) are not considered is **£1.2bn**. For details on the attribution of mitigation technologies to applications, please see A4.2 in Annex 4.

eLoran and STL are by far the most applicable mitigation technologies, with Locata and Omnisense required for high precision applications in agriculture and surveying.

¹⁸⁹ EndRun Technologies. *PTP/IEEE-1588 Frequently Asked Questions*. Retrieved 13/12/2016 from <https://www.endruntechnologies.com/ptp-ieee-1588-faq.htm>

¹⁹⁰ National Physical Laboratory (2016). *UBS and TMX Atrium use new NPL network timing service*. Retrieved 09/12/2016 from <http://www.npl.co.uk/news/ubs-and-tmx-atrrium-use-new-npl-network-timing-service>

¹⁹¹ Government Office for Science (2016). *The Quantum Age: technological opportunities*. Recommendation 3 and 4

7 Contribution of UK public funding

This chapter presents a high-level assessment of the impact of UK public funding of GNSS. It begins by considering the economic rationale for public intervention applied to GNSS, and then summarises (known) UK funding invested in the field of GNSS to date, and a qualitative analysis of the impact of UK public funding – including Impact Logic Models.

7.1 Rationale for public funding for GNSS

Access to highly reliable and accurate positioning, navigation and timing (PNT) data that GNSS provides is **fundamental to many critical areas of our economy** and to the daily lives of UK citizens, as presented in chapter 4 of this report. However, certain characteristics of GNSS mean that the total investment in GNSS, if left to private investors, would be below the level that is most optimal for society – a situation known as ‘market failure’. There is therefore a strong case for **active government support for GNSS** to overcome the sources of market failure, as outlined below.

7.1.1 General case for investment in research and innovation

All standard theories of economic growth highlight **technological development** as an important driver of growth. Investments in R&D programmes – like GNSS – have been strongly associated with high, though varied, returns. Aghion and Hewitt (2007)¹⁹² find that Total Factor Productivity (a measure of technological change to which R&D contributes) accounted for about 70% of UK economic growth between 1960 and 2000. Similarly, Salter et al. (2000, 2001)¹⁹³ find that most research studies estimate that the social returns to publicly-funded R&D are between 20 and 50%, while Griffith et al. (2003)¹⁹⁴ estimated a social rate of return to R&D-based innovation of 40 to 60%. Despite the strong evidence of high returns from these investments, if left to private investors, the total amount invested will always be below what is optimal from the point of view of society. This is because a significant proportion of the returns to investments in R&D programmes that share similar characteristics to GNSS cannot be monetised by the private investor as they benefit wider society (termed ‘spillovers’). These public returns are approximately two to three times the size of private returns according to research from the UK’s Department for Business, Innovation and Skills (BIS)¹⁹⁵.

7.1.2 Specific case for investment in space-related research and innovation

The space sector is a leading example of the economic value of R&D spending. Research by London Economics¹⁹⁶ and Oxford Economics¹⁹⁷ suggests that the supply-side benefits of public investments in the space industry are very large, with R&D investment by the space sector generating a **social return** (the benefits experienced by the rest of society) of 70% (i.e. every £1 invested in R&D generates £0.70 in benefits for the rest of society), and investments in space producing **higher returns than average science and innovation** investments¹⁹⁸. These supply-side benefits arise because R&D investment in the space industry results in a number of benefits. These include: the **broad diffusion of knowledge** and technology; the **development of a wide range of new services**

¹⁹² Aghion, P. and Howitt, P. (2007). *Capital, Innovation, and Growth Accounting*. Oxford Review of Economic Policy, 23, 79-93.

¹⁹³ Salter, A. and Martin, B. (2001). *The Economic Benefits of Publicly Funded Basic Research: a Critical Review*. Research policy

¹⁹⁴ Griffith, R. Redding, S. and Van Reenen, J. (2003). *R&D and Absorptive Capacity: Theory and Empirical Evidence*.

¹⁹⁵ Knowledge & Innovation Analysis, BIS (2013): *Net Present Values of proposed investments in science and innovation capital in 2015-16, 9 May 2013*

¹⁹⁶ London Economics (2015). *The Case for Space 2015: The impact of space on the UK economy*.

¹⁹⁷ Oxford Economics (2009). *The Case for Space: The Impact of Space-Derived Services and Data*.

¹⁹⁸ London Economics (2015). *Return from Public Space Investments*.

that either could not be offered or only offered at significantly higher cost, in the absence of space-derived data. Together, these effects enhance consumer choice and help UK companies to operate more efficiently; and enable the UK's economic infrastructure to be used more effectively.

Nevertheless, the space sector and GNSS more specifically is characterised by a number of **market failures** that mean that these benefits cannot be fully exploited¹⁹⁹. These market failures include:

- **Public good and coordination failure between upstream and downstream:** The Open Service (OS) signals of GNSS are made freely-available and are both **non-excludable** and **non-rivalrous** – the definition of a public good. The availability and non-excludability of the signals mean that a private investor would not be able to impose a charge on users in order to recoup an attractive return on investment. Therefore, the OS signals, on which the majority and most popular uses of GNSS are based, would not be provided by the private sector. Since the commercially lucrative downstream sector relies on this data to produce goods and services that offer value to manufacturers, vendors, users and wider society (detailed in the logic models in Annex 6 and Annex 7), the under provision of this data would mean a loss of the large benefits associated with these downstream applications.
- **Externalities:** GNSS offers many benefits to society beyond those that are enjoyed by sellers or users of GNSS applications (the definition of a positive externality). Conservative estimates of the **social returns to investments in satellite navigation range between £4 and £5 per £1 of public investment**²⁰⁰. For example, agricultural applications of GNSS can lead to more efficient use of fertiliser, representing a cost saving to the farmer and reduced pesticide damage to the environment. This means that private investors lack an incentive to provide GNSS at the socially optimal level as they cannot monetise all the benefits.
- **Private capital market imperfections:** GNSS has three characteristics that mean that private capital markets are not able to provide the necessary financing: i) **High uncertainty** or risk, particularly in the launch of GNSS satellites; ii) **Large fixed costs** to develop GNSS infrastructure; iii) **Long lead times** for GNSS project development and long payback periods.
- **Government prominence:** Government has always played a prominent role in the space industry, as investor, owner, operator, regulator and customer (as highlighted by the Government's Space for Smarter Government programme²⁰¹) for space infrastructure – a manifestation of the factors outlined above. Government intervention is not limited to the achievement of economic objectives. In fact, policy may be further influenced by adjacent objectives of national strategic interest (e.g. resilience of critical infrastructure), defence (e.g. government as a user of Galileo's Public Regulated Service), political goodwill (e.g. being seen to participate in a multi-national program), political prestige, technological leadership and international competitiveness. These parallel objectives can run contrary to purely economic ones, but suggest a further reason for government intervention in GNSS.

These special characteristics of GNSS mean that there is a **strong economic justification for government intervention** to ensure sufficient investment in GNSS to generate benefits beyond what private investment alone would deliver.

¹⁹⁹ Knowledge & Innovation Analysis, BIS (2013). *Net Present Values of proposed investments in science and innovation capital in 2015*

²⁰⁰ London Economics (2015). *Return from Public Space Investments*.

²⁰¹ The SSGP programme aims to promote the use of space technology and data – including GNSS – to enable the public sector save money, innovate and market more effective policy decisions.

7.2 Overview of UK public funding for GNSS

For the reasons outlined above, the UK supports the development and utilisation of GNSS through the investment of public funds. However, the development of GNSS infrastructure is a high risk undertaking with very large fixed costs (e.g. to build, launch and operate satellite missions). For this reason, the UK works in partnership with other European governments to share costs and risks and better leverage wider investment whilst **building selectively on UK core strengths**. This increases the amount of research and innovation that can be undertaken per £ invested.

For this reason, UK public funding of GNSS (infrastructure and R&D) has primarily been channelled through the UK's contribution to the EU's budget for the European Global Navigation Satellite System (EGNSS, comprising the EGNOS²⁰² and Galileo programmes), and Framework Programmes such as FP6, FP7 and Horizon 2020, as well as ESA contributions and national programmes. Taken together, these funds can be categorised under two broad categories of investments:

- **Upstream investments** to support the development and operation of GNSS infrastructure that provides signals to users.
- **Downstream investments** in the hardware and software applications needed to exploit the signals in downstream markets and in the delivery of public services.

Details of these funds – with an estimate²⁰³ of the UK's contribution sourced from London Economics' own internal analysis – are provided in Annex 5. In summary, we estimate the UK has invested **€1,474m** for GNSS in 2016 prices since 2000 (**82%** of this since 2007) through the EU, ESA and national funds for which we have been able to obtain data²⁰⁴.

As detailed in the previous chapters, there are four GNSS constellations that provide positioning, navigation and timing data that can be used to support downstream applications. GPS, GLONASS, and BeiDou are all foreign, military-controlled systems that are funded by their own national authorities (the U.S., Russia and China, respectively) so UK investment in these systems is limited to that which support the general exploitation of GNSS in the downstream sector. For this reason, the UK's upstream investments – spent via the UK's membership of the European Space Agency – are focused on European GNSS. This fact is reflected in the **logic models** in Annex 6 and Annex 7.

Breaking the total down by category shows that the vast majority of the UK GNSS investment (**€1,379m²⁰⁵ or 94%**) is accounted for by upstream investments, largely via the UK's contribution to the EU's Galileo and EGNOS programmes budget (**€1,348m**). The remaining **6%** or **€94.9m** is allocated to downstream investments and comes from a variety of EU, ESA and national funds. Selected examples of these downstream funds are provided in the box below.

²⁰² European Geostationary Navigation Overlay Service (EGNOS) is a satellite based augmentation system (SBAS) developed by the European Space Agency, the European Commission and EUROCONTROL.

²⁰³ To generate these figures, a number of assumptions have been made: i) It was assumed that financial allocations that covered multiple years were evenly distributed across years in nominal terms unless specific annual allocations were detailed; ii) Funding allocations that covered a period beyond 2017 were adjusted to consider funding spent before 2017 using the first assumption; iii) Nominal figures were converted into real figures by applying ONS estimates of UK GDP deflators to the annually adjusted figures; iv) For European level funds, the UK's contribution was assumed to be equal to the UK's contributing share to the EU budget, where specific details were not provided. In 2015, this contribution was 12.57% after accounting for member state rebates. Details can be found here:

HM Treasury (2015). *European Union Finances 2015: statement on the 2015 EU budget and measures to counter fraud and financial mismanagement*.

²⁰⁴ We have been unable to obtain data on the following funds: ESA TRP; UK SA IPP, UK SA BIC and any funds not yet detailed.

²⁰⁵ Funding figures in this section are presented in 2016 prices unless otherwise stated.

Box 1 Selected downstream funds available to UK firms

Fundamental Elements (EU): With a budget of €111m for the 2015-2020 timeframe, ‘Fundamental Elements’ aims to develop market-ready GNSS chipsets, receivers and antennas that integrate EGNSS into competitive devices for dedicated user communities/target markets.

H2020 (EU): Horizon 2020 is the current EU Research and Innovation programme, offering nearly €80bn in funding for the 2014 – 2020 period and is funded by the UK’s and other member states’ contribution to the EU budget. ‘European GNSS applications’ are part of the Space Theme and is intended to encourage the adoption of EGNSS via content and application development. It also supports the integration of their services into devices, along with their eventual commercialisation.

FP7 (EU): From 2007 to 2013, European GNSS Downstream R&D was funded under the Transport Theme of the 7th Framework Programme for Research and Technological Development (FP7). The GSA managed a portfolio of 86 R&D GNSS projects from a total budget of € 66m. FP7 projects covered a wide range of market segments: Road, LBS, Precision, Professional and Scientific Applications, International Cooperation, Aviation, Rail, Maritime.

Integrated Applications Promotion (ESA): Initiated in 2008, this programme has received a total of €288m from ESA, with the UK as the largest contributor, and aims to develop sustainable operational services for a wider range of users through the combination of different systems (space and terrestrial) and space assets (EO, satcom, Satnav, manned space technologies etc.).

General Support Technology Programme (ESA): With a budget of €1,491m for GNSS and other ESA service domains since 2000, the GSTP has successfully bridged the gap between fundamental technologies and products that can be used by ESA, national programmes and the open market.

Navigation Innovation and Support Programme (ESA): NAVISP, following agreement at the 2016 ESA Ministerial, will strengthen the industrial base of the European navigation sector and support innovation along the entire value chain by facilitating partnership between Member States and industry. The programme will commence in 2017.

National Space Technology Programme (UK): The NSTP programme is intended to complement existing funding streams to progress products up the technology readiness ladder, positioning them for ESA funding or commercial viability. Up until 2014, 4 GNSS projects were funded.

As such, the UK’s returns from the EGNSS programme will have a disproportionate impact on the return from the UK’s overall investments in GNSS, which are in turn reflected in the analysis framework presented in Annex 6.

If we consider UK investment by funding channel, we see that the vast majority (**94%**) comes from EU channels, with EGNSS and the EU’s research funds (FP6, FP7 and H2020) accounting for **92%**, **2%** respectively. ESA accounts for a further **4%** - largely driven by the UK’s contribution to the ARTES 20 IAP – and the remainder (**£19.9m**) comes from national programmes for which we have data.

