Intelligent Railways via Integrated Satellite Services (IRISS)

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Train passengers and authorities demand trains' timeliness, comfort, safety and energy efficiency. Train fleets, over their multiple-decade lifetimes, will therefore typically undergo various modernizations, in order to improve fleet monitoring and management. It is then advantageous if additional equipment is highly integrated due to lack of on-train space. The IRISS project (Intelligent Railways via Integrated Satellite Services) proposes such an integrated service. It provides Train Operating Companies with essentially uninterrupted monitoring of train stock based on terrestrial and satellite communications, satellite navigation and conventional train metering. IRISS is a feasibility study initiated by the European Space Agency's Integrated Applications Programme.

The involved user, East Midlands Trains (EMT, a UK Train Operating Company), has expressed the need for affordable and continuous tracking of their trains, as well as data communication between their control center and rolling stock. Information to be exchanged are e.g. messages & alerts, train location, diagnostic data, and camera footage (CCTV), both in real-time (to reduce service interruptions) and historical (e.g. to resolve disputes and optimize energy efficiency and maintenance). IRISS has investigated whether space assets can add value where conventional technologies face limitations. For example the existing 'balise' train location system provides low accuracy, while backcountry routes may still have poor communications coverage by terrestrial networks.

Nottingham Scientific Ltd. has defined a service architecture centered around the TITAN on-board unit that integrates satellite navigation (GPS, EGNOS, GLONASS), with satellite and terrestrial communication and that is fed by on-train sensors and CCTV. The control center collects the TITAN real-time and historical data (using 3G/GPRS, SatCom, Wifi), tagged with time and location. The data can be retrieved and displayed for asset management, incident investigation and driver management purposes, whilst messages, alerts and commands can be exchanged with on-train personnel equipped with WiFi-enabled PDAs.

IRISS has performed a proof of concept demonstration of the TITAN system on both a rural train and a high-speed train in the East Midlands region of England. The added value of Iridium satellite communication as compared to terrestrial networks has been assessed, as well as the continuity and coverage of GPS and EGNOS based navigation capability for railway applications. The development of a pre-operational service together with the involved users is foreseen as a next step.

I. IRISS AND ESA'S INTEGRATED APPLICATIONS PROGRAMME

Intelligent Railways via Integrated Satellite Services (IRISS) is a Feasibility Study of the Integrated Applications Program (IAP) of the European Space Agency (ESA).

ESA's Agenda 2011 contains a key objective: "*Development and Promotion of integrated applications (space & non-space) and integration of security in the European Space Policy. New concepts, new capabilities and a new culture have to be developed in order to respond to a multitude of needs from users who are not yet familiar with space systems*." Responding to this objective are the Integrated Applications Programme (IAP), also known as ESA's ARTES 20 element (user-driven applications), as well as the ARTES 3-4 Telecommunications Applications element (product-driven applications). These elements are dedicated to development, implementation and pilot operations, utilising not only Telecommunications satellites, but also combining the use of different types of space assets, including Earth Observation and Navigation, as well as Human Spaceflight technologies.

The overall goal of the IAP program is the *"the development of operational services for a wide range of users through the combination of different systems".* The goal is to incubate sustainable services to the benefit of society that obtain their added value from the innovative integration of existing terrestrial technologies with space assets, such as Telecommunications, Earth Observation, Navigation, and Human Spaceflight technologies. "*Sustainable*" means here: triggered by, responsive to and sustained by real user demand, while taking into account financial (e.g. commercial) and non-financial (e.g. environmental, legal, adoptability) constraints. The provision of commercial *services* (rather than of mere products) is seen as a key outcome - one that offers flexibility and increases sustainability of demand, supply, and indirectly, up the value chain, also of space assets. In this way, "our satellites help to do better the daily work of society".

Such services are to be incubated through two steps or levels of ESA IAP activities:

1. Basic activities, which aim at generating, assessing and studying ideas for projects. Feasibility Studies provide the preparatory framework to identify, analyse and define new potentially sustainable activities.

2. Demonstration activities which aim at development and demonstration of the novel services identified in the first element, until an operational maturity is achieved that is satisfactory to the users.

IAP activities cover a wide range of themes, including Health, Transport, Energy, Environment, Development, Safety, Agriculture and Fisheries.

IRISS is a Feasibility Study, within the theme of Transport. A Demonstration Projects is now aimed for to demonstrate the IRISS services to the involved users.

