System Description

Continuous railway track quality and ride comfort monitoring on in-service vehicles

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About

MoniRail is a recently established spin-out company that originated from the Birmingham Centre for Rail Research and Education (BCRRE) after over 15 years of research into low-cost, vehicle-mounted sensor systems to measure track geometry and ride quality.

After developing an initial prototype, which was successfully tested and proven on an in-service passenger train, MoniRail is now focused on commercialising the system and its data analytics platform.

The objective is to provide a commercially robust system that offers continuous monitoring of both track and train conditions, while detecting and identifying performance issues related to each. This will allow train operators and track maintainers to gain better insights into the condition of their assets, enabling them to make informed decisions regarding maintenance and upgrades.

The MoniRail sensor system collects data from the vehicle-mounted sensors, which is then processed and visualised through MoniRail's data processing and visualisation platform. This platform converts the collected data into actionable condition information that predicts potential failures and provides customers with a better understanding of the evolving condition of their assets.

Through this system, MoniRail can provide continuous monitoring and early detection of any issues, enabling customers to take preventive measures before major failures occur. By providing valuable insights into asset condition, MoniRail helps customers make informed decisions about maintenance and upgrades, ultimately saving them time and money.

The overview of the system is shown in Figure 1 below:

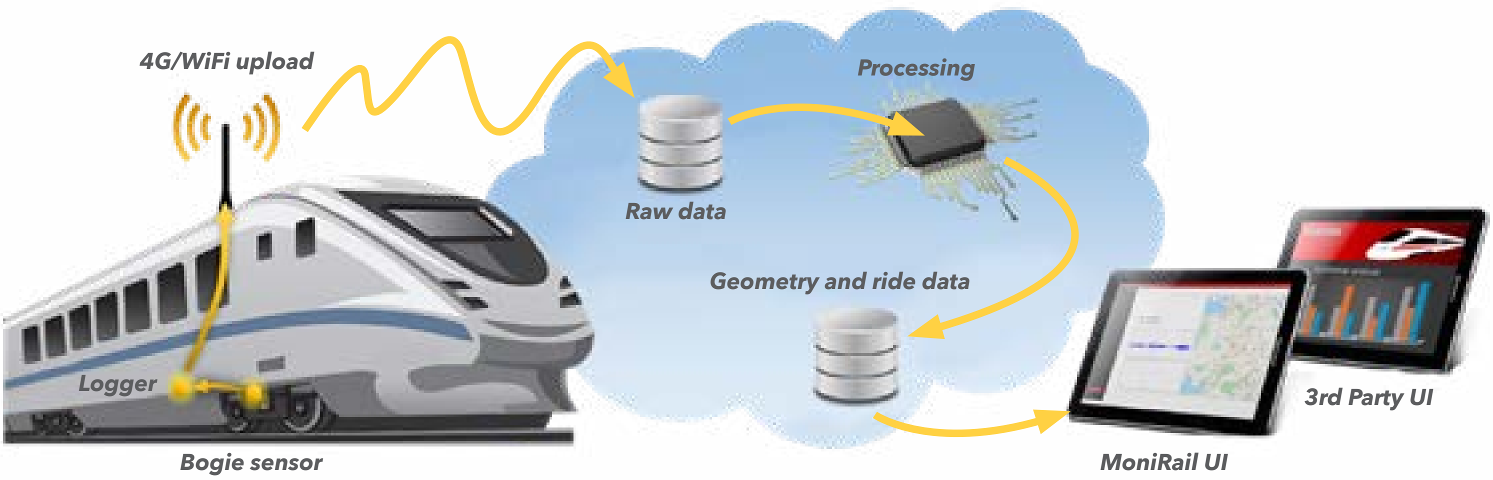


Figure 1: MoniRail system overview

MoniRail System

The MoniRail system consists of two parts - software and hardware. The hardware consists of sensor units on the body, bogie (optional) and on axleboxes (optional).

The data from the sensors combined with accurate positioning system are transferred to Azure storage via 4G connection, where the data will be aligned, and the track and vehicle response data are processed.

All the data will pass through our vehicle body logger system and get transferred to the secure cloud storage. The data from the cloud will then be processed, and the analysed data can be accessed via a web-based portal, which displays filterable track and ride information using an array of parameters.

Figure 2 provides an overview of the system:

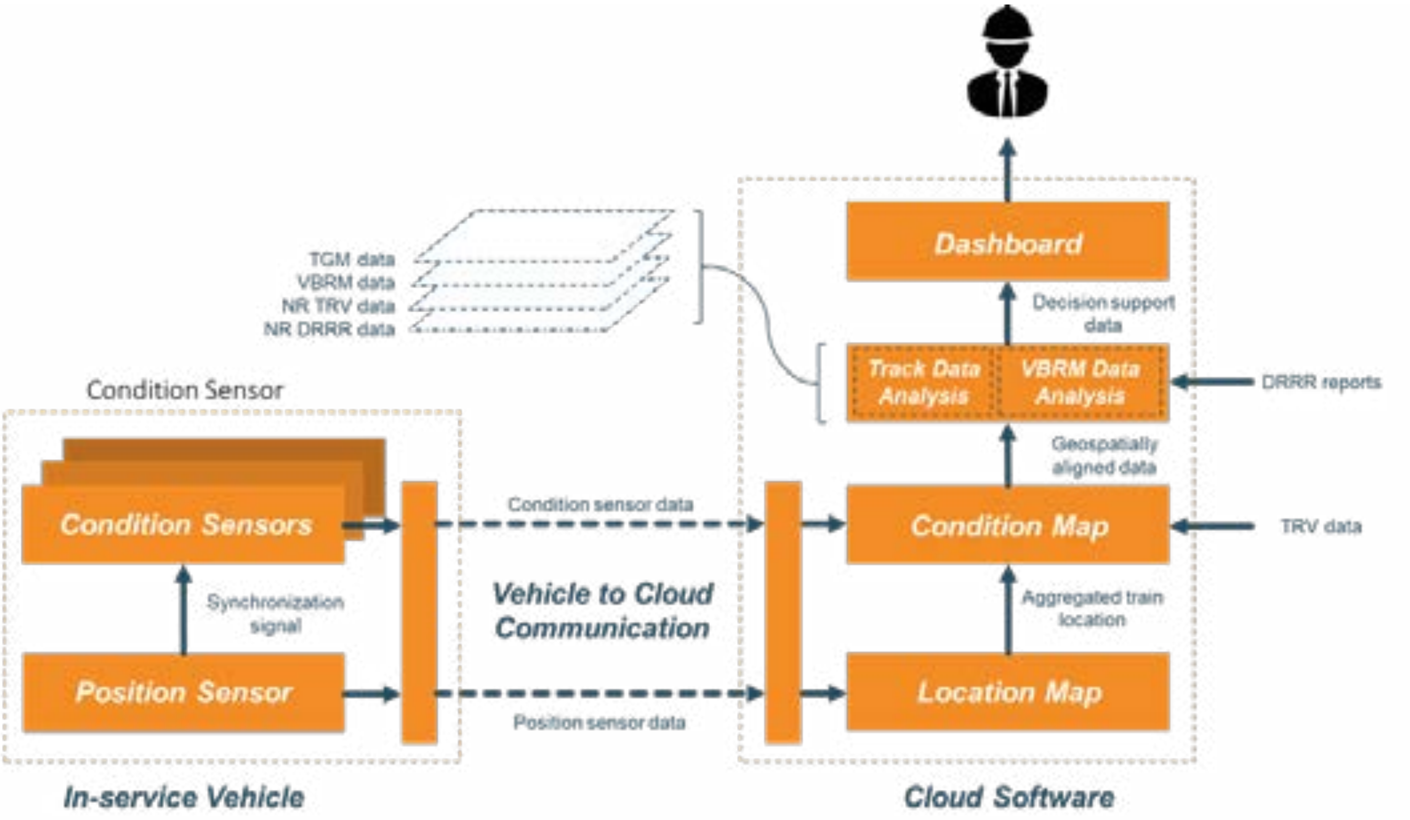


Figure 2: Overall system architecture

Hardware

The MoniRail Sensor System is a low cost, robust, accurate system that can collect data from the bogie, body and axlebox levels.
MoniRail hardware systems consist of three parts:

1) Vehicle Body Logger (VBL), installed on secondary suspension (body)
2) Track geometry monitoring (XIS), installed on primary suspension (bogie - optional)
3) Axlebox system (AXS), installed on axlebox (optional)

The components, data communication, power and overall diagram of the hardware is shown in Figure 3:

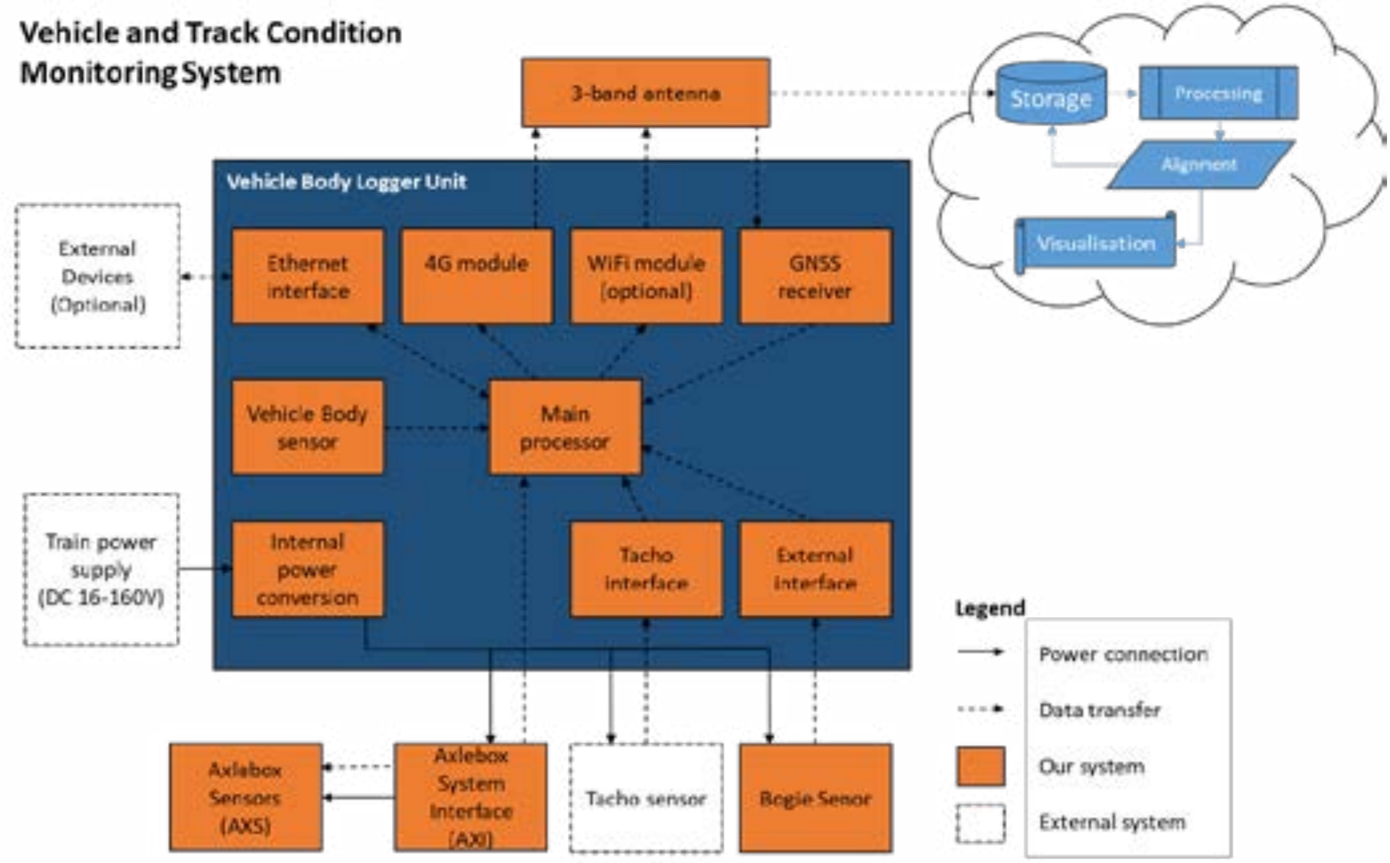


Figure 3: Overview of the hardware components

Hardware continued

Examples of the hardware and their capabilities are shown in Figure 4:

Figure 4: Body, bogie and axlebox modules

Vehicle Body Logger (VBL)

This unit, shown in Figure 5, is the communication core which also includes a proprietary sensor that provides accurate data to measure the following parameters:

- Ride comfort indices (EN 12299:2009)
- Vertical and lateral displacement of the body
- Secondary suspension movements
- Body resonance frequency and secondary suspension performance
- Body running safety EN14363
- Estimation of driver rough ride reports and hunting
- Pseudo track geometry parameters (excluding gauge)

The VBL also includes, GNSS, 4G, power modules. An example of the system fitted to a highspeed freight train is shown in Figure 5. The unit overall specifications and dimensions are shown in Figure 6.

Figure 5: (Left) Vehicle body logger unit (Right) System mounted on under carriage of C374

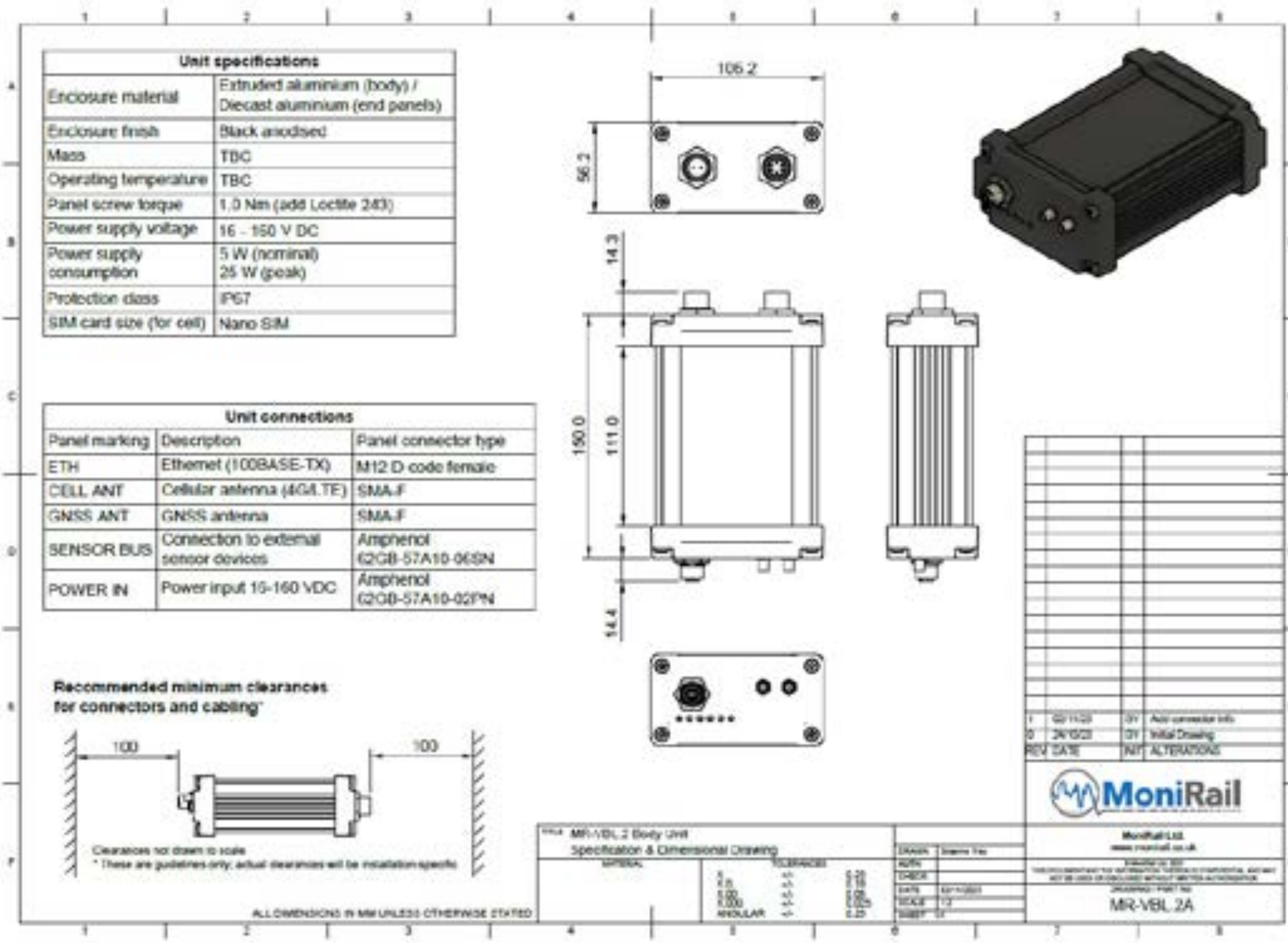


Figure 6: VBL specifications and dimensions

Positioning

The MoniRail GNSS modules delivers precision timing. It uses BeiDou, GLONASS and Galileo constellations up to 72-channel. The GNSS features are as follows:

GNSS Module	
Receiver type	GPS/QZSS L1 C/A, GLONASS L10F, BeiDou B1 SBAS L1 C/A: WAAS, EGNOS, MSAS, GAGAN Galileo E1B/C
Output rate	5 Hz
Sensitivity	-166 dBM (GPS)
Horizontal position accuracy	3 m
Velocity accuracy	0.05 m/s
Time pulse accuracy	Clear sky < 20ns Indoor < 500ns

The system can also be fed with a tacho pulse to achieve the sub-metre accuracy in position estimation. MoniRail can provide a non-intrusive solution for measurements of speed using Doppler radar.

Vehicle Body Logger (VBL) continued

Communication

4G link
The 4G module is compatible with most used LTE, UMTS/HSPA+, and GSM/GPRS/EDGE bands in Europe, Asia, and America. The module is certified to work in Europe, Australia and America.

Ethernet
The system has a 10/100 MB ethernet connection with M12 connector. This can be used for on-board tacho systems or synchronisation with any other external systems/sensors.

Power and Connectivity Requirements
MoniRail VBL power input is 16-160 VDC (EN50155 certified module). The system maximum power requirement is under 25 W (including continuous 4G transmission @ 100 kb/s). The system can communicate with optional bogie sensor using CAN bus and 24 VDC power line.

Electrical isolation
Internal circuit is electrically isolated into various groups to maintain isolation from train components. Each group is isolated from others by at least 1kV.

Mechanical and environmental
The VBL unit size small enough to be mounted beneath train body or inside cabinets within the car. Dimensions are 150x106x56 mm.

VBL is designed to conform to BS EN 50155 and BS EN 61373 (shock and vibration) Category 1B requirements (5.1 g peak / 0.6 g rms), IP67 rating and operational temperature rating of -20°C to 60°C.

Track Geometry Monitoring (TGM)

A single TGM sensor unit, as defined in Figure 7, is positioned on the vehicle bogie (primary suspension). To use this sensor, a VBL unit is system is required. The VBL unit is normally placed on the carriage (secondary suspension).

The enclosure size is 45x45x28 mm and designed to conform to BS EN 50155 and (30 g rms) with IP68 rating and operational temperature rating of -20˚C to 60˚C.

Figure 7: Track geometry sensor

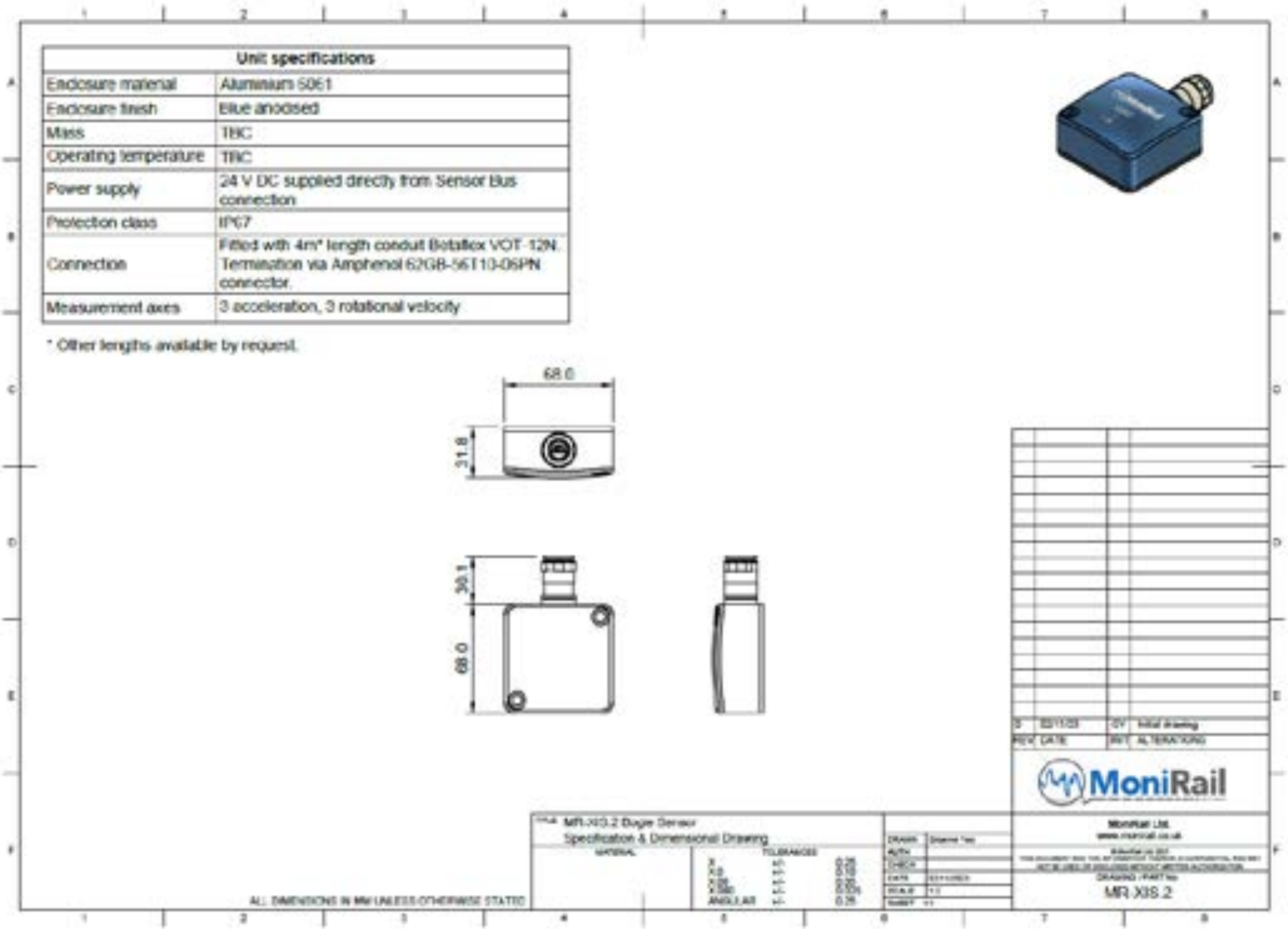
The bogie unit can be mounted to existing fixing points, shown in Figure 8 (left), does not need to be centrally mounted as offsets can be accounted for during data processing. The sensor can be affixed to a clear and flat surface on the bogie using adhesive, Figure 8 (right).

Figure 8: Bogie mounted system on an in-service train (left) using existing fixing points - C374 (right) using adhesive - C170

The following track geometry and vehicle parameters are calculated:

- Vertical alignment, including wavelengths of 35m, 70m, and 140m, with the option to add other wavelengths (±1mm accuracy)
- Lateral alignment of the bogie, including wavelengths of 35m, 70m, and 140m, with the option to add other wavelengths (±1mm accuracy)
- Cyclic Top 4m, 9m, 13m, and 18m, with the option to add other wavelengths
- Twist 3m and 5m, with the option to add other wavelengths – the accuracy is dependent on the distance between the wheelsets on the bogie – Twist 3m measurement accuracy on 2.6m wheelset spacing is above 70% compared to NMT, 5m is above 90%
- Crosslevel (±1mm accuracy)
- Curvature
- Cant deficiency (line speed information is required)
- Bogie instability

Overall TGM unit specification and dimension are shown in Figure 9.



Unit specifications	
Enclosure material	Aluminium 6061
Enclosure finish	Blue anodised
Mass	TBC
Operating temperature	TBC
Power supply	24 V DC supplied directly from Sensor Bus connection
Protection class	IP67
Connection	Fitted with 4m* length conduit Betaflex VOT-12N. Termination via Amphenol 62GB-56T10-06PN connector.
Measurement axes	3 acceleration, 3 rotational velocity

* Other lengths available by request.

Figure 9: TGM unit specifications and dimensions

Axlebox system

MoniRail provides axlebox sensors for wheel monitoring and higher accuracy for shorter track geometry wavelength. The weight of sensor is 65g and can measure up to 200g. The dimensions are shown in Figure 11.

Figure 10: Axlebox sensor installed on C374

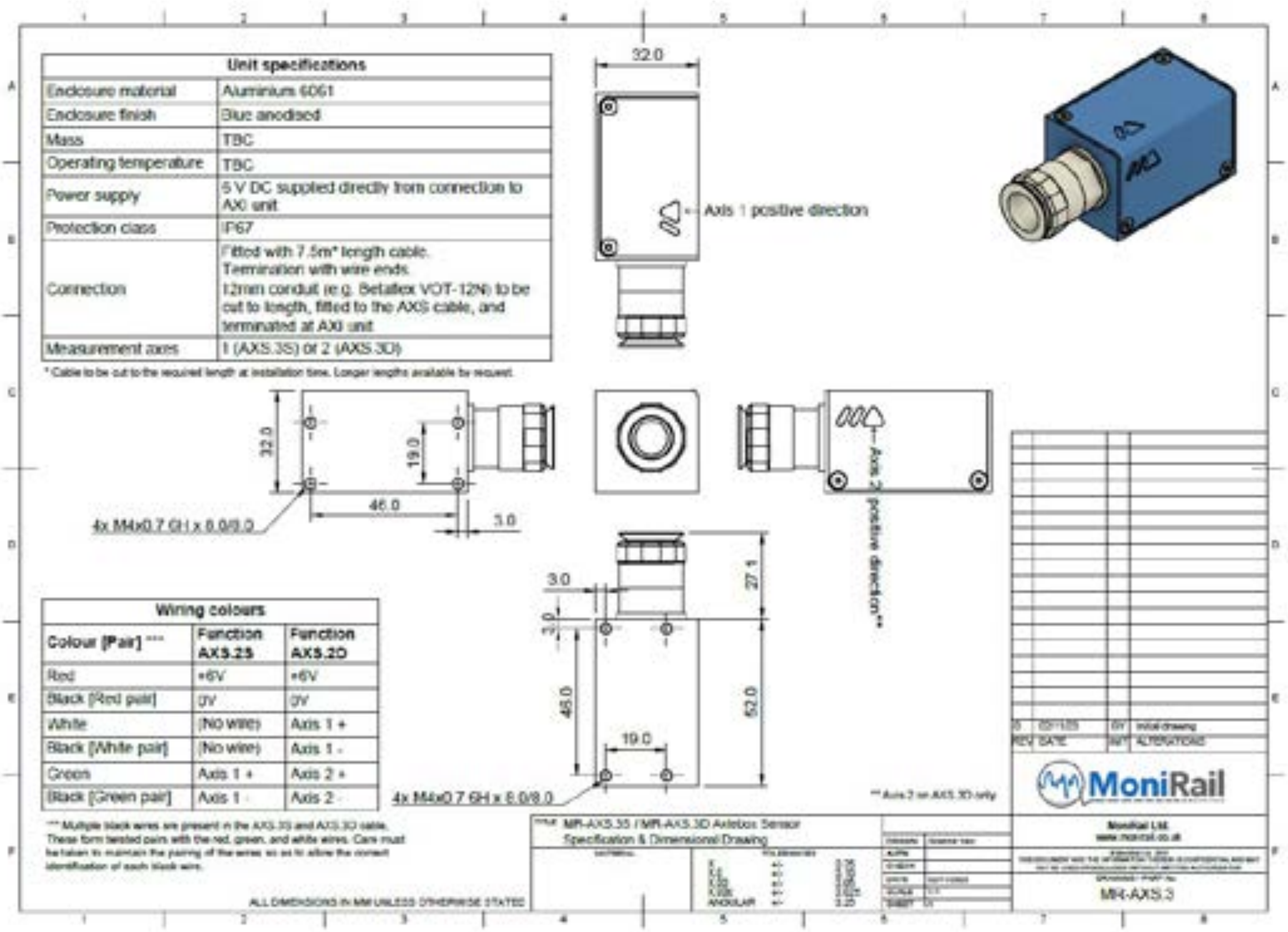


Figure 11: Axlebox sensor dimensions

Software

To ease the use of the data for infrastructure manages and track engineers, our team of experienced data scientists and software designers extract the relevant elements and present meaningful information in a variety of ways, which has received extremely positive feedback from multiple customers. We provide data analytics and visualisation services to multiple ROSCOs, Train Operators, Freight Operators and Maintainers.

Aligning data is key and our comprehensive geo-location solution, coupled with GNSS time synchronisation, provides increased accuracy for reliable data. The sensor data, combined with location and open-source data, can also provide an improved picture of when an event has happened, as well as where and what the surrounding scenario was.

We combine the information with multiple sources using our knowledge graph database and intelligent algorithms to determine if there are other contributing factors such as temperature, humidity and even driver behaviour, to provide detailed insight as to why an incident may have occurred.

During the initial stages of monitoring, a baseline of track geometry monitoring (TGM) data will be established by verification of the in-service TGM data with TRV data. To provide confidence in the in-service track condition data, comparison against up-to-date TRV data will be done on an ongoing basis.

Vehicle body response monitoring (VBL) data will capture a baseline 'signature' for each monitored vehicle. This data will be recorded, and subsequent runs will establish a database of 'signatures' over time for that vehicle, with associated time, location and accurate speed data.

A feed of Driver Reported Rough Rides (DRRRs) can be integrated into the system, with locations mapped accordingly to align with other data captured. This will provide a comparative, cross-referenceable database for all runs of monitored vehicles, to monitor changes from the initial signature, and match with any changes to track conditions being monitored daily by vehicles fitted with track condition sensors.

This is coupled with vehicle speed data for all runs, to ensure speed differences are considered as part of the 'signature' mapping process. Data will be normalised and interrogated to discover significant patterns and relationships between the data set and key predictors.

In training a statistical model to estimate key predictors, our steps include partitioning data into training, testing and validation sets. By computing and comparing the accuracy of several supervised and unsupervised machine learning algorithms, this will produce reliable outputs.

The signatures of potential Driver Reported Rough Rides (DRRRs) will be validated during the project and algorithms refined to provide accurate reports, with the ultimate objective being that DRRRs are recognised and reported without relying on subjective train-crew reports. Utilising the time and location-based data, the severity of potential vehicle and/or track faults can be identified and categorised accordingly.

Our experience of monitoring track geometry has proven that a system of bogie mounted sensors, vehicle body movement and ride comfort sensors can accurately identify potential DRRRs and link this directly to track faults or specific individual vehicle faults. We will be able to determine track degradation to the extent that advance warnings of potential SAF can be alerted to Network Rail staff with at least 14 days' notice.

Software continued

Our experience has shown that representing the condition of track or rough rides using simple colour-coding allows the condition to be understood in seconds. The charting and mapping of the data into an easy-to-use format will be available to anyone who needs it at their fingertips. An example of track condition data and vehicle response data visualised with thresholds are shown in Figure 12:

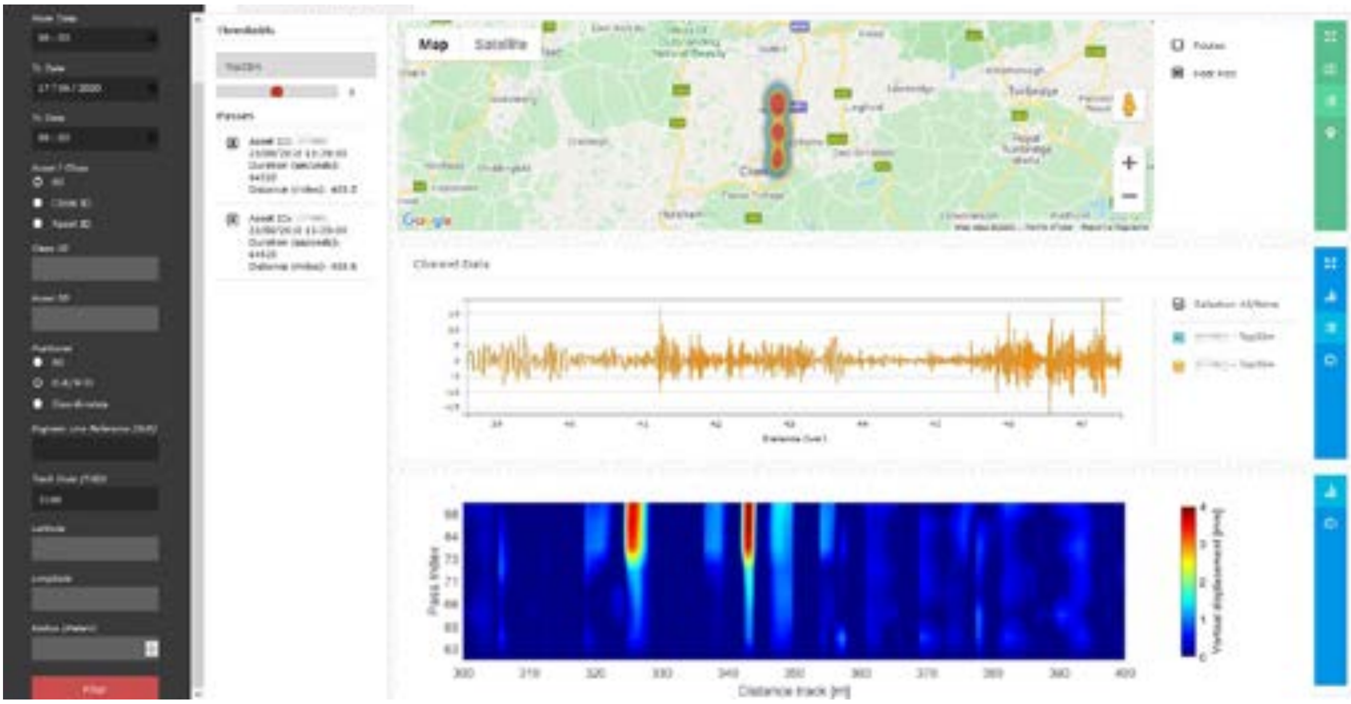


Figure 12: Example Visualisation of Track Condition Data

Multiple customisable visualisations can be developed via the use of filters across multiple parameters within the system. Individual vehicle pass data can be analysed and visualised along with multi run analysis and visualisation.

The flexibility of the visualisation ensures that end-users gain valuable insights into the data collected. Thresholds can be set across multiple parameters, triggering alerts when these thresholds are breached. Notifications will be sent via email or text to parties when investigation or action is required. Long term analysis of events will also ensure the algorithms are constantly evolving and improving, ensuring the end user gets the most value from our solution.

The flexibility of our systems has allowed the equipment and analysis to be utilised for multiple vehicle types and monitoring requirements, mitigating the impact of variability.

Data Structure

Location series data

Following recordings, 8 samples per metre along track, are reported through the MoniRail cloud processing:

Recording	
Track ID part 1 (ELR)	String
Track ID part 2 (TrID)	String
Kilometres along route	km
Route Miles	Mi
Time at location	ms past Unix epoch
Train speed	ms-1
Mean Top 35m	mm
Mean Top 70m	mm
Crosslevel	mm
Curvature	mm-1
Twist 3m	mm
Twist 5m	mm
Cant deficiency	radians
Vertical ride comfort	ms-2
Lateral ride comfort	ms-2
Longitudinal Jerk	ms-3
Body vertical displacement	mm
Body lateral displacement	mm

Positional data

The system provides WGS84 coordinates and converts Track IDs and km along route to coordinates:

Position Translation	
Track ID part 1 (ELR)	String
Track ID part 2 (TrID)	String
Kilometres along route	km
Route Miles	Mi
Latitude	WGS84 coordinates
Longitude	

Data Structure continued

Recording metadata

Metadata is provided once per recording dataset:

Recording Meta	
Train Unit ID	String
Recording Start Time	yy/mm/dd hh:mm:ss
Recording Duration	s
Recording Miles	Mi

Fault data

Detected faults based on a pre-defined thresholds are tagged with following information:

Position Translation		
Fault Latitude	WGS84 coordinates	Double
Fault Longitude		Double
Fault Start Time	yy/mm/dd hh:mm:ss	Date Time
Track ID part 1 (ELR)		String
Track ID part 2 (TrID)		String
Kilometres along route	km	Float
Other fault information as key-value pairs e.g. "EventType" : "Threshold exceeded" "ExceedanceLevel" : 4		

Data Structure continued

Data and standards

MoniRail data output can partially comply with BS EN standards for track geometry and ride quality, e.g. EN 13848 and EN 12299. MoniRail system is not certified but the current data output and comparison to Network Rail track recoding vehicle data, shown in Figure 14, demonstrate the accuracy of the system and its capability. Table 1 shows the MoniRail system output and the standards it can comply with:

System output	Description	Relevant Standards	
		BS/EN/ISO etc	Complicane - full/partial/no
Top (Vertical geometry)	Loaded geometry of the track on the vertical axis (mm)	BS EN 13848	Full - mean top (left+right)/2 Partial - individual left & right
Crosslevel	The height difference between the left and right (mm)	BS EN 13848	Full
Curvature	How much the track curves in the horizontal plane at a given position (radians/m)	BS EN 13848	Full
Twist	Magnitude change of crosslevel at both 3m and 5m base lengths (mm)	BS EN 13848	Partial
Cant Deficiency	The difference in angle between the measured crosslevel, and the desired crosslevel of a curved track, based on the line speed of the track (radians)	BS EN 14363	Full
Alignment (Lateral geometry)	The difference between the projected track centreline and the measured lateral geometry (mm)	BS EN 13848	None - currently outside spec Only bogie and wheelset lateral alignments
Body and bogie running safety	Instability and running safety performances	BS EN 14363	Full
Vertical comfort	Continues comfort index in lateral axis (standing position)	BS EN 12299/ BS 6841	Full
Lateral comfort	Continues comfort index in vertical axis (standing position)	BS EN 12299/ BS 6842	Full
Curve transition	Comfort on curve transitions (roll velocity)	BS EN 12299/ BS 6843	Full
Whole-body vibrations	Evaluation of human exposure to body vibration	ISO 2361	Partial

Certification

MoniRail system currently has EN50121 certification, shown in Figure 13:

eurofins E&E

Eurofins York Castleford
Unit 5, Speedwell Road
Castleford, WF10 5PY
United Kingdom
+44 (0) 1977 731173
enquiryyork@eurofins.com
eurofins.co.uk/york

EMC TEST CERTIFICATE

Issued to: -	Mr Luke Sykes 7 Pride Point Drive Derby DE24 8BX	**Project No. C6457**

Electromagnetic Compatibility Tests were performed on the apparatus as detailed: -

Description	MoniRail Inertial Logger system		
Type number	ILS.1A		
Serial Number	MR-ILS.1A-999-003		
Mode of Operation	Powered at 24V dc, Logging GPS and Inertial data, and uploading via network connection		
Date received	15th October 2021	**Dates Tested**	15th, 18th, 19th, 20th and 21st October 2021
Specification	EN50121-3-2:2016+A1:2019	Electrical apparatus for Railway environment	

The apparatus to which this certificate relates was tested against the above specifications. Full results are retained on file at Eurofins York Castleford. The apparatus was found to be compliant with the above specifications subject to the following conditions: see additional information on page 2

UKAS Accreditation

Tests marked "Not UKAS Accredited" in this certificate are not included in the UKAS Accreditation Schedule for our laboratory.

Opinions and interpretations expressed herein are outside the scope of UKAS Accreditation.

EUT Submitted

These results apply only to the particular EUT submitted, in the configuration used and in the mode of operation tested.

Certificate No: -	**14373TC1**	**Job No: -**	**C6457**	**Date: -**	**27th October 2021**	**Page 1 of 2**	
PDF copy							

Tested by: - D Horry Senior EMC Technician	**Approved Signatory: -** Colin Greenfield, Laboratory Business Manager

EMC Certificate Issue 8

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54 Business Park, Valiant Way
Wolverhampton, WV9 5GB, UK
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VAT Reg. No. GB 887 1276 83

Figure 13: EN50121 Certificate

Case Studies

Comparison to measurement fleet

The measurements from the bogie level have been proven to be comparable to those obtained by the Network Rail Measurement train. An example of vertical displacement (Top35) results compared to the NMT is shown in Figure 14:

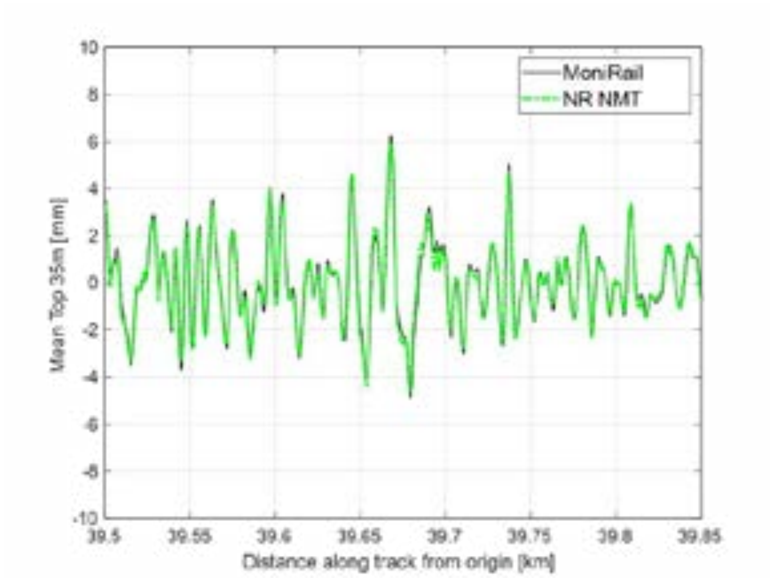

Figure 14: Data comparison, MoniRail System vs Network NMT

Case Studies

Driver Reporting Rough Ride

The system has been tested and proven to identify the driver rough ride reports up to 94% accuracy. The system uses a combination of bespoke algorithms and EN 12299:2009 standard to estimate the rough rides. Our studies have also shown that the reported rough rides can be up to 500m away from the actual event due to inaccuracies and time delays in the reports.

Figure 15 shows then the driver estimates the rough ride is located and our processing provides the where the rough ride has occurred:

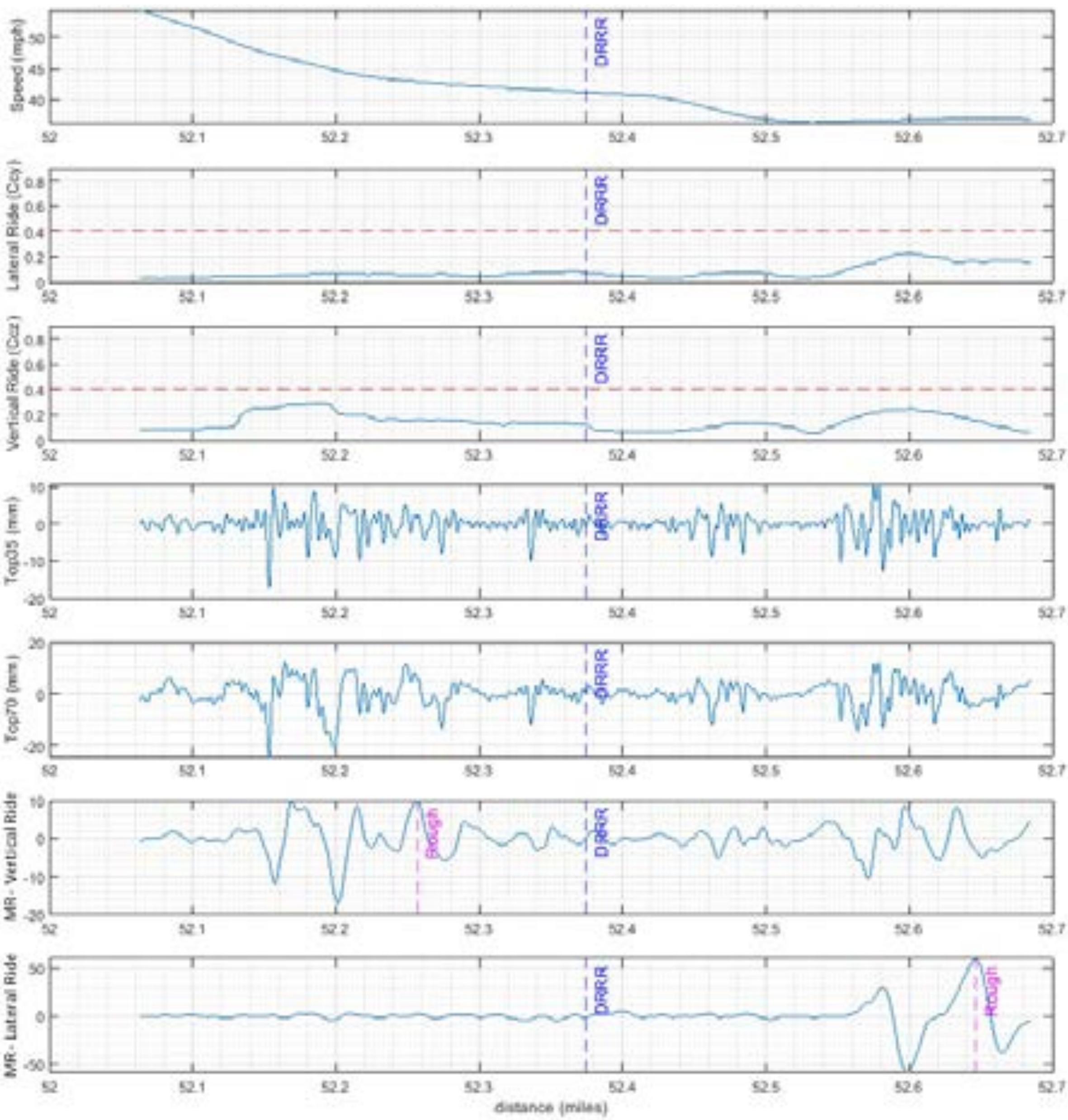

Figure 15: Rough ride detection

Case Studies

Track maintenance performance monitoring

Figure 16 shows a problem with the track identified by the Infrastructure Monitoring (IM) fleet (blue) and the results after replacing ballasts and track (red). The overall profile is improved, however, a new problem around a level crossing was introduced (highlighted).

This clearly demonstrated the usefulness of the track monitoring system for in-service vehicles in evaluating renewed sections and identifying newly developed track faults. Additionally, this could also potentially aid in the removal of ESR/TSRs.

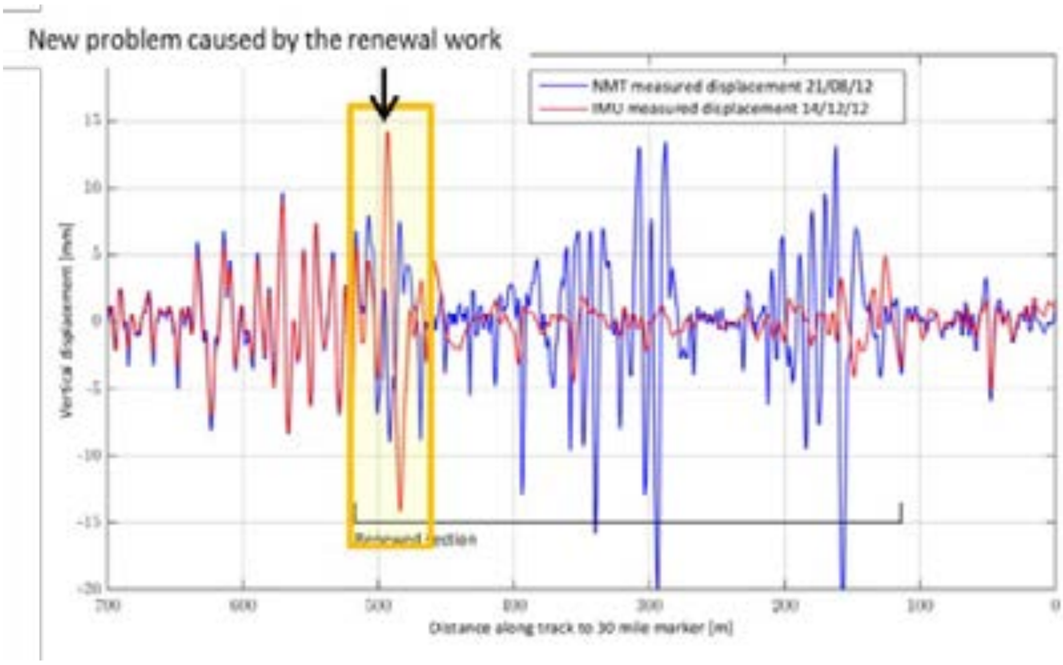

Figure 16: Renewal work and inspection with in-service vehicle

Case Studies

Degradation analysis

By using multi-pass analysis of TGM unit data from fitted vehicles, the system can perform degradation analysis. Since data is collected daily, the degradation model can confidently demonstrate both sudden and long-term changes in the track. By setting appropriate thresholds, early warnings of track faults at specific locations can be provided, defined in Figure 17 below:

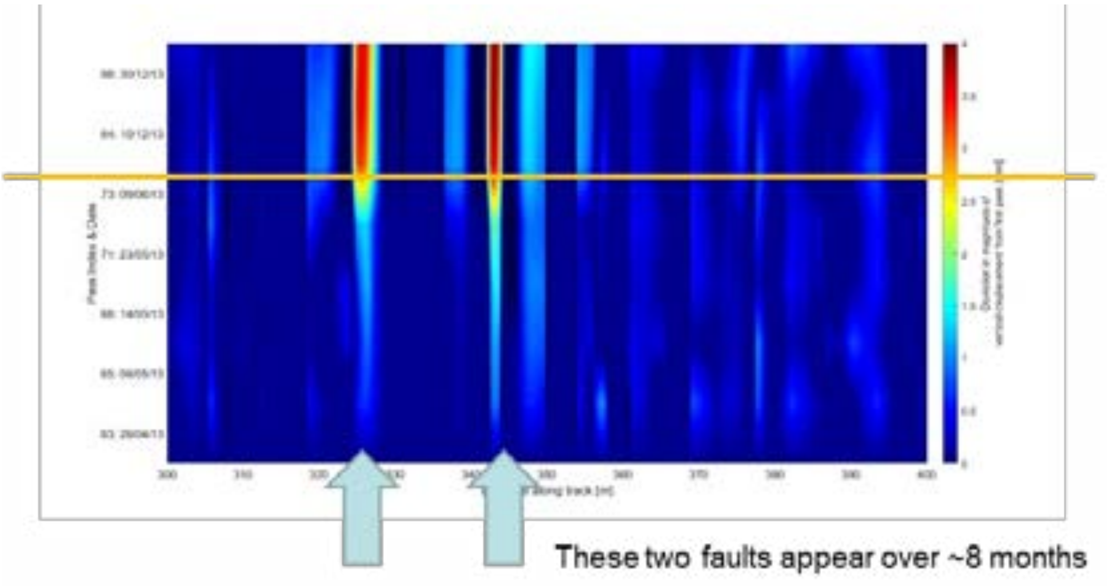

Figure 17: Renewal work and inspection with in-service vehicle

Vehicles are also fitted with VBL units, capturing data that is then mapped to the TGM data. Analysing VBL data against known track faults demonstrated that specific vehicle signatures could be identified for these track fault. However, the accuracy of this method does not match that of the TGM or IM fleet, see Figure 18:

