FINAL

Economic impact to the UK of a disruption to GNSS

Showcase Report

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Introduction

Ask an average person on a typical UK street and they'll probably tell you that GPS is a satellite-based navigation system that they use to work out where they are, and how to get somewhere. But it is so much more than that …

The Global Positioning System (GPS) is one – albeit the original and most utilised – of four Global Navigation Satellite Systems (GNSS) that provide 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.

This capability underpins much of everyday life in the UK, as in all modern economies (see *'A day in the UK with GNSS'* on the following page). The free-at-point-of-use and global availability features of the civilian open service has driven a growing proliferation of applications and use of GNSS.

Applications that use GNSS are widespread, but the full extent and nature of use, as well as their resilience to a GNSS outage, has not been well understood. This gap in knowledge is concerning, as GNSS is subject to various vulnerabilities to failure. Given the coincidence of widespread use (including safety-critical applications) and vulnerability, the question naturally follows:

What would happen if GNSS were not available temporarily?

This study aims to provide an answer in terms of estimated economic impact: comprising lost Gross-Value Added (GVA) and loss of utility benefits, including damages. Note that the impact of a GNSS-reliant present-day UK losing GNSS functionality unexpectedly, is much greater than the incremental benefit to the UK of using GNSS rather than the well-functioning next best alternative to GNSS.

Using a combination of desk-based research and a programme of more than 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 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 methodology, 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.

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

- The study is constrained by the availability and accuracy of published information, and user/expert knowledge and assessment of risks. Estimates may contain an optimism bias.
- The report is agnostic to the actual source of the considered disruption.
- The disruption to GNSS is considered as a standalone event.
- The analysis relates to current modern-day UK. However, as GNSS applications are dynamic and reliance changes over time, the validity of the results is time-sensitive.

The box overleaf seeks to provide an insight into the myriad ways in which GNSS is used – knowingly and unknowingly – by an average UK citizen in a typical day.

A day in the UK with GNSS

At home:

- Wake-up with an alarm on a smartphone which sources precise time information from GNSS
- Check email, social media and online news, using Internet data centres synchronised using GNSS
- Switch on a DAB radio, receiving radio signals synchronised using GNSS time
- Switch on lights, and put on the kettle, drawing electricity from the GNSS-synchronised grid
- Go for a morning run, tracked using GNSS
- Check the weather forecast, which has been enhanced by GNSS radio occultation and other techniques

On the move:

- Drivers benefit from turn-by-turn navigation optimised using crowd-sourced congestion information
- Public transport users benefit from GNSS-based bus/train tracking and passenger information systems
- Pedestrians and cyclists use GNSS-based local search, route-planning and navigation
- Smartphone users can order a car to their GNSS-derived location using a variety of popular apps
- Travellers on airplanes, trains and boats indirectly benefit from GNSS being used to operate those modes efficiently and safely – including satellite communication links enabled by GNSS

With others:

- Personal trackers can be used to monitor the location of children, loved ones with dementia, pets and personal possessions (e.g. luggage, bikes, keys, wallets, etc.)
- Augmented-reality games and travel guides leveraging GNSS offer entertainment and convenience
- Meet up with friends using a 'share my location' function

At work:

- Whilst the role and importance varies by occupation, most workers use GNSS to some extent, e.g.: **High-frequency-traders** require GNSS timestamps to synchronise their systems and ensure 'freshness' of data so that the advertised price and trade is achieved; **Farmers** use GNSS for precision agriculture; **Construction workers** control heavy machinery using inputs from **surveyors** who strongly rely on GNSS; **Fishermen** need GNSS to comply with regulation and return to bountiful waters; **Merchant vessels** use GNSS as a 'lighthouse in the sky' for positioning, route-planning, ETA estimation and satellite communications to update port schedules; **Road transport operators** use GNSS for navigation and fleet management systems optimising operations and reducing downtime; and **shops and factories** rely on timely inputs to keep operations going and shelves full; **Scientists** can use GNSS signals for a variety of research (e.g. tracking of rare wildlife; tectonic plate monitoring) and testing (e.g. ionospheric scintillations)

At the shops:

- Supermarkets, like many stores, operate just-in-time stock management systems, relying on GNSS-based fleet management systems to deliver in a consistently timely manner
- Food prices are lower as GNSS enables more efficient precision agriculture production and fisheries
- Goods purchased online are dispatched, scheduled and delivered efficiently using GNSS
- GNSS is used to track and secure transport of high-value and dangerous goods (e.g. cash, chemicals)

When things go wrong:

- All blue-light services (Police, Ambulance, Fire Brigade, Coast Guard) use GNSS to locate the emergency, dispatch the most appropriate vehicle, and navigate there and away in as little time as possible
- GNSS-guided satellite imagery and positioning is used for risk monitoring and disaster response planning
- Personal alarms with GNSS provide safety protection and peace-of-mind for lone workers

Back at home:

- Smart home technology (e.g. thermostat) linked to a GNSS-derived user location ensures a heated home whilst minimising energy consumption
- After a day at work, groceries or a take-away might be delivered using GNSS navigation and positioning
- Watching TV relies on broadcast signals that are synchronised using GNSS
- Using a standard landline for a phone call relies on the GNSS-synchronised network

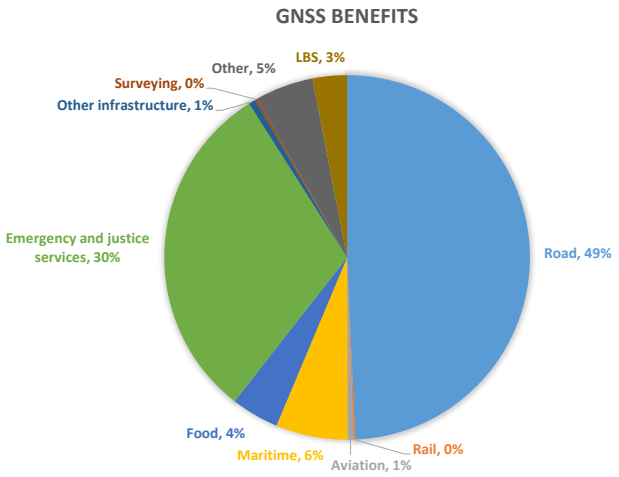
Plus: There are many further examples of indirect usage (using a system that relies on GNSS), whilst in the future, the range of applications, and diversity of users, of GNSS is predicted to continue to grow apace

Current usage and benefits of GNSS

GNSS 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, and Transport identified as particularly intensive users. The reliance on GNSS has developed over decades, based on assumed availability and continuity of GNSS. 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 PNT services in 2014/15, supporting 4,000 jobs. More broadly, **sectors generating a total of £206bn in Gross Value Added (11.3% of UK GDP) are supported *directly* by GNSS**, but the primacy of GNSS in critical national infrastructures means that an even wider range of economic activity is underpinned by GNSS *indirectly*.

Quantified direct benefits to the UK of GNSS (business-as-usual) have been monetised at £6.7bn per annum. This is made up of a £1.2bn boost to GVA plus £5.5bn worth of utility benefits.

With annual direct benefits of **£3.3bn** and **£2.1bn** respectively, applications in **road** and **emergency services** account for almost 80% of all estimated benefits. The vast majority of the benefits in road are associated with improvements to driver performance and reduced congestion that come from professional and consumer applications of turn-by-turn road navigation. These benefits, estimated at **£3.1bn** per annum, are monetised as **time savings**, **fuel savings**, **reductions in emissions**, and **reduced accident risk**.



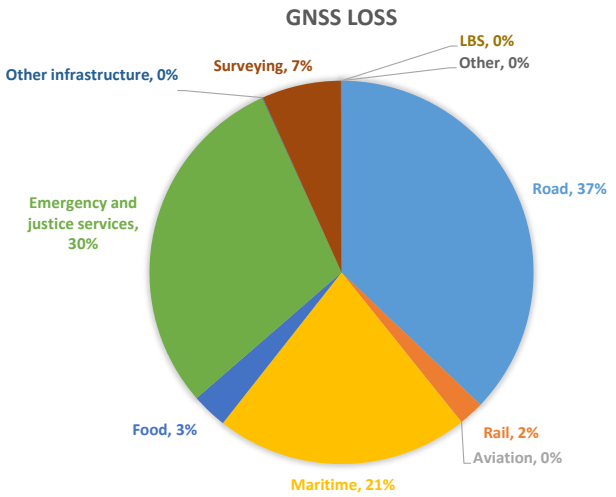
For **emergency and justice services**, almost all of the benefits come from the impact on the public-safety answering points (PSAP) – a service which receives emergency calls and provides the GNSS-derived mobile phone location data to the emergency services when available – **reducing call and search times**. Other notable benefits come from: the **time and fuel savings** that GNSS-supported navigation enables in the maritime industry (**£350m**); the impact for precision agriculture on **increased crop yields** and the **more efficient application of pesticides and fertiliser** (**£284m**), and the monetisable benefits that are associated with GNSS's contribution to the **accuracy of weather forecasting** (**£100m**).