II. INTRODUCTION

II.1   Modernization needs in the rail sector

Train passengers and authorities are demanding with respect to trains' timeliness, comfort, safety and energy efficiency. Better fleet monitoring and management is required. Over their multiple-decade lifetimes train fleets will thus have to be modernized.

Train Operating Companies aim to reduce operational costs and at the same time meet the demands for maintaining timetable performance, increased energy efficiency and safety. There is thus a need for affordable and continuous communication between control centers and the rolling stock to exchange messages & alerts and to reliably monitor train location, speed and diagnostic data (status, condition, metering), including camera footage (CCTV). Real-time data is necessary for operations management and to reduce service interruptions. Historical data to be retrieved from a central database is needed e.g. to improve driving-style and energy efficiency (by analysis and training), resolve disputes, analyse incidents and optimize maintenance scheduling.

Currently, these requirements can only be addressed in those geographical areas where adequate communications infrastructure exists. Backcountry routes routinely traversed by trains often still have poor communications coverage by terrestrial networks. If these services become too patchy and unreliable, it can severely restrict the benefits that can be realised. Fleet-wide deployment of real-time information and management services is only possible through access to seamless and reliable communications services across the network. Unfortunately, the rail network does not at the moment have access to such services. Satellite communications do provide continuity and integrity but are relatively expensive.

Another issue is train positioning which is still mostly done using costly on-track equipment placed every few kilometres. These so-called 'balises' provide low accuracy solutions. A more accurate alternative based on satellite navigation should reliably perform also in mountainous areas, which is not trivial.

This challenge calls therefore for an integrated approach through the use of both terrestrial and satellite communications in combination with traditional reporting systems and satellite navigation services. A single system should ideally target these multiple problems at once. Such an integrated solution is not trivial. A general challenge for train modernization to be taken into account is the inaccessibility of the market, lack of space on the trains for equipment and the demanding environment (safety, durability).

II.2   IRISS Feasibility Study

The goal of this activity is to develop and validate a viable and robust business model for the introduction of integrated satellite navigation and satellite communications services within the UK rail transport sector. This capability will allow Train Operating Companies to communicate with their assets irrespective of location and status enabling data to be

uploaded and offloaded in real time to support decision making processes and to improve the management of operations and incidents. Given a properly adapted service provision scheme, other stakeholders may benefit as well (network operators, rolling stock owners). As this activity focuses on services for the Train Operating Companies, to generate savings, maintain timetable and improve users' safety and comfort, rather than e.g. passenger internet, it does not require a continuous broadband link.

An integrated service test-bed is to be delivered with the involvement of stakeholders, as to experiment and showcase the potential of deploying the proposed service portfolio.

II.3   Partners, user and stakeholders.

NSL (Nottingham Scientific Ltd) is the Project lead and TITAN developer. Avanti Communications is responsible for SatCom and service provision aspects.

EMT (East Midlands Trains) is the Train Operating Company (TOC) that participates as user with their HST Class 43 and rural Class 158 trains (Figure 1).

For the case of the UK, other relevant stakeholders that may benefit from IRISS and the data that can be provided through it are:

- Rolling Stock Companies (ROSCO) own and lease the trains to the TOCs, and are therefore naturally a key stakeholder and decision maker.
- RSSB – Rail Safety and Standardization Board
- Network Rail – owner and operator of the railway system (e.g. IRISS data may be relevant to monitor infrastructure problems such as cable theft). In coordination with the TOCs, delay management is a joint application.
- Rolling Stock manufacturers may want to integrate IRISS into new train designs.

The typical high-level interactions between IRISS services and these stakeholders are presented in Figure 2.

Figure 1. EMT rural and high speed trains. Image credit: David J. Smith
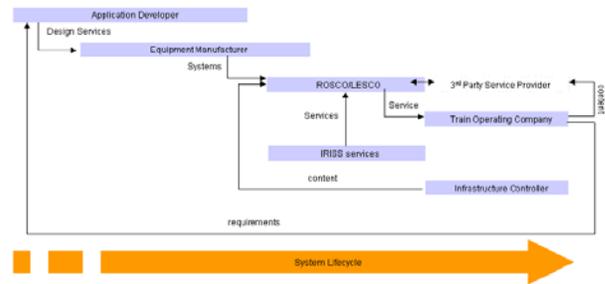
Figure 2. IRISS and stakeholder interactions