7.3 Impact of UK public funding for GNSS

7.3.1 Impact analysis and logic model

As described above and in the logic model below (Annex 6 and Annex 7), UK public funding for GNSS can be classified into segments: upstream and downstream investments.

Upstream investments

The UK's upstream investments – worth a total of **€1,379m** since 2016 prices since 2000 (see Annex 5) – are channelled through the UK's contribution to the EU's EGNSS programme to support the delivery and operation of Galileo and EGNOS. Participation in this programme comes from the UK's contribution to the EU budget that funds it.

This contribution allows **UK industry to compete for contracts** to supply and help operate this programme. For example, Surrey Satellite Technology Limited (SSTL) and Airbus Defence & Space have manufactured satellites and payloads for EGNSS in the UK²⁰⁶ and CGI (formerly Logica) have delivered the security systems for Galileo²⁰⁷. The box below provides a short introduction to these selected UK companies that have, via the UK's 12.57% post-rebate contribution to the EU budget (a London Economics' assumption for the purpose of developing illustrative figures), **secured more than 20% of all commercial upstream contracts** under the European Galileo programme²⁰⁸.

Box 2 Selected UK companies that have secured upstream contracts for EGNSS

Surrey Satellite Technology Limited (SSTL)

Originally a spin-out company from Surrey University, SSTL is a world leader in the manufacture of small satellites for use in Earth Observation. The company manufactured the prototype GIOVE-satellite which helped test Galileo signals and proved invaluable for the execution of the project²⁰⁹. In 2010, SSTL, in partnership with OHB Systems of Germany, was awarded a **€566m** contract (of which €236m went to SSTL) to construct 22 payloads for the deployment phase of Galileo²¹⁰.

CGI UK (formerly Logica)

CGI is an end-to-end IT and business services company that delivers complex, mission critical space systems. It is the largest independent supplier of security systems for the Galileo programme and has secured a total of over **€100m**²¹¹ as a prime contractor for the design of Galileo's ground segment and management of the encryption keys for Galileo's Public Regulated Service (PRS). CGI UK was also involved in the delivery of EGNOS as a provider of the system that validates the integrity of the GPS signal, thereby ensuring its use in safety critical applications.

Airbus Defence & Space (formerly Astrium)

Airbus Defence and Space has significant manufacturing operations in the UK and holds the space activity of the European multinational Airbus Group. The company manufactures satellites for

²⁰⁶ UK Space Agency (2014). *Galileo*. Retrieved 6/9/2016, <https://www.gov.uk/government/case-studies/galileo>

²⁰⁷ London Economics (2015). *The Case for Space 2016: The impact of space on the UK economy*

²⁰⁸ House of Commons (2007). *Galileo: Recent Development. First Report of Session 2007-2008*. Available here: <https://www.publications.parliament.uk/pa/cm200708/cmselect/cmtran/53/53.pdf>

²⁰⁹ Please see: <https://www.sstl.co.uk/Missions/Europe-s-Satellite-Supported-Navigation-System>

²¹⁰ House of Commons (2011). *Transport Committee – Written Evidence, EU transport policy*. Available here: <https://www.publications.parliament.uk/pa/cm201012/cmselect/cmtran/751i/751we04.htm>

²¹¹ Please see: https://www.cgi-group.co.uk/sites/default/files/files_uk/brochures/br_spacestory_jl_v2.3_lr_new.pdf

satellite communications and Earth Observation, and is a prime contractor on a number of ESA science missions. Under Full Operational Capability phase of the Galileo programme, Astrium (UK) secured **€73.5m**²¹² from ESA to be the prime contractor for the Ground Control Segment, covering the provision of the facilities that will operate the Galileo constellation²¹³.

Other UK success

Contracts were also awarded to UK companies prior to 2007 for the validation phase of the programme where different technologies and systems were tested. These contracts were extended and included contracts, worth **€100m**²¹⁴, to UK companies to build: the validation ground control systems (EADS Astrium Ltd), the four validation satellites (Astrium Ltd), and other aspects of the validation activities (Thales ATM Ltd, Thales Communications UK, Vega Group, and SCISYS Limited). More recently, BT has also secured contracts to provide satellite communication infrastructure and networks services for Galileo and EGNOS respectively²¹⁵.

Consultations with stakeholders suggest that involvement in the Galileo programme has secured significant commercial advantages for UK companies. These advantages include:

- **Growth:** After securing a **€236m** contract to deliver 22 payloads for the Galileo programme with OHB Systems in 2010, SSTL's turnover more than doubled in size²¹⁶. The programme also remains SSTL's largest contract to date, accounting for more than one third of SSTL's export sales as of 2015²¹⁷, and has helped SSTL dominate the small satellite market, with a self-proclaimed **40%** market share in 2015^{218 219}. Similarly, CGI have said that growth in the UK space sector's revenue and employment is an indicator that the UK is getting value for money from ESA membership²²⁰ and therefore investments in programmes such as Galileo.
- **Scale and capabilities:** Some of the stakeholders suggested that in some cases, the large Galileo contracts enabled their companies to achieve a scale that allowed them to take on other non-Galileo related projects that would previously have been out of reach. For example, the Galileo payload contracts enabled SSTL to build an advanced 3700 sqm facility in 2012²²¹. This allowed SSTL to: build larger and more advanced satellites (the size of the old facilities were a constraint); deliver higher reliability missions (e.g. Eutelsat Quantum), and ensure that they could meet an ambitious 5-10 year business plan²²².
- **Spillovers to other business units:** Some of the stakeholders that were interviewed indicated that their involvement as suppliers to the Galileo programme and the subsequent knowledge of GNSS that they gained benefited the more downstream focused parts of their business (e.g. those concerned with the development of GNSS receivers).

²¹² Please see: http://www.airbusgroup.com/int/en/news-media/press-releases/Airbus-Group/Financial_Communication/2012/04/20120426_astrium_galileo.html

²¹³ London Economics (2015). *The Case for Space 2016: The impact of space on the UK economy*

²¹⁴ House of Commons (2011). *Transport Committee – Written Evidence, EU transport policy*. Available here: <https://www.publications.parliament.uk/pa/cm201012/cmselect/cmtran/751i/751we04.htm>

²¹⁵ Please see: <https://signalofsatellite.wordpress.com/2013/03/13/bt-ses-to-support-galileo-with-satellite-communications-services/>
<http://www.globalservices.bt.com/uk/en/news/bt-to-provide-new-network-for-europes-first-satellite-navigation-system>

²¹⁶ Please see: https://www.iop.org/activity/business/calendar/info/file_60221.pdf

²¹⁷ LE analysis of SSTL sales data: <https://www.sstl.co.uk/getattachment/Press-2/Media-Contact/SSTL-Media-backgrounder.pdf>

²¹⁸ Please see: <https://www.sstl.co.uk/getattachment/Press-2/Media-Contact/SSTL-Media-backgrounder.pdf>

²¹⁹ Please see: <https://www.ft.com/content/076f6374-0944-11e5-b643-00144feabdc0>

²²⁰ Parliament (2013). *Science and Technology – Written Evidence submitted by CGI IT UK Limited, October 2013*: <https://www.publications.parliament.uk/pa/cm201314/cmselect/cmsctech/253/253vw14.htm>

²²¹ See: [http://www.esa.int/ESA_in_your_country/United_Kingdom/Opening_of_UK_site Producing_the_heart_of_Galileo/\(print\)](http://www.esa.int/ESA_in_your_country/United_Kingdom/Opening_of_UK_site Producing_the_heart_of_Galileo/(print))

²²² Please see: <http://www.sstl.co.uk/Blog/July-2011/Inside-SSTL-s-new-Kepler-building>

- **Reputation:** As a result of involvement in the Galileo programme, SSTL has built a worldwide reputation for the development of small satellites that have helped lower the cost of operational space missions²²³. This success was acknowledged by the European Space Agency with an ‘**outstanding contribution**’ award for rapidly building the GIOVE A satellite on time and ensuring that ESA was saved the embarrassment of losing the rights to the Galileo programme²²⁴. This has helped cement the UK’s reputation as a reliable partner in European space programmes.

As well as generating **revenue, employment and taxes**, Galileo contracts for UK businesses also generates further **multiplier** and ripple effects. This is because space companies source inputs from other UK companies and employ workers that generate further activity through the expenditure of their salaries. For the space industry as a whole, these multiplier effects are estimated to be 1.97²²⁵. This implies that **each £1 of output generated by Galileo contracts generates £0.97 worth of additional economic output** in the UK supply chain and supporting sectors.

Cooperation in such a large multilateral programme also garners **softer impacts** for the UK, such as **prestige** for the UK government and **goodwill** from other participating states. These ‘soft’ diplomatic benefits are not quantifiable, but lead to cooperation benefits in other space programmes and increase the UK’s credibility as a partner for future multi-lateral projects beyond the space industry.

Finally, there are a number of positive **spillovers** that may come from the knowledge and expertise developed by the involvement of UK space companies in the EGNSS programme. These spillovers include: **benefits to other companies** in the space industry as Galileo-related **knowledge ‘leaks’** elsewhere; benefits to companies in unrelated markets as the **stronger scientific base** and new expertise is applied to different situation, and even benefits to wider society from the development of sovereign cyber security and encryption capabilities that helps support UK national security.

Providing the UK with access to Galileo’s Public Regulated Service

Participation in Galileo will also give the UK with access to Galileo’s Public Regulated Service (PRS) for security-related and other sensitive applications which require a high level of service continuity. This service is similar to Galileo’s other GNSS services, but **encryption** of the signal and its **restriction** to authorised government users mean it will be more **resilient** (provide better continuity of service to authorised users when access to other navigation services may be degraded) and **robust** (more resistant to malicious attack via spoofing or jamming)²²⁶, which could offer significant benefits to emergency services, critical national infrastructure and national security services²²⁷.

Downstream investments

The UK’s downstream investment in GNSS hardware and applications come from a variety of EU, ESA and UK funds and was worth, according to London Economics’ estimates of publically available data, a total of **€94.9m** in 2016 prices since 2000 (see Annex 5). A proportion of these funds are won by UK recipients through open competition.

²²³ Please see: <http://www.sstl.co.uk/Press/EADS-Astrium-acquires-Surrey-Satellite-Technology>

²²⁴ Please see: <https://www.sstl.co.uk/Press/SSTL-earns-ESA-award-for-its-role-in-Galileo>

²²⁵ London Economics (2016). *The Size & Health of the UK Space Industry*.

²²⁶ Please see: <https://www.gsa.europa.eu/security/prs>

²²⁷ UK Space Agency (2012). *Impact Assessment: Competent PRS Authority*, June 2012. Available here: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/298025/competent-prs-authority-impact-assessment.pdf

These investments are used to support internal R&D and business development activities that focus on developing the exploitation of GNSS in a global downstream market that is estimated to be worth **€168bn/year by 2030**²²⁸ (with the UK forecast to capture between 2% and 4% of this market²²⁹).

These R&D and business development activities generate direct **socio-economic benefits** in the form of employment, revenues, and taxes which in turn generate further **multiplier effects**. The involvement of these firms in GNSS programmes also generates **spillover effects** in terms of the knowledge, expertise and technology that their activities generate. These benefits will exist even if the GNSS funded projects are not successful. However, they will be bigger if the projects successfully generate products or services that use GNSS data since the recipient company will be able to generate a commercial return in the form of higher revenues. For example, the 86 projects under the GNSS FP7 budget resulted in: **45 commercialised products and services, 80 prototypes, 13 patents, 115 demonstrations, and supported a total of over 600 FTE jobs**²³⁰. The FP7 SAFEPORT project is a notable UK-led success story that demonstrates how UK investments have helped bring a value-added application of GNSS to market. Details of this project are provided in the box below.

Box 3 FP7 success stories with UK involvement

SAFEPORT

This project, funded with an EU contribution of €1.9m, developed a GNSS-based Active Vessel Traffic Management and Information System (A-VTMIS) to manage vessel movements. This ensures that ships stay safe when at port and improves the efficiency of all port operations. The project has also developed a navigation aid called 'SafePilot', which helps pilots safely and efficiently navigate courses provided by the A-VTMIS. SAFEPORT's A-VTMIS and SafePilot have **now been launched on the commercial market** where consortium members say they are experiencing some success.

UK involvement: BMT Group Ltd (Lead), University of Glasgow, University of Strathclyde.

Once brought to market, innovations like SAFEPORT would provide **benefits to users** – in the form of **time** and **cost savings** (e.g. pilots using SAFEPORT to navigate more efficiently at port, pedestrians using mobile navigation and motorists avoiding fuel burn), and wider benefits for society in the form of **environmental externalities** (e.g. pollution reductions from more efficient transport and precision agriculture as detailed in chapter 4), **lives saved** (e.g. trains avoiding derailment and vessels avoiding collision), as well as **R&D spillovers**.

UK involvement in manufacture of PRS technology

PRS technology development and piloting represents one areas where UK industry has played a key part, in large part because of the downstream investment that has been secured by UK companies. The box below provides a short introduction to some of these UK companies:

²²⁸ GSA (2015). *GNSS Market Report, Issue 4*; March 2015. Available here: <https://www.gsa.europa.eu/market/market-report>

²²⁹ Estimate sourced from unpublished UK SA analysis based on GSA's GNSS market report 2015 and London Economics analyses provided in the 'Case for Space 2015' and 'Size and Health of the UK space sector' publications.

²³⁰ GSA (2015). *Overview of results from GNSS research under the FP& R&D Programme (2007 – 2013): From Research Applications to Market*. Available here: https://www.gsa.europa.eu/sites/default/files/FP7-brochure2015_7.pdf

Box 4 Selected UK companies that have secured upstream contracts for EGNSS**QinetiQ**

QinetiQ is an engineering company operating primarily in the defence and aerospace markets and has secured several downstream investments to develop receivers for PRS applications. Together, these contracts have enabled QinetiQ to lead the development of PRS receivers¹ and placed the UK in a strong position to benefit from their export. These investments include:

- **FRAME (EU):** The first phase of the FRAME contract to support the development of PRS applications, worth £5m¹, was awarded to a 37 partner consortium, with QinetiQ as lead partner.
- **NSTP ASPIRE programme (UK)¹:** this project is intended to explore how PRS can be delivered to a wide range of users cost-effectively and with minimal security requirements, thereby driving the availability of very low-cost PRS-enabled receivers ahead of the launch of Galileo's services.
- **H2020 PRISMA project (EU):** A €20m project to develop low-end PRS receivers

Nottingham Scientific (NSL)

NSL are one of Europe's leading GNSS companies and have developed PRS expertise following involvement in EU and UK funded R&D programmes – including ASPIRE and FRAME. An early outcome of this work has been 'GRIPPA', a secure mobile phone sleeve for government authorised users developed in partnership with QinetiQ. While the commercial potential of this can only be tested after full operation of Galileo, this innovation – enabled by UK investment in PRS applications development – was formally recognised as the 'world's most commercially advanced solution for end-users' with a prize at the European Satellite Navigation Competition 2016¹.

Interviews with stakeholders suggest that these R&D investments have placed the UK in a strong position to exploit the PRS market, estimated to be worth £1bn per year in 20 years²³¹ both at home and abroad. The PRS market would be particularly lucrative for the UK defence industry. The Government has already made a commitment in the Strategic Defence and Security Review 2015 to use Galileo to improve the **resilience of the UK military**. The need for receivers for even a small proportion of the armed forces' 145,000 combat personnel and military vehicles could still represent a significant domestic market for the UK defence industry²³², and an anchor for export sales.

²³¹Please see: <https://nsm.stat.no/globalassets/dokumenter/lindsay.pdf>

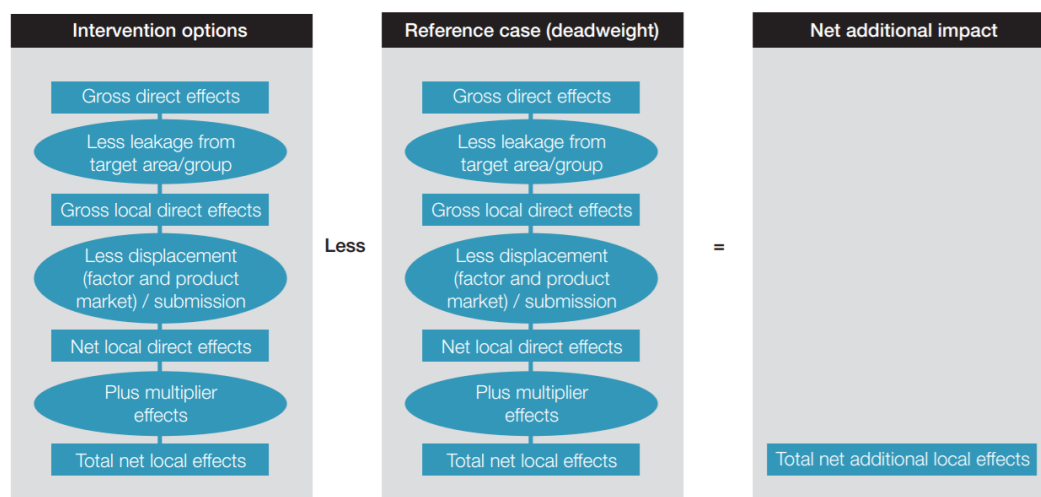
²³² London Economics (2015). The Case for Space 2015: The impact of space on the UK economy.

7.3.2 Counterfactual scenario and identification of additionality

To assess the impact of UK funding for GNSS it is important to compare the outcomes that can be expected to occur in the situation where there is UK funding for GNSS with the outcomes that are likely in the absence of this funding. This estimation of what would have happened in the absence of this funding is known as the ‘counterfactual’. By comparing this counterfactual (Annex 7) with the current situation where there is UK funding (Annex 6), the impacts that can be observed now or expected later are likely to be the result of the UK’s investment in GNSS and not some other factor.

In other words, it is important to assess the ‘**additional**’ value of the UK’s GNSS investment, which can be, as shown Figure 3 below, defined as: **Gross benefits** (i.e. utility from all uses of GNSS) *minus* the **deadweight** (i.e. outcomes associated with the counterfactual); *minus* the **leakage of benefits** outside of the UK; *minus* any **displacement** and **substitutions** effects (i.e. foregone benefits from economic activity that might be reduced or replaced); *minus* any **crowding out or in** through general equilibrium effects; *minus* any **unintended consequences**; *plus* any **multiplier benefits** that result.

Figure 3 Assessing additionality



Source: English Partnerships (2008). *Additionality Guide: A standard approach to assessing the additional impact of interventions*.

Upstream investments

The counterfactual scenario implies a situation where the UK never contributed to the development of EGNSS. As a result, UK businesses would have been unable to compete for commercial EGNSS tenders, given the strategic nature of the programme and the EU’s stated industrial policy of “making use in the first place of the existing industrial potential of all Member States” and giving “preference to industry and organisations of the Member States”²³³. The UK space industry would therefore **forego some** (if not all²³⁴) **of the significant commercial advantages** mentioned in 7.3.1, and the UK as a whole would therefore **lose out on the employment, tax revenues, and multiplier effects** that this commercial activity would generate.

²³³ ESA (2003). *Convention for the establishment of a European Space Agency & ESA Council*. The extracts relate to Article’s II and VII and can be found here: http://www.kosmos.gov.pl/download/ESA_Convention.pdf

²³⁴ Without access to ESA contracts, it is likely that some UK firms would have developed expertise and competitiveness in other markets so some of these industrial benefits may still occur in the counterfactual scenario (i.e. involvement in the Galileo programme may have displaced other commercial activities).

Even so, it is **likely that Galileo would be completed** and the public good nature of the Open Service would mean that it would be available to UK users in both the ‘UK-contribution’ and counterfactual scenarios. This has been verified by stakeholder interviews and can be assumed because the EU’s stated strategic objectives for GNSS would remain²³⁵ even without UK funds. Europe still sees a need for a civilian controlled GNSS services that is independent of other foreign controlled military structures²³⁶ and therefore a guarantor of the resilience of Europe’s critical national infrastructure.

However, a situation without UK involvement could still imply significant difficulties. The UK has been a key member of the EGNSS supply chain so this scenario would imply a loss of technical expertise, **supply chain disruption**, loss of UK political pragmatism, and therefore a significantly **higher cost burden** for other member states, compared to the current situation where the UK is contributing. In particular, the stakeholder interviews suggested that **UK industry played a significant role in providing competition** to existing European contractors and moving Galileo forward at a time when it was otherwise characterised by major procurement²³⁸ and political disputes²³⁹ – such as Germany’s, Spain’s and Italy’s over the location of the ground control systems²⁴⁰ – that contributed to the programme’s delay and cost overruns during the development phase²⁴¹. For example, SSTL were able to design, build and test the GIOVE-A test satellite in a rapid 30-month schedule²⁴², thereby ensuring that ESA could retain control over the Galileo programme at a time when it was at risk of losing it²⁴³. The value of this specific contribution was indeed recognised by ESA with an ‘outstanding contribution award’.

‘The GIOVE-A success for Europe was only possible because of the UK expertise in small satellites.’

*Surrey Satellite Technology Limited*²³⁷

These additional costs and difficulties would be on top of the higher costs that would be implied by the loss of UK funding.

Together, these impacts suggest that Galileo could not be delivered in the same form and budget as is currently proposed. Thus, while the UK could still **‘free ride’ on the EU’s investment in EGNSS** and gain resilience of critical infrastructure through Galileo’s Open Service platform in the scenario where the UK does not contribute to it, the functional capabilities of Galileo and therefore the performance of GNSS devices and applications that rely on it in downstream markets may be marginally lower. This loss would be approximately equal to: the additional benefits of Galileo (over and above other constellations) – from the improvements to accuracy, availability and time to first fix performance parameters that an additional constellation to the GNSS infrastructure will bring²⁴⁴ – multiplied by the reduction in Galileo performance implied by the situation without UK funding.

Without contributing to the EGNSS programme, the **UK could also forego authorisation to access PRS** and the significant advantages that it offers. For example, PRS offers an enhanced and

²³⁵ Please see: http://www.esa.int/Our_Activities/Navigation/Galileo/Why_Europe_needs_Galileo

²³⁶ The USA’s GPS, Russia’s GLONASS and China’s BeiDou GNSS systems are all military controlled GNSS systems.

²³⁷ Parliament (2006). *Select Committee on Science and Technology. Written Evidence – Submission from Surrey Satellite Technology.* Available here: <https://www.publications.parliament.uk/pa/cm200607/cmselect/cmsctech/66/66we77.htm>

²³⁸ Please see: <http://www.economist.com/node/9214968>

²³⁹ Please see: <http://www.reuters.com/article/us-eu-galileo-idUSL2937381020071129>

²⁴⁰ Please see: <http://news.bbc.co.uk/1/hi/sci/tech/7625357.stm>

²⁴¹ Please see: <http://spacenews.com/european-governments-trim-galileo-system-cost-overruns/>

²⁴² Please see: <https://www.sst-us.com/missions/giove-a--launched-2005/giove-a--giove-a--the-mission>

²⁴³ Please see: <https://www.sstl.co.uk/Press/SSTL-earns-ESA-award-for-its-role-in-Galileo>

²⁴⁴ GSA (2016). *GNSS User Technology Report Issue 1.* Available here: <https://www.gsa.europa.eu/european-gnss/gnss-market/2016-gnss-user-technology-report>

encrypted capability that makes it a better guarantor²⁴⁵ of the resilience of the UK's critical national infrastructure compared to the Open Service which is vulnerable to interference, jamming and spoofing²⁴⁶. Similarly, the manufacture of PRS technologies (receivers and security modules) is restricted to contributing EU member states. The scenario where the UK is not contributing would therefore imply a **loss of the commercial PRS opportunities** and of a potentially lucrative export avenue for UK defence companies²⁴⁷. However, it is not clear that access to PRS is tied to financial contributions to the programme. The EU will open negotiations with the U.S. on access to PRS, and while the U.S. may be expected to make a small contribution to the programme, it is likely to be far short of the burden faced by current member states²⁴⁸. This suggests that access to PRS is not necessarily limited to the scenario where the UK is contributing as much as it is today.

Total foregone benefits would also extend beyond the potential reduction in Galileo baseline performance and the loss of access to PRS outlined above. This is because a lack of UK involvement would also imply the **loss of: prestige and goodwill** that would come from involvement in a large multi-lateral programme and **socio-economic benefits** – in the form of revenue, employment, wages and taxes – that would come from the foregone commercial activities generated by EGNSS-related contracts for UK industry, and any associated **multiplier and spillover effects**.

Downstream investments

The loss of UK funding for GNSS would imply the loss of current funding that is directed towards the development of the UK's downstream applications of GNSS.

In some cases, UK funding could be replaced by other sources of investment (e.g. R&D financed internally), particularly in those cases where this investment is used to support applications that are close to market. However, most projects that currently receive UK funding through mechanisms such as H2020 are focused on exploiting early stage technologies or research that would otherwise not reach market for the market failure arguments mentioned in 7.1.2. These research funds have also historically been directed at SMEs. For example, **40% of the FP7 funds allocated to GNSS went to SMEs**²⁴⁹ compared to the EU FP7 average of <15%. Since SMEs typically have very limited access to finance, it is likely that many of the FP7 project would not have been funded on their own.

Network effects of research collaboration means that the loss of UK involvement in EU R&D projects would extend beyond the loss of UK-specific projects and the potentially smaller budget available to member states. This is because larger and more diverse collaborative networks support a greater degree of specialisation among member states. This implies the development of expertise and knowledge that can **improve the quality of R&D** by organisations in the UK and other member states and therefore the likelihood of it being commercialised and used by end-users of GNSS downstream applications^{250 251}.

²⁴⁵ PRS increases the likelihood of the continuous availability of the Signal-in-Space (robustness) since its signal and system design makes it more costly and difficult to attack signals as detailed by the GSA here: <https://www.gsa.europa.eu/security/prs>

²⁴⁶ The following article discusses the need for and applications of PRS the service, drawing on information from the PACIFIC project (PRS application concept involving future interested customers.): <http://www.insidegnss.com/node/364>

²⁴⁷ The stakeholder interviews suggested that access to a significant number of the Galileo contracts would have been impossible without a UK contribution to the EU budget because access to PRS projects is tie to the UK's contribution.

²⁴⁸ Please see: <http://spacenews.com/u-s-norwegian-paths-to-encrypted-galileo-service-open-in-2016/>

²⁴⁹ Please see: <https://www.gsa.europa.eu/sites/default/files/introduction%20to%20Galileo%20Call.pdf>

²⁵⁰ Nieto, M.J., Santamaria, L. (2006). *The importance of diverse collaborative networks for the novelty of product innovation*. Available here: <http://www.sciencedirect.com/science/article/pii/S0166497206001064>

²⁵¹ Wazzenboeck, I.; Piribauer, P. (2015). *R&D networks and regional knowledge production in Europe. Evidence from a space-time model*. Available here: http://druid8.sit.aau.dk/acc_papers/4m96eshna2t0vqfshsha459mq54n.pdf

A loss of UK downstream funding would therefore result in a loss of socio-economic benefits – in the form of revenue, employment and taxes – that would otherwise arise from these R&D activities. Since these R&D activities could have generated further innovations, the counterfactual scenario would also imply a loss of the socio-economic benefits that would be associated with any new or improved products and services that could have come from these innovations.

This consequence would extend beyond the downstream market. UK users would forego any potential productivity gains, and wider society would lose out on potential spillovers and public utility gains that these new products or services could have provided.

7.4 Conclusion on the contribution of UK public funding

GNSS is characterised by a number of market failures that mean that there is a strong economic case for government intervention. This includes large benefits for society that are estimated to be between £4 and £5 per £1 of public investment. In order to capture these benefits, the **UK has made a €1,474m investment in GNSS since 2000**. Most of this investment (94%) has occurred through EU channels so the **overall impact of the UK's investment in GNSS is strongly tied to the UK's benefits from the EGNSS programme**.

The benefits associated with the UK's upstream investments since 2000, which account for the vast bulk of the UK's investment to date (94%), are driven by the industrial activities of UK firms that have secured contracts to supply critical parts for the Galileo and EGNOS programmes. As well as generating significant revenue streams, high-productivity jobs and taxes for the UK, these contracts have improved the overall competitiveness of the UK space sector and helped cement the UK's reputation as a leading partner in European space programmes.

The UK's **€94.9m** downstream investments have also unlocked significant benefits to end-users and the rest of the society that would have been lost without UK funding. These include: the significant commercial opportunity offered by **domestic PRS sales and exports, which is tied directly to the UK's contribution to the Galileo programme**, and **early-stage R&D that support** the development of new GNSS applications that generate revenue for UK companies, productivity benefits for end-users, and environmental benefits for society.

8 Conclusions and recommendations for future research

This section summarises and concludes on the research objectives of the study, and suggests ideas for further research to be undertaken in this and related fields.

8.1 Conclusions

This research has answered the five research objectives posed in section 1.3, summarised below.

8.1.1 Identified economic sectors and industries supported by GNSS in the UK

A very wide range of economic sectors in the UK rely on GNSS for their daily activities. All **critical national infrastructures** rely on GNSS to a greater or lesser extent. Communications, emergency services, finance, Government and transport have been identified as heavy users of GNSS with the global availability and consistency playing a key role for some. Those critical infrastructures that rely on GNSS have developed over decades to a current situation in which GNSS is an integral source of timing and positioning information, where systems are defined on the basis that GNSS is available.

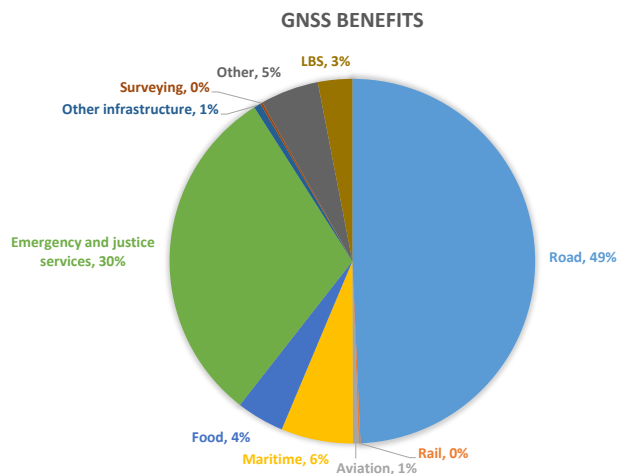
For **professional activities** in the UK, GNSS is a primary input for transport (road, air, maritime, and rail) workers, farmers, surveyors and lawyers. Sectors generating 11.3% of UK GDP have been identified as reliant on GNSS to greater or lesser extent, and the primacy of GNSS inputs in critical infrastructures means that a wide range of sectors is underpinned by GNSS.

Outside of professional activities (or in the **household sector**), GNSS is used for navigation and information gathering for all types of transport (leisure, commuting), and underpins insurance telematics that rewards safe drivers.

8.1.2 Quantify the economic benefit that GNSS brings to the UK

Quantified annual direct economic benefits to the UK from the use of GNSS have been monetised at **£6.7bn**. Benefits are estimated against a counterfactual scenario in which GNSS had not been developed or chosen as the primary source of PNT in the applications covered by this study.

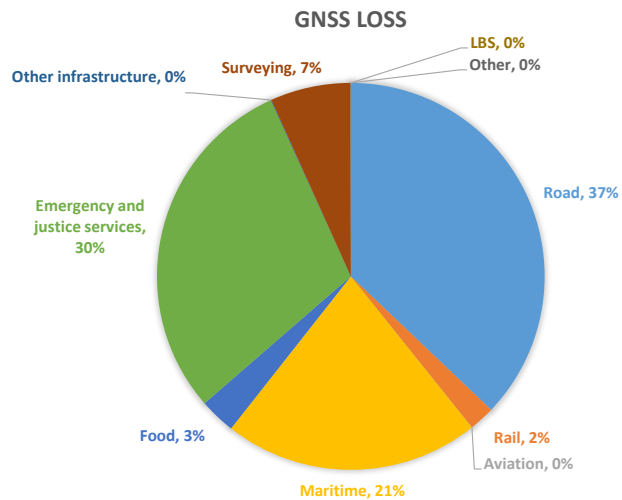
The road sector generates the majority of benefits (50%), driven by the efficiency gains provided by GNSS materialise in the form of time and fuel savings, and the associated benefits for the environment. Efficiencies in operations of the public safety answer points and other emergency and justice services make up 30% of benefits.



8.1.3 The economic impact to the UK (government and private sector) of a disruption to GNSS functionality of up to five days

The economic impact on the UK through loss of GNSS for five days has been estimated to be **£5.2bn** through direct and indirect channels.

The impact has been estimated based on current reliance on GNSS, and reflects that certain applications have developed over recent decades to a situation in which GNSS provides a critical input for which no backup is available. The implication of this reliance is that loss of GNSS would not only significantly disrupt those applications, but also sectors and industries that rely on goods or services from the same applications.



The majority of impacts are due to disruption of the by road transport network, resulting in increased congestion (37%), problems for emergency and justice services (30%), severe disruption of the maritime transportation sector (21%), and the surveying sector grinding to a halt with further impacts on civil engineering (7%).

8.1.4 Identify the cost and effectiveness of mitigation strategies

A number of mitigation strategies have been discussed in this report. The most applicable mitigation strategies for the largest number of applications are eLoran and STL.

With strict assumptions on the applicability of these service, loss of **£1.2bn** could be mitigated. With more relaxed assumptions, where form-factor of receivers is less of a constraint and local networks from Omnisense or Locata are widely established for high precision applications, as much as £4.2bn of loss could be mitigated.

8.1.5 High-level assessment of the impact of UK public funding of GNSS

GNSS is characterised by a number of market failures that mean that there is a strong economic case for government intervention. This includes large benefits for society that are estimated to be between £4 and £5 per £1 of public investment. In order to capture these benefits, the **UK has made a €1,478m investment in GNSS since 2000**, based on London Economics' estimates of publically available information. Most of this investment (94%) has occurred through EU channels so the **overall impact of the UK's investment in GNSS is strongly tied to the UK's benefits from the EGNSS programme.**

The benefits associated with the UK's upstream investments since 2000, which account for the vast bulk of the UK's investment to date (94%), are driven by the industrial activities of UK firms that have secured contracts to supply critical parts for the Galileo and EGNOS programmes. As well as generating significant revenue streams, high-productivity jobs and taxes for the UK, these contracts have improved the overall competitiveness of the UK space sector and helped cement the UK's reputation as a leading partner in European space programmes.

The UK's estimated **€94.9m** downstream investments have also unlocked significant benefits to end-users and the rest of the society that would have been lost without UK funding. These include: the significant commercial opportunity offered by **domestic PRS sales and exports, which is tied directly to the UK's contribution to the Galileo programme**, and **early-stage R&D that support** the development of new GNSS applications that generate revenue for UK companies, productivity benefits for end-users, and environmental benefits for society.

8.2 Recommendations for future research

This study has investigated a scenario of loss of GNSS that employed simplifying assumptions in order to manage the study within the time and resources that were made available. Future research that relax these assumptions is recommended as the current picture remains partial and stylised. The list below suggests different ways of relaxing the assumptions:

- **The mechanism of GNSS loss.** In broad terms, there are three possible reasons that GNSS might be lost. Jamming (intentional or unintentional), space weather, or conflict. Future work should explore the first two.
 - **Jamming** is the most likely source of local unavailability of GNSS, and multiple reports and stakeholder have highlighted the abundance and ease of access to GNSS jammers from the internet as well as unintentional jamming from faulty antennae. Future work should identify particular sites where jamming would imply the greatest impact, with a view to strengthening resilience.
 - **Space weather** events on the scale required to knock out GNSS are extremely rare, and only one event has been documented, the Carrington Event of 1859. Future work should identify the impact of a large-scale space weather event on assets in space, and ascertain whether it is possible to reset the satellites and whether they would be able to continue operating after the event. The outcome of such a study would be important to test the validity of the scenario assumption that 'GNSS services return to normal after five days'.
 - **Spoofing** is the practice of cheating GNSS-receivers into thinking they are somewhere they are not. Spoofing involves faking GNSS signals and therefore make devices report erroneous position or time. A successful spoofing attack of a financial institution could result in significant losses and it has been demonstrated that a sophisticated spoofing attack can completely fool a yacht's autopilot and steer it off course.²⁵² The ramifications of spoofing attacks at busy road junctions include confused drivers recklessly correcting wrong turns, with accidents to follow.
- **The impact of signal degradation.** The scenario investigated by this report assumes that the loss of GNSS is clean cut, but in reality this is very unlikely. If the outage is, for example, caused by jamming or a space weather event, the most likely outcome is some staggered degradation of the signal before final outage. This could have a much greater impact because of the impact on GNSS timing equipment. For example, GNSS timing equipment might receive a final timing value from the satellites as the signals degrade (akin to a spoofing attack). Some timing equipment is sophisticated enough to filter erroneous readings out, but some users may go into holdover from a time point that is not synchronised with the rest of the network. This would result in significant detriment, and should be investigated further. For transport applications, degrading signals that make

²⁵² The University of Texas at Austin News (2013) *UT Austin Researchers Successfully Spoof an \$80 million Yacht at Sea*. Available at: <https://news.utexas.edu/2013/07/29/ut-austin-researchers-successfully-spoof-an-80-million-yacht-at-sea>

GNSS equipment report misleading information could be hazardous and increase the likelihood of accidents, and of vessels on autopilot running ashore.

- **Time period of analysis.** This study has considered the present only, with current usage patterns of GNSS analysed for benefits, vulnerability and loss. However, many stakeholders have commented that the future may mean greater reliance on GNSS. For example, the aviation community is set to adopt the SESAR²⁵³ recommendations; the rail community moves towards ERTMS level 3, and autonomous vehicles will become more widespread on roads and in the sky. These and many other developments are testament to the efficiency gains offered by GNSS, but increase the UK's reliance and vulnerability.

Aside from the definition of the scenario analysed in this study, a recurring theme of many stakeholder consultations, and indeed across this report, is **people's ability to navigate without GNSS**. The ability of mariners to navigate without GNSS has been questioned by multiple stakeholders, and conversations related to road transport suggest that few individuals have access to paper maps and many also lack the necessary skills to use them as navigation aids. It is therefore recommended that a representative survey is undertaken of the (driving) population (professional, commuting, and leisure) to elicit availability of maps and navigation skills with a view to refining the estimates of the impact on the road transport network.

eLoran has been identified as the most versatile and useful mitigation technology across the widest range of applications. Its impact on loss has been assessed in a scenario in which all relevant users would add resilience through incorporation of eLoran. Further research is recommended to ascertain the propensity of users to actually equip – a decision that will depend on the cost and complexity as well as weight and size of equipment, which should be investigated further.

Finally, as shown in section 4, a wide range of GNSS benefits remain non-monetised, meaning that the benefits of GNSS are underestimated. Better understanding of the economic benefits brought about by GNSS could help inform political decisions to pursue GNSS solutions for dementia patients, dangerous goods tracking, and recreational non-road transport (maritime and aviation).

²⁵³ Single European Sky ATM (Air Traffic Management) Research

References

- ACIL Allen Consulting (2013). *The value of augmented GNSS in Australia: An overview of the economic and social benefits of the use of augmented GNSS services in Australia*. Available at: http://www.acilallen.com.au/cms_files/ACIL_GNSS_positioning.pdf [Accessed 7 September 2016]
- Aghion, P. and Howitt, P. (2007). Capital, Innovation, and Growth Accounting. *Oxford Review of Economic Policy*, 23, 79-93.
- Alstom Grid (2015). *Event Detection SMART Frequency Control*. Available at: http://www.nationalgridconnecting.com/The_balance_of_power/National_Grid_Event_Detection_SMART_Frequency_Control.pdf [Accessed 9 December 2016]
- Andrew Taratola (2014) This "Flying Banana" Keeps Britain's Trains from Running off the Rails. Available at: <http://gizmodo.com/this-flying-banana-keeps-britains-trains-from-running-1656940177> [Accessed 27 March 2017]
- ASF 2015: Jose del Rosario of NSR on satellite mobility markets. Available at: <https://www.slideshare.net/CommsDay/asf-2015-jose-del-rosario-of-nsr-on-satellite-mobility-markets>
- Association of Ambulance Chief Executives (2016), *Annual Report 2015-2016*. Available at: <http://aace.org.uk/wp-content/uploads/2016/10/AACE-A4-ANNUAL-REPORT-2015-2016-W.pdf>
- Baraniuk, C. (2016). *GPS error caused '12 hours of problems' for companies*. Available at: <http://www.bbc.co.uk/news/technology-35491962> [Accessed 6 September 2016]
- Barnes J. et. al. (2004). *Structural Deformation Monitoring Using Locata*. Available at: https://www.fig.net/resources/proceedings/2004/nottingham/proc/ts_04_4_barnes_et.al.pdf [Accessed 9 December 2016]
- Bartlett, S. et. al. (2015). *Innovation: Enhanced Loran*. Available at: <http://gpsworld.com/innovation-enhanced-loran/> [Accessed 6 September 2016]
- Brokers' Association (2016) *40% increase in telematics motor policies in a year*. Available at: <https://www.biba.org.uk/press-releases/40-increase-in-telematics-motor-policies-in-a-year/>, [Accessed 17 March 2017]
- BT (2011), *UK Emergency calls*. Available at: http://www.eena.org/ressource/static/files/112_in_uk.pdf
- Cabinet Office (2016). *Summary of the 2015-16 Sector Resilience Plans*. Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/526351/2015_16_summary_of_the_srp.pdf [Accessed 6 December 2016]
- CableNet (2017) *Fibre Optic Cable*. Available at: <http://www.cablenet.co.uk/catalogue/fibre-cable.htm> [Accessed 20 March 2017]
- Cameron, A. (2014). *GNSS Backup Delivers 5-Meter Accuracy*. GPS World. Available at: <http://gpsworld.com/gnss-backup-delivers-5-meter-accuracy/> [Accessed 20 October 2016]

Carrol, J. V. (2003). Vulnerability Assessment of the U.S. Transportation Infrastructure that Relies on the Global Positioning System. *The Journal of Navigation*, vol. 56, pp. 185-193

Centre for Economics and Business Research (2015). *The economic costs of physical inactivity in Europe - An ISCA and Cebr report*

Centre for the Protection of National Infrastructure (CPNI). Available at: <https://www.cpni.gov.uk/about-cpni> [Accessed 5 December 2016]

Chronos Technology Ltd (2010). *Dependency of Communications Systems on PNT Technology*. Available at: http://www.chronos.co.uk/files/pdfs/wps/Dependency_of_Comms_on_PNT_Technology.pdf [Accessed 5 December 2016]

Chronos Technology (2016), *GPS Anomaly Event – Chronos keeping your networks operational*. Available at: <http://www.chronos.co.uk/files/pdfs/cs-an/26%20January%202016%20GPS%20Event.pdf> [Accessed at 1 December 2016]

College of Policing (2015) *College of Policing analysis: Estimating demand on the police service*. Available at: http://www.college.police.uk/News/College-news/Documents/Demand%20Report%2023_1_15_noBleed.pdf

Connolly, P., and Bonte, D. (2016). *Low-Cost Precision GNSS Receivers*, ABI Research.

Cospas-Sarsat (2016). *Preliminary Results of the 2016 Beacon Manufacturers Survey*. Available at: http://www.sarsat.noaa.gov/BMW%202016_files/BMW%20Presentation%20Beacon%20Manufacturers%20Survey%20-%20003.pdf [Accessed 8 December 2016]

Cospas-Sarsat (2016), Cospas-Sarsat report on system status and operations C/S R.007 No.32: January – December 2015.

Curry, C. (2014). *Delivering a National Timescale using eLoran*. Available here: <https://rntfnd.org/wp-content/uploads/Delivering-a-National-Timescale-Using-eLoran-Ver1-0.pdf>

Curry, C. (2016) A2.3 – SVN 23 (aka UTC Anomaly Event') International Navigation Conference 2016 presentation. Available at: http://www.chronos.co.uk/files/pdfs/pres/2016/INC_SVN23%20What%20Happened.pdf

Curry, C. (2016). *eLoran – The Future of Resilient PNT*, conference presentation at ITSF, 1-3 November 2016.

Curry et. al. (2014). Report on GNSS Vulnerabilities. SENTINEL Project – GNSS Vulnerabilities. Available at: http://www.chronos.co.uk/files/pdfs/gps/SENTINEL_Project_Report.pdf, pp. 34-39 [Accessed 6 September 2016]

Divis, D.A. (2014). Proposal for U.S. eLoran Service Gains Ground. *InsideGNSS - Washington View*, January/February 2014. <http://www.insidegnss.com/node/3853> [Accessed 8 December 2016]

Department for Environment, Food and Rural Affairs (2016). *Agriculture in the United Kingdom*

Department for Business, Innovation and Skills (2015). *Space Weather Preparedness Strategy*.

Department for Transport (2007), Highways Economics Note No. 1 2005 Valuation of the Benefits of Prevention of Road Accidents and Casualties. Inflated using the GDP deflator (sourced from the ONS)

Department for Transport (2015). *Values of travel time savings and reliability: final reports*

Department for Transport (2016) *Domestic Road Freight Statistics 2015*

Department for Transport Statistics (2015) *Average value of prevention per reported casualty and per reported road accident [RAS60001]*

Department for Transport (2016) Accident and casualty costs (RAS60). Available at: <https://www.gov.uk/government/statistical-data-sets/ras60-average-value-of-preventing-road-accidents> [Accessed 17 March 2017]

Department of Homeland Security (2011). *National Risk estimate: Risks to U.S. Critical Infrastructure from Global Positioning System Disruptions*

Elsevier (2013). *International Comparative Performance of the UK Research B Base – 2013*.

EndRun Technologies. *PTP/IEEE-1588 Frequently Asked Questions*. Available from <https://www.endruntechnologies.com/ptp-ieee-1588-faq.htm> [Accessed 13 December 2016]

Eurocontrol (2015) Standard Inputs for EUROCONTROL Cost Benefit Analysis Ed. 7. Available at: <http://www.eurocontrol.int/documents/standard-inputs-eurocontrol-cost-benefit-analyses>

European Commission (2015). *eCall in all new cars from April 2018*. Available at: <https://ec.europa.eu/digital-single-market/en/news/ecall-all-new-cars-april-2018> [Accessed 8 December 2016]

European Commission's Directorate-General for Enterprise and Industry (2014). *Public Consultation Document: Applications of EU satellite navigation programmes (Galileo and EGNOS)*. Available at: <http://ec.europa.eu/DocsRoom/documents/10843/attachments/2/translations/en/renditions/native> [Accessed 5 December 2016]

European Emergency Number Association (EENA) (2014). *112 Caller Location & GNSS*. Available at: <http://ec.europa.eu/DocsRoom/documents/5372/attachments/1/translations/en/renditions/native> [Accessed 6 December 2016]

European GNSS Agency (2015). *GNSS Market Report Issue 4 2015*.

European GNSS Service Centre (2016) FAQs. Available at: <https://www.gsc-europa.eu/helpdesk/faqs> [Accessed 18 October 2016]

European Securities and Markets Authority (2014). *Discussion Paper: MiFID II/MiFIR*. Ref. 2014/548. Available at: https://www.esma.europa.eu/sites/default/files/library/2015/11/2014-548_discussion_paper_mifid-mifir.pdf [Accessed 4 November 2016]

European Space Agency (2003). *Convention for the establishment of a European Space Agency & ESA Council*. The extracts relate to Article's II and VII. Available here: http://www.kosmos.gov.pl/download/ESA_Convention.pdf

- European Space Agency (2015). *Monitoring Bridges from Space*. Available at: <https://artes-apps.esa.int/projects/showcases/monitoring-bridges-space> [Accessed 7 December 2016]
- European Space Agency (2016). *Monitoring Bridges Opens Vast Markets*. Available at: <https://artes-apps.esa.int/projects/showcases/structural-health-monitor-vast-markets> [Accessed 9 December 2016]
- European Space Agency (2013). *What is EGNOS?* Available at: http://m.esa.int/Our_Activities/Navigation/EGNOS/What_is_EGNOS [Accessed 6 September 2016]
- Eurostat (2016) *Fishery statistics*. Available at: http://ec.europa.eu/eurostat/statistics-explained/index.php/Fishery_statistics
- Financial Fraud Action UK (2017) *Fraud The Facts 2016*. Available at: <https://www.financialfraudaction.org.uk/fraudfacts16/> [Accessed 16 March 2017].
- Financial Times (2016) *UK car industry fears effects of Brexit tariffs on supply chain*. Available at: <https://www.ft.com/content/c397f174-9205-11e6-a72e-b428cb934b78> [Accessed 15 March 2017]
- Financial Times (2016) *Insurers test the limits of telematics' big data*. Available at: <https://www.ft.com/content/86e62742-21d9-11e6-9d4d-c11776a5124d> [Accessed 17 March 2017]
- Georgette Lalis, Director of consumer goods and EU satellite navigation programmes in the European Commission's Directorate General of Enterprises and Industry, quoted in <https://www.gsa.europa.eu/news/support-egnos-and-galileo-crucial-europes-citizens>
- Gibbons Media & Research LLC (2016). *BBC, Chronos Report on Lengthy Disruptions Caused by GPS Timing Problem*. Available at: <http://www.insidegnss.com/node/4839> [Accessed 6 September 2016]
- Google Blog (2016). *Helping emergency services find you when you need it the most*. Available at: <https://blog.google/topics/google-europe/helping-emergency-services-find-you/> [Accessed 6 December 2016]
- Google Inc. (2012) *Spanner: Google's Globally-Distributed Database*. Available at: <http://static.googleusercontent.com/media/research.google.com/en//archive/spanner-osdi2012.pdf>
- Griffith, R. Redding, S. and Van Reenen, J. (2003). *R&D and Absorptive Capacity: Theory and Empirical Evidence*. *Scandinavian Journal of Economics* 105(1), 99-118.
- GSA (2008). *European Union 6th Research Framework Programme 2002 — 2006 Project Synopsis*. Available here: https://www.gsa.europa.eu/sites/default/files/TS7807240ENC_002.pdf
- GSA (2015). *Overview of results from GNSS research under the FP& R&D Programme (2007 – 2013): From Research Applications to Market*. Available here: https://www.gsa.europa.eu/sites/default/files/FP7-brochure2015_7.pdf
- GSA (2016). *GNSS Opportunities database*. Available at: <https://www.gsa.europa.eu/opportunities/gnss-opportunities-database>

- GSA (2016). *GNSS User Technology Report Issue 1*. Available here: <https://www.gsa.europa.eu/european-gnss/gnss-market/2016-gnss-user-technology-report>
- GSA (2017) *GNSS Market Report Issue 5*, forthcoming
- Helios (2017) The benefits of satcom to airlines. Available at: <https://www.inmarsataviation.com/dam/jcr:08c077ff-e783-4460-88a9-ee77cd4969fc/Airline%20Benefits%20of%20Satcom%20-%20A%20Report%20for%20Inmarsat.pdf>
- HM Treasury (2015). *European Union Finances 2015: statement on the 2015 EU budget and measures to counter fraud and financial mismanagement*.
- Home Office (2016) *Fire Statistics England, 2014/15*. Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/532364/fire-statistics-england-1415-hosb0816.pdf
- House of Commons (2007). *Galileo: Recent Development. First Report of Session 2007-2008*. Available here: <https://www.publications.parliament.uk/pa/cm200708/cmselect/cmtran/53/53.pdf>
- House of Commons (2011). *Transport Committee – Written Evidence, EU transport policy*. Available here: <https://www.publications.parliament.uk/pa/cm201012/cmselect/cmtran/751i/751we04.htm>
- ICOMIA (2016) *Recreational Boating Statistics 2015*
- INCA Vidensformidling & InnovationsHus Syd (2011). *Demonstrationsprojekt med brug af GPS system i eget hjem*. Available (in Danish) at: <http://www.digst.dk/~media/Afsluttede-projekter/GPS-med-tilkaldeknop-til-demente/Bilagsrapport---GPS-til-demente.pdf> [Accessed 9 December 2016]
- Ingenia Online (2015) *Precision farming*. Available at: <http://www.ingenia.org.uk/Ingenia/Articles/972> [Accessed 12 April 2017]
- International Loran Association (2007). *Enhanced Loran (eLoran) Definition Document*. <https://www.loran.org/otherarchives/2007%20eLoran%20Definition%20Document-1.0.pdf>
- Jaldell, Henrik (2004). *Cost-benefit analysis and life saving-operations*, University of Karlstad. Based on data from the Swedish Rescue Services statistical unit.
- Jamie Robertson (2017) *Why carmakers have the most to fear from protectionism*, BBC News. Available at: <http://www.bbc.co.uk/news/business-38570387>
- Javadi, A-H; Emo, B; Howard, L R; Zisch, F E; Yu, Y; Knight, R; Pinelo Silva, J; Spiers, H J (2017) *Hippocampal and prefrontal processing of network topology to simulate the future*
- Knowledge & Innovation Analysis, BIS (2013): *Net Present Values of proposed investments in science and innovation capital in 2015-16*, 9 May 2013
- Leveson, Irv (2015). *The Economic Value of GPS: Preliminary Assessment*. National Space-Based Positioning, Navigation and Timing, Advisory Board Meeting, June 11, 2015. Available at:

<http://www.gps.gov/governance/advisory/meetings/2015-06/leveson.pdf> [Accessed 6 September 2016]

Lloyd's (2010). Space Weather: Its impact on Earth and implications for business. 360° Risk Insight.