It should be noted, however, that these benefits have all been estimated **conservatively** as the **incremental benefit of using GNSS rather than the well-functioning next best alternative**. Also, that **in many cases it has not been possible to monetise benefits** – e.g. where GNSS underpins activity for which a global source of accurate timing is a necessity; including 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.**

Impact of a disruption to GNSS

The economic impact to the UK of a five-day disruption to GNSS has been estimated at £5.2bn. This is comprised of **£1.7bn** in lost GVA and **£3.5bn** in lost utility benefits (including damages). Applications in road, maritime, and emergency and justice services account for 88% of all impacts.

The impact on the **transport network** would be substantial, at **£2bn.** Navigation devices for road applications would fail soon after losing signal. GNSS-dependent drivers, particularly delivery and minicab drivers, would therefore lose their preferred method of navigation, increasing congestion and journey times for *all* drivers – including commuters who know their route.



Emergency services would also be severely impacted and struggle to cope with demands. Longer emergency calls, less efficient dispatch, navigation, and congested roads would mean a total estimated loss of **£1.5bn**.

Another substantial source of disruption would come from the **maritime** sector, where a five-day GNSS loss would disrupt all ports and the loading and unloading of containers for the duration of the outage, imposing **£1.1bn** in lost GVA over the five-day period. 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 bulk container or vehicle would be severely delayed as ports and other transport operations would lose all the efficiencies brought about by GNSS. For this reason, as with many other applications, immediate impacts would be felt far beyond the maritime industry. Similarly, the **surveying** sector which provides critical inputs in all construction activities would need to shut down for the entire duration of the outage very soon after GNSS was lost. This effect is estimated at **£345m**.

The impact of a disruption to GNSS is limited by resilience measures that stakeholders have confirmed are in place for a duration of five days. Interviews with stakeholders, for example, suggest that financial services are resilient to a five-day loss of GNSS, with traders and stock exchanges maintaining advanced holdover capacity and high street banks using lower grade oscillators that would, nevertheless, give them sufficient protection. Similarly, both the fixed and cellular telecommunications networks have sufficient holdover to maintain timing synchronisation throughout the five-day outage period. As a result, there would be no impact on the functionality of the telecommunications network, and therefore no economic loss.

The estimated economic impact of a disruption to GNSS is also limited by the difficulty of robustly estimating the costs associated with the loss of certain activities. For example, the National Grid relies on GNSS to ensure correct synchronisation of energy transmission between substations. In the event of loss of GNSS, manual staffing would likely be required, which would be challenging at a national level. The precise probability and impact of disturbances to the network and the ability to supply power to critical infrastructure that rely on GNSS timing and are in holdover is unknown.

Details of the impact of a five-day loss of GNSS are summarised in Table 1 below, with a RAG rating (red=high | amber=medium | green=low) summarising the overall impact on the application.

Table 1 Summary of economic loss to the UK as a result of a five-day loss of GNSS