III. IRISS RESULTS AND STATUS

III.1   System design

The IRISS system architecture is based on the integration of satellite navigation (GPS and EGNOS) and satellite communications and consists of the following major elements (Figure 3):

- Trainborne subsystem (including the Trainborne Information, Telecommunication and Navigation (TITAN) units)
- Station/Depot subsystem (incorporating a Bulk download server)
- Operations centre (that includes a Central Server and Application Server)

Segment	Description

On-Train	On-train System fitted on multiple vehicles, consisting of the following components:
	
	• Single intelligent device
	  ○ Positioning system (GNSS + INS)
	  ○ Communications system(s) (SatCom, GSM, WiFi)
	  ○ Other components (storage etc)
	• Antennas
	• Interfaces with other on-train equipment e.g. OTMR

Station/Depot	Multiple station and depot locations. At each the Station/Depot System will simply consist of a localised means to communicate with On-Train Systems i.e. WiFi hot-spots
Back-Office	Back-Office System at single back-office location, featuring the following components: • Server • Data hub • Analysis applications

Figure 3. IRISS high-level architecture and interfaces

An overview of the IRISS system elements and the functions of the on-train components is provided in Figure 5 and Table 1.

The IRISS system is centered around a single, modular box on-board the train (TITAN, see also Figure 4) that integrates multiple satellite navigation systems (GPS, EGNOS, GLONASS), with satellite (Iridium) and terrestrial communications systems (GPRS, 3G, 2 networks) and that is fed by various on-train sensors and forward facing CCTV (FFCCTV). The on-train sensors include on-train metering of critical status (OTMR), engine monitoring system (EngMon), as well as the possibility to extend to other analogue and digital signals (e.g. door opening etc.). Switching software automatically selects the optimal means of communication. TITAN also allows for messages, alerts and commands to be exchanged with on-train personnel (equipped with PDAs) through an internal Wifi system. An external Wifi system allows for regular broadband download of historical data (e.g. CCTV) at selected hotspots (during stops at stations or depot). A VSAT connection between Wifi hotspot and Control Center is not yet included but may be considered in remote locations (link 4 in Figure 3).

An Inertial Navigation System (INS) is an option for future extension of TITAN's integrated navigation equipment, if users would wish to extend the availability of a navigation solution (e.g. inside tunnels).
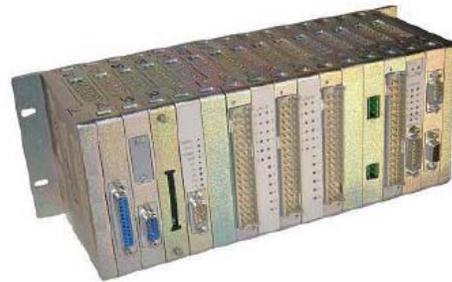
Figure 4. The TITAN II unit is based on the Eurotech Stack 104

The Train Operator's control center collects and stores the TITAN real time data (using 3G/GPRS, SatCom) and historical data (using also Wifi at Stations or Depots). This data is tagged with the precise time and train location. It can be conveniently retrieved and displayed for asset management, incident investigation and driver training purposes.
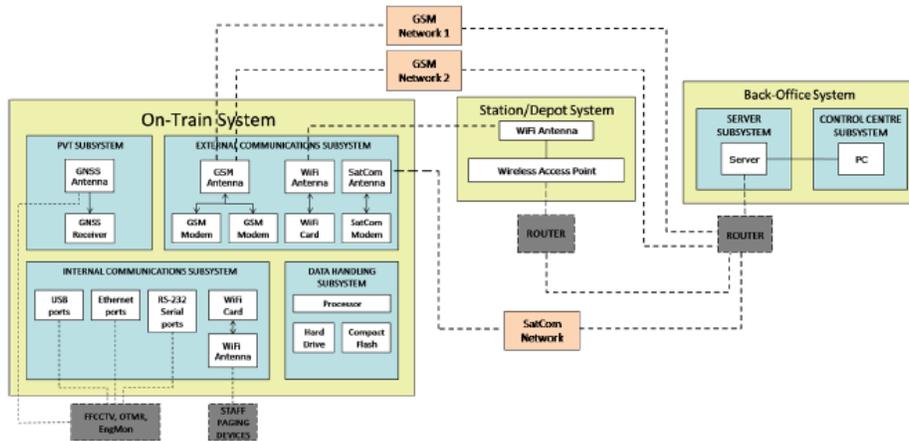
Figure 5. IRISS system architecture

On-Train System Logical Component		Function
PVT Subsystem	PVT Software	Computes 3D position, speed, direction and current time solutions by integrating outputs from GNSS receiver and INS on an automated basis
External Comms Subsystem	External Comms Management Software	Manages all communications between the On-Train System and the Back-Office System including triggers for reporting, priority, scheduling, raw data packaging and channel selection.
Internal Comms Subsystem	Internal Comms Management Software	Manages all communications between the On-Train System and other on-train sensors and systems, supporting wired Ethernet and WiFi communications and enabling onboard internet access.
Data Handling Subsystem	Data Handling Software	Handles all messages received from the Back-Office Subsystem and crew mobile devices, tags datasets with time and location information, creates Train Tracking Service bulletins, manages logging of data and messages and maintains communications logs.
Staff Paging Devices	Paging Software	Allows messages sent from the Back-Office System to be received and responded to via a Graphical User Interface.
Driver Display Units	Driver Information Software	Allows advisory information sent to Driver Display Units to be viewed via a Graphical User Interface.

Table 1. IRISS on-train component functions

The control center is based on TrainTrax (Figure 6). TrainTrax is an application which allows the real time tracking of multiple trains using a map display. Traintrax can be used to monitor the location of trains when they are in remote areas that have poor coverage of train detection systems. Other data related to each train may be integrated and updated in real time e.g. route/service, fuel levels. Other applications which are based around real time data may also be integrated within the control centre.

A second IRISS user application is OCULUS (Figure 7). OCULUS is not a real time application but rather is designed for use in post journey analysis e.g. driver performance analysis and training. It synchronises CCTV data with PVT-derived data as well as data related to communications channels.
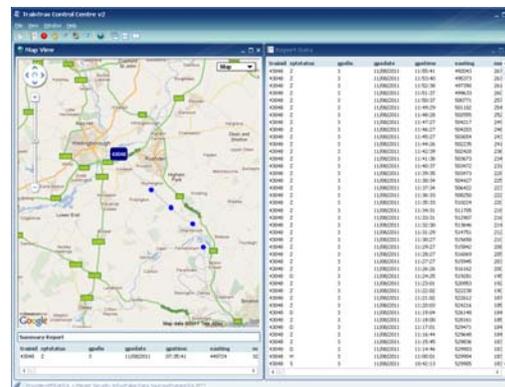
Figure 6. TrainTrax application screenshot
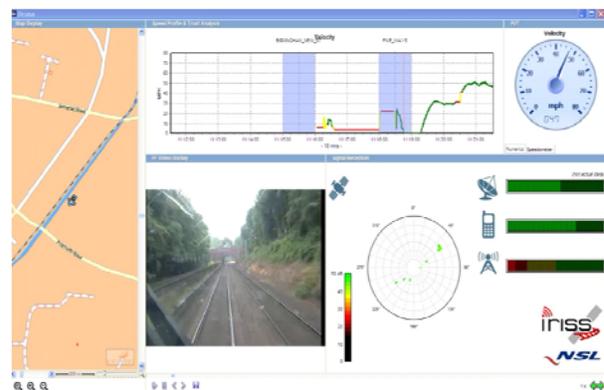
Figure 7. OCULUS application screenshot

III.2 Services

Using the IRISS system and user applications, based on an analysis of user priorities, the following services are currently being developed and explored:

- OTMR download
- CCTV download, image extraction
- EngMon download
- Other on-train metering
- Train tracking & geofence alerting
- Driver training/energy management
- Paging/messaging (Figure 8)
- GNSS feed to EngMon, CCTV, OTMR
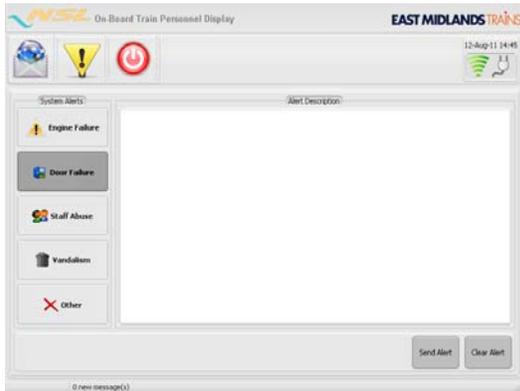
Figure 8. Crew messaging application screenshot

III.3   Proof of Concept

The objective of the Proof of Concept is three-fold:
- Demonstration of IRISS potential to the user
- Validation of user requirements
- Assessment of added value of space assets

A Proof of Concept has been implemented with the user EMT. Two generations of TITAN (v.I and v.II) have been developed and qualified for train use. They have been installed on two trains operated by EMT:
- PoC #1 : A rural train (Class 158)
- PoC #2 : A high speed commuter train (HST, Class 43)

This selection guarantees coverage of a range of situations (connectivity, environment and landscape, types of servicing and driving, types of passengers). The subsets of equipment, services and interfaces demonstrated are indicated in Figure 9. The installation diagram of PoC #2 is provided in Figure 10.
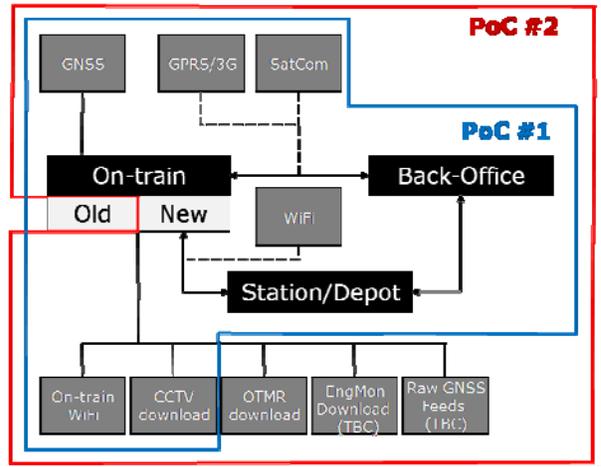
Figure 9. Proof of Concept part 1 and 2 systems, services and interfaces demonstrated.
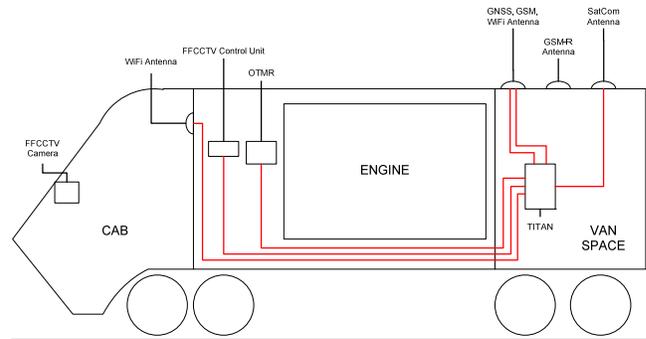
Figure 10. PoC #2 installation diagram (HST).

Figure 11 presents the overall logical architecture for the IRISS system interfacing as developed for the proof of concept activity including data flows and a description of the IRISS services that it can in principle provide. The Station/Depot segment, not shown, is based on COTS hardware. It may be thought of as being a means, alongside GSM and SatCom, to establish the „Optimized and Encrypted Tunnel" between the on-train and back-office systems. The „Optimized and Encrypted Tunnel" represents a Virtual Private Network (VPN) connection between on-train and back-office systems based on the Advanced Encryption Standard (AES).
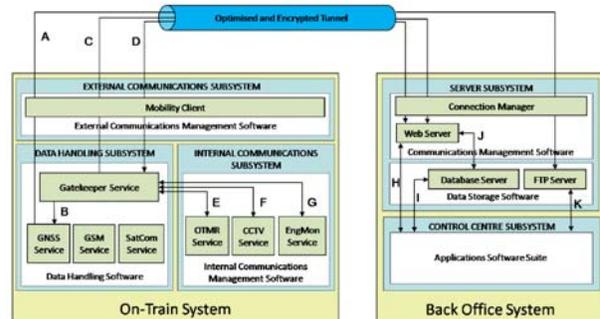
System Element	Function
Mobility Client	Based on a priority list of network interfaces and their current availability, the client intelligently selects an interface for 2-way communications
Gatekeeper Service	Receives all commands from the back-office system, validates and either executes or forwards them to the appropriate services
GNSS Service	Logs GNSS data and transmits position-based report messages
GSM Service	Logs GSM data including signal strength and quality
SatCom Service	Logs SatCom data including signal strength and quality
OTMR Service	Extracts raw data from OTMR and packages it for transmission
CCTV Service	Extracts raw data from forward facing CCTV and packages it for transmission according to request
EngMon Service	Extracts raw data from EngMon and packages it for transmission according to request

Figure 11. Interfacing and services as developed for Proof of Concept.

Intermediate PoC results (as of Aug. 2011)

The train tracking functionality has been successfully demonstrated. It provides the following reports:
- Tracking reports from the train to the shore at a 60s rate (this is configurable).
- Train stopped: triggered by train speed dropping below configurable threshold
- Train departing: triggered by train speed increasing above configurable threshold
- Heartbeat: sent every 30 minutes when stationary

All reports are viewable through the TrainTrax Control Centre software. This has been implemented as a back-office fleet management application. In addition the most recent reports from a unit can be viewed through a TrainTrax Online website.

The CCTV download functionality has been demonstrated through the following tests:
1. Streaming whilst stationary in Neville Hill depot using a 3G mobile connection
2. Download of 30s of data whilst stationary at Nottingham Station by connecting to the in-cab WiFi from the platform.
It is found that 1s of video data (about 1 MB) takes less than 4s to download over the internal WiFi. Use of an external access point should reduce this significantly. The clock on the CCTV unit (which may be off by minutes) can now be corrected by GPS time.

The train crew paging application was tested on the HST, through the exchange of messages (pre-defined alerts and customised text) between the back-office (connected to TITAN over mobile communications networks) and a tablet on board the train (connected to TITAN through the in-cab WiFi).

Remote configuration of TITAN from the Control Centre has been successfully demonstrated.

It has been demonstrated that logged GPS and communications signal quality data, not sent in the regular reports, can be downloaded via FTP on demand, using the TrainTrax Control Centre software. One of the main reasons for doing this is to assess the mobile communications network coverage along the routes used. Through repetition, 'black spots' may be identified in which there are no such communications available at any time of day. The quality of the satellite communications available at those locations may then be investigated and an understanding of the overall ability to provide seamless communications gained.

The aim of the performance evaluation campaign has been to gather statistics about the three communications networks (two GSM networks and one satellite network) that are to be used in IRISS, as well as GNSS coverage. The desired statistics include:
- Coverage – Area where signal strength is enough for communication.
- Byte throughput
- Message throughput
- Latency– Latency when sending short messages.
- Jitter – Irregularities in the latencies. May be caused by channel access issues inside coverage areas. May also be caused by cell switching or GPRS/3G switching.

Some IRISS data for 1 hr operation is illustrated in Figure 12-Figure 15. Although this data is to be further processed, the added value of SatCom to obtain continuity is quite apparent.
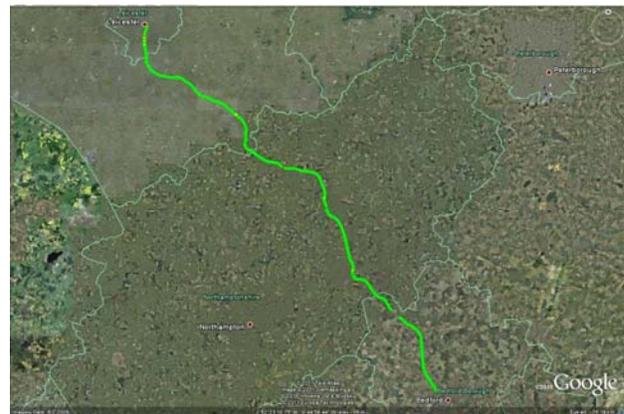
Figure 12. IRIDIUM SIGNAL QUALITY INDICATOR (0-1 = Red, 2-3 = Yellow, 4-5 = Green)
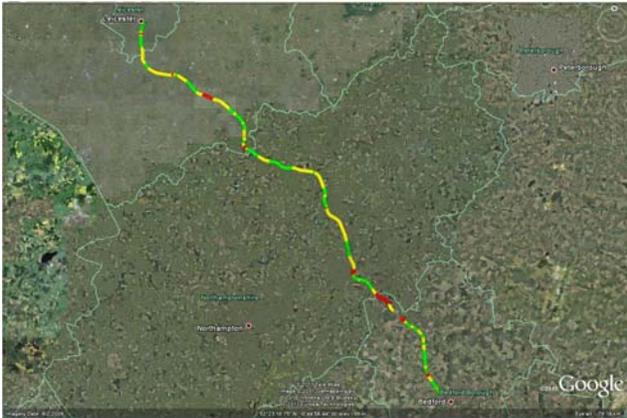
Figure 13. MODEM A (ORANGE) SIGNAL STRENGTH INDICATOR (0-10 = Red, 11-20 = Yelow, 21-31 = Green)

Figure 14. MODEM B (VODAFONE) SIGNAL STRENGTH INDICATOR (0-10 = Red, 11-20 = Yelow, 21-31 = Green)
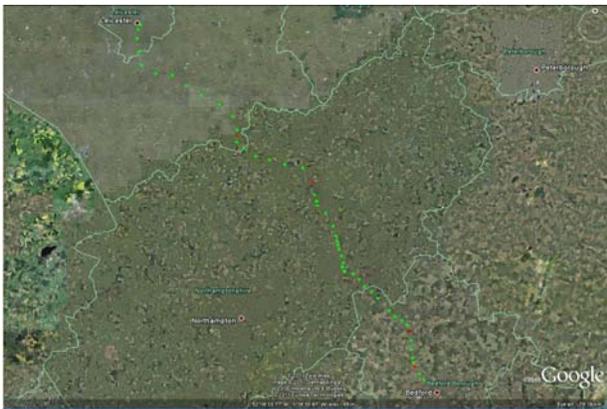
Figure 15. REPORTS: RECEIVED INDICATOR (Unsuccessful = Red, Successful = Green)

III.4 Potential benefits

It is believed that the proposed solution can support the business through delivering the following benefits:

- Improve performance through accurate knowledge of train performance, driver performance and network performance which will support identification of lost time and failing resources/operations.
- Cost savings through more efficient operations as well as savings associated with fuel efficiency. Further savings will be realised through reduced need to remove drivers from duty following accidents (during investigations) through access to CCTV footage and use of datasets to improve training.
- User friendly interfaces will ensure that information is presented in an intuitive manner which will lead to reduced time of training and operation as well as associated efforts.
- Proof of competence and compliance will be achieved through access to accurate information from the train-borne systems which will support the determination of the cause of faults, failures and delays.
- Records of performance for claim mitigation will be available through archived datasets.
- Minimal interfaces to train systems and processes will ensure rapid take-up and acceptance of the services.
- Future proofing by providing a communications and navigation hub, which may be used by any application (preventing the need for dedicated equipment) and which is easily upgradeable due to its modular form.

III.5 Future additions

The core IRISS services are planned to be extended within the scope of an IAP Demonstration Project and an operational system and service (Figure 16). To enable some of these services, additional modules may also be added to TITAN, e.g. to integrate also INS navigation, Galileo navigation solutions, and/or further analog or digital train meterings.

ID	IRISS Service	Feasibility Study	Demo Project	Operational System
1	Trainborne Dataset Downloading	OTMR Download FFCCTV Download from HST EngMon Download from HST (TBC)	Development of applications with automated and on-demand functionality. Download of data from other sensors e.g. wheel slip sensors	Operational back-office applications – download of data from all sensors as required by customer
2	Train tracking	Continuous tracking of both trains	Extension to a sub-fleet, possibly different TOC(s) New applications if non-TOC users involved e.g.	Entire fleets Traffic management application Individual carriages for asset tracking application Integration with other rail location systems e.g. ERTMS
3	On-Train GNSS Feed	Provision of NMEA feed to CCTV	Provision of feed to further applications/systems e.g. Selective door opening	IRISS antenna and receiver to feed all applications/systems on train which require GNSS input
4	Staff Paging / Messaging	Demonstration of staff paging on both trains using notebook	Driver display units Extension from tablet PC to mobile phones/PDAs (requires software development)	Passenger service?
5	Trainborne Dataset Analysis	Driver training application based on OCULUS CCTV image extraction	Development of driver training application with input from drivers and TOC performance managers Further applications e.g. Energy Metering, and those of non-TOC organisations e.g. FFCCTV download for capturing trespass (Network Rail)	Operational back-office applications – all applications required by customer

Figure 16. Current status and planned extensions.

V. CONCLUSION

IRISS (Intelligent Railways via Integrated Satellite Services) offers a service to provide Train Operating Companies with essentially uninterrupted monitoring of train stock by integrating terrestrial and satellite communications, satellite navigation services and conventional train metering.

As a result of the IRISS project, Train Operating Companies can communicate with their on-board personnel and can monitor without significant interruptions and both in real-time and in retrospect their assets' position, status and forward-facing CCTV. Individual train downtime and overall service interruptions and delays are reduced while more consistent driving styles lead to better energy efficiency. IRISS thus results in an increase of safety, timeliness and customer satisfaction as well as in significant cost savings.