

## VALISE

### Video Balise for dependable train positioning

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#### SUMMARY

*For many years, the rail industry has been carrying out research and development towards a 'virtual balise' that can be deployed to locate a train at a precise track position at significantly lower cost than a physical transponder or balise.*

*The primary focus has been to realise a Global Navigation Satellite Systems (GNSS) system capable of use in a safety critical ('SIL4') signalling system. There has been considerable progress with the first systems now operational on low density lines<sup>1</sup>.*

*At the same time, there have been rapid developments in other industries, most notably the emergence of sensors and software for the safe positioning of autonomous road vehicles.*

*With a range of virtual balise technologies emerging, this paper considers the standards and interfaces needed for a competitive supply market which preserves the interoperability of rail operations.*

*The paper presents one system in development that utilises a forward-facing camera with machine vision to provide a 'Video Balise' version of a virtual balise. It describes the core technology and initial performance results and summaries the overall operating concept.*

*It also provides details of the VALISE Project, which is being conducted in Great Britain to demonstrate and trial applications for temporary speed restrictions and selective door opening using Video Balise technology. The safety approach being developed is also described.*

## 1 INTRODUCTION

Rail transportation, like every industry, has to reduce costs and improve performance in order to survive and prosper. In many cities, rail operators need to increase capacity for growing numbers of commuters.

With limited land for expansion, new control systems, offering improved performance, are seen as key components of the capacity solution.

However, the introduction of new technology into safety critical signalling systems is not straightforward to achieve. There is a perception that rail cannot keep up with the rapid advances in autonomous driving technology in the automotive sector and that rail may soon become obsolete.

The European Train Control System (ETCS) which began specification around 30 years ago, has to date, achieved very little penetration into its home European market.

One of the reasons for the limited progress of ETCS is the difficulty in matching investment costs to benefit returns. All trains operating over a route have to be fitted with ETCS equipment before the operational benefits can be realised. However, train fitment is costly and takes a long time.

There is the potential for new technology to reduce these 'upfront' ETCS costs and to support the next generation of control system beyond ETCS. This paper describes the train positioning technology developed by RDS International and considers how this and similar systems can be introduced to provide a virtual alternative to physical transponders and transponder readers.

Section 2 introduces the virtual balise, summarises progress so far and proposes an architecture and interfaces for the deployment of systems from different vendors.

Section 3 presents the Video Train Positioning System technology that RDS has developed to provide a virtual balise capability and section 4 provides an overview of the VALISE trial programme that is underway.

## **2 VIRTUAL BALISE CONCEPTS**

### **2.1 Train Positioning Overview**

In conventional signalling systems, track circuits or axle counters are used to detect the presence of a train in a track section or block. They constrain the capacity of the system because only one train can occupy a section at any one time. In addition, track circuit faults are typically one of the main causes of signalling failures<sup>2</sup>.

For ETCS, physical transponders or 'balises' are used as part of train location. A balise reader fixed under the train receives data from the balise as it passes over it. The train then measures the distance travelled from the balise using odometry. The combination of balise location and odometry measurement defines the train location used within the ETCS system. The odometry system comprises multiple speeds sensors, such as Doppler radars or axle end odometers to ensure that any failures can be detected. Odometry errors unavoidably build up with increasing distance, but these last only until the next balise is encountered and the distance measurement begins again.

In addition to ETCS balises, other track-mounted transponders and similar devices are used in a range of systems providing, for example, train protection, traction changeover, selective door opening and tilt supervision.

There is a trend in extending the scope of ETCS to provide additional functionality and thus increasing the benefits that can be obtained from train fitment. The primary example is Automatic Train Operation (ATO) over ETCS, which is now being standardised. Another example is Automatic Braking and Door Opening (ABDO) being implemented by South Western Railway in the UK.

For the infrastructure managers, there is also a desire to implement the 'Level 3' version of ETCS which does not require track circuits or axle counters, leading to both cost savings and capacity improvements. Level 3 systems have not yet been realised, although work has progressed on an intermediate 'hybrid' Level 3 approach.

### **2.2 The virtual balise**

As individual items of equipment, balises have the advantage of being low cost, reliable and relatively easy to maintain. However, for the infrastructure operator, the management and cost burden increase as more balises are installed to meet an expanding range of needs. Once installed, balises are fixed and relatively inflexible, reducing the maintainability of the railway.