Domain	Applications	RAG	Loss of GVA (£m)	Loss of utility (£m)	Total loss for five days (£m)
Road	Road transport infrastructure Road navigation / Advanced Driver Advisory Systems Logistics and fleet management Insurance telematics Emergency and breakdown call		24.2	1,896.0	1,920.2
Rail	Rail transport infrastructure Passenger information systems Asset management Driver advisory systems		94.9	15.5	110.4
Aviation	Automatic Dependent Surveillance - Broadcast system Air transport infrastructure Navigation under visual flight rules Cospas-Sarsat search-and-rescue (SAR) system Mobile satcoms		0.1	0.3	0.4
Maritime	Maritime transport infrastructure Navigation and shipping Search and rescue applications Fishing Recreational boating		1,103.7	0.1	1,103.8
Food	CAP and CFP compliance monitoring Cultivation Livestock tracking, hunting and silviculture		151.6	4.3	155.7
Emergency and justice services	TETRA Public-safety answering point Emergency vehicles Offender tracking		0.4	1,531.5	1,531.9
Surveying	Cadastral surveying Mapping Mining Construction (person and machine-based) Marine surveying Infrastructure monitoring		344.8	-	344.8
LBS	Smartphones Pedestrian navigation Fitness tracking		-	0.8	0.8
Other infrastructure	Transport of dangerous or classified goods Telecommunications – fixed-line & cellular Broadcast – DVB & DAB Internet data centres Electricity transmission Fixed-location noise loggers		0.7	2.3	3.0
Other	Banking and stock exchanges Weather forecasting People tracking LEO satellites and ground stations Timesheets and billable hours		2.5	1.1	2.6
Total			**1,721.9**	**3,451.8**	**5,173.6**

A day in the UK without GNSS

At home:

- Most activities at home are unaffected, but the morning run is no longer tracked and the weather forecast would be less accurate

On the move:

- The satnav in the car doesn't work so the journey must be memorised based on waypoints, road numbers and destinations from mobile phone apps that no longer place you where you are, or paper maps
- In fact, nobody's satnav works so there are more vehicles on the road, and they stop at inopportune moments to consult their maps and verify they are on the right track to the next waypoint
- For those wanting to take the train, there is no information on the next departure (as the trains are no longer tracked by the same system), and overcrowding on the platform. When the train eventually arrives, the doors remain locked for a minute until the train system is reset at every stop
- Trying to book a minicab, the app doesn't work, and there is a long queue on the phone line. When eventually they pick up, they cannot make promises on when the taxi will arrive

With others:

- It is no longer possible to track children, loved ones with dementia, pets and personal possessions with great accuracy, resulting in increased risk of loss and anxiety
- Friends no longer share their location, and meetings may be missed
- Whilst augmented reality games do not work anymore

At work:

- Depending on occupation, GNSS loss could affect working life to a high degree, e.g.:
  Merchant skippers lose access to speed over ground measurements and estimated time of arrival, and without satcoms are unable to schedule a port unloading slot; **Maritime pilots** lose functionality of portable pilot units and twice as many pilots spend twice as long docking each vessel using only visual aids; **Container cranes** stop working and containers remain on vessels; **Logistics drivers** cannot pick up the cargo that should be moved, but also satnav, dispatch efficiencies, and substantial amounts of time are lost on the more congested roads; **Factory workers** are sent home as inputs no longer arrive 'just-in-time'; **Farmers** lose efficiencies gained from GNSS and spend more time navigating tractors around the field, damaging plants and suffering reduced yield at harvest; **Fishermen** lose the ability to navigate straight to bountiful waters, and large proportion return to port; **Food processors** suffer from price increases due to reduced agricultural yield and lower supply of fish; **Construction workers** cannot operate autonomous construction machinery and inputs from **surveyors** are no longer forthcoming – workers in both professions are sent home

At the shops:

- Supermarket shelves run out of products and perishable goods no longer arrive on time, resulting in stock shortages and reduced retail sales
- People begin to hoard products and a higher priced black market may emerge
- Delivery of online shopping loses efficiency, many orders are undelivered and perishable goods go bad

When things go wrong:

- PSAPs lose access to the location of mobile callers and spend more time handling emergency calls
- First responders (police, ambulance, and fire services) can no longer use the location to navigate to an incident, but instead need to rely on postcodes, addresses and street numbers, prolonging response
- First responders spend more time navigating to incidents without satnav, and dispatchers no longer assign the optimum vehicle to incidents, and increased congestion prolongs response even further
- Lone workers lose the safety and peace-of-mind that someone is on hand to support them if needed

Back at home:

- After a day at work, the groceries or take-away food is significantly delayed as the driver needs to navigate (more traffic) using waypoints and paper maps

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 existing back-up systems. 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. Similarly, for timing applications, loss 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 many months. However, higher quality equipment with longer holdover periods is more expensive. Hence, loss of the 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.

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 keep ports open (especially if satcoms would continue to function). The cost of resurrecting (e)Loran to a usable 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, or even urban-based emergency services). 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.

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 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.

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