Study into the impact on capability of UK Commercial and Domestic Services Resulting from the loss of GPS Signals

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S J HARDING

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Company Name	Radiocommunications Agency
Customer Contact	Dominic Hayes
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Authorisation

Prepared by	S J Harding
Title	Principal Navigation Engineer
Signature	
Date	
Location	X107 Room 1003

Authorised by	P Briggs
Title	Technology Chief
Signature	
Date	

Authorised by	
Name	S J Horrocks
Appointment	Business Group Manager
Location	X107

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Executive Summary

Global Positioning System (GPS) as offered by the United States operates in the band 1559 - 1610 MHz, which is allocated for use (under the International Telecommunication Union (ITU) Radio Regulations) by aeronautical radio navigation and radio navigation-satellite services. The United Kingdom has agreed under these ITU regulations to the transmission of the GPS L_1 frequency (1575.42MHz). However, protection of the GPS receivers using L_1 has not been agreed in the UK. Therefore GPS receivers within the UK operate on a non-interference basis and can claim no protection from other users of the radio spectrum.

Questionnaires were sent to many different organisations, central and local Government and many commercial services. The Majority of responses showed very little awareness of the underlying vulnerability of GPS/GNSS to interference or its potential loss of positioning data in situations of low satellite visibility. An example of GPS's sensitivity to interference is that if the same rf power as a car remote door opener operating continuously and centred on GPS then reception would not be possible within a radius of less than ~0.5km .

Against this background the study investigated the impact and reliance on GPS and Global Navigation Satellite Systems (GNSS) of UK's civil domestic and industrial commercial services and assessed the effect of the loss of the GPS/GNSS Signal in Space (SIS)

The study identified three application areas where international regulatory organisations are developing plans for the implementation of GNSS based navigation or timing systems to a degree where disruption to the GNSS SIS could potentially have a significant impact on the UK infrastructure. Disruption to the GPS SIS would result in a significant reduction in service.

Aviation applications will include use of GNSS to fly "virtual" routes and for Precision Approach. Regulations require that appropriate reversionary navigation equipment is available. However, the CAA together with Air Traffic Service (ATS) providers, are actively seeking to protect the radio spectrum around GPS and GNSS frequencies to safeguard air traffic operations.

GPS and DGPS are used extensively for Maritime applications. In case of loss of GPS signal a ship's captain would revert to Radar, LORAN, Charts or Dead Reckoning. The Maritime community sees the adoption of a WorldWide Radio Navigation System as key to improving ship safety and for preventing pollution. The IMO have mandated the carriage of GNSS as the means of meeting maritime navigation accuracy requirements for ships over 300 tons from July 2002. In addition GNSS is advocated as the most appropriate technology to provide position information to the Global Maritime Distress and Safety System, Vessel Tracking Systems and the Automatic Identification System.

The emergency and law enforcement agencies operate autonomously at regional levels. Each force makes its own equipment procurement decisions. GPS is entering service for Automatic Vehicle Location (AVL), asset tracking and fleet management purposes. Disruption to the GPS SIS could impact significantly on these operations. The emergency and law enforcement services should identify appropriate protection measures to safeguard specific operations in case of signal loss or unintentional interference.

The Telecommunications Industry requires accurate time for synchronisation of networks. Three techniques are used. Caesium clocks have been the traditional means of timing. These however are expensive. Increasingly GPS is used in two configurations. The first is to condition a Rubidium clock, however over time the clock drifts if the GPS signal is removed. The other is a GPS/Rubidium clock continuously conditioned using a distributed Caesium Primary Reference Clock. . There should be no impact to communications networks using Caesium or Caesium conditioned clocks from disruption to GNSS SIS. Developments in the next generation of global, mobile telephones may introduce more complexities. The proposed developments of the CDMA based IMT2000 (UMTS), for which some base station transmitters may depend solely on GPS timing, may be vulnerable to interference.

The Ordnance Survey operates systems that will rely increasingly on GPS. These organisations need to identify appropriate protection measures to safeguard specific operations in case of deliberate signal loss or unintentional interference.

GPS is used extensively in Road and Rail Transport. These applications are commercially driven. On the current data these groups will suffer significant inconvenience and annoyance if the SIS is disrupted. Users should be able to revert to traditional ways of obtaining navigation and position information if the SIS is denied

The Gas, Water, and Electricity supply industries currently rely on traditional means for asset location. Some companies are introducing AVL but current use of GPS appears to be at a low level.

The growth in the number of applications relying on GPS is significant. Most users acknowledge that the free service carries no guarantees and that the frequency is not protected. The development of a civil operated and controlled satellite navigation system, such as Galileo would significantly improve availability of satellite based positioning information, timing and back up to the loss of GPS.

The report concludes with recommendations that: -

> The UK is growing more reliant on GPS for fundamental activities. The fundamental weakness and vulnerabilities of GPS signal reception should be more widely publicised, especially for those services where significant inconvenience or critical impact could occur, although more GPS satellites may be launched.
>
> Business and emergency service efficiency gains provided by GPS and AVL should be better assessed. Possibly by using limited representative examples to determine the cost benefit impact.
>
> A more permanent and robust mechanism for notification of GPS signal information is developed and those services identified as ‘critical’ operating close to any MOD GPS trials are identified and more actively notified.
>
> The MOD still need to conduct GPS trials and to develop appropriate measures to prevent the hostile use of satellite navigation without hindering peaceful civil use of the system.

1 Introduction

1.1 Contractual matters

QinetiQ has conducted a programme of work for the Radiocommunications Agency contract number RA_AY3976.

The study investigated the following issues.

- Identify the use/likely use of GPS/GNSS by domestic and commercial users.
- Assess the dependence of domestic and commercial services on GPS/GNSS signals.
- Consider means for better co-ordination and dissemination of information if GPS signal loss does occur.

1.2 Background to the study

1.2.1 Approach to the study

The study comprised two main phases: the collection of data relating to the use and dependence on GPS within UK commercial and domestic services, and the assessment of the impact of the loss of GPS to these services.

The collection of data was achieved by three means:

- Document research
- Questionnaire
- Visits to specific industry/service to elicit further information

The document research included specific requests to organisations for relevant documents and a search on the Internet.

Questionnaires were distributed, to known members of UK Governmental Departments and to other industrial contacts identified in a previous GPS impact study conducted by DERA. These contacts provided considerable assistance either as responses relating to specific departments or introductions to others that could respond more fully.

Information obtained from the previous study responses is also included, if these is subject to commercial, confidentiality, or operational restrictions, this is made clear. It was noticeable that in the intervening period between this study and its predecessor, the majority of confidentiality concerns have disappeared, as knowledge of that specific use of GPS is now in the public domain.

Questions that were asked of the GPS user communities: -

Question: Do you use GPS? If you do, to what uses/applications do you apply it to?

Question: If GPS is used, what benefits do you gain from using GPS? Please clarify this in terms of criticality to your operational need and specify if it is an economic benefit. If so what form does this take? Please describe any element that involves passenger/public safety.

Question: What happens to your facilities if your GPS system can no longer receive the radio signal from the GPS satellites? Has any assessment been conducted into the impact of GPS non-availability? Have any mitigation techniques been designed/installed to take over if GPS becomes unavailable?

1.2.2 Report layout

The report is presented in five parts :-

Section 2 provides an introduction to the GPS Commercial and Domestic Impact study.

Section 3 provides a look at GPS signal in space reception.

The following sections consider GPS use in groupings related to the support to UK domestic and commercial services: -

- Section 5 Utilities Power, Water Gas industries
- Section 6 Transport Road Rail Aviation and Maritime
- Section 7&8 Economic Scientific Exploration and Survey industry
  Financial, Telecommunications and Broadcasting industry
- Section 9 Domestic Health, Safety and Emergency
- Section 10 Miscellaneous
- Section 11 Consolidated Conclusions

Within each of these groupings individual applications of GPS within the UK infrastructure were researched, analysed and conclusions reached.

Section 12 considers co-ordination issues related to information dissemination concerning the loss of GPS and is covered in

Section 13 part 5 includes a summary of recommendations

2 Introduction to the GPS commercial and domestic impact study

This section provides some background to GPS and its vulnerabilities.

2.1 GPS and GNSS services provision

Two satellite services are currently available for global navigation applications; The US Global Positioning System (GPS) and the Russian GLONASS. Both systems were originally developed as military systems designed to improve weapon delivery. Since public access of these satellite positioning services signals has been possible for many years, a global industry based on satellite navigation has now grown, its economic value is in the $Billions/year, almost exclusively based on GPS as the service available for GLONASS is minimal. This study only concerns the use of GPS.

Augmentations to GPS include various Differential Correction services and the area augmentation systems; Wide Area Augmentation Service (WAAS) covering the Americas and the European GPS Navigation Overlay Service (EGNOS) covering the ECAC region and Africa, a similar system is being developed in Japan.

GPS as offered by the United States operates in the band 1559 - 1610 MHz, which is allocated for use (under the International Telecommunication Union (ITU) Radio Regulations) by aeronautical radio navigation and radio navigation-satellite services. The United Kingdom has agreed under these ITU regulations to the transmission of the GPS L_1 frequency. However, protection of GPS receivers using L_1 has not been agreed in the UK. Therefore GPS receivers within the UK operate on a non-interference basis and can claim no protection from the other users of the radio spectrum.

In Europe, the European Commission and European Space Agency have received authority from their respective member states to enter the detailed definition phase and development of a civil operated and controlled satellite navigation system, called Galileo. This will be a competitor to GPS; it is planned to provide a guarantee of service, a legal liability and some form of controlled access service. This system is planned to have an initial operating capability in 2008. This system is not covered within this study, although any conclusions reached in regard to GPS would almost certainly apply to Galileo if it were used to the same extent as GPS in future.

2.1.1 GNSS user application growth

The number of applications and users of GPS is growing at an explosive rate. High production volumes of the core GPS integrated circuits has allowed the purchase cost of a GPS chip to fall to the less than $10 range, these low costs stimulating the commercial market to develop units that allow the creation of added value to existing or new markets. One major market growth area is currently in the use of GPS/GNSS for automatic vehicle location services. Another market area for personal location services is less developed at the moment, though it is expected to be a large future market for GPS/GNSS based positioning services.

GPS/GNSS supports many other markets e.g. the professional survey, transportation and telecommunications industry.

All of the above industries or markets use GPS/GNSS in specific ways and may or may not be aware or understand the limitations of the above systems. Well organised and safety conscious organisations such as the International Civil Aviation Organisation and the International Maritime Organisation are intimately involved in the development of GPS/GNSS for safety related applications and are knowledgeable in these matters.

3 GPS Signal In Space (SIS) reception

3.1 GPS/GNSS vulnerability

All of the GNSS systems in existence or planned by the USA, Russian Federation or Europe have some common attributes. The received signal powers available at a user terminal are extremely small; they range from -160dBW to –155dBW. The transmissions are usually of a spread spectrum nature and their 'resistance' to interference ranges from a value of ~20 to ~30dB; giving very low threshold interference limits of –140dBW to –125dBW.

Users of GPS/GNSS who are aware that there is no guarantee of continuous GPS service should have taken account in their application design the possible natural loss of the signal due to building shadowing in cities, towns, or tunnels or interference. Reduced GPS signal strength also occurs in forested areas.

3.2 Unintentional GPS signal loss

The timing and positioning data from the GPS signal can be lost if for instance a vehicle enters an urban area, where GPS satellite visibility, is very low, this can also occur in mountainous or hilly areas. This loss may not be of a continuous nature, but sufficient to affect certain applications.

Alternatively the GPS signal can be lost through an external interference source that exceeds the GPS threshold limits. GPS/GNSS applications are very susceptible to relatively low-level radio frequency interference. Spurious and harmonic emissions from other radio frequency transmissions such as mobile satellite terminals could be one cause of interference; others sources could be broadcast transmissions.

The UK Ministry of Defence retains the rights to conduct legitimate research on the effect of GPS loss to its forces trials to ascertain these effects are usually conducted in remote area's. Assessment and due regard to the effect on the public use of GPS is performed, together with wide dissemination of the times of these trials as required by the "Procedures for the co-ordination of peace time jamming January 2001".

Although more GPS satellites may be launched in future, this will only slightly increase the number of satellites in view and help reception in areas blocked by terrain or buildings. It will not help against malicious or external interference.

4 GPS use related to the support of UK domestic and commercial services

Sections 5 to 10 review the impact of GPS loss on the majority of GPS/GNSS user communities. These range from applications used in support of Government departments (i.e. emergency services), through to commercial GPS/GNSS operations such as freight tracking and roadside assistance.

GPS loss in the context of this report is considered the complete loss of the radiated satellite signal and not any localised loss due to terrain/building shadowing or interference effects.

5 Utilities – Power, water gas/oil delivery industries

5.1 Introduction

This section identifies the use of and reliance on GPS within the water, gas and electricity industries. An assessment is made on the impact the loss of satellite navigation signals would have on these users.