Locata Corporation (2013). *Superb performance demonstrated in world-first paper on Locata's time synchronization*. Available from <http://www.locata.com/article/locatas-time-synchronization-capability/> [Accessed on 8 December 2016]

Locata Corporation (2014). *Technology Brief*. Available at: <http://www.locata.com/wp-content/uploads/2014/07/Locata-Technology-Brief-v8-July-2014-Final1.pdf> [Accessed 18 October 2016]

Locata Corporation (2015). *Locata Positioning will Underpin Future Unmanned Aerial System Research at NASA's Famed Langley Research Center*. Available at: <http://www.locata.com/2015/09/locata-positioning-will-underpin-future-unmanned-aerial-system-research-at-nasas-famed-langley-research-center> [Accessed 18 October 2016]

London Economics (2015). *The Case for Space 2015: The impact of space on the UK economy*. Available here: <http://www.ukspace.org/wp-content/uploads/2015/07/LE-Case-for-Space-2015-Full-Report.pdf> [Accessed 18 April 2017]

London Economics (2015). *The Case for Space 2015 (iii) Case Studies*

London Economics (2015). *Return from Public Space Investments: An initial analysis of evidence on the returns from public space investments*. Available here: <https://londoneconomics.co.uk/wp-content/uploads/2015/11/LE-UKSA-Return-from-Public-Space-Investments-FINAL-PUBLIC.pdf> [Accessed 18 April 2017]

London Economics (2016). *The Size and Health of the UK Space Industry 2016*. Available here: <https://www.gov.uk/government/publications/uk-space-industry-size-and-health-report-2016> [Accessed 18 April 2017]

London Economics (2016) General Review. Available at: <http://londoneconomics.co.uk/blog/publication/met-office-general-review-march-2016/> [Accessed 18 March 2017]

Marine Management Organisation (2016) *UK Sea Fisheries Statistics 2015*. Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/598208/UK_Sea_Fisheries_Statistics_2015_full_report.pdf [Accessed 27 March 2017]

McShane, R., Gedling, K., Keene, J., Fairburn, C., Jacoby, R. and Hope T. (1998). *Getting lost in dementia: a longitudinal study of a behavioral symptom*. *Int Psychogeriatr*. 10(3). 253-260.

MDS Transmodal (2016) *The value of goods passing through UK ports*. Available at: <http://www.abports.co.uk/content/files/downloads/The%20Value%20of%20Goods%20Report.pdf>

Meinberg Funkhrehn GmbH and Co. KG (2015). *Oscillator Options*. Available at: <https://www.meinbergglobal.com/download/docs/other/oscillator-options-en.pdf> [Accessed 2 December 2016]

National Grid (2017) UK Transmission. Available at: <http://www2.nationalgrid.com/Contact-us/UK-Transmission/> [Accessed 20 March 2017]

National Physical Laboratory (2016). *UBS and TMX Atrium use new NPL network timing service*. Available from <http://www.npl.co.uk/news/ubs-and-tmx-atrium-use-new-npl-network-timing-service> [Retrieved 9 December 2016]

National Rail (2017) *About your rail fare*. Available at: http://www.nationalrail.co.uk/times_fares/ticket_types/83871.aspx [Accessed 16 March 2017]

Nieto, M.J., Santamaria, L. (2006). *The importance of diverse collaborative networks for the novelty of product innovation*. Available here: <http://www.sciencedirect.com/science/article/pii/S0166497206001064>

Office of Rail Regulation (2014) *Passenger compensation and refund rights for delays and cancellations*

Omnisense (date unknown) *Market Sectors / Applications*. Available here: <http://www.omnisense.co.uk/markets.html> [Accessed 13 December 2016]

ONS (2017) *Annual Business Survey* for 2015.

ONS (2017) *UK input-output analytical tables*. Available at: <https://www.ons.gov.uk/economy/nationalaccounts/supplyandusetales/datasets/ukinputoutputanalyticaltablesdeatiled>

Oxera Consulting (2013). *What is the economic impact of Geo services?* Available at: http://www.oxera.com/Oxera/media/Oxera/downloads/reports/What-is-the-economic-impact-of-Geo-services_1.pdf?ext=.pdf [Accessed 18 October 2016]

Oxford Economics (2012). *The economic impact of physics research in the UK: Satellite Navigation Case Study*. Available at: <https://www.stfc.ac.uk/files/satellite-navigation-case-study/> [Accessed 2 December 2016]

Oxford Economics (2009). *The Case for Space: The Impact of Space-Derived Services and Data*.

Oxford Economics (2015), *The economic impact of the UK Maritime Services Sector: Shipping*

Parliament (2006). *Select Committee on Science and Technology. Written Evidence – Submission from Surrey Satellite Technology*. Available here: <https://www.publications.parliament.uk/pa/cm200607/cmselect/cmsctech/66/66we77.htm>

Parliament (2013). *Science and Technology – Written Evidence submitted by CGI IT UK Limited, October 2013*. Available here: <https://www.publications.parliament.uk/pa/cm201314/cmselect/cmsctech/253/253vw14.htm>

Pham, D. N. (NDP Consulting) (2011). *The Economic Benefit of Commercial GPS use in the US and the costs of potential disruption*. Available at: http://www.gpsalliance.org/docs/GPS_Report_June_21_2011.pdf [Accessed 6 September 2016]

Pham, N. D. (2013). *The Economic Benefits of Global Navigation Satellite System and its Commercial and Non-Commercial Applications*, NDP analytics. Available at:

<https://static1.squarespace.com/static/52850a5ce4b068394a270176/t/52d57f29e4b0dad117c5e3bb/1389723433433/Economic+Impacts+of+GPS+December+2013.pdf> [Accessed 18 October 2016]

Public Health England (2014) *Radiological Consequences Resulting from Accidents and Incidents Involving the Transport of Radioactive Materials in the UK – 2012 Review*

Radiodetection (2011). *Water leak detection products*.

Rail Accident Investigation Branch (2017), Fatal accident involving the derailment of a tram at Sandilands Junction, Croydon 9 November 2016.

Rail Safety and Standards Board (2015) *Guidance on the Use of On-Train Satellite Positioning Technology Based Locator for Railway Applications*

Rispoli, F. (Ansaldo STS) (2016). *GNSS – The Game Changer for Competitive Train Control Systems*. Presentation at International Navigation Conference 2016

Reuters (01 April 2016), South Korea fishing boats turn back after North 'disrupts GPS'. Available at: <http://af.reuters.com/article/worldNews/idAFKCN0WY3I5>

Royal Yachting Association (RYA) (undated) *Chart plotter – friend or foe?*. Available at: <http://www.rya.org.uk/knowledge-advice/cruising-tips/navigation/Pages/chart-plotter-friend-or-foe.aspx> [Accessed: 27 March 2017]

Salter, A. and Martin, B. (2001). *The Economic Benefits of Publicly Funded Basic Research: a Critical Review*. Research policy 30, 509-532.

Scottish Government (2013). *Development of Electronic Monitoring in Scotland*. Available at: <http://www.gov.scot/Publications/2013/09/7937/3> [Accessed 5 December 2016]

Skyguard (undated) *Why more than 100 NHS trusts use Skyguard to protect their lone workers?*. Available at: <http://skyguard.co.uk/nhs/>

Statista (2016) *Number of connected cars in the United Kingdom (UK) from 2014 to 2020 (in millions)*. Available at: <https://www.statista.com/statistics/523800/digital-market-outlook-total-number-of-connected-cars-in-the-uk-statistic/> [Accessed 03 March 2017].

Surveillance Camera Commissioner and Tony Porter (2015) *Benefits of sharing CCTV and networks*. Available at: <https://www.gov.uk/government/speeches/benefits-of-sharing-cctv-and-networks>

Symmetricom (2010). *NTP and PTP (IEEE 1588) - A Brief Comparison*. Available from: <http://www.en4tel.com/pdfs/NTPandPTP-A-Brief-Comparison.pdf> [Retrieved 13 December 2016]

The Allen Consulting Group (2008). *Economic benefits of high resolution positioning services: Final Report*. Available at: <http://www.crcsi.com.au/assets/Resources/ffa927a7-55d1-400a-b7d6-9234f4fe4ad2.pdf> [Accessed 7 September 2016]

Texas Transportation Institute (2012). *Urban Mobility Report*. Available here <https://mobility.tamu.edu/ums/archive/#umr2012>

The General Lighthouse Authorities of the United Kingdom and Ireland (2010). *Briefing Note: Evolution from Loran-C to eLoran*. Available at: http://www.gla-rnav.org/pdfs/evolution_from_loran_c_to_eloran_v11.pdf [Accessed 18 November 2016]

The Marine Management Organisation (MMO) (2016) *Fishing industry in 2015 statistics published*. Available at: <https://www.gov.uk/government/news/fishing-industry-in-2015-statistics-published> [Accessed 16 March 2017].

The Marine Management Organisation (2016) *VMS 5: UK fishing boats satellite tracking device specification*. Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/498453/vms5.pdf

The Royal Academy of Engineering (2011). *Global Navigation Space Systems: reliance and vulnerabilities*. London: The Royal Academy of Engineering.

The Royal Academy of Engineering (2013). *Space Weather: Full Report and Curry, C. (2010). Dependency of Communications Systems on PNT Technology*. Chronos Technology

The Royal Institute of Navigation (2016) *SATNAV Use in VFR Navigation*. Available at: <https://liveicomgrshot.blob.core.windows.net/rinfiles/Uploadedpdfs/StaticPages/GPS%202017RIN.docx.pdf>

The University of Texas at Austin News (2013) *UT Austin Researchers Successfully Spoof an \$80 million Yacht at Sea*. Available at: <https://news.utexas.edu/2013/07/29/ut-austin-researchers-successfully-spoof-an-80-million-yacht-at-sea>

Traffic Commissioners for Great Britain (2016) *Traffic Commissioners' Annual Reports 2015-16*. Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/567036/tc-annual-report-2015-2016.pdf

Tsapakis, I., et al. (2011). *Effects of Tube Strikes on Journey Times in the Transport Network of London*. Transportation Research Record.

UK Space Agency (2012). *Impact Assessment: Competent PRS Authority*, June 2012. Available here: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/298025/competent-prs-authority-impact-assessment.pdf

UK Space Agency (2014). *Galileo works, and works well*. Available at: <https://www.gov.uk/government/news/galileo-works-and-works-well> [Accessed 6 September 2016]

UK Space Agency (2014). *Galileo*. Available at: <https://www.gov.uk/government/case-studies/galileo> [Accessed 6 September 2016]

UK Space Agency (2014). *UK leads the way in using Galileo*. Available at: <https://www.gov.uk/government/news/uk-leads-the-way-in-using-galileo> [Accessed 6 September 2016]

Volpe, J. A., U.S. Department of Transportation (2001). *Vulnerability Assessment of the Transportation Infrastructure Relying on the Global Positioning System: Final Report*.

Volpe, J. A., U.S. Department of Transportation (2009), The Use of eLORAN to Mitigate GPS Vulnerability for Positioning, Navigation, and Timing Services: Benefit-Cost Assessment Refresh, Available here: <https://rntfnd.org/wp-content/uploads/Benefit-Cost-of-eLoran-Volpe-Center-2009.pdf> [Retrieved 1 November 2017]

Wazenboeck, I.; Piribauer, P. (2015). *R&D networks and regional knowledge production in Europe. Evidence from a space-time model*. Available here: http://druid8.sit.aau.dk/acc_papers/4m96eshna2t0vqfshsha459mq54n.pdf

Wired (2012) The Inside Story of the Extra Second That Crashed the Web. Available at: <https://www.wired.com/2012/07/leap-second-glitch-explained/>

Wired (2016). *Uber can now track your location even when you're not on a ride. Here's how to turn it off*. Available at: <http://www.wired.co.uk/article/uber-track-location-data-update-turn-off> [Accessed 9 December 2016]

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ANNEXES

Annex 1 Definitions

GNSS signals	The information (carrier identification, ranging code, navigation data, timestamp, etc.) transmitted by a satellite of any global navigation satellite system (GPS, GLONASS, Galileo, BeiDou-2), or EGNOS regional system.
Disruption event	An unforeseen situation of the complete loss of GNSS signals and all associated functionality, howsoever caused, for a period of up to five days.
User groups	<p>Critical National Infrastructures (CNIs): The UK's Critical Infrastructure is defined by the Government as: "Those critical elements of infrastructure (namely assets, facilities, systems, networks or processes and the essential workers that operate and facilitate them), the loss or compromise of which could result in:</p> <ul style="list-style-type: none"> a) major detrimental impact on the availability, integrity or delivery of essential services – including those services, whose integrity, if compromised, could result in significant loss of life or casualties – taking into account significant economic or social impacts; and/or b) significant impact on national security, national defence, or the functioning of the state."²⁵⁴ <p>There are 13 UK CNIs: Chemicals; Civil Nuclear; Communications; Defence; Emergency Services; Energy; Finance; Food; Government; Health; Space; Transport; and Water. CNIs are typically characterised by specialists with a clear understanding of technical need and implementation of GNSS.</p> <p>Professional/Industrial: UK businesses (sole trader, limited company or partnership) using GNSS in their operations or integrated within the functionality of their commercial offerings. This group also includes non-commercial researchers. They are often, but not always, characterised by specialists with a clear understanding of technical need and implementation of GNSS.</p> <p>Mass market: The general public of UK citizens using GNSS within generic applications developed for a large-scale market. These users have typically only a rudimentary grasp of technical need and implementation of GNSS.</p>
Uses of GNSS	Universe of applications of GNSS used by any type of user.
Role of GNSS	The functional role of GNSS within a system, including consideration of the resilience (e.g. redundancy) systems and strategies. This is important, as it separates 'equipage' from 'usage' – if GNSS is used in a redundancy role, a disruption to GNSS may not have any impact if the primary system remains fully functional.
User	<p>An economic agent (individual or organisation) that is benefitting from GNSS-supported functionality in the current business-as-usual counterfactual scenario. Such use may be direct or indirect, defined as follows:</p> <ul style="list-style-type: none"> ■ Direct use: An individual (e.g. a private citizen using GNSS positioning on a smartphone map application) or organisation (e.g. energy network distributor using GNSS timing for synchronisation) that employs GNSS as a direct input to its operations, an application being used, and/or a product or service provided.

²⁵⁴ Cabinet Office (2016) *Summary of the 2015-16 Sector Resilience Plans*. Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/526351/2015_16_summary_of_the_srp.pdf

- **Indirect use:** An individual or organisation that uses a product or service of a direct user (e.g. electric railway company using electricity from an energy network distributor).

Note that any individual or organisation may be simultaneously a direct and/or an indirect user.

Disruption A loss of GNSS service, howsoever caused, for a period of up to five days.

Annex 2 Benefits of GNSS

Author	Title	Coverage	Benefit type	Sector	Benefit value (annual)	As % of GDP
Oxera (2013)	What is the economic impact of Geo services?	Global	Direct	LBS + Geographic Mapping	\$113bn	0.15%
Pham, N. D. (2011, NDP Consulting)	The Economic Benefit of Commercial GPS use in the US and the costs of potential disruption	United States	Direct	Agriculture	\$19.9bn-\$33.2bn	0.13%-0.22%
				Engineering Construction	\$9.2bn-\$23.0bn	0.06%-0.15%
				Commercial surface transportation	\$10.3bn-\$15.1bn	0.07%-0.10%
				All other commercial GPS users	\$28.2bn-\$51.1bn	0.19%-0.34%
				Total	\$67.6bn-\$122.4bn	0.44%-0.81%
Pham, N. D (2013, NDP Analytics)	The Economic Benefits of Global Navigation Satellite System and its Commercial and Non-Commercial Applications	United States	Direct, Indirect and Induced	GNSS-related manufacturing industry	\$38.8bn	0.21%
Leveson (2015)	The Economic Value of GPS: Preliminary Assessment	United States	Direct (+ some indirect ²⁵⁵)	Consumer Location-Based Services	\$7.3bn-\$18.9bn	0.04%-0.11%
				Precision Agriculture	\$10.0bn-17.7bn	0.06%-0.11%
				Surveying	\$9.8bn-13.4bn	0.06%-0.08%
				Fleet Vehicle Connected Telematics	\$7.6bn-16.3bn	0.05%-0.10%
				Total	\$37.1bn-74.5bn	0.22%-0.45%
Allen Consulting Group (2008)	Economic benefits of high resolution positioning services: Final Report	Australia	Direct and indirect	Agriculture	AUD152m-206m	0.01%-0.02%
				Mining	AUD371m-744m	0.03%-0.05%
				Construction	AUD306m-535m	0.02%-0.04%
				Total	AUD829m-1,486m	0.06%-0.11%
ACIL Allen Consulting (2012)	The value of augmented GNSS in Australia: An overview of the economic and social benefits of the use of augmented GNSS services in Australia	Australia	Direct and indirect	Agriculture	AUD298m-466m	0.02%-0.03%
				Mining	AUD683m-1,085m	0.05%-0.07%
				Construction	AUD448m-723m	0.03%-0.05%
				Road transport and logistics	AUD154m-213m	≈ 0.01%
				Total	AUD2.3bn-3.7bn	0.15%-0.25%
				Potential benefit by 2020	AUD7.8bn-13.7bn	0.5%-0.9%
				Satellite navigation industry	£113m	0.01%
				Benefits of satellite navigation	£146m	0.09%

²⁵⁵ Initial estimates are mainly for direct benefits, however, he did include indirect benefits where they involved documented cost savings.

Annex 3 Oscillator errors over time

Oscillator	Cost	Accuracy (ms) free run three days	Accuracy (ms) free run five days	Required accuracy		
				Mobile billing systems < 1s (1000ms)	Financial transaction < 1ms	Mobile networks, Smart Grid, DVB, DAB, CFT† < 1µs (0.001ms)
TCXO	A few pence	38.88	108.00	✓✓	✗✗	✗✗
OCXO LQ	£10s-£100s	7.78	21.60	✓✓	✗✗	✗✗
OCXO SQ		1.94	5.40	✓✓	✗✗	✗✗
OCXO MQ		0.58	1.62	✓✓	✓✗	✗✗
OCXO HQ		0.19	0.54	✓✓	✓✓	✗✗
OCXO DHQ		0.039	0.108	✓✓	✓✓	✗✗
Rubidium	£1,000+	0.008	0.022	✓✓	✓✓	✗✗
Rubidium XPRO	£10,000+	0.000	0.000	✓✓	✓✓	✓✓

Notes: Calculations assume a constant ambient temperature (i.e. drifts due to fluctuations in temperature are not accounted for). †: Computer-automated financial trading. ✓✓: Holdover sufficient for five days; ✓✗: Holdover sufficient for three but not five days; ✗✗: Holdover insufficient for three days.

Source: London Economics. Oscillator accuracy information based on Meinberg Oscillators and Microsemi. Accuracy calculations based on Rakon Calculator. Cost information for oscillators and accuracy requirements for sectors based on Curry (2010).

Annex 4 Supplementary information – mitigation strategies

A4.1 eLoran and compact fluorescent lamps

The eLoran carrier wave is on the 100kHz frequency, but because it uses pulsed signals, its energy covers the range from 90kHz to 110kHz. eLoran receiver front-end therefore needs to allow signals on those frequencies to pass through and be decoded by the receiver.

Unfortunately, compact fluorescent lamps (also known as low-energy lightbulbs) operate on a frequency in the range of 40-80kHz, and therefore emits that and its harmonics, including the 2nd which is within the eLoran receiver passband. The emitted frequency of low-energy lightbulbs comes from the plasma of the actual lamp, and changes when the product nears end-of-life. Dimmed bulbs also emit different frequencies than those on full power.²⁵⁶ This range of frequencies emitted means the 2nd harmonic may cover the entirety of the baseband, which makes it impossible to insert a narrowband notch filter and remove the interference from receivers. In the 100kHz frequency range, the broadband noise amplitude emission is the range 30-45 dBµV/m at 0.74m.²⁵⁷ eLoran's field strength with a 100kW transmitter is 45-120 dBµV/m depending on distance to the mast, and approximately 70 dBµV/m at 300km.²⁵⁸

The development of H-field antennae was an important step towards useful eLoran equipment as the size of the antenna has decreased, and p-static can be filtered out, and better results be achieved at indoor locations compared with E-field antennae.²⁵⁹ H-field antennae may be able to filter out the lightbulb emission issue as they are able to detect the direction of the signal, and for stationary sites, therefore only let in signal from the eLoran transmitter's direction.

A4.2 Effectiveness of mitigation

Infrastructure	Aspect	Loss (five days)	Mitigation technology	Mitigated loss
Chemicals	Transport of dangerous goods	-		
Civil nuclear	Tracking of classified goods	-		
Communications	Fixed-line telecommunications	-	eLoran, STL, (Precise Time)	
	Cellular telecommunications	-	eLoran, STL, (Precise Time)	
	Broadcast – DVB	-	eLoran, STL	-
	Broadcast – DAB	-	eLoran, STL	-
	TETRA (PMR)	-	eLoran, STL, (Precise Time)	
	Internet data centres	-	eLoran, STL, Precise Time	
Defence	<i>Out of scope</i>	-	-	
Emergency services	Public-Safety Answering Points	£508m	<i>None</i>	
	Emergency vehicle logistics	£1,023.5m	STL, eLoran, Locata/Omnisense**	£1,023.5m

²⁵⁶ Smith G. and I. Berta (2011) *Radiated Radiofrequency Emission from the Plasma of Compact Fluorescent Lamps*, International Journal of Plasma Environmental Science & Technology, Vol.5, No.1, March 2011

²⁵⁷ Smith G. and I. Berta (2011) *Radiated Radiofrequency Emission from the Plasma of Compact Fluorescent Lamps*, International Journal of Plasma Environmental Science & Technology, Vol.5, No.1, March 2011

²⁵⁸ Lo, S. and B. Peterson (no date) *Enhanced Loran*. Available at: https://web.stanford.edu/group/scpnt/jse_website/documents/Enhanced_Loran_rv2-short.pdf

²⁵⁹ Jie, W., L. Hang, Z. Jian (2010), *Application Research of H-field Antenna in Enhanced Loran*

Annex 4 | Supplementary information – mitigation strategies

Energy	Electricity transmission	-	eLoran, STL, (Precise Time)	
Finance	Bank trading centres	-	eLoran, STL, Precise Time	
Food	Food security	-	-	
Government	Weather forecasting	£1.9m	None	
	Offender tracking	£0.7m	None	
	Evidence management	-	eLoran, STL, (Precise Time)	
	CAP and CFP compliance monitoring	-	eLoran, STL*	
Health	Dementia tracking	-	None	
	Lone worker tracking	-	None	
Space	LEO satellites	-	MSF, eLoran, STL, Precise time	
	Ground stations	-	MSF, eLoran, STL, Precise time	
	Satellite communications	£22.5m	STL*	£22.5m
Transport infrastructure	Road transport infrastructure	-	STL*	
	Rail transport infrastructure	-	eLoran, STL	
	Maritime transport infrastructure	£1,069.3m	eLoran, STL	£1,069.3m
	Air transport infrastructure	-	MSF, eLoran, STL, Precise time	
Water & sewerage	Fixed-location noise loggers	-		
Road	Navigation	£26.3m	STL*	£26.3m
	Logistics and fleet management	£24.2m	STL*	£24.2m
Maritime	Navigation	£4.8m	eLoran, STL	£4.8m
	Search and rescue applications	£0.1m	None	
	Fishing	£7.1m	eLoran, STL*	£7.1m
Aviation	Reduction in DDC and CFIT	£0.1m	None	
	Search and Rescue (ELTs and PLBs)	£0.3m	None	
Agriculture	Cultivation	£155.7m	Locata/Omnisense**	
	Livestock tracking, hunting and silviculture	-		
Surveying	All applications	£344.8m	Locata/Omnisense**	
Rail	Driver advisory systems	£17.2m	eLoran, STL	£17.2m
	Automatic train doors	£2.8m	eLoran, STL	£2.8m
	Train cancellations	£90.4m	eLoran, STL	£90.4m
Legal	Timesheets and billable hours	-		
Location-based services	Public transport modal shift	£0.8m	None	
	Pedestrian navigation	-		
Road	Navigation	£1,869.7m	STL*	£1,869.7m
	Insurance telematics	-	STL*	
	Emergency and breakdown calls	-	STL*	
Non-road transport	Recreational boating	-	eLoran, STL	
	VFR aviation	-	eLoran, STL	
Total		£5,172.9m		£4,160.8m (£1,187.5m)

Note: One asterisk in the column of mitigation assumes the form factor of the listed mitigation technologies is such that they are useful for the application. When no asterisk is included, this is considered certain. Two asterisks refer to Locata/Omnisense solutions and indicate coverage is not likely to be national in reality. Total in brackets indicate the mitigated loss independent of form-factor assumptions.

Annex 5 Estimated UK public funding for GNSS

NB: the following estimates comes from London Economics' analysis of publically available information as referenced. They are for illustrative purposes and are not guaranteed to be accurate in light of information that could not be obtained for this report. The interested reader should consult published UK SA annual reports and source material, as referenced, for accurate figures.

Programmes	Objectives	Theme	UK investment, €m (2016 prices)		
			2000-2006	2007-2013	2014-2017
EU Galileo and EGNOS programme budget	Build the EGNSS infrastructure, operations, provision of services	Upstream	242.3	720.7	385.3 ²⁶⁰
ESA GNSS Evolution Programme (EGEP)	Studies and development of technologies associated with Europe's GNSS	Upstream	-	14.7	15.7 ²⁶¹
EU/GSA Aviation Grants	Equip airports with capabilities for EGNOS operations	Downstream	-	-	1.5
EU/GSA Fundamental Elements – Galileo	Support development of chipsets and receivers	Downstream	-	-	0.9
EU/GSA Fundamental Elements – EGNOS	Support development of chipsets and receivers	Downstream	-	-	2.2
EU FP6 GNSS R&D programme	Develop GNSS capacity in Europe (user recognition, market penetration)	Downstream	17.6 ²⁶²	-	-
EU FP7 GNSS R&D programme	Accelerate downstream GNSS market and support European industry	Downstream	-	9.6	2.5 ²⁶³
EU/GSA H2020	Develop Galileo applications and market uptake	Downstream	-	-	9.2 ²⁶⁴
ESA ARTES 20 Integrated Applications Promotion (IAP)	Develop, implement and pilot applications that integrate data from at least two existing space assets (satcom, EO, satnav etc.)	Downstream	-	11.2 ²⁶⁵	14.9
ESA GSTP	To convert promising engineering concepts into mature products	Downstream	2.8	2.5	2.3 ²⁶⁶
ESA/UK GNSS Demo Centre	Support exploitation of GNSS technologies	Downstream	-	-	0.3 ²⁶⁷
Innovate UK – funding for GNSS	Innovate UK's work to support satellite navigation and PNT	Downstream	-	7.1	5.5
UK SA National Space Technology Programme	Develop growth of the UK Space sector as embodied in the Space IGS	Downstream	-	2.0 ²⁶⁸	0.7
UK SA International Partnerships Space Programme (IPSP)	To test an approach to enable UK satellite and other space sector companies to develop international partnerships for mutual benefit	Downstream	-	-	4.6 ²⁶⁹
Total (of programmes LE have obtained data on*)			262.7	767.8	445.6

Note: Upstream covers infrastructure and downstream applications and hardware. *No data available for ESA TRP, ESA NAVISP, UK SA IPP, UK SA BIC

Source: LE analysis of information provided by UK Space Agency, Innovate UK, and GSA (2016). GNSS Opportunities database. Available at: <https://www.gsa.europa.eu/opportunities/gnss-opportunities-database>

²⁶⁰ Figures based on following estimates of EGNSS expenditure: £1,480m (2000-2006); £5,006m (2007-2013); £7,072 (2014-2020). Source: http://europa.eu/rapid/press-release_MEMO-13-718_en.htm

²⁶¹ UK figures are available here: <https://tk.parp.gov.pl/files/74/575/590/729/16294.pdf>

²⁶² Assume UK contribute EU budget share of €110m, based on following source: https://www.gsa.europa.eu/sites/default/files/TS7807240ENC_002.pdf

²⁶³ GSA (2008). *European Union 6th Research Framework Programme 2002 – 2006 Project Synopsis*. Available here: https://www.gsa.europa.eu/sites/default/files/TS7807240ENC_002.pdf

²⁶⁴ GSA (2015). Overview of results from GNSS research under FP7 R&D programme (2007-2013). Available here: https://www.gsa.europa.eu/sites/default/files/FP7-brochure2015_7.pdf

²⁶⁵ Actual UK contributions figures are €13.2m for CMIN-08, €57.55m for CMIN-12 & CMIN-14, €60m for CMIN-16, assuming GNSS share is 25%.

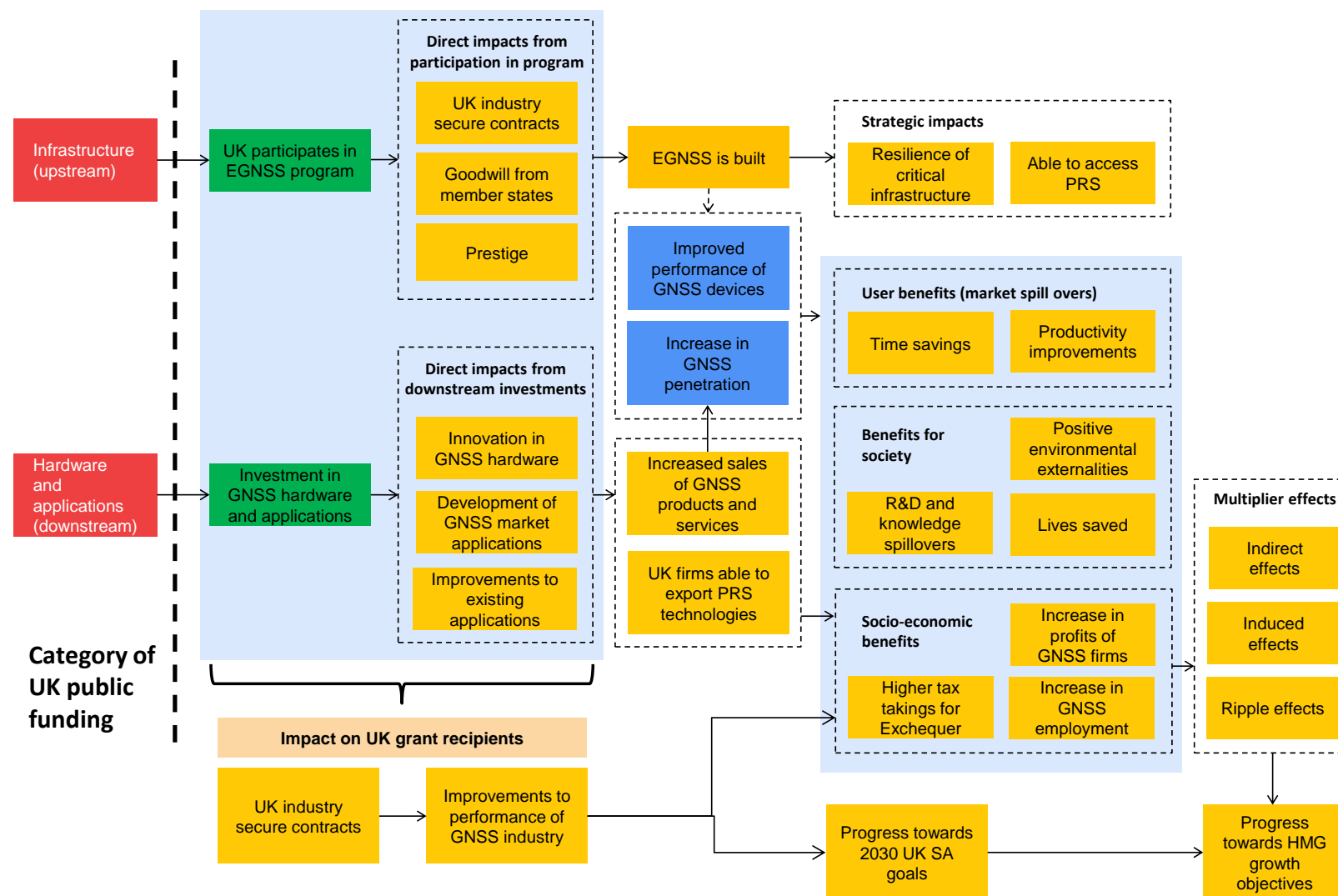
²⁶⁶ EU budget for GSTP was €1,492 for 2000-17 period. UK contributed ~10%, 5% of which was GNSS relevant: co https://tect.prox.esa.int/GSTP/GSTP%20Annual%20Report/GSTP_ANNUAL_REPORT_2015.pdf

²⁶⁷ GNSS Demo Centre is no longer proceeding, but Innovate UK confirm that first phase was worth £300,000.

²⁶⁸ 20% of £10m for GNSS. PNT represents 1/5 areas of focus. Funding occurred in 2012. Since no specific details are given, have used average exchange rate for each year of funding (£:€ = 1.15 – 1.24): https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/375153/NSTP_review_final.pdf

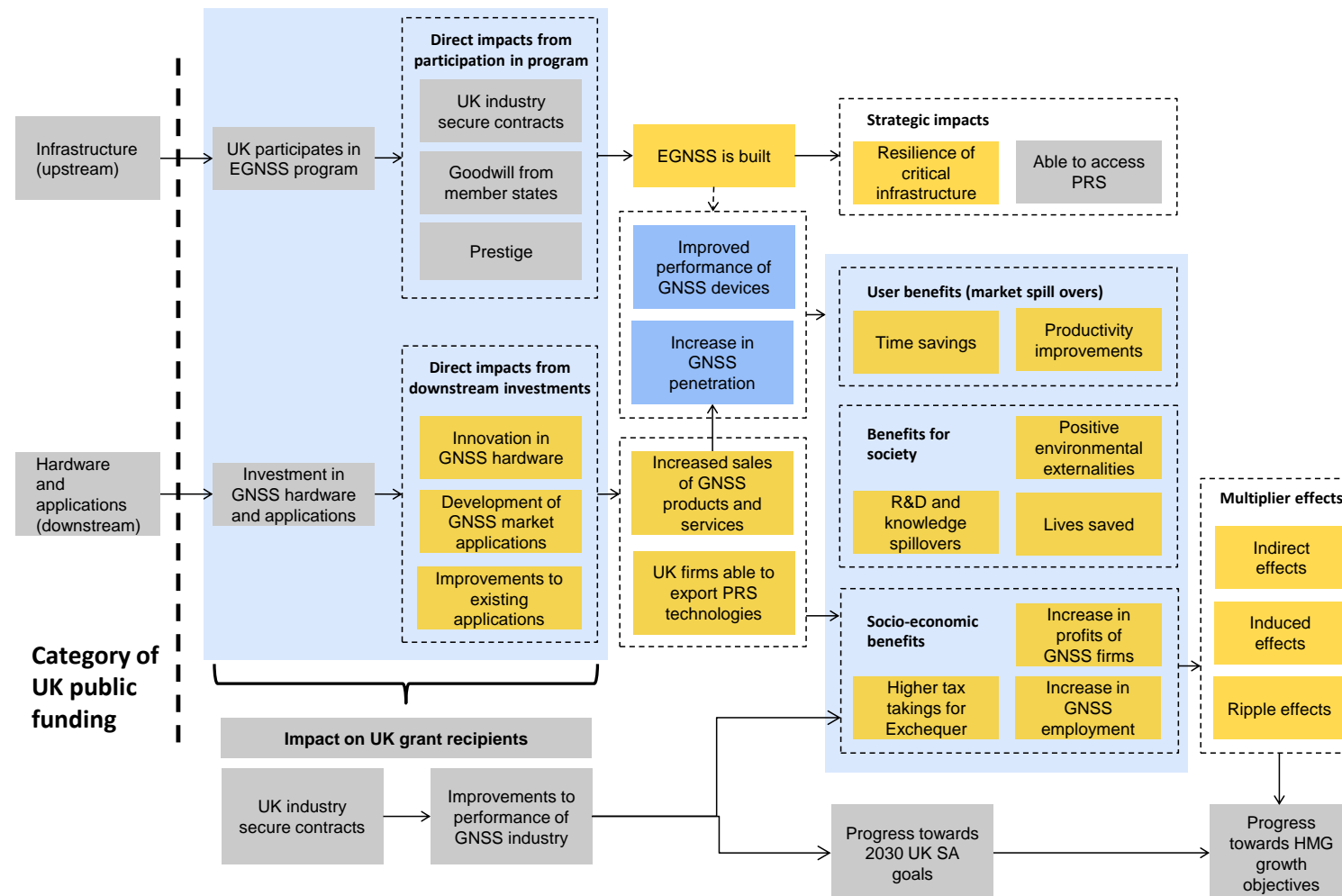
²⁶⁹ £32m programme between 2015 and 2016. 1/7 projects where GNSS relevant so have taken this to be the GNSS share: <https://www.gov.uk/government/collections/uk-space-missions-case-studies-and-programmes#international-partnership-programme>

Annex 6 Impact logic model: UK funding for GNSS



Annex 7 Impact logic model: counterfactual

NB: Impacts from the scenario with UK funding that are: i) the same colour – are impacts that are unchanged; ii) cloudier in colour – are impacts that are reduced; ii) grey – are non-existent impacts





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