For many years the industry has carried out research and development into 'virtual balise' technology. This has focussed on the use of Global Navigation Satellite Systems (GNSS) to position a train without the need for any physical infrastructure.

Significant progress has been made in developing a safety case for low density lines. The Roy Hill line in Australia operates using GNSS virtual balises as part of a control system supplied by Hitachi STS. However, the technology cannot yet provide the necessary levels of safety everywhere. It does not have the accuracy to discriminate between two closely spaced tracks and the error bounds cannot be reliably predicted in areas where there are radio signal reflections, such as in deep cuttings or near large metal structures.

In the automotive sector, there have been rapid advances in dependable and accurate positioning of road vehicles. These typically involve a range of sensors (GNSS, cameras, radar) to match detected features (lane markings, signs) and signatures to pre-stored high definition maps. However, despite bold claims, the era of the autonomous car has not yet arrived.

Unlike cars, trains are constrained to run on tracks, and the maps can be of much lower definition and of manageable size. Consequently, the era of the virtual balise is now very close.

Virtual balise systems can be realised in many different ways. There is the GNSS approach referenced above, the RDS system described below and other approaches for example using live train describer data and GPS, or automotive systems with radar, lidar and high definition maps. The following section discusses the architectures and standards needed to allow the widespread introduction of virtual balise technology from different suppliers.

### **2.3 Virtual balise specification**

Industry wide specification of architectures and interfaces are beneficial in building a competitive market for products and services that drives continuous innovation. This section discusses the key interfaces for a virtual balise system.

For a physical balise, the infrastructure manager determines where the balise is to be bolted to a sleeper and what data is to be stored on it. The balise reader on the train, does not know the whereabouts of the balise until it encounters it. Similarly, it has no knowledge of the data until it is received.

For a virtual balise system, the location of each balise needs to be 'known' in advance by the on-train equipment. In addition, the system also needs to 'know' the information to be transferred when the balise is triggered.

In ETCS, location is specified as a distance from a balise. The location is initialised when the first balise is encountered. If there are virtual balises, but no physical balises, there is a need for an alternative reference system, to specify the location of at least the first balise.

The natural choice is to use latitude and longitude. However, this is not sufficient as no positioning system will be accurate enough to exactly measure this point. We therefore also need to specify some region around the balise that would be acceptable. The width of this region has to be less than the spacing between adjacent tracks. We propose an approach that defines a virtual balise as a line between two specified points: A and B (see Figure 1) When the positioning system determines that line has been crossed, the virtual balise is triggered.

Using this approach, it is also possible to specify directionality. Reference directions can be defined by creating an axis ('Y') in the direction A to B and another axis ('X') perpendicular to this and passing through A. The balise can be triggered in the direction of increasing X values, decreasing X values or both (see Figure 1).

Defining a balise as a line between 2 points, provides the possibility of having a balise extend across multiple tracks on a route. This may be of benefit for some applications or for virtual balises systems that cannot discriminate between closely spaced tracks (see Figure 1).

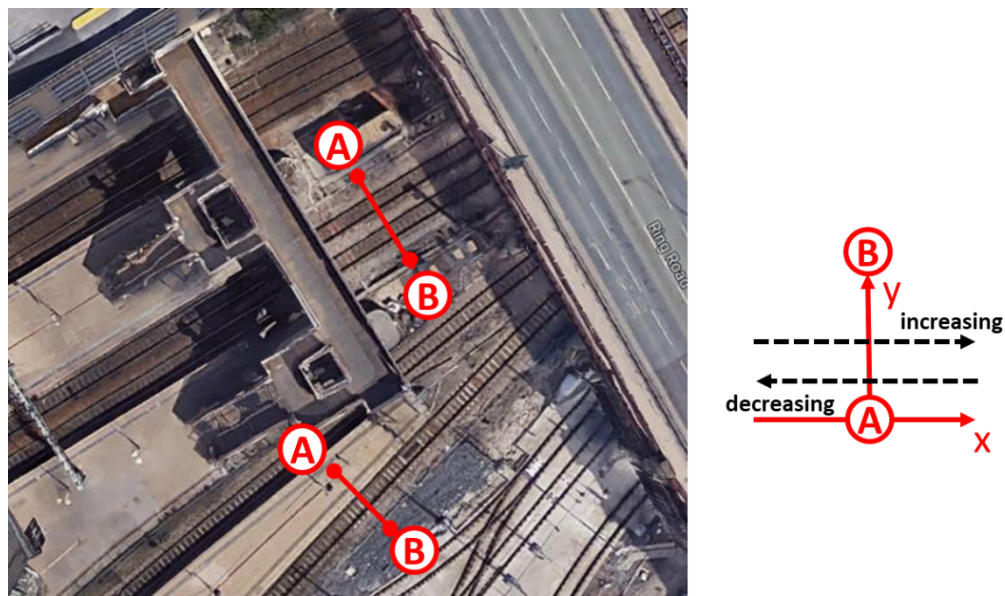


Figure 1: Specification of virtual balise location and directionality

There is also a need to be able to discriminate between tracks where one is above another. In this case latitude and longitude are not sufficient to identify a unique track. One approach would be to include height in the definition of the balise location. However, this would add to complexity by moving from a 2D to 3D reference system. Instead, we propose that these limited occasions are managed by engineering rules (ie not placing a balise in ambiguous locations). As physical balises require several engineering rules to control their placement, the deployment of virtual balises would be more flexible.

The latitude and longitude on a map may not correspond to those used by a GNSS receiver, because they use different datums. So the datum also has to be specified. For GPS, this is the World Geodetic System WGS84.

Turning to the data stored in a virtual balise, there are less constraints on message size than in a physical balise. Potentially, virtual balises could be implemented for other applications than train protection and signalling (for example for door control). In these cases, the virtual balises may have different owners and the data messages

could be destined for different applications on board the trains. We can therefore consider introducing the concept of data owners (eg infrastructure manager) and sub-owner (eg ETCS).

An initial list of attributes for a virtual balise, could therefore be:

- Virtual balise ID;
- Location (latitude, longitude of A and B ends, and datum);
- Owner and sub-owner
- Data content.

## 2.4 Virtual balise system architecture

To operate, the on-train system needs details of virtual balise implementation for the area in which it is operating. This can be obtained by querying a ground-based database and retrieving details of virtual balises in the local area.

On the train, there may be multiple applications that need to be notified when their virtual balises have been triggered.

To allow interoperability in rail operations and to provide multi-vendor supply of virtual balise readers, it is proposed that these interfaces are standardised (see Figure 2). There are clearly issues of data validation, integrity, safety and cyber-security which need to be addressed as part of the standardisation process.

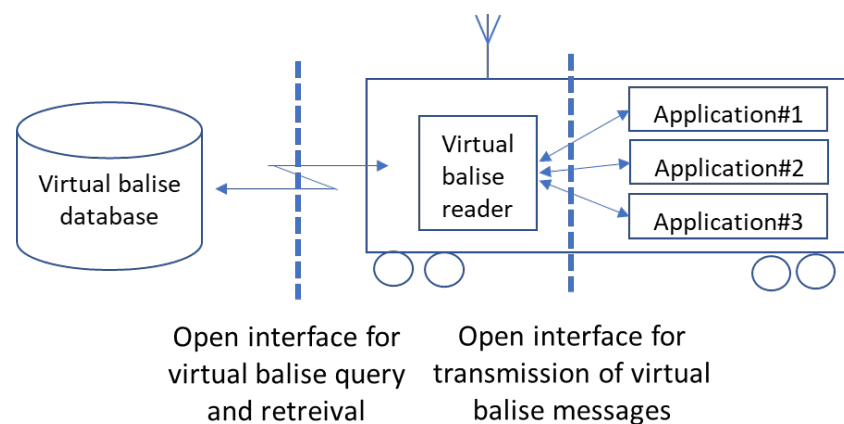


Figure 2: Virtual balise open interfaces

## 3 VIDEO TRAIN POSITIONING SYSTEM

### 3.1 Background

In parallel to wider industry GNSS R&D activities, RDS has been focussed on developing a complementary technology based on real-time image processing of forward-facing CCTV images. The objective is to overcome the limitations of satellite-based positioning, including the errors caused by reflection of the satellite signals in the railway environment which prevent dependable track discrimination.

The initial prototype of the Video Train Positioning System (VTPS) used a technique called visual odometry (VO) to measure the speed and distance travelled by the train. This approach was successfully trialled in northern Sweden in the winter and at high speed in Italy. For absolute or spot location, the forward-facing camera read bar code signs ('visual balises') at the side of the track. This system was described in a paper at ASPECT 2008<sup>3</sup>.

Feedback from infrastructure managers indicated a reluctance to deploy additional signs at the trackside. As a result, the VO capability was extended to measure 'sideways' displacement on curves in addition to longitudinal odometry. This enabled VTPS to determine the direction taken through switches and crossings. Combined with a

track map, the system could then navigate around the network without the need for signs. However, the system still needed to be told its starting location.

In working towards a solution to the initialisation challenge, RDS has developed a more general approach to locate a train at a point on a specific track using video - a video equivalent of a GNSS 'fix'.

### 3.2 The video 'fix'

Broadly, the live images from the camera are matched with a database of images taken at known locations on previous journeys. When a match is found, the location of the train is known.

In order to optimise the matching process, the system compares small 'fingerprints' that are derived from the much bigger images. The design of the fingerprint enables the technique to be resilient to changes in environmental conditions, such as day, night, rain and snow.

To illustrate the approach, Figure 3 shows fingerprints A to L generated from video images from previous journeys. When the train travels from track segment X to track segment Y, the live video is matched to fingerprints A to H. When it travels from track segment X to track segment Z, the live video stream matches fingerprints A to D and I to L.

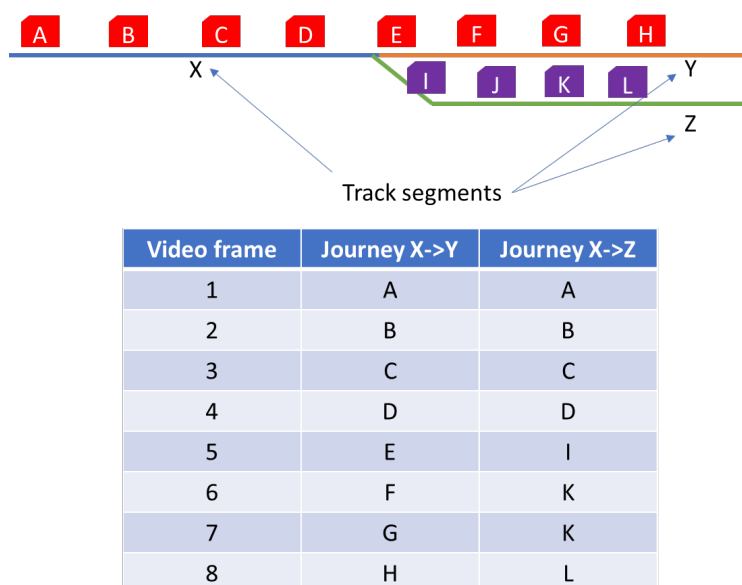


Figure 3: Fingerprint matching for a train travelling on two different routes

### 3.3 Performance

Initial development and testing used video recordings from forward facing cameras passing multiple times over different tracks on the same route in different conditions.

One set of videos was used to create the fingerprints (fingerprint videos) and the remainder were used to test the performance of the positioning (test videos).

In Figure 4, the left-hand image is where the train actually is, and the right-hand image is where it 'thinks' it is. In more detail, the left-hand image is the 'live' video frame from a test video. In real-time this is converted to a fingerprint and matched to the fingerprints in the map. One of the stored fingerprints is identified as the best match. To visualise the performance, the image on the right-hand side is shown. This is the video frame from a fingerprint video corresponding to the best match fingerprint.



Figure 4: Live image (left) versus estimated position (right)

### 3.4 Results analysis

It can be seen that the matching process has successfully determined the correct track, otherwise the frame on the right-hand side would show a view from the wrong track (the adjacent track on the right).

For the data sets used in the initial development, correct track selection for a single match is over 99% in normal daylight conditions (including rain) and over 92.5% for night. In snow, the match is over 99% for fingerprints also taken in snow, and over 75% when matching normal conditions with snow conditions.

It is important to note that these results are for a single match only. In practice a sequence of results is used within VTPS in conjunction with other sensor measurements.

By post-processing of the results, the relative 'along-track' accuracy can also be estimated. This is carried out by 'unwarping' the lower region of each image to give a view as if looking from above (see Figure 5). The image on the left is then shifted up and down until the features in both images are best aligned. (This is carried out by an automated cross-correlation process). The offset between them provides an estimate of the error: in this case 28cm.

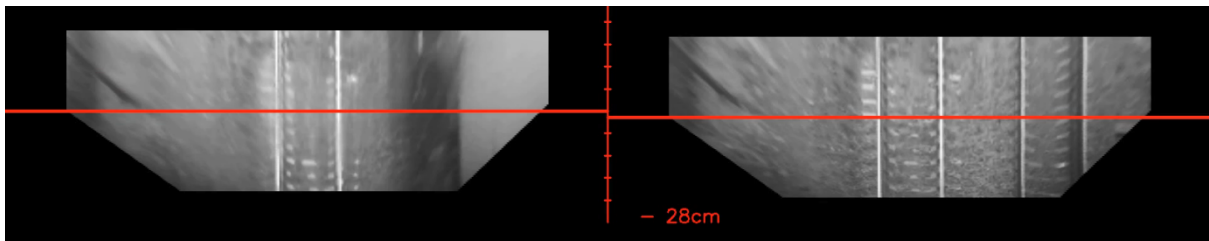


Figure 5: Error estimation by automated alignment of 'unwarped' images

The distribution of errors over many matches is shown in Figure 6 below. The left-hand side shows the error offset for each frame in sequence. The right-hand side shows the distribution of these errors. The 1-sigma value is  $\pm 49\text{cm}$ . (In this case, fingerprints were spaced with a separation of approximately 1m, so an average error of  $\pm 25\text{cm}$  is the best that could be expected)

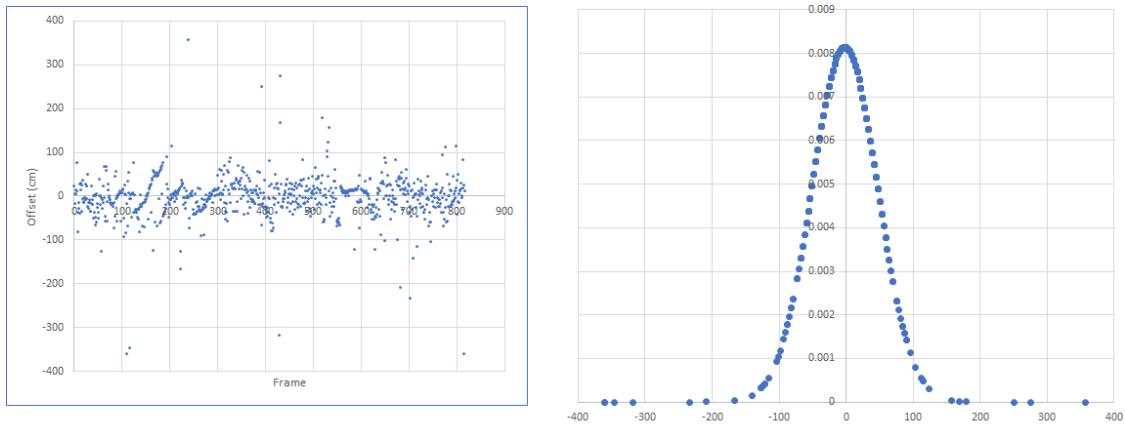


Figure 6: Error v frame number (left), distribution of errors (right)

### 3.5 Concept of operations

#### 3.5.1 Introduction

The previous section has described the core technology that enables VTPS to position a train on a precise track. This capability is used as a component of an overall virtual balise system. The operating concept for the complete system is outlined in this section.

#### 3.5.2 Building the fingerprint map

In the set-up phase, VTPS systems are fitted to trains. These systems collect and store video of the routes over which the trains are operating. The footage is collected and used to create the video map. The video is divided into sections between points ends. The frames within each video section are geospatially located using GNSS, inertial measurements and visual odometry (see section 3.1).

The number of frames is then reduced to meet positional accuracy requirements and storage constraints. For example, if video is captured at 50 frames per second, whilst a train is stationary at a station for 1 minute, 3000 frames will be generated. All of these frames will contain similar scene information and only 1 needs to be retained. Where high accuracy is required, such as at platforms or at switches and crossings, video frames might be retained for every metre travelled or less. On long stretches of plain line, a video fix may be needed only every 10m.

Fingerprints are then created from each video frame. This process captures key information from the scene in a way that is resilient to changes in environmental conditions: sun, rain, snow, fog, day, night, summer, winter, etc. The data reduction is in the range of 1000 times, so a 2MB 1080p video frame reduces to around 2kB of data. Fingerprints spaced at 10m for 100km of track occupy around 20MB of storage.

The maps are divided into smaller ‘tiles’ corresponding to sections of a route so that onboard systems can rapidly obtain and update just the tiles needed for operation in a local area.

Once a tile is complete it can be uploaded to the central update server and made available for distribution to on-train systems.

#### 3.5.3 Onboard system operation

The onboard system contains a map updater module. Whenever communications are available, the updater connects to the central server to check that its tiles are up to date. If any new tiles have been created or any previous tiles updated, the updater requests and obtains the new tiles or updates. Validity checks confirm that the onboard updated tile matches the central one. The updater prioritises the update of tiles in its local area, progressing to neighbouring tiles.

The onboard system can only operate once it has confirmed that the tile containing its current location is valid. This is achieved through checking with the central server and updating the tile if necessary. Depending on the required

integrity, more relaxed policies can be used, for example, the tile is deemed valid if has been confirmed up to date with the central server within the last hour, day, week, etc.

Once the system has a valid tile for the local area, it can commence operation. The live video feed from one or more cameras (for diversity) is received by the processor where frames are converted into fingerprints and matched with fingerprints stored in the track database. The location obtained from the fingerprint matching process is fused with GNSS, inertial and track map information in the navigation engine. The outputs from the navigation engine are its estimates of location, track, speed, direction, time and quality. (The quality output provides a measure of confidence in the positioning values).

#### **3.5.4 Map maintenance**

Railways and the surrounding environment are constantly changing and so a continuous business process of keeping the maps up to date is required. Whenever new track has been laid or previous track has been realigned, new fingerprints need to be obtained. Typically, engineering vehicles will pass over the new track before it is opened to traffic and these vehicles can be used to capture the video needed to generate the map updates.

Other parts of the scene from the forward-facing video may not be under the control of the infrastructure manager. For example, new buildings may be built in the surrounding area, or trees might be felled. Typically, these changes will only form part of the overall scene and will result in a reduction in the performance of the fingerprint algorithm and not a failure of it. By tracking the drop in matching performance for each fingerprint, it can be determined when a fingerprint needs to be refreshed. This is achieved by requesting a section of video from a passing service train, creating new fingerprints and uploading back to the map server.

#### **3.5.5 The virtual balise reader**

Virtual balises are defined (see Section 2.3) by their owners and uploaded to the virtual balise database. VTPS queries the database to retrieve the virtual balise details. This process uses the proposed open interface described in Section 2.4. It is suggested that this interface allows VTPS to confirm the validity of virtual balises in its local area, perhaps using the tile updating approach outlined for fingerprint data.

The virtual balise reader functionality in VTPS compares the virtual balise locations with the reported train position and triggers when a balise is passed. The balise details and message content are transmitted to the relevant application in accordance with the specified user destination.

### **3.6 VALISE Project**

#### **3.6.1 Overview**

The VALISE (Video Balise) project is developing an on-train demonstrator of a virtual balise system using the video 'fix' technology and demonstrating its performance in a range of applications, including for platform stopping and temporary speed restrictions and provision of a regular network 'video snapshot' for remote monitoring. These elements of the project are illustrated in Figure 7.

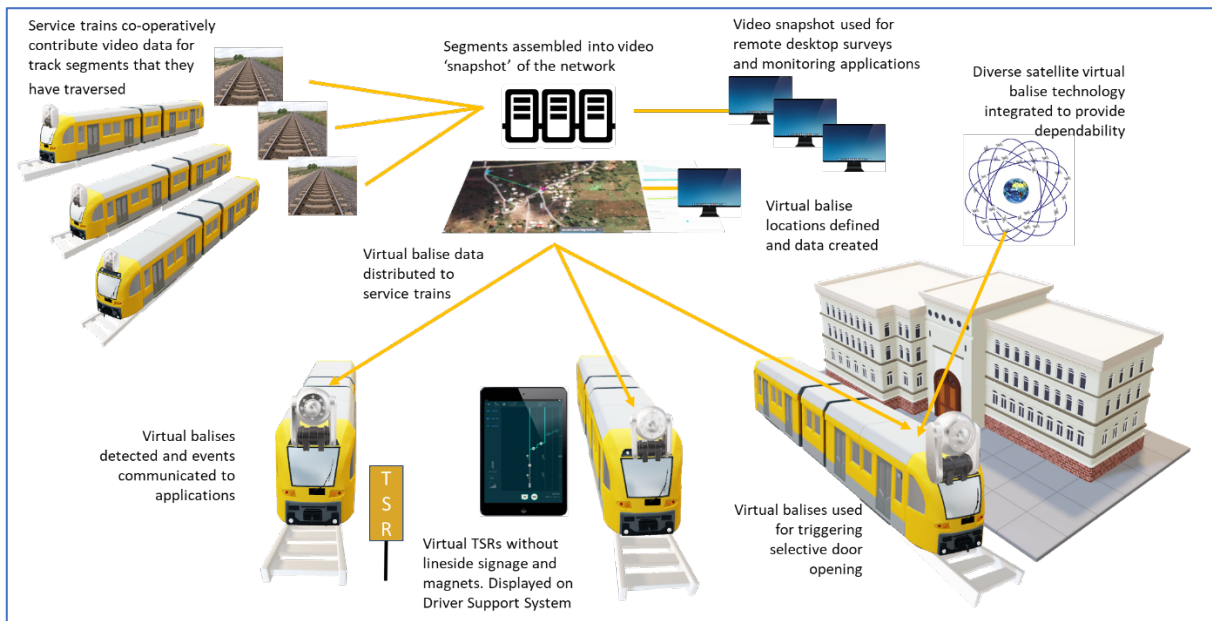


Figure 7: VALISE Project overview

More specifically, the on-train demonstrator comprises a VTPS system (comprising a forward-facing camera and processing unit) integrated with an RDS Driver Support System (DSS) display to show the triggering of Valise events. (The RDS DSS system is a tablet application showing a real-time rolling schematic map of the route ahead to support driver route knowledge. It is used in the VALISE project to provide an in-cab driver display of VALISE applications). Figure 8 shows VTPS equipment installed in a cab, together with the DSS tablet application).



Figure 8: VTPS camera installation (left), VTPS 1U rack processing unit (centre), Driver Support System tablet application (right)

The VALISE project is developing user demonstrations via the RDS DSS display of how two safety-related applications can be realised:

- For temporary speed restrictions, trackside TSR boards will be indicated on the DSS display, potentially allowing TSR without physical boards – providing increased flexibility in placement, eg in restricted clearance areas not suitable for boards, and a reduction in trackside installation and maintenance work resulting in workforce safety and cost benefits;
- For selective door opening, a virtual balise rather than track-based transponder will trigger platform stopping information.

### 3.6.2 Temporary Speed Restrictions with virtual balise

In GB operations, temporary and emergency speed restrictions comprise, in physical terms, a series of signs and magnets located at the trackside (see Figure 9). The magnets provide the driver with an audible alert through the AWS (Automatic Warning System) and the signs provide advance and immediate warning of the speed restriction. The precise location of the physical infrastructure is defined as part of an existing process.

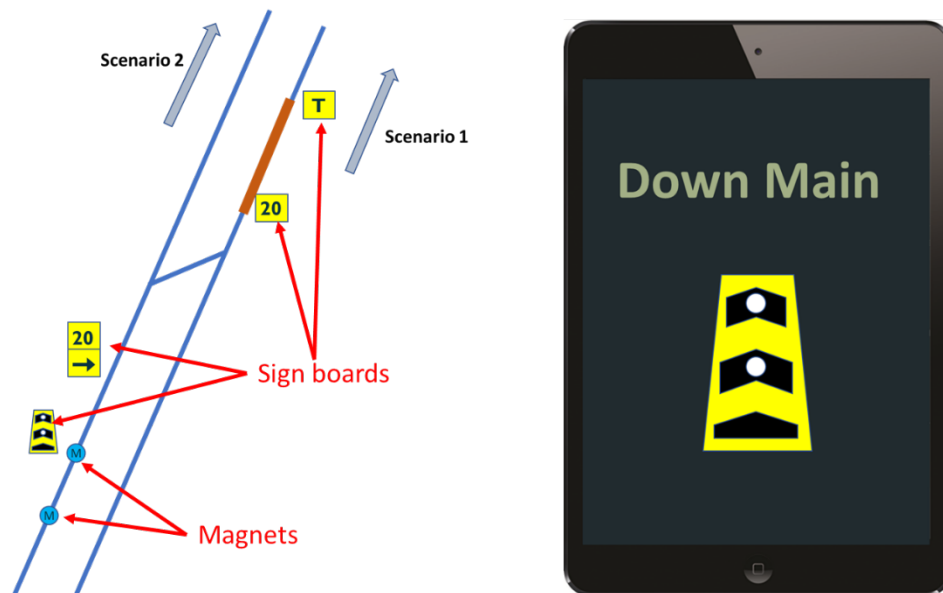


Figure 9: Existing Emergency Speed Restriction installation (left);  
In cab display of sign board triggered by virtual balise (right)

For an 'infrastructure-free' virtual TSR system, a user will first create a virtual balise for each of the signs and magnets by entering their track location and specific details into the ground system database. Details include the type of board, speed and the period the TSR is in force. The valise data is then passed to the on-train system (a subscribed user of the TSR service) and stored in its local database.

The on-board virtual balise reader monitors the train position and identifies when relevant balises are in close vicinity. As the train passes the location of the first 'virtual magnet' the balise reader sends the balise data to the TSR application. The TSR application determines the visual and audible indications to be displayed (in this case an audible alert and an icon depicting the warning board (see Figure 9).

The DSS display updates as the train passes the location of the other virtual signs. It also updates if the train is routed away from the TSR area, and thus the speed restriction no longer applies.

### 3.6.3 Automatic Selective Door Opening with virtual balise

Modern ASDO systems determine which doors can be safely opened by reading platform length data encoded in a trackside beacon or balise. The train is fitted with a beacon/balise reader that passes data to the ASDO application as the train passes over the beacon on entry to a platform. By comparing the train length with the platform length, the ASDO application determines which doors can be opened and which shall remain closed.

For the virtual ASDO system, a virtual balise replaces the beacon/balise. A user first creates virtual balises located at the end of platforms; the user enters balise data including location, platform length and distance to the start of the usable platform, into the ground system database. The data is then passed to the on-train system and stored in its local database.

The virtual balise reader monitors the train position, detects when the train passes over the balise and passes the balise data to the ASDO application. The system also provides an odometry feed to the ASDO application.

Upon receipt of virtual balise data the ASDO application calculates which doors will not be over the platform should the train be stopped at the correct stopping point. This door enable pattern is displayed on the DSS (see Figure

10) showing which doors could be released by the driver or train crew (and which thus could then be opened by passengers).

The ASDO application monitors the distance to the correct stopping point using the odometry feed, and once the train has stopped it recalculates the door enable pattern. If this is different to the initial pattern, because the train has stopped short or overrun the platform, a warning is presented on the DSS (see Figure 10). This indication can be used to inhibit an unsafe door release attempt.



Figure 10: Driver display for Automatic Selective Door Opening using virtual balises

### 3.6.4 Safety approach

ETCS balises are used as part of a safety critical ('SIL4') control system. Separation between balise and balise readers is very small and the components can be virtually treated as part of a 'closed' system. In contrast, the VTPS positioning system that underpins virtual balise operation is very much 'open'. The video 'fix' operates by visual sensing of the environment, which is subject to variability which cannot be treated deterministically.

The proposed approach to safety case development is therefore to establish a number of independent positioning channels of which the video 'fix' is one. By checking that all independent channels are giving consistent output, a higher degree of dependability can be justified.

Within the VALISE project, work is being undertaken to build a comparator of VTPS output using video, with independent positioning using integrated GNSS/ inertial sensors. The latter incorporates concepts from work on GNSS-based virtual balises (see section 2.2), such as protection limits.

Because of the novelty of this technology for rail use, it is also important to build safety in service evidence initially through non-safety applications. An example application is a virtual balise system integrated with trainborne survey equipment to record the precise track and location at which survey measurements are made. The next step is then to move to safety-related (eg 'SIL2') applications such as the ASDO example described in the previous section.

## 4 CONCLUSION

This paper has highlighted the emergence of different technologies to underpin virtual balise systems. It suggests that the industry should establish standards and interfaces to ensure a competitive supply market and to provide operational interoperability.

It specifically presented one technology that uses a forward-facing camera with machine vision to provide a 'Video Balise'. Initial results were presented, and the overall concept of operations was summarised.

The paper concluded by presenting the VALISE project to trial the use of Video Balise in applications on the operational railway. Two of these applications were described: virtual temporary speed restrictions and 'infrastructure-less' automatic selective door opening.

## 5 REFERENCES

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