5.1.1 Organisations consulted

- Gas industry and Gas transport company
- Water and Electricity industry - radio telemetry support company
- Regional Electricity Companies and National Grid Plc
- Water Company

5.1.2 Background and Current use of GPS

The majority of the utility industries such as the National Grid and British Gas use GPS for reporting of vehicle positions. The survey position of assets, such as power and pipelines etc. is usually conducted by traditional techniques, but also by GPS assisted aerial survey techniques. All utility companies have a common interest and work together to create an asset location database using a common grid Geographic Information System (GIS). Improved efficiency in use of utility maintenance vehicles is obtained with the availability of an accurate database locating these assets.

To enable the rapid location of lightning strikes, one system has been developed that relies on accurate timing of data from geographically separate monitoring stations, this relies on timing based on the use of GPS.

To enable accurate location of cable ducts etc. one company uses GPS to record as-laid positions of ducts, buildings and boxes, transferring this information to an Ordnance Survey background. The information retrieved on site is used to relocate the buried apparatus. Although the services of GPS are useful in this process, the old fashioned time served method was to record positions on site using fixed bearings and civil surveying techniques. This worked perfectly well although its ease of use, cost of surveying and accuracy of information are all improved by GPS availability. There would be little or no impact on this business from loss of GPS. Locating buried equipment relying solely on OS information is easy, helped by the burial of a tracer wire on which a signal can be transmitted to aid location.

The gas delivery industry does not use GPS at this time, though it may be considered in the future to ensure that work (first visit to a publicly reported gas escape) is issued to the best placed (geographically) employee. There is no current direct effect on gas transportation but there could be an indirect effect if for example a GSM network dependent solely on GPS timing were affected. Therefore no mitigation for the loss of GPS is required at this time.

5.1.3 Analysis

From the data collected there appears to be no sole reliance on GPS. The loss of GPS would impact the improved efficiency gains made by better management information on asset and vehicle location. Loss of GPS would force a fall back to use of voice/data communications for vehicle location management and normal civil survey techniques for asset management.

Efficiency gains made available from the use of GPS positioning information are forcing greater reliance on it for the future.

5.1.4 Conclusions

Analysis indicates that a loss of GPS at this time may only have an inconvenient or annoyance effect on the above utility services. No critical impact issues were identified. However, the impact of loss in the future may become a significant inconvenience, if traditional survey techniques are no longer taught/used.

6 Transport – Road, rail, aviation and maritime

6.1 Road - Introduction

This Chapter identifies the use of and reliance on GPS within the UK land transport industry. An assessment is made of the impact the loss of satellite navigation signals would have on these users. The Chapter does not include Emergency Service and law enforcement applications.

6.1.1 Organisations consulted

- County Council
- Road Organisations
- Government Transport Department (Various topic areas)

6.1.2 Background and current use of GPS

The UK Government department responsible for transport identified the keen awareness of the commercial sector for the use vehicle positioning and route guidance systems, which rely on GPS/GNSS. GPS/GNSS use for freight haulage is also considered under part of the European Commission TENS programme, where a considerable number of studies have been conducted on use of GNSS positioning. At present there are no regulations applied to the use of satellite navigation.

Applications of GPS/GNSS can be divided into two main categories: -

- Those associated with the road infrastructure
- Those associated with traffic using the roads

6.1.3 Road transport infrastructure consideration of GPS/GNSS

The use of GPS/GNSS positioning has been examined as part of a motorway-tolling programme. The concern in the case of tolling is that one of the technical options proposed for use on the UK motorway network relies on GPS. Essentially an in-vehicle charging unit would identify using a GPS receiver, whenever the vehicle was at a virtual charging point on a motorway network and deduct a toll from the account stored in the unit, probably on a smart card or by a mobile GSM call etc. However, this option is unlikely to be used, as the loss of a GPS signal due to terrain/ building shadowing or other causes might prevent the tolling system from operating and thus revenues would be lost. Additionally public/Government confidence in the reporting accuracy of such a system would be lost. However there is still considerable interest in the potential of using satellites for this purpose. It is suspected that by the time GPS/GNSS applications saturate commercial services in the UK, satellite-based tolling systems may be much nearer the market place. The availability of more than one fully functioning GNSS system may remove the problem of signal blockage.

A Government study has considered the benefit of tracking dangerous goods on UK roads for any potential safety benefits. One example is that there are 16,000 petrol tankers in UK. Tracking of these tankers had not been proved to increase safety and would be extremely costly to administer, however to improve company efficiency, most tanker operators have installed tracking devices. The motivation is the need to locate for either their own purposes or to advise customers of the whereabouts of goods.

Studies have identified that satellite systems have other potential uses such as the monitoring of driver's hours and their travel patterns, progressing and tracking containers, providing navigation, providing road surveying facilities and possible applications related to speed control and traffic management. One example of this is the Highways Agency, an Executive Agency of Government, responsible for the provision, operation and maintenance of the trunk road network in England. Satellite positioning has revolutionised its surveying techniques, it is now used exclusively for the building and maintenance of roads. It may still be possible to perform the functions by traditional technique, however there will come a time when this is no longer practical.

6.1.4 Commercial road transport use of GPS/GNSS

The study identified that there are potential transport applications using GPS/GNSS where the loss of positioning information may be problematical. Many vehicle fleet management systems offer the operator and customer a more effective and faster response in tracking their vehicles. Depending on how long the particular systems has been in operation and the degree of reliance on the positioning system it might take considerable time to re-adjust to a manual mode of operation if the signals failed. Several bureau services offer support for freight and fleet operators, using GPS for vehicle location and tracking. All of these organisations use GPS/GNSS facilities at their own risk, though they may not be aware of this. No assurance is given for GPS/GNSS availability.

Several roadside support organisations use GPS position location services extensively. The position information helps them to locate the position of their patrols so that they can be confident of allocating the nearest patrol to a broken down vehicle. A large number of vehicles are installed with GPS. Each vehicle is monitored at a set time period or distance travelled and a message sent to the operational HQ. Despatch decisions are based on last known patrol location: usually the location of the last job. It is probable that AVL capability will be rolled out across the majority of all roadside fleets. The benefit of AVL to a vehicle responding to a members call is a significant reduction, between 4% and 10% in average response time. Loss of GPS would deny this advantage and despatch decision would be likely to revert to a basis of last known location. Given a scenario, in which resources were allocated automatically to a roadside job, the location and other parameters being inputs to the decision, loss of GPS data would have a significant impact on efficiency. The study identified that there was consideration to using GSM triangulation. This was dependent on the development of position determination systems within GSM telecommunication systems.

The study also identified that other value-added information can be provided to a customer, if their location is known. This is termed 'telematics' and can provide traffic information, route information or any other assistance; other location-based services are in development. The majority of vehicle manufacturers are developing added value options based on telematics systems and GSM mobile communication, if the positioning service were lost, the customer would complain to the telematics provider.

GPS is becoming fundamental to the commercial fleet transport market, AVL techniques allows efficient use of these fleets. One operator has over 19,000 systems in operation, where GPS is used to provide position information, another operator uses GPS to track secure freight, while long haul truck operators use GPS for the efficient management of their fleets. Commercial stolen car recovery systems use GPS.

6.1.5 Vehicle navigation systems and intelligent driver assistance.

The future of telematics and intelligent transport systems (ITS) in vehicles will be dependent on knowing where vehicles are. There are several ways of doing this including sensors and beacons as part of the road infrastructure, but it is expected that the most likely method will be by the use of GPS. Such applications will include logistics (planning the optimisation of the transportation of goods by road), navigation, congestion monitoring and avoidance, intelligent speed adaptation, theft countermeasures; breakdown and occupant injury response and insure as you drive.

One of these applications, supported by GPS and map matching algorithms may support automatic emergency diver assistance, where airbag deployment triggers a GSM distress call to the an emergency call centre. This application of in-vehicle navigation has the following benefits; it is free, its accuracy if supplemented by map matching is sufficient, though it is not a safety critical system. There will be a cost of saving a life benefit from these systems, there will be a reduction in costs of emergency services and medical treatment due to the more efficient deployment of resources and a reduction in pain and suffering. However, with all these added benefits, there has been no assessment of what would happen if the SIS were no longer available. The navigation systems would simply no longer work, and the emergency driver assistance systems would not be viable, reversion to current situation of the need to voice call to emergency services would occur.

Another future application is for intelligent driver assistance and speed adaptation (ISA), a means to aid the driver, or ensure that the driver does not exceed the correct speed for the current driving situation. This, again, could be effective without the need of GPS. It would almost certainly need the benefit of roadside beacons. However, it is expected that any initial stage of implementation of ISA would use GPS, as this would allow it to be effective anywhere without the need for a comprehensive network of roadside beacons. There is considerable interest in this idea both by individual members of the European Union and within the European Commission. For most of the systems listed above temporary loss of the GPS signal could be tolerated, by predicting the vehicle's position during any gap or temporary interference, with self-correction once the GPS signal was again detected. Dead reckoning could do this.

The effect of the loss of the signal in space (SIS) would have varying effects. All the advantages of the location information would be lost. In most cases, at present, this would result simply in a degradation of information back to the pre ITS era with the consequential loss of the efficiency improvements. However, in the near future, it is expected that the efficiency gains will be assumed and no fall back would be acceptable in anything but temporary terms without major disruption both in terms of efficiency and safety. In the longer term the dependence on GPS may decline so the loss of SIS would not be so dramatic. The time scale of this would depend on the speed at which sensors and beacons become part of the road infrastructure.

6.1.6 Local public transport use of GPS/GNSS

Within the UK, the Government has consulted on a strategy to meet the objectives established by 'The Real Time Information Group', a forum comprising representatives from local authorities and public transport operators. The Real Time Information Group was to "Enable real time technology to deliver better public transport services and information to the public about such services at an affordable price".

The common interest in the strategy can be defined as the recognition of the need to use real time technology to address three issues:

- Service reliability/consistency
- Traffic Management and managed bus priority
- Improved accessibility of public transport information to encourage a shift from car to public transport services and integration

Within the local public transport field, several county councils are adopting new technology to assist passengers by displaying the time of the next bus. The accuracy of this data provides confidence to the passenger/customer that they can rely on public transport for their needs. It also allows the operating company to efficiently plan their services. In one organisation, a differential GPS service is the primary location device for vehicles. The vehicle location is used to compare to actual running time to the timetable for the purposes or providing real time information and requesting priority control at traffic lights for vehicles more than two minutes late.

Bus companies are expected to see significant cost savings from bus priority due to lower fuel costs and staff savings. Use of these systems is designed to increase bus usage and to encourage a modal shift away from cars. In the case of short-term GPS/GNSS loss of signal the telematics system can determine a vehicle location from odometer reading and door contact at bus stops. This is however only a backup and will not work for prolonged periods as the risk of providing false information is too great. No formal assessment of impact has been conducted and no mitigation techniques are in place to reduce GPS unavailability. Future plans include bringing other vehicles such as gritting lorries into the system. Both cost effectiveness and political concerns drove implementation of the system. GPS systems are proving popular and it is expected that there will be few of the alternative bus-stop based beacon-based system outside of the major cities.

Local public transport operators are not aware of any threat to life issue associated with GPS non-availability. Embarrassment and user dissatisfaction would arise of there was a system failure, long term GPS signal loss or a significant inaccuracy in displayed data would not give customer confidence in moving from car to local transport. The fall back position for the system is one of reverting to a printed timetable and working at best efforts on the part of each driver.

For the taxi trade which are most likely to take advantage of GPS systems, the reducing cost of the in-vehicle navigation systems as supplied by the motor manufacturers provides added customer benefit and more efficient operation for the taxi company.

6.1.7 Analysis

GPS is in widespread use in UK in land transport applications. The degree of use is almost totally driven by commercial interests. These could not, at present, be considered critical applications but if a significant number of users were reliant on satellite navigational aids and these no longer worked there is bound to be some impact on traffic and network operation. Government sponsorship of the use of GPS is minimal, though its growing reliance on GPS, especially for highway surveying could in future be termed critical.

GPS signal loss will have a major inconvenience impact on efficient business operations of commercial organisations. The majority of applications, certainly for fleet tracking and vehicle emergency services also include GSM or another radio based system. Operators indicate that they would revert to voice operations. Though this would be an inconvenience and may become intolerable in the long term, due to their loss of efficiency and the response time to customers.

Vehicles are becoming more “intelligent” and the balance between infrastructure based control and information systems and vehicle-based systems will change. Vehicle telematics and positioning is an important enabler within this and GPS/GNSS has a critical role to play.

Other alternative means of positioning information are available; using either a Low Frequency Positioning/High speed data network or via other two-way satellite position fixing systems. However, these services are usually augmented by GPS position data. No reliable back up is available yet. Operators are looking at triangulation systems embedded within GSM or planned (U-MTS) networks with interest.

6.1.8 Conclusions

Analysis indicates that a loss of GPS has an inconvenient business effect on the above transport services. No critical impact issues were identified, except Governments growing reliance on GPS for surveying. The business inconvenience could however have a large economic effect. If long term GPS signal loss is encountered, it may become a significant block on the expected growth of vehicle telematics.

6.2 Rail introduction

This Chapter identifies the use of and reliance on GPS within the UK rail industry. An assessment is made on the impact the loss of satellite navigation signals would have on these users.

6.2.1 Organisations consulted

- Several Railway operating companies
- The Underground
- Government Rail Transport Department

6.2.2 Background current use of GPS - Rail

The rail industry in Great Britain no longer operates in the public sector privatisation has established many independent public transport and rail freight companies. The rail network operator Rail Track has a contractual obligation to the Rail Regulator to report on the train operator's schedule time keeping. Some operators already use GPS in their train tracking systems

GPS is used for monitoring the position of assets, including location of unserviceable trains; in addition the system is used to advise passengers where they are (Passenger Information System). Any impact on safety, would be dependent on a risk assessment of any design, which should acknowledge that system will be unavailable at certain times i.e. when in tunnels, deep railways cuttings etc.

One manufacturer produces GPS monitoring systems for positioning and timing in the rail industry, over 100 systems are in operation on trains, many 1000's of trains using such systems are expected in the future.

GPS timing is also used to keep the railway telecommunication network in synchronisation.

GPS is an essential part of one system used for rail condition monitoring, though software is available for locating features on the railway without the continuous use of GPS. There are no safety implications, the system uses a pattern recognition technique during short periods of GPS outage.

One operator conducted trials of some GPS tracking systems applications. However their requirement more biased to data transfer than location information, and used GSM. TETRA, a future alternative could be used for transmission of data including GPS position. The operator addressed the potential interference to and loss of the GPS signal, it concluded that a better (available) service could be obtained through use of a GSM triangulation system. The particular requirement was for a system giving position of approximately 300 meters, as trains are on tracks of known position.

The tracking of wagons carrying dangerous goods using GPS could have a safety issue, though GPS would not be the sole positioning system.

6.2.3 Underground

The extent of operational use GPS is very limited due to the fact that >40% of the network is underground. Thus if an absolute position system was needed for operational purposes it might be extended onto the surface areas. However the main dependency on GPS is for the essential and accurate surveying of position of underground assets and the line of route. GPS is necessary to accurately position surveys to the London Underground master geographic grid. GPS is considered the ideal tool for this. Tunnels cannot access the satellites, but accurate co-ordinates are taken by traversing down from surface control stations, whose position has been determined by GPS, or near station entrances. Internal car and truck fleets use a position reporting system. Considerable benefit is derived from more accurate surveys and thus the avoidance of potential errors. None of this involves passenger/public safety.

6.2.4 Analysis

The current rail infrastructure includes devices to detect the passage and therefore location of a train; GPS is not used for safety critical applications, as terrain/building shadowing is a significant issue affecting position determination. The movement detection of a train is as important as absolute position and is where GPS with an integrated data broadcast system provides a benefit over a fixed-point detection system.

There is a great increase in use of GPS for rail asset management purposes, in terms of vehicle location (locomotive and wagons) and accurate surveying of assets e.g. buildings and rails

GPS loss of signal could cause disruption and an increase in commercial costs as alternative position location systems linked to systems such as GSM or more labour intensive survey methods would have to be used.

For rail systems, the designs acknowledge that the GPS/GNSS system will be unavailable at certain times i.e. when in tunnels, and cuttings, therefore short term loss is mitigated.

Value added services such as passenger information systems, if reliant on GPS for position information, would have to be designed to cater for signal loss. It is likely that mitigation using dead reckoning techniques from last reported position would be used.

At least one operator had assessed the impact of GPS and concluded it was not a viable sole means of position location. An integrated solution was necessary.

6.2.5 Conclusions

There is an acknowledgement that, for this industry, the GPS/GNSS signal can not be guaranteed continuously, taking into account tunnels, cuttings etc. There is a clear realisation that the use of

GPS/GNSS as a sole means solution is not viable. However research is progressing for the inclusion of GNSS as part of an integrated system.

A short-term loss of a GPS signal would be an inconvenience and have no critical impact. However, in the future, a longer-term GPS signal loss could impact business efficiency because of the growing reliance on it for asset management and survey purposes.

6.3 Aviation

6.3.1 Introduction

This Chapter identifies the use of and reliance on GPS within the UK Aviation industry.

The data for the Aviation applications derives from an analysis of regulatory documents relating to the use of GPS in European and UK airspace.

This Chapter includes sections on the role of GPS and current and future use of GPS/GNSS in UK airspace. The chapter provides an assessment on the impact the loss of satellite navigation signals would have on these users.

- The CAA
- Airlines
- Pilot
- Air Traffic Service Operators

6.3.2 Background

The UK Civil Aviation Authority (CAA) defines the policy on the use of navigation aids in United Kingdom airspace. This includes GPS and other satellite systems. The CAA policy for the use of GPS in UK airspace is harmonised with the EUROCONTROL strategy. In the European Region the European Civil Aviation Conference (ECAC) co-ordinates the use of European Airspace in compliance with ICAO conventions.

Consultation with the Civil Aviation Authority elicited information with respect to the impact of loss of GPS. It includes references to material that describes in detail the UK policy on use of GPS for aviation. As an entity the CAA does not itself ‘use’ GPS, but from an aviation perspective it does regulate its use.

Current CAA policy and requirements for the use of GPS in civil aviation is stipulated in Aeronautical Information Circular number, AIC 113/1998. This relates to navigation purposes, the most widespread being the use of GPS to support Basic RNAV in the airspace of the European Civil Aviation Conference (ECAC). The use of GNSS for civil aviation purposes is expected to increase over the next decade requiring both positions in space and precision timing. These applications are most likely to be new types air traffic services made possible by the performance of GNSS, e.g. Automatic Dependent Surveillance, reduced separation, direct routing of aircraft etc.

The use of GPS for safety related purposes is an ongoing institutional issue because of the inability to attest its reliability or integrity using conventional UK safety regulatory means. For this reason present applications are designed to readily tolerate failure of GNSS whilst maintaining safety. Currently this is achieved by comparing with, or reverting to, traditional systems and this method automatically restricts the potential benefits of GNSS to the industry. The augmentation of GPS/GNSS in future by ground and space based systems (GBAS/SBAS), depends less on traditional systems, and likely to provide more benefit.

A significant issue raised by the CAA in the GPS debate was the question of frequency protection. It not only affects the current position and reaction when, for example, the Ministry of Defence quite legitimately conduct GPS trials, but also will determines the ability and willingness of CAA to allow greater reliance to be placed on GPS. It is important that aviation establishes the level of protection that would be required to assure the integrity and availability necessary to support potential operational applications. Institutionally, this may be further complicated by the fact that aviation, which is in many respects a minority user of GPS, may demand the most stringent protection. The CAA indicated that if this issue remains unresolved, GPS was likely to remain limited in its aeronautical application. Aviation will need to determine the level of progress needed on protection or if it is content to await developments.

6.3.3 Current use of GPS

For Oceanic and North Sea operations, and because of the benign environment, the CAA does not require a reversion capability, but operators are required to have contingency procedures in the event of source data failure. For other UK airspace Basic Area Navigation (BRNAV) the Joint Aviation Authorities TGL No 2 details BRNAV requirements, which in the case of GPS requires a reversion capability using the existing terrestrial navigation aids VHF Omni-directional Range, VOR Distance Measuring Equipment DME, and Automatic Direction Finder ADF.

Use of GPS in the North Atlantic region. It is difficult to receive most terrestrial navigation aids other than LORAN C system in this region and aircraft are typically reliant on Inertial Navigation Systems (INS). Approval currently exists for aircraft to utilise GPS as a primary means of navigation in the North Atlantic region as GPS provides a highly accurate positioning source. The nature of the North Atlantic traffic is such that it is the larger, better equipped, aircraft most, if not all, of who will be carrying multiple inertial systems and/or GPS, the aircraft will simply revert to INS navigation. The separation standards in the North Atlantic Region region are significant and provide large separation between aircraft, thereby preserving safety margins.

B-RNAV allows aircraft to operate along defined Air Traffic Service (ATS) routes that are independent of the ground infrastructure, whereas historically all ATS routes were defined by two navigation aids, one at each end. Many navigation systems are capable of supporting B-RNAV operations including those using multi-sensor Flight Management System techniques, but most notably, GPS was permitted so that low-end aircraft users could affordably equip to become B-RNAV compliant. GPS equipment is accepted as a means of compliance subject to it being approved, installed and operated in accordance with the criteria contained in JAA GAI-20 AMC/IEM 20X2 (JAA Admin and Guidance material TGL No 2. In the event that a GPS B-RNAV equipped aircraft suffered from a loss or corruption of the GPS position the flight crew are required to revert to existing ground based navigation aids such as Non-Directional Beacons (NDB), VHF Omni-directional Ranges (VOR) and Distance Measuring Equipment (DME). If they find that they are incapable of navigating successfully using this approach they are required to contact Air Traffic Control (ATC) to request radar vectors to their destination or a nearby diversionary airfield. Irrespective of the safety levels for aircraft affected, there would certainly be an operational impact on those aircraft reliant on GPS only to achieve B-RNAV compliance. Such aircraft could be held on the ground and prevented from departing on a BRNAV flight path until the signal became available again for a significant period. This would manifest itself as a potentially significant economic penalty to those users of UK airspace."

Helicopter and offshore use of GPS - the loss of the GPS positioning service would cause the helicopter operators some difficulty in finding the rigs in poor visibility conditions. However, the nature of North Sea operations, a loss of GPS guidance would not be a more significant safety issue than the loss of previously supported operations that were predicated upon the existence of the Decca ‘Navigator’ system or Non-Directional Beacons located on rigs themselves. Note that the DECCA ‘Navigator’ system is no longer operational.

For general aviation (GA) and glider users, a response to our survey indicated that they do benefit from the use of GPS as a modest safety benefit (although the extent is difficult to quantify). It improves their situational awareness, thus reducing to some extent the small risk of controlled flight into terrain or airspace infringement. However, it is not critical to their operation. They must abide by the CAA AIC and JAA regulations as appropriate. One of the main GA hazards observed has been an over dependence on GPS at the expense of traditional navigation, as evidenced in the CAA General Aviation Safety Information Leaflets.

The gliding community relies on GPS to provide the evidence of waypoints achievement during gliding competitions, this is not a safety requirement, only an efficiency gain. Previously cameras were used.

Aeronautical crop spraying relies on accurate delivery, GPS is used for this, it is not an aviation regulatory requirement. In today’s environmental aware culture, inaccurate delivery on, for instance an organic farm, adjacent to the wanted farm could have some economic impact, though GPS is not the sole position sensor in this instance, the mark-one eyeball is!

Satellite Based Augmentation Systems (SBAS) supporting the first use of GPS/GNSS for precision approach and en-route navigation applications are expected to arrive around the year 2005. SBAS uses a geostationary satellite-based downlink on the GPS L1 frequency to carry differential corrections and integrity data to users. Hence, any loss of GPS signal due to unintentional or intentional interference will equally affect the SBAS downlink, rendering it unusable. Loss of the GPS signal due to GPS system operation failure would also render the SBAS signal unusable for navigation.

There will be increasing adoption of Ground Based Augmentation Systems (GBAS) in the shorter term to support GPS operations in the vicinity of airfields, where a local differential broadcast signal could be capable of providing adequate performance down to altitudes of 350 feet above the airfield surface.

For the terminal areas within Europe the most demanding use of GPS will be RNAV approaches to a near CAT 1 minima where warnings need to be given to the pilot when the RNAV is not being achieved. In the longer term some airlines expect to have on- board systems that will allow aircraft to continue on its prescribed course when GPS is lost or erroneous signals are detected, a fly wheel effect. Loss of GPS due to interference may preclude RNAV approaches. GPS as a single source for purposes of Category 2/3 landing is not an expectation in the very near or medium term.

GPS is an input sensor to Enhanced Ground Proximity warning system, but in this instance is harmonised with Barometric Altitude and the aircraft Radio Altimeter. GPS is not the prime altitude sensor.

With the additional potential introduction of standalone GPS as a means to fulfil the area navigation requirements of Terminal Manoeuvring Areas (the area of controlled airspace in the vicinity of major aerodromes) GPS/GNSS will gradually becoming an integral part of ATS operations.

The use of GPS and GNSS for future aircraft navigation applications is expected to be significant.

The current plans for the next 15 years show a significant move from ground-based navigation systems to satellite-based navigation systems as shown below, DME is still retained as a terrestrial navigation mode: -

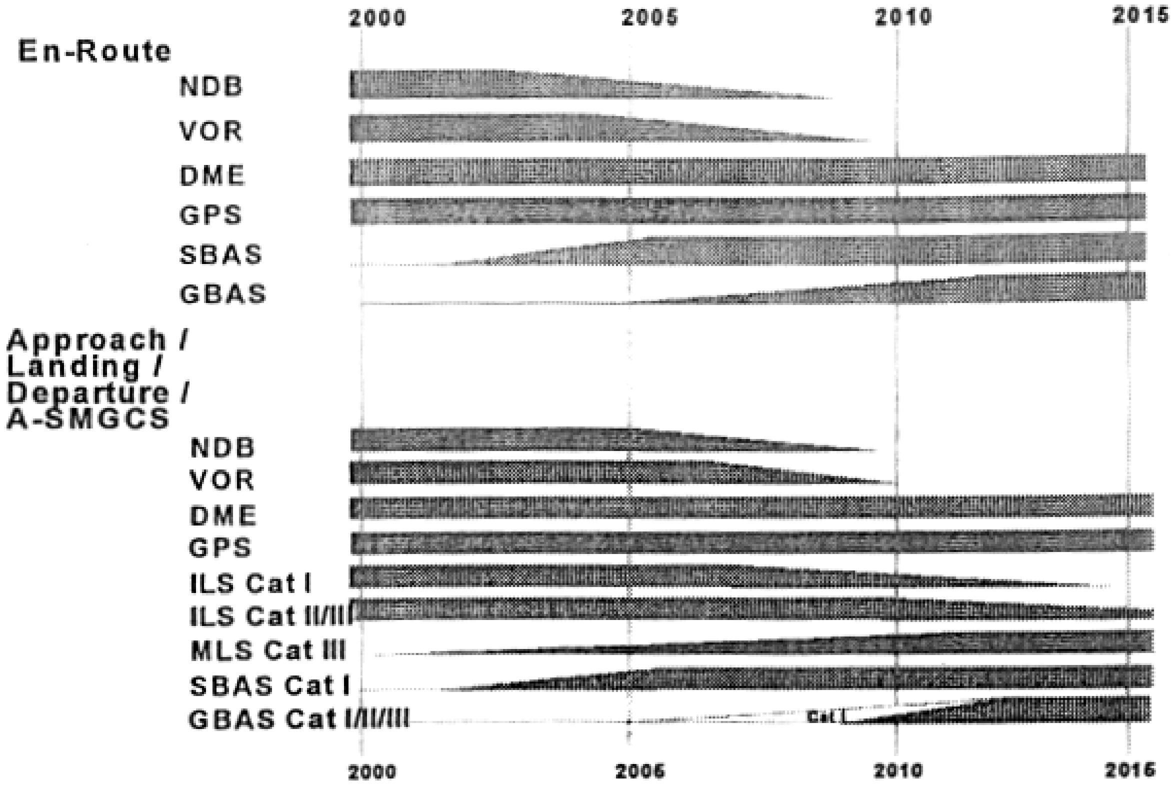

Figure 1 ATS Navigation Aids to 2015

6.3.4 ATS Data networks time stamping of data

The impact of loss of GPS to air traffic providers could come from an impact on their supporting telecommunications infrastructure, due to the loss of data timing synchronisation. It could alternatively come from increases in air traffic controller workload, due to an increased number of position requests from aircraft that have just lost their BRNAV ability.

6.3.5 Airlines

From an airline perspective the gradual move from terrestrial based to satellite based navigation systems is expected to eventually provide benefits in terms of lower user charges compared to the 'old' terrestrial navigation systems such as VHF Omni-directional Range VOR and Non Directional Beacon (NDB).

Major passenger and charter airlines responded to the questionnaire and showed adherence to the CAA and JAA guidance on GPS use, in that GPS use in RNAV is backed up by use of terrestrial DME and VOR position fixes. For the en route phase of flight, a location fix is the resultant position derived from several navigation sensors. If the GPS fails, then there is a fall back to DME VOR. GPS is not used for precision approach, the Instrument Landing System ILS is. So the loss of one source (GPS) for intermittent periods will not affect operation. Airlines noted that they do not have a quick mechanism to notice that the GPS signal is not available. The CAA produced AIC and

NOTAM procedures may not be reactive enough.

Airlines do not expect safety to be compromised as a result of short-term loss of the GPS signals or intermittent periods of interference on the basis of their foreseen applications. However there would be a commercial impact of raising landing minima or creating a diversion if it was eventually used for precision approaches. New applications for GPS/GNSS positioning are found all the time, airlines indicated their support for the need for the frequency protection of this navigation signal.

6.3.6 Analysis

The use of GPS to support Basic Area Navigation (B-RNAV), offshore en-route, Oceanic, remote operations and General Aviation is accepted. However, at face value no user should be relying on GPS. The CAA issued Guidance Documents caution that traditional IFR aids (VOR/DME) should be available as reversionary modes.

Present applications are designed to readily tolerate failure of GNSS whilst maintaining safety. Currently this is achieved by comparing with, or reverting to, traditional systems and this method automatically restricts the potential benefits of GNSS to the industry.

The implementation of the EUROCONTROL Navigation Strategy for ECAC with the continued introduction of BRNAV and the move to Free Routes will result in increased reliance on GNSS. In future the same strategy identifies that existing terrestrial navigation aids, VOR and NDB are planned for a phased gradual decommissioning, therefore the number of reversion possibilities is reduced.

It is also evident that there is a degree of economic reliance on GPS. If for instance an aircraft was reliant on GPS only for its B-RNAV compliance, then during a period of GPS loss it would be held on the ground and prevented from departing, until the signal again became available, unless it requested an alternative point-to-point non-BRNAV route.

6.3.7 Conclusions

Currently the impact of a short-term loss of GPS signal will be an inconvenience, although it is used extensively. The current inability to attest GPS reliability or integrity using conventional UK safety regulatory means (safety case methodology) is covered by the use of reversionary navigation modes and the requirement to readily tolerate GPS/GNSS loss. However, the Eurocontrol navigation strategy for ECAC indicates increasing reliance on satellite navigation in the coming years and reduced availability of terrestrial aids. The impact of GPS/GNSS loss will therefore grow, even though other supporting satellite and ground based augmentation signals will be available.

In future, the loss of GPS signals is likely to have a critical impact on air traffic operations.

6.4 Maritime

6.4.1 Introduction

This Chapter identifies the use of and reliance on GPS within the UK maritime industry. The data for the Maritime applications derives from an analysis of IMO proposals relating to the inclusion of radio navigation systems as components of a world-wide Radio Navigation System and to meetings with a number of authorities with responsibilities for marine navigation.

This chapter includes sections on the International Maritime Organisations strategy to improve ship safety and prevent pollution responsibilities for UK Marine Navigation Policy and implementation, and the current and future use of GPS/GNSS in UK waters. The chapter provides an assessment of the impact the loss of satellite navigation signals would have on these users.

6.4.2 Organisations consulted

- Maritime Coastguard Agency MCA
- Government Transport Department
- Health and Safety Executive (for offshore oil industry see Survey industry section)

6.4.3 Background

The phases of navigation are classified as: -

Ocean: where the distance from the nearest fixed obstacle is greater than 50 nautical miles. The principal use of navigation systems in this phase of the voyage is for the execution of safe and efficient routes, accounting for weather conditions.

Coastal: where distance from the coats is 50 nautical miles or less or at the limit of the continental shelf (where the depth is approximately 200 meters), which ever is greater. The typical width of safe paths is 2 nautical miles one way or 4 nautical miles two way. The probability of encounters with other vessels and grounding is higher than for the ocean phase but lower than that for ports, port approaches and restricted water phase. The principle uses of navigation systems in this phase of the voyage are associated with maintaining safety.

Ports, Port Approaches, Restricted Waters and River Navigation: where freedom to manoeuvre is limited and it is often necessary to keep to specific channels accounting for channel width, under keel clearance and local conditions. Typically channel width may be 200 to 600 metres wide at the seaward end and as narrow as 100 metres at the harbour end. The need for frequent manoeuvring, close proximity to other vessels and grounding hazards, and to support docking of some HSCs, which may require 1 metre accuracy, mean that navigation requirement are more stringent than for the coastal phase.

The relevant convention relating to the use of marine navigation aids is SOLAS 74, Safety of Life at Sea, Chapter V, which stipulates the carriage requirements for navigation equipment, by July 2002 the current regulations will change. Currently for radio navigation, there is only a requirement for radio direction-finding equipment for vessels over 1600 GT (SOLAS Chapter V, Regulation 12(p). There is no carriage requirement for a GPS or any other kind of radio navigation receiver. However, by July 2002 these regulations mandate the use of GNSS equipment for ships over 300 tons. The direction finding capability will be withdrawn as an IMO carriage requirement.

In 1998 IMO amended the Safety of Life At Sea (SOLAS) Convention requiring ships, subject to fit Global Maritime Distress Safety System (GMDSS) equipment (this includes VHF and Satellite communications systems). From 1 February 1999 ships subject to the SOLAS Convention have to fit GMDSS equipment.

The UK Government is committed to meet the international requirements of the GMDSS around the UK coastline. MCA is installing VHF Digital Selective Calling (DSC) at 105 remote radio stations around the UK.

GMDSS requires an accurate position input. GPS/GNSS is the only effective aid.

6.4.4 Current use of GPS

IMO has recognised the use of GPS on all vessels as a component of a future Worldwide Radio Navigation System. It is extensively used as such for Ocean, Coastal, Ports, Port Approaches and Restricted Water phases of navigation. The Radio Communications Agency advises that ship borne use of GNSS receivers is unlicensed i.e. there was no regulatory guarantee of receiving the service.

Differential GPS (DGPS) is by far the most common mode of GPS used in offshore vessel operations. The Marine Differential GPS Service is the latest element in the mix of visual, audible and electronic aids to navigation. It is an open system. The DGPS system is a network of 12 GPS Reference Stations giving coverage up to 50 nautical miles around the coast of the UK and ROI

Major floating aids have station monitoring using GPS. This includes all light vessels, light floats and critical buoys. The current system is a fully automatic obtaining position information from a GPS navigation receiver. Position data is transmitted to a central control station via a two-way data communications link.

The following Cautionary Notice is given to Mariners using DGPS services.

> *"Users of the GLAs DGPS system need to be aware that:*
>
> *DGPS relies inherently on GPS, the operation and characteristics of which are outside the control of the General Lighthouse Authorities and their respective Governments.*
>
> - *Trinity House Lighthouse Service – responsible for UK, Wales, Channel Islands and Gibraltar*
> - *The Northern Lighthouse Board – Scotland*
> - *The Commissioners of Irish Lights – Ireland*
>
> *All radio navigation systems are susceptible to interference and environmental effects, which can adversely affect their reliability.*
>
> *Various DGPS receiver types are available, some of which may not have the facility to provide transformations from WG84 Datum to the regional datum of the chart or provide appropriate or timely integrity warnings in respect of the system*
>
> *The GLA's strongly advise that no single aid to navigation system should be used in isolation and that DGPS users should use all alternative means available to cross check the information received. Users should also ensure that they have a receiver which gives sufficient warning of the complete loss of the DGPS signal and reversion to GPS."*

The ITU, IMO and the International Association of Lighthouse Authorities (IALA) are developing the standards for a Universal Automatic Identification System (AIS). By July 2002, this AIS objective will be incorporated into the Universal AIS in SOLAS Chapter V, mandating the carriage of AIS equipment on ships over 300 tons, flagged in countries that have accepted the SOLAS Convention. The implementation of this system is designed to enhance the general safety at sea and to give ships and VTS operators improved control and surveillance of vessel traffic. The desire is to start implementation of AIS by 2002 with full operational capability, FOC, by 2015.

Automatic Identification Systems use radio transponders to broadcast data such as vessel identification, position, course, speed, navigation status, dimensions and cargo. Combined with a shipboard display capability the AIS system presents critical navigation and vessel traffic information to the bridge team.

Coastal Radar monitoring is used to provide a coastal reporting picture. However radar coverage suffers from the effects of clutter and cannot see round corners or over obstacles. AIS offers the ability to ‘see through’ clutter and to fill some of the physical gaps left by radar. The proposal is to integrate UAIS with the radar picture to improve the performance of the coastal reporting picture.

The transmission of heading allows the use of rule based systems for conflict alert and collision avoidance, both in shore based VTS and in other ships and provides an essential piece of information not available from radar. The ability to automatically identify approaching vessels will assist operators to make contact with conflicting vessels.

The number of shipping lanes requiring compliance with mandatory routing and mandatory position reporting will increase. Ships must make contact on entering the restricted zone. The continued introduction of automated Vessel Traffic Systems (VTS) will contribute significantly to meeting this requirement.

One manufacturer of marine GPS equipment in Europe has reported a perception–that Masters of large merchant ships are becoming almost total reliant on GPS for speed and position, despite the IMO warnings on the vulnerabilities of GPS.

The use of GPS in yachts and craft taken offshore is extensive if not universal. If GPS were lost, navigation should revert to classical techniques using maritime NDB stations, sight bearings and radar. Therefore GPS loss should not be critical, however some yachtsmen may be incapable of reversion to traditional techniques.

Harbour authorities indicate that GPS is used to check positions of buoys and floating navigation marks, but it is a convenience as they would still be able to check via radar and sight bearings. It is not critical to their operations and has a slight economic effect in that position checking is faster. There are no mitigation techniques installed. Loss of GPS would be an irritation only.

For some maritime services the accuracy of DGPS positioning has become essential for the final phases of docking at ports. In particular some high-speed passenger ferries would be affected where automated systems have been introduced with the objective of reducing human error.

The Coastguard is not reliant on GPS. They occasionally do lose GPS but it is usually because of water penetration and antenna list, ships should drop back to manual less accurate and slower methods of navigation. It is popular because of its ease of use.

Automatic emergency position indicating radio beacons EPIRBS are now produced with an integral GPS receiver. This additional data is transmitted to the COSPAS/SARSAT organisation and to the relevant rescue co-ordination centre. The loss of signal would therefore remove the extremely useful position data. However, it must be remembered that it would be very unlikely for the GPS signal source to be interfered with in these remote locations. It is only when the radiated signal was completely lost, that reversion to a satellite-derived position would occur.

6.4.5 Analysis

The loss of GPS SIS would have a significant impact on maritime operations that could affect both safety and environment. There are concerns within UK Government about third world crewing/training and the use of cut price ships. Evidence for the lack of training and maintenance of vessels has occurred with the recent detention of a cruise ship by UK authorities. Lack of compulsory navigation training for yachtsmen.

The scope to reduce operating costs of the traditional navigation aids because of the introduction of GNSS would be removed.

Compared to the civil aviation environment, the loss of GPS for maritime would require reversion to more manual navigation methods. Navigation reversionary modes include:

- Radar
- LORAN C/CHAYKA
- Visual/Chart
- Dead reckoning

The trend in the maritime industry is to introduce technologies to improve safety whilst being able to reduce manning levels. The introduction of Ship automated bridge systems that provide automatic position input into ship electronic and auto pilot systems increases the reliance on GPS. VTS systems are dependent on GPS for position input

The General Lighthouse Authorities and Commercial DGPS services are dependent on continued reception of GPS

The implementation of IMO Resolution 860(A20) will increase reliance on GNSS to meet accuracy requirements.

6.4.6 Conclusions

GPS/GNSS is extensively used in all phases of marine navigation

GNSS is the only effective aid to provide position information for GMDSS.

The adoption of AIS will depend on the continuous availability of an input of GNSS derived position via the available GMDSS communications.

Particular consideration of GPS signal loss will be required especially after July 2002 when GNSS equipment is mandated for use by the IMO.

Therefore for maritime there could be a significant impact due to the loss of GPS for the GNSS based maritime navigation environment.

7 Positioning for the Scientific Exploration and Survey industry

7.1 Introduction

This chapter identifies the use of and reliance on GPS within the UK Survey and Scientific community. An assessment is made on the impact the loss of satellite navigation signals would have on these

7.1.1 Organisations consulted

- Ordnance Survey
- Meteorological Office
- Ashtech Europe
- Satellite Navigation Consultancies
- Scottish Office
- Oil Industry

7.1.2 Background

The ability of GPS to provide accurate and fast position fixing data has revolutionised the general survey industry. This use has been further enhanced in the oil industry where dynamic use of GPS position fixing has enabled the development of more efficient exploration and drilling techniques.

Within the survey industry greater efficiency is provided by use of GPS.

7.1.3 Current use of GPS

From a Government point of view the Health and Safety Executive does not operate GPS equipment, but as a regulator is concerned regarding safety implications of loss of GPS information for North Sea oil / gas and related installations.

During a study of the safety implications of the GPS rollover in August 1999, the HSE conducted a brief internal review of known industrial GPS users. The review was unable to establish that any onshore industries used GPS in safety critical applications. The only identified use onshore was agricultural - tracker guidance. Offshore many activities are highly critical for safety.

7.1.4 Oil Gas Exploration Industry

Dynamically positioned vessels for oil exploration are major users of GPS equipment on the United Kingdom Continental Shelf. The operators of these are mostly in the trade association IMCA (International Marine Contractors Association). A number of UK oil production companies operate installations that use "heading control" equipment. The trade body for these is UKOOA.

The UK oil producers have a significant interest in the use of GPS. It is used in navigation and surveying services provided by third party service companies. The main uses are: -

- Real-time accurate (sub-metre accuracy differential or kinematic techniques) positioning of seismic survey, hydrographic survey and pipeline/oilfield facility inspection vessels.

- Navigation of mobile drilling rigs to new work locations and accurate positioning of the rigs at the new locations.
- Positioning of dynamically positioned drill ships and oil field safety vessels. Dynamically positioned installations are highly dependent on GPS.
- Emplacement on new oil field facilities.
- Navigation of offshore oil field support helicopters and supply boats.
- Topographic mapping.

As with other large non-oil related companies, extensive use is made of GPS for asset maintenance and vehicle fleet tracking, etc. These activities are more efficient using GPS technology. However they are in general not critical to safety or to economic performance. GPS is also used to time synchronize private telecommunications networks.

Of the activities listed, no safety-critical elements are dependent upon GPS alone. Vessels and aircraft carry normal navigation safety aids. In most of these tasks, GPS or differential GPS (DGPS) is the main component of positioning. GPS has completely replaced former positioning technologies, in particular optical-mechanical surveying instrumentation onshore and Radionavigation systems offshore. The skills to use these former technologies have essentially been lost. Although GPS may in some cases be supplemented by another positioning system such as an inertial navigation system or underwater acoustics, generally they are entirely reliant upon GPS as an essential component.

For dynamically positioned (DP) vessels more than one system input is usually used, (taut wire and acoustic positioning systems also provide location fixes). The DP need is different than other DGPS users in that position reliability rather than absolute accuracy is needed. DP needs a continuous update and the reliability of this has large bearing on the position excursion monitoring of vessel movement. There is some system redundancy in DP control systems in that failure of one system should have little effect on the station keeping performance. This is done by provision of other references and by mathematical control system prediction, derived from recent performance (this includes detection and exclusion of unreliable data). DGPS gives 24-Hour coverage. DGPS gives greater flexibility, taut wire systems are limited to 300-500M depth, while acoustic references degrade with depth and propagation, the references can be degraded due to the movement of taut wire clusters or thruster wash affecting the acoustics. Some DP relies solely on GPS.

GPS is the main positioning input. There is a minor use of GPS for timing purposes. GPS is used primarily in connection with marine positioning and seismic surveying.

Total expenditure in the exploration industry activities is huge, while only a small fraction of this is spent directly on GPS services; virtually the whole amount is either directly or indirectly dependent on positioning, of which GPS is the core component. The economic benefit derived from GPS has not been formally evaluated: it is however enormous, partially in direct cash flow terms (GPS positioning, even with differential correction surcharges, it is considerably cheaper than any alternative terrestrial based radio-navigation system), mainly in productivity gains. For information the commercial implications of inadequate navigation on these activities is significant up to $5000 per hour for seismic spreads and $20000 hour for drilling rigs.

The growing use of GPS by the leisure yacht industry for instance could pose problems if GPS signal loss occurred in the vicinity of oil/gas installations.

7.1.5 Ordnance survey

From general indications in the survey industry it is apparent that considerable use of GPS is used for surveying and asset management purposes.

The UK's prime survey organisation the Ordnance Survey (OS0 makes considerable use of GPS. Its reliance on the system will grow over the next two years. GPS within the OS is used for two main applications:

Revising map detail in the field:

OS has a pilot project, which has run until July 2001, whereby some field offices are being solely equipped with GPS to look at efficiency gains and changing work practices. There are approximately 30 receivers being used at present. It is envisaged that between July 2001 and the end of 2002, GPS will provide the main data capture method in the field, with up to 300 receivers being used daily

Permanent differential base stations:

the OS has established 28 at present for users to take data from and post process their own relative GPS data. See Figure 2

Figure 2 Ordinance Survey DGPS stations (© OS)

The OS plan a national RTK correction service, whereby the whole of the country will have GPS corrections to a few cms. This would be available to OS internal as well as external users. If OS does provide an RTK correction service, then there will be a dissatisfaction factor from their customers if the service goes down for whatever reason. A liability issue may arise if warnings are not given that this correction relies inherently on GPS; the operation and characteristics of which are outside the control of the OS.

At present the permanent GPS reference stations provide the primary method for OS and it's customers to transform from GPS to the National Grid co-ordinates. GPS therefore plays a key role in providing the reference frame for the country, and this will not change in the future.

It is envisaged that OS will rely on GPS to provide the primary data capture technology for OS and its' customers. At present, OS could return to using traditional survey techniques in the field. However, in the future OS reliance on GPS will be so high that operations will be greatly effected if the signal is not available. OS has not done an assessment on the loss of satellite availability.

7.1.6 Analysis

It was recognized by the oil/gas and survey industry that the GPS system is a US military endeavor, and that the military authorities have the capability to block satellite signals. However, those same authorities could equally block alternative Radionavigation signals. However, they consider the likelihood of anything other than temporary short-duration outages of GPS or the differential correction signals as low risk. There is no contingency in place were GPS to become unavailable.

If they were no longer able to receive the radio signal from GPS, there would be great difficulties until terrestrial radio positioning system was re-established. There has been no impact assessment of GPS non-availability. For the majority of applications there are no mitigation techniques designed or installed to take over if GPS is lost.

The oil exploration industry has become so used to it providing adequate positioning that it is taken for granted. Some users would be unable to discriminate if positions were significantly incorrect. This potentially could lead to a catastrophe; one of the worst-case scenarios would be for a vessel to sail into an offshore oil or gas production platform causing a Piper Alpha style catastrophe incident.

GPS is used everywhere in the survey industry with continued growth of this application.

7.1.7 Conclusions

In most environments GPS is more convenient than the alternatives, allowing significant timesaving in procedures. However the survey and exploration industries are very nearly entirely dependent upon GPS being available. The economic and safety consequences to these businesses associated with the loss of positioning are very high. The same quality consistency and flexibility of services are unattainable with other positioning systems.

From a safety point of view GPS loss could have significant implications, if it leads to a major incident, it could be critical especially during movement of vessels in close proximity to each other during low visibility. GPS signal loss would be critical if it occurred during low visibility when vessels need to accurately position themselves.

Interruption to the GPS signal would cause disruption to the large-scale national network of DGPS stations now being installed by the OS.

8 GPS services for the Financial, Telecommunications and Broadcasting industry

8.1 Introduction

This Chapter identifies the use of and reliance of GPS supporting the UK telecommunications and broadcasting industry. An assessment is made on the impact the loss of satellite navigation signals would have on these users and whether such loss would effect the UK infrastructure.

8.1.1 Organisations consulted

- Cable Network Operators
- Mobile Telecommunications Operators
- Fixed Telecommunications Operators
- Broadcast industry
- Broadcast Transmission Service industry
- Radio Astronomy
- International Stock broker company
- Timing Industry

8.1.2 Background

Time synchronisation is fundamentally important to the performance of digital networks including fixed telecommunication networks, mobile telephones and mobile radio. Precise synchronisation is required to prevent loss and corruption of data. It is the process by which transmission rates of elements within a network are locked to a common frequency source. Synchronization is defined as an arrangement for operating digital switching and transmission systems at a common clock rate.

Special purpose receivers are available for many time-dissemination services, including the Global Position System (GPS) and other services operated by various national governments. For reasons of cost and convenience, it is not possible to equip every computer with one of these receivers. However, it is possible to equip some number of computers acting as primary timeservers to synchronise a much larger number of secondary servers and clients connected by a common network. In order to do this, a distributed network clock synchronisation protocol is required which can read a server clock, transmit the reading to one or more clients and adjust each client clock as required. Protocols that do this include the Network Time Protocol (NTP), Digital Time Synchronisation Protocol (DTSS).

UTC is based on International Atomic Time (TAI sic), which is derived from hundreds of Caesium clocks in the national standards laboratories of many countries. Around the world there are about 50 worldwide timing centre that keep an estimate of the Universal Time Coordinated (UTC). Each estimate is usually within 10ns of UTC. The international benchmark is taken as that provided by BIPM in Paris.

The GPS composite clock CC gives GPS time. GPS system time, in turn, is referenced to the Master Clock (MC) at the US Naval Observatory and steered to UTC (USNO) from which system time will not deviate by more than one microsecond. The exact difference is contained in the GPS navigation message in the form of two constants, A0 and A1, giving the time difference and rate of system time against UTC(USNO,MC). UTC (USNO) itself is kept very close to the international benchmark UTC (BIPM), and the exact difference, USNO vs. BIPM is available in near real time. The USNO MC reference for GPS is about 10ns of UTC**.** The frequency stability of GPS system time is about $2*10^{-14}$, the USNO is about 10 times better. GPS is used widely for network synchronization timing standards requiring accuracy of $>1*10^{-11}$.

Timing impairment or slips occurs when receive clocks run faster or slower than the transmit clock. This results in a repetition or deletion of data. Enhanced timing accuracy allows increased throughput of data. Service and reliability are enhanced.
Typical effects due to timing inaccuracies are: -

Voice	-	Increase in noise
Fax	-	Loss of picture content
Data	-	Re-transmission
Video	-	Occurrences of freeze-frames
Encryption	-	Re-transmit of key codes.

8.1.3 Current use of GPS - Telecommunications and Financial industry

The introduction of high-speed data systems with transmission rates of up to 10Gbps requires the adoption of significant investments in data synchronisation systems. Independent synchronised platforms are usually developed to deliver improved timing quality references direct to every element in a network.

For resilience, 2 geographically separate sites are usually required to effectively create main and standby ‘master’ clocks, referred to as the primary master and secondary master clocks. From a clock distribution perspective, it is important to locate master clocks centrally within a network to ensure that a minimum number of digital multiplexers are passed through when extending to the extremes of the network. CCITT recommendations G.811 limit the number of clock re-generations in a cascaded system to 20 as each element will introduce varying degrees of noise.

One synchronisation solution used is to employ caesium technology, and this has been used for many years to provide required level of frequency stability. It is suitable for creating master clocks, which distribute timing throughout a national transmission network. Slave synchronisation equipment is usually installed further into the network, where the timing signal is ‘cleaned up’, and re-transmitted to the network extremes. This topology ensures that all network elements are traceable to a single caesium based master clock. Additional synchronisation equipment can be installed further into the network to remove noise introduced as the timing signal is passed around the national transmission network.

A second solution is to use GPS timing, and this has been heavily promoted in some areas. This system meets the requirements of G.811, and returns a large cost saving in comparison to caesium. However, GPS being a radio-based system is subject to radio interference. Practical experience has shown that GPS integrity is adversely affected by more common factors e.g. birds landing on the GPS antennas, and masking of the RF signal!

It is now usual for systems to combine caesium and GPS timing sources for network synchronisation. A synchronisation network based upon deployment of a small number of caesium sources with GPS is considered a resilient solution, caesium clocks the expensive primary reference source and GPS the cheaper slaved source. Conditioning of short-term instability and hold over in case of GPS disruption can be provided by inputs from other local synchronisation sources, these may be GPS or GPS disciplined rubidium clocks for instance. Thus continuity of service is maintained. Timing could also be distributed to other telecommunication service providers as necessary. One example of a timing strategy: -

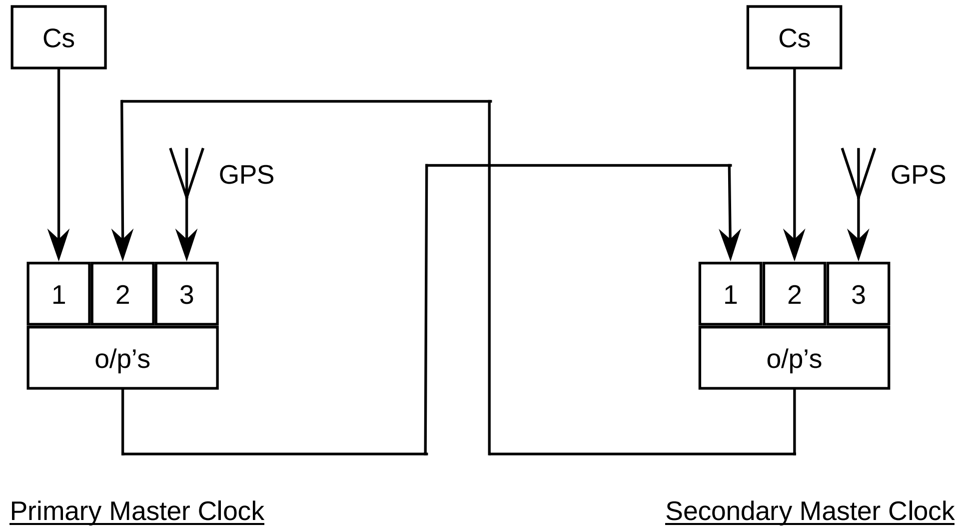

Figure 3 Primary/Secondary Master Clock Relationship

Reference outputs provided by the clocks are passed across the national network, and used to drive local synchronisation units located at additional sites further into the network in a master/slave arrangement. A basic configuration can be identical at all sites, the 1st and 2nd choice reference inputs always being recovered from the national network, therefore traceable to the Primary Master Clock and a 3rd choice could be GPS disciplined rubidium clock.

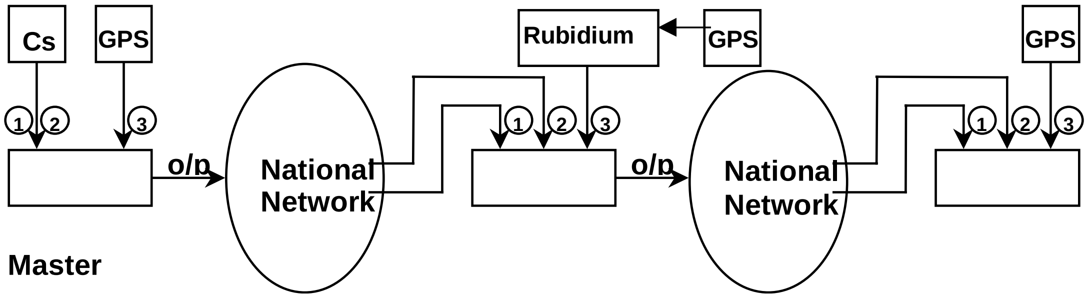

Figure 4 – Master/Slave Clock Arrangement

The above configuration ensures that the number of clock re-generations is reduced at the extremes of the network to conform to CCITT recommendations. Re-timing the clock signal is a distinct advantage when considering the effect on traffic passing across a synchronisation boundary.

GPS provides with little problem accuracy of 1us. However, telecommunications networks and the distribution of electrical power are two applications that require greater accuracy. Within some telecommunications offices, GPS is used to condition or discipline rubidium clocks or high performance quartz clocks. These disciplined sources provide buffering and isolation between the network elements and GPS. In case of GPS degradation or interruption, these oscillators will maintain the synchronisation quality of the telephone network at the ITU interface standard of $1*10^{-11}$ for a week to one month, depending on the design parameters used.

There is no negative impact on telephone signalling network from partial GPS availability as one GPS satellite in view for part of the day is sufficient to derive timing accurate to meet the standards. However, if a total GPS constellation or signal failure occurs, it is estimated that for a period of one week to one month the effect would be minimal. After one-month data slips would certainly start to occur and increase in frequency. As time goes by some parts of the public telephone network could fail due to an inability to signal.

8.1.4 Mobile telecommunications providers

The network infrastructure supporting wireless communications rely on the same timing requirements as those of the main telecommunications links and therefore have similar vulnerabilities and available mitigation techniques. However, they have additional timing requirements for their air interface.

For any CDMA network that use GPS receivers coupled to low cost quartz oscillators. In a hypothetical case of GPS failure it would be 1-3 days before system has serious problems.

For GSM/TDMA systems that are dependent on access to a Primary Reference Source, tolerance to GPS loss would be in the order of one week to one month

Another digital telecommunications system reliant on accurate timing is TETRA (Trans European Trunked Radio), the latest development in public and private mobile radio, which started operation in mid-1999. TETRA is a new service intended for emergency services and business users. It is based on a Time Domain Multiple Access system, network and timing configuration of calls requires accurate timing, tolerance to GPS loss would be in the order of one week to one month.

The mobile telecommunications industry also uses GPS to conducted map surveys to assess the customer perceived quality of service.

The use of GPS or another position services to provide location based service information is also planned. At least two positioning techniques are being looked at. One assisted GPS – where GPS receivers would be built into mobiles and a handful of base station reference receivers incorporated into the GSM network. Secondly the use of Enhanced Observed Time Difference Of Arrival (E-OTD) – where the mobile measures the time difference between transmissions from a number of GSM base stations. A percentage of these base-stations would have a reference GPS receivers located at them to enable mobiles to calculate their position.

The addition of location based information at the mobile, will allow operators to gain the benefit of increased revenue. In an emergency within the United States a mobile telephone must be able to locate down to approximately 125 m, rather than just to cell level as now, which in a rural areas may be a cell size in km. If a GPS based service goes down the accuracy of these services becomes so poor that they could not offer location measurements based using these two techniques. The best that could be done would be accuracy down to a single cell.

In general no assessment has been made on the loss of GPS apart from knowing the impact on services that non-availability would give. No mitigation techniques have been considered, as it is believed there are no alternatives that give the required accuracy. Loss of this service, therefore, could have a significant economic impact on effectiveness of location-based services.

8.1.5 Manufacture of timing equipment

Within the manufacturing industry, GPS is used for instrument calibration and the manufacture of instruments that contain GPS receivers provide precise time references. The time reference from GPS in these instruments is used to allow the control of oscillators, to enable the instrument user accurate frequencies and precise time. Some instruments have been manufactured as Primary Reference Clocks for Telecommunications applications using GPS as a reference source. The industry benefits from access to low cost, high accuracy time and frequency references that would be difficult or impossible to replace immediately.

If GPS becomes temporarily unavailable there are time & frequency standards which will continue to operate with aging from the time of loss. Serious disruption to these standards would be caused by any subsequent mains power loss. Substitute calibrations of frequency to accuracy similar to GPS from MSF signals are possible. Time calibration would be seriously degraded from about 20ns or better to about 1ms from MSF.

8.1.6 International Financial industry

For any international financial trading company, synchronization of dedicated telecommunications network is vital. This is achieved usually by the use of an installed master radio clock. Which is then synchronized to all other systems worldwide using either the NTP protocol or another timing protocol. The synchronization is done in a hierarchical manner so two units (redundant pair) synchronize off the master unit and other systems synchronize to these local masters. Hence, if they lose either of the local masters, there is no impact. If they lose the remote master, the system uses the local clocks (which may drift slightly during the outage). Short term GPS loss is not considered as an issue. If the outage is of a significant period, the drift of local masters may cause gradual disruption to the network. The impact of loss of trading capability would seriously harm the financial industry. Mitigation techniques are necessary if there is any reliance placed on GPS for timing. In the responses received none were mentioned.

8.1.7 Broadcasting

An internal review within the Radiocommunications Agency indicated that terrestrial broadcasting, satellite broadcasting and broadband wireless fixed access use of GPS timing was limited. However there is growing use of GPS timing for digital broadcasting transmitters, though some broadcasters were moving towards synchronization via satellite feeds. GPS is used for the following applications within broadcasting and for the following reasons: -

Precision frequency and frequency offset working:

> The carrier frequencies of some analogue broadcast transmitters are locked to GPS to provide a known and highly stable carrier frequency. The carrier frequencies are chosen to reduce the effects of co-channel interference between service areas. The service areas may not be adjacent to each other in this case, but predictions or experience indicate that interference can occur. With no GPS signal the receivers would enter holdover mode. After a period they would expect to get viewer or listener complaints of interference in some parts of the 2 service areas. However the complaints would be propagation condition dependent. Again the time this would take would be dependent on the rate of drift of the respective oscillators in the GPS receiver.

Digital Audio Broadcasting:

> The DAB system relies on GPS for its timing reference and for its frequency reference. Terrestrial DAB services use single frequency networks; national services cover the whole of the UK whilst local services cover a small part of the UK. To provide network gain the DAB transmitters in a particular single frequency network <u>must</u> all broadcast on exactly the same frequency, <u>and must</u> all broadcast the same data at exactly the same time, this is a particular requirement of the modulation method used.

After a period with no GPS signal, listener complaints of degraded service areas could be expected, as the single frequency network loses frequency and timing accuracy. The time this would take would be dependent on the rate of drift of the respective oscillators in the GPS receivers. From some experiments that have been done this may not occur for several weeks. However, during holdover, mains failure at a site will render that site useless, as it will not be able to re-establish correct timings until GPS returns. In that case the site will have to be shutdown until GPS returns. The longer that GPS is lost, the more sites DAB expects to loose due to mains failure problems. It is expected that a GPS disciplined rubidium oscillator would enter a holdover mode and still produce a standard frequency reference. In the worst case the service would degrade to rubidium accuracy. Rubidium accuracy would still be within the published accuracy for the service.

The DAB origination system uses time and frequency references derived from GPS but, unlike the DAB transmitter sites, it is not critically dependent on it as an absolute time reference.

Broadcasting of standard frequencies:

The Droitwich transmitter on 198kHz is used as a standard frequency reference. At present the frequency source is a free running rubidium oscillator. However, a GPS disciplined rubidium oscillator may be used in the future.

GPS is also used for time reference information on the broadcast telecommunications and computer network. Losing time reference information on the computer network was not thought to be a serious problem.

Satellite uplink trucks for video links for news reports and sports events. These often carry handheld GPS to find position in order to obtain ad-hoc permission to transmit. This is a convenient method, but the location could also be determined from a map.

Helicopter-based surveys of broadcast transmit antennas:

Once a large broadcasting antenna has been erected, it is essential that its actual radiation pattern be checked to ensure that it matches the theoretical pattern. To verify this, a helicopter is used to fly around the mast, at a distance of around 1km, while on-board equipment records both the received signal level and the helicopter's position. This technique requires accurate 3-D position information from the on-board GPS, supplemented with real-time differential GPS data from a temporary local ground station. If GPS were not available, then reversion to less efficient terrestrial means would have to occur. A temporary loss of the GPS signal would cause delays to this work.

New generations of TV detection vehicles are being developed which use GPS position information. If GPS data were not available, then a less accurate positioning system would be acceptable in most cases.

8.1.8 Radio Astronomy

The radio astronomy community makes large-scale use of GPS time signal as one of the primary reference (Stratum 0) time sources for its central Network Time Protocol (NTP) service. This central service, termed JANET, is used to synchronize large numbers of hosts at numerous institutions. One of the main recommendations for running an NTP based service is the diversity of reference sources and receivers. This aids resilience in that it prevents the failure of a single reference and/or receiver from seriously impacting or even disabling the NTP service.

The GPS signal is used widely in the UK, as the receivers themselves are relatively inexpensive. This allows the community to provide reasonably accurate and reliable time service without being restricted in where the servers can be placed or spending large sums of money on expensive time reference equipment.

Sites connected to JANET are encouraged to use the central service, as it means that all hosts are then synchronized to at least the same second of the day. This helps considerably when tracking down host break-ins or other abuse, especially for very busy hosts that may generate large logfiles.

JANET's NTP service is based around 2 separate reference time sources, GPS and Rugby MSF, plus access to other Stratum 1 NTP servers using other non-GPS sources i.e. Frankfurt (DCF) and 'atomic' clocks. Loss of GPS as a reference time source will not disable JANET's service however it will have an impact on its reliability until a replacement can be found and installed (ie Germany's DCF time signal can be received reliably in southern England and the midlands. There are also pseudo 'atomic' clocks such as rubidium crystal oscillators that are cost-effective). Should the GPS signal disappear NTP will automatically recalculate the next best reference source and use that in its place.

8.1.9 Analysis

Telecommunications networks are reliant on a hierarchy of timing sources, and timing re-generation systems. The primary time references are usually Caesium based, although less expensive GPS based sources are used extensively by some operators elsewhere in their networks. One operator has decided not to use GPS as its main source of Prime Reference Clock due to potential for the loss of signal.

Loss of synchronisation between circuit elements, due to the lack of a GPS signal (and any backup), would begin to occur in days for systems reliant on GPS conditioned high quality quartz clocks, and a week to a month for those using GPS conditioned rubidium sources. These times are dependent on the systems timing accuracy requirements. Interconnection with other operators to obtain a timing reference is a backup option, but considered both a risk and a short term fix, as it is completely out of an affected operators control, especially as GPS in this instance is a single point of failure.

For wireless services a partial constellation failure would not be noticeable. A total constellation failure would begin to show a week to month after the event.

The sales of GPS timing reference sources continues to grow.

8.1.10 Conclusions

Earlier studies established that GPS time and time stamping are widely employed to synchronise large telecommunications networks. Most networks have a reversion backups (free running Rubidium or Caesium clocks) but if the GPS loss persisted for some time the network performance would gradually suffer, depending on the stability of any backup time source.

Therefore the short term loss less than 1 week of the GPS signal for telecommunications networks would be an inconvenience, however in the longer term greater than one week/month the effect could be critical.

For broadcast systems such as DAB, the loss of GPS signal would cause a gradual decrease in reception quality, which could only be maintained if all GPS transmitter timing references were replaced with Rubidium sources.

The impact of a combined effect of multiple telecommunications network timing losses due to GPS signal problems was unclear.

9 UK Domestic applications - Health Safety and Emergency

9.1 Emergency Services - Introduction

This chapter identifies the use of and reliance on GPS within the Emergency Service; Police, Fire, Ambulance and Coastguard. An assessment is made on the impact the loss of satellite navigation signals would have on these users and whether such loss would effect the UK infrastructure.

9.1.1 Organisations consulted

- Police Service
- Fire Service
- Ambulance Service
- Coast Guard Mountain Rescue SAR
- Emergency Service Support Company
- Home Office

9.1.2 Background current use of GPS -Ambulance

The Government, through the Patients Charter, imposes performance standards for Accident and Emergency (A&E) 999 calls upon ambulance services. These standards stipulate that services must arrive with the patient within prescribed standard times. New standards apply to all services which, in the case of the London Ambulance Service, commenced on 1st April 2000.

For Category A Calls, which are life threatening, an ambulance must arrive at the scene within 8 minutes for 75% of those calls and within 14 minutes for 95% of those calls by April 2003. An interim target in progressing to this new standard has been set as 55% within 8 minutes by April 2001, 75% by December 2002.

For a Category B Call, which is not life threatening, an ambulance must arrive at the scene within 14 minutes (19 minutes in rural areas) for 95% of all calls.

On the 3 May 2001 the NHS put forward public consultation proposals to modernise ambulance services for patients in the South East of the UK. The consultation document describes how ambulance services must continue to develop if they are to make the maximum contribution to a modern NHS. The NHS wants to see a service that delivers the best care for the individual patient's needs. One that gives consistent, high quality care based best practice and makes use of new technologies so that it can respond to patients' needs more quickly, to maximise the resources available for the care of patients. The consultation document also sets out how region wide support services and functions - for example, control and communications - would underpin the essential day-to-day delivery of ambulance services in local communities "People in the region require local, flexible, and responsive ambulance services….”. In June 2001 the Government allocated £3.4Million to equip all of England’s emergency ambulances with satellite tracking and navigation systems.

GPS and Geographical Information Systems are underpinning technologies of the above strategy for the improvement of ambulance services within the UK. Some of the priorities are driven by political considerations. Ambulance services will be seen as failing if they turn up late for an incident (compared to Government targets) and the patient lives, yet will be seen as succeeding if they turn up on time even if the patient dies. Underpinning these response times for emergency response is the so-called "Golden hour" and more sensibly the "Golden 30 minutes". In terms of surviving a febrile heart attack or severe trauma the "Golden 5 minutes" is probably more correct.

From questionnaires and visits to several ambulance services, GPS is providing large benefits in efficiency and operation of the various fleets. Each ambulance region operates autonomously. Various systems are used for Automatic Vehicle Location including GPS. There is extensive use of GPS for positioning vehicles (automatic vehicle location) and reporting these position to near real-time command and control (resource management) systems.

Currently fixed telecommunications systems allow BT to locate an emergency caller and pass position information to emergency services based on postcodes. Currently mobile telecommunication caller location is determined by triangulation techniques within GSM cells.

GPS timing in some instances also provides the master clock for the command, control and communications systems. In case of a failure of this clock, and depending on systems design, each PC or computer would revert to using its own internal clock or a backup timeserver. It is expected that no effects would be seen up to one day, after those differences of 1 second might be seen. The impact of this variation was not known.

One force is in the process of rolling out AVL on all front line vehicles. The plan is to become high volume users of GPS information and utilise System Status Management (SSM) techniques to improve response times. The loss of GPS would severely hinder progress with the implementation of SSM and in effect cost a lot of money invested in AVLS technology. The AVLS server will be taking time off the GPS clocks as well.

In another force, a pilot system employs low frequency (LF) triangulation/high speed data networks and GPS. It is in two systems layers. The system is on board for aid only, and the combination of GPS+LF improves the availability of the system. However, It is now considered an important system; the impact of its GPS loss would be a serious loss of efficiency.

Another commercial system sold extensively to the ambulance service interfaces to their ambulance and paramedic vehicle dispatch system via an in-house UNIX based system. This allows a number of modes of data display and shows the bulk of their vehicles, their operational status (working, broken down, undergoing service), their location (en-route, on station, at an incident), how recently they were polled and whether or not the incident was life threatening. Polling is used in addition to the vehicle staff using an analogue radio communication link to indicate their location. The operational software is quite sophisticated and, in addition to helping vehicle selection, employs stochastic statistical techniques to predict where vehicles may be required during the next few hours. These predictions allow vehicle re-deployment to maximise coverage and reduce response times. Some vehicles also employ a system that allows the vehicle to help navigate the driver to the incident. This is especially useful in single user vehicles covering a large area.

GPS appears to form a valuable, but not safety essential, sub-system of the vehicle dispatch system. The system can operate without the input from GPS (as the crews, via the radio communications channels, can indicate vehicle location). Non-availability would have a significant impact on efficiency as the GPS information improves the response time and coverage of the service. This would clearly diminish cost effectiveness and have some implications for patient health.

The impact of GPS non-availability does not appear to have been formally assessed. With AVL systems operating within intense urban and city centres, through to rural and mountainous areas, an availability factor for the temporary loss of GPS signal must already be accounted for in AVL system design due to the effect of ‘urban canyons’ etc.

9.1.3 Police and Fire services

The police and fire, services, are making increased use of GPS. Each police constabulary operates autonomously, including the purchasing of new systems, although the Police Engineering Technology Office does provide a centre of expertise to support systems development.

In today's VHF/UHF networks, GPS is used as a reference source for the Radio Frequency carrier and audio synchronisation of its simulcast VHF and UHF radio networks. These systems generally have a free running rubidium standard at each site that will compensate for the loss of GPS. Lack of GPS would force the use of this backup. The rubidium would be good for a while, 1-2 weeks, if there were no power supply outages to the separate transmitter sites in the system.

For the police service the transition from analogue VHF/UHF radio systems to one based on TETRA technology is now underway. This system is based on a TDMA modulation format, which is reliant on accurate timing. The Lancashire police force are already using TETRA, another 50 forces will use this system in the immediate future. Therefore, loss of timing would become critical if based on GPS alone currently this is not the case.

The density of transmit installations will not allow consideration of auto-triangulation technology such as E-OTD or TDOA and therefore GPS is likely to be the main positioning system for the police. A prime concern of GPS signal loss, would be the impact on the expected future response time improvement and efficient use of resources from use of AVL techniques, similar to the ambulance service expectations.

GPS is also used to assist in Prison Service prisoner escort duties.

Expansion of location technology from AVL to a personal location service is expected to be much slower. Some trials have been performed; its use is likely to expand rapidly.

For the police GPS use is well advanced for some operations. The expansion of AVL techniques matched to use of TETRA data will expand rapidly.

For the fire service AVL using GPS use is not so well advanced although the possible use of TETRA in the future would remove the barrier of an additional radio system needed for AVL data transmission.

9.1.4 Probation service

The Home Office probation service indicated that their panic buttons are mostly located within buildings and not mobile and therefore they do not use GPS for this application. Hence it is not an issue.

9.1.5 Mountain Rescue

A survey of the use of GPS for search and rescue purposes identified that it is used as a land and waterborne aid for training and in operational circumstances, in all types of environmental conditions. It is used primarily for position fixing on land and for ranging onto programmed waypoint. Secondary uses include the plotting of wreckage and use as a base line for corridor search or as an aid to identify specific cliff top searches. On water, GPS is used when searching Lake/Loch and side locations and for position fixing and ranging. It enhances the ability to search for a specific location or reach a casualty.

GPS provides economic benefits, both human and material. Human benefits are in the time required to get a rapid position fix, to finding a specific location or group in poor conditions. Material benefits would be in terms of directing helicopters or other assets to a precise location. At all times maps and compass are used as a time proven ultimate backup. Land base operations mainly rely on fundamental map and compass techniques and the skill obtained through practise. They would continue to operate effectively as they did before without GPS. Therefore no mitigation techniques are required as GPS provides efficiency gains.

GPS loss would have minor effect on mountain rescue operation, However it has proven a very valuable navigation cross-check at times of genuine poor weather position uncertainty.

9.1.6 Airborne Search and Rescue

Airborne Search and Rescue operators use GPS as an aid to navigation during SAR operations. Its loss could constitute a risk to flight safety and the ability to save lives, as conventional navigation-aids are of little or no use in the environment in which they operate, typically below 200ft in all weather conditions, day or night. GPS is used for automated search patterns.

The only backup that would appear to mitigate loss of GPS for a period would be the use of inertial navigation systems. The accuracy of which degrades over time. However, most of the helicopter SAR support aircraft do not have this facility, therefore in general any mitigation may only be the visual cues available to a pilot.

9.1.7 Analysis

Indications are that the loss of GPS would have an increasing impact on the Emergency and Law enforcement service, especially for any AVL techniques that assist the improvement of operational efficiencies to meet Government targets. It is anticipated that upon migration to a digital communications solution for the Emergency Services, then GPS would play an integral part of this, so the use for other applications would therefore increase over the next few years.

The Ambulance Police and Fire services would revert to voice communications giving location via the radio systems if GPS were lost.

9.1.8 Conclusions

Currently short-term loss of GPS would not have a great impact on the emergency services. However, the impact would appear to grow to a critical level if GPS were lost in the long term, because of the target levels of performance required by Government and the current large scale implementation of AVL devices into ambulances, and the expected use of AVL/TETRA by the police. Short term loss, would appear not appear so critical as voice communications are still available, except that a loss of confidence in system would be generated.

10 Miscellaneous

10.1 Introduction

This section considers some miscellaneous and potential uses of GPS.

10.1.1 Leisure industry

Many other applications are using or will use GPS for position location e.g. taxi firms, sports (Golf, Racing Rallying) and hill walkers, all of these reliant on either the position, velocity or time element available from GPS. These applications are too numerous to list. Most have not considered the potential impact of loss of GPS, short-term loss was considered an annoyance factor.

10.1.2 GPS Use -RNIB disabled elderly

There are relatively few devices giving a precise location for disabled and elderly people. However it is anticipated that market penetration of such devices for all people will increase (particularly Scandinavia) unless UMTS can provide inexpensive positioning to within 20-30 metres.

10.1.3 Analysis

If the GPS signal were lost for whatever reason, loss of efficiency and possibly cessation of service would occur for any business based sport application that was dependent on the position reporting. No mitigation techniques against unintentional or intentional signal loss are usually included. The loss of GPS for most of these applications would be classed as an inconvenience.

10.1.4 Conclusions

GPS Applications are developing continually; sporting uses and the disabled and elderly are only some possibilities. Other GPS applications under development show support for the location of vehicle and people position monitoring at sporting events and for other business efficiency needs. GPS loss for these was considered an inconvenience.

11 Consolidated conclusions on the impact of GPS loss on UK domestic and commercial service

The survey of impact of loss of GPS was split into various parts, Utilities (section 5), Transport (Section 6), Survey (Section 7), Economic (Section 8), Domestic (Section 9) and Miscellaneous (Section 10). These were analysed for the expected impact of short and long term GPS signal loss based on annoyance inconvenience or critical (safety) impact.

Short-term loss is defined as temporary loss of all GPS signals for less than 1 week. Long-term loss is defined as loss of GPS for greater than 1 week. This decision point is based on the likely start of any major affects on telecommunications timing, as this is a core activity for a majority of GPS applications. As GPS use continues to evolve we have also considered the effect of short and long term GPS signal loss in the near and medium future (near term <3 years medium term >3 years). This is summarised below.

Industry	Near Term <3 years		Medium Term >3 years	
Complete signal loss	GPS loss < 1 week	GPS Loss >1 week	GPS loss < 1 week	GPS Loss >1 week
Gas Water Electricity	Inconvenience	Inconvenience	Inconvenience	Significant Inconvenience
Road	Inconvenience	Inconvenience	Inconvenience	Significant Inconvenience to critical (road survey)
Rail	Annoyance	Inconvenience	Annoyance	Inconvenience
Aviation	Inconvenience	Inconvenience	Critical (safe operation)	Critical (safe operation)
Maritime	Inconvenience	Critical (from July2002)	Critical (safe operation)	Critical (safe operation)
Oil Gas Exploration Survey	Inconvenience	Significant Inconvenience to critical	Inconvenience	Significant Inconvenience to critical
Ordinance Survey	Inconvenience	Inconvenience to Significant Inconvenience	Inconvenience	Significant Inconvenience
Telecommunications	Inconvenience	Inconvenience	Inconvenience	Significant Inconvenience
Mobile Communications	Inconvenience	Inconvenience	Inconvenience	Significant Inconvenience
Timing manufacturer	Annoyance	Inconvenience	Annoyance	Inconvenience
Finance	Inconvenience	Inconvenience	Inconvenience	Significant Inconvenience
Broadcasting	Annoyance	Inconvenience	Annoyance	Inconvenience
Radio Astronomy	Annoyance	Inconvenience	Annoyance	Inconvenience
Ambulance	Inconvenience	Significant Inconvenience	Significant Inconvenience	Critical (response targets)
Police	Annoyance	Annoyance	Inconvenience	Significant Inconvenience
Fire	Annoyance	Annoyance	Annoyance	Inconvenience
Mountain Rescue	Annoyance	Inconvenience	Inconvenience	Inconvenience
Airborne SAR	Significant Inconvenience	Critical	Significant Inconvenience	Critical (Navigation)
Miscellaneous	Annoyance	Annoyance	Annoyance	Inconvenience

Table 1

Table 1 above summarises information of the impact of loss of GPS, in terms of complete loss of signal for the stated periods.

The dependence on GPS for many user groups has grown or will grow to a critical need, although as mentioned in section 3, the relatively low level of received power of GPS means that in many key areas of low satellite visibility, reception of the signal may not be possible. Some of the communities account for these losses others do not.

Even with predicted signal losses, GPS use is widespread because of the gain to be made in terms of efficient management of transport fleets and improvements to emergency response times by using of GPS and AVL techniques.

Widespread dependence on GPS in the survey and exploration industries exists.

12 Loss of GPS signal in space - information dissemination and co-ordination.

12.1 Overview on US GPS Navigation Policy.

The US developed GPS as a means of improved navigation for its military systems. It was originally intended that unauthorised users would be prevented from gaining access to the full accuracy of the system by use of encryption of the signal-in-space. Encryption is used to prevent spoofing of the signal (i.e. the deliberate re-play/ re-broadcast of the signal or generation of a false signal to fool a potential user).

At the time of its development, technology did not allow direct access to the GPS Precise Positioning Service (PPS), access was achieved through an open signal GPS C/A code. This open signal had a deliberate degradation of its positioning accuracy, called selective accuracy (SA). However, the civil community developed techniques to mitigate against this degradation to the point where the commercial lobby in the US argued successfully for the removal of the deliberate degradation. This was done by Presidential Decree on the 1st May 2000.

In removing the deliberate (SA) degradation to the GPS C/A code open signal, the US also stated they had developed the means to deny hostile use of GPS on a regional basis, when their security was threatened, without hindering the peaceful civil use of the system elsewhere. GPS in the next few years will undergo a radical modernisation program to achieve the above aims and to provide improved navigation performance by the addition of other open access civil signals.

12.2 UK overview on the use of satellite navigation

The commercial use of GPS for positioning or timing applications parallels the growth seen within the US. The survey and questionnaire identify a great number of different GPS applications.

The importance of accurate, available and reliable navigation services in areas other than over and around the UK is well recognised and afforded protection through the ITU of which the UK is a member.

It is important to note that the UK has no control over the operation of GPS. In addition there are no agreements that provide for the control of any operating modes of GPS or its augmentations in the event of hostile or malicious use of accurate navigation against one state within the ECAC or EGNOS coverage areas.

Every state retains the right to degrade or deny access to accurate navigation and positioning information over or around its territories in the event that the availability of this accurate, navigation positioning information to an adversary might be detrimental to its interests. Any denial will depend on the nature of the crisis. Therefore there is a complex problem in developing appropriate measures to prevent the hostile use of satellite navigation without hindering peaceful civil use of the system in the UK or elsewhere. The UK Ministry of Defence has a continuing need to develop technological means and to conduct trials on GPS to achieve the above aims, in 1981 the MOD gave this insight to industry on their navigation needs, it is not a formal policy statement.

In the next 15 years a major transition to satellite-based systems is anticipated for many users. For the aeronautical operational environment, this will result in a growing dependence upon GPS/GNSS and severe consequences if there was a loss of navigation and timing capability without warning. Currently there is no reliance placed on GPS for precision approach and landing operations.

12.2.1 Improved GPS information dissemination,

One of the problems identified by response to the questionnaire was the lack of a co-ordinated central UK sponsored site that informed affected user communities of problems encountered with GPS or any planned trials. Many GPS Internet resources are available although these are usually dedicated to one user community and not as central resource of co-ordinated UK GPS information. It would perhaps be useful if a Government sponsored Internet news group server (broadcast only) be used to link timely GPS information to all interested communities.

13 Summary

This report has highlighted the growing importance of GPS; Table 1 consolidates in a short form the likely impact over the next few years of GPS signal loss. For the Maritime and Aviation communities it will grow to a critical issue in terms of continued safe operation (Note that GPS for airborne SAR appears critical now). For the emergency services the impact will grow to be critical for them to meet their target response times. For other industries the loss of GPS signal will grow from an inconvenience to a significant inconvenience and therefore could have a large economic impact in future (note this report does not cover the economic impact of GPS loss).

The received power of a GPS signal is inherently low; other radio frequency signals of low power near to the GPS L1 centre frequency can cause loss of signal. Mitigation techniques using frequency domain adaptive filters to remove narrow band interfering signals are available. MOD trials of GPS interference mitigation techniques requires live trials for GPS loss of signal, these trials are designed to mitigate GPS loss effects on other services mentioned in this report. However, it is apparent that the notification of these trial events does not reach enough GPS user communities.

14 Recommendations

The report concludes with recommendations that: -

As the UK is growing more growing reliant on GPS for fundamental activities. The fundamental weakness and vulnerabilities of GPS signal reception should be more widely publicised, especially for those services where significant inconvenience or critical impact could occur.

Business and emergency service efficiency gains provided by GPS and AVL should be better assessed. Possibly by using limited representative examples to determine the cost benefit impact.

A robust mechanism for notification of GPS signal information is developed and those services identified as ‘critical’ operating close to any MOD GPS trials are identified and more actively notified.

The MOD still need to conduct GPS trials and to develop appropriate measures to prevent the hostile use of satellite navigation without hindering peaceful civil use of the system.

Glossary of Aviation and Maritime terms

Primary means navigation system: A navigation System approved for a given operation or phase of a flight that must meet accuracy and integrity requirements, but need not meet full availability or continuity of service requirements. Safety is achieved by limiting flights to specific time periods, and through appropriate procedural restrictions.

Sole-means navigation system: A sole means navigation system approved for a given operation or phase of a flight must allow the aircraft to meet, for that operation or phase of flight, all four navigation systems performance requirements: accuracy, integrity, availability and continuity.

Supplemental means navigation system: A navigation system that must be used only in conjunction with another (sole-means) navigation system. Approval for supplemental means for a given phase of flight requires that a sole means navigation system for that phase of flight must be on board. Amongst the navigation system performance requirements for a given phase of flight, a supplemental-means navigation system must meet the accuracy and integrity requirements for that operation or phase of flight; there is no requirement to meet the availability and continuity requirements."

Ocean phase of navigation: where the distance from the nearest fixed obstacle is greater than 50 nautical miles. The principal use of navigation systems in this phase of the voyage is for the execution of safe and efficient routes, accounting for weather conditions.

Coastal phase of navigation: where distance from the coats is 50 nautical miles or less or at the limit of the continental shelf, (where the depth is approximately 200 meters), which ever is greater. The typical width of safe paths is 2 nautical miles one way or 4 nautical miles two way. The probability of encounters with other vessels and grounding is higher than for the ocean phase but lower than that for ports, port approaches and restricted water phase. The principle uses of navigation systems in this phase of the voyage are associated with maintaining safety.

Ports, port approaches, restricted waters and river navigation phase of navigation: where freedom to manoeuvre is limited and it is often necessary to keep to specific channels accounting for channel width, under keel clearance and local conditions. Typically channel width may be 200 to 600 metres wide at the seaward end and as narrow as 100 metres at the harbour end. The need for frequent manoeuvring, close proximity to other vessels and grounding hazards, and to support docking of some HSCs, which may require 1 metre accuracy, mean that navigation requirement are more stringent than for the coastal phase.

Area Navigation (RNAV)

RNAV is a method of navigation that permits aircraft operation on any desired flight path within the coverage of referenced navigation aids or within the limits of the capability of self-contained aids, or a combination of these. 2D RNAV relates to RNAV capabilities in the horizontal plane only; 3D RNAV includes a guidance capability in the vertical plane and 4D RNAV provides an additional timing function.

The RNAV concept represents a fundamental change in navigation philosophy. Traditionally aircraft were required to fly to and from specific navigation aids, using each navigation aid as a source of data. An RNAV-capable aircraft can automatically determine its position, from one or more of a variety of inputs. These include VOR, DME, GNSS, INS. Single-sensor RNAV systems only use one source of navigation data, such as DME stations, while multi-sensor RNAV systems monitor a number of navigation aid systems to determine the best source of navigation data.

The RNAV system has access to an on-board navigation data base containing details of the pre-programmed routes, the airspace through which the routes pass, the navigation aids servicing this airspace and the departure, destination and planned diversion aerodromes. The system identifies the next way point on the planned route, selects the most appropriate navigation aids to determine the aircraft position. An RNAV route can be flown automatically, with the autopilot coupled to the RNAV system, or manually, with the RNAV system outputs displayed on the flight director/course deviation indicator.

RNAV enables States to design and plan routes not necessarily defined by point source navigation aids. This enables greater flexibility in airspace design and potential user advantages i.e. fuel savings, direct tracks etc.
Required Navigation Performance (RNP)

ICAO has endorsed the concept of Required Navigation Performance (RNP), which is a statement of the aircraft navigation performance defined in terms of accuracy, integrity, availability and continuity of service necessary for operations within a defined airspace. The RNP determines the accuracy with which the RNAV system is required to determine the aircraft *absolute* geographical position (instead of only in terms of its position *relative* to a navigation aid, as is the case with conventional VOR/DME display instruments).

For en-route purposes currently four RNP “Types” have been defined (RNP1, RNP4/5, RNP12.6/10, RNP2O). Where the type number indicates the containment value in miles. The containment value is the distance from the intended position within which flights would be found for at least 95% of the total flying time. The extension of the RNP concept to the precision approach and landing phase and the corresponding RNP “types” are currently under development.

Acronyms

ANSO	Air Navigation Services Organisation
AIC	Aeronautical Information Circular
AOC	Advanced Operations Capability
ATC	Air Traffic Control
ATCC	ATC Centre
ATS	Air Traffic Service
AVL	Automatic Vehicle Location
CAA	Civil Aviation Authority
DAB	Digital Audio Broadcast
DGPS	Differential GPS
ECAC	European Civil Aviation Conference
EGNOS	European Geostationary Navigation Overlay Service
EOC	EGNOS Operational Capability
ESA	European Space Agency
GIS	Geographic Information Systems
GLA	General Lighthouse Authorities
GLONASS	GLObal NAvigation Satellite System
GNSS	Global Navigation Satellite System
GMDSS	Global Maritime Distress and Safety Systems
GPS	Global Positioning System
IMO	International Maritime Organisation
ILS	Instrument Landing System
ITS	Intelligent Transport Systems
ITU	International Telecommunications Union
NOTAM	Notice to Airmen
NTP	Network Transfer Protocol
OS	Ordnance Survey
SIS	Signal in Space
SOLAS	Safety of life at SEA
TETRA	Trans European Trunked RAdio
UKOOA	UK Offshore Oil Operators Association
VHF	Very High Frequency
VOR/DME	VHF Omni-directional Ranging/Distance Measuring Equipment
VTS	Vessel Traffic Service
WAAS	Wide Area Augmentation System

Annex A Background information

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FAA Advisory Circulars on Approval of US Operators and Aircraft to Operate Instrument Flight Rules (IFR) in European Airspace designated for Basic Area Navigation
JAA, The Application of GPS to Basic RNAV, JAA Administrative & Guidance Material
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International Maritime Organisation, Resolutions on World-wide Radio-navigation System,
General Lighthouse Authorities of the United Kingdom and Republic of Ireland, Marine Navigation Plans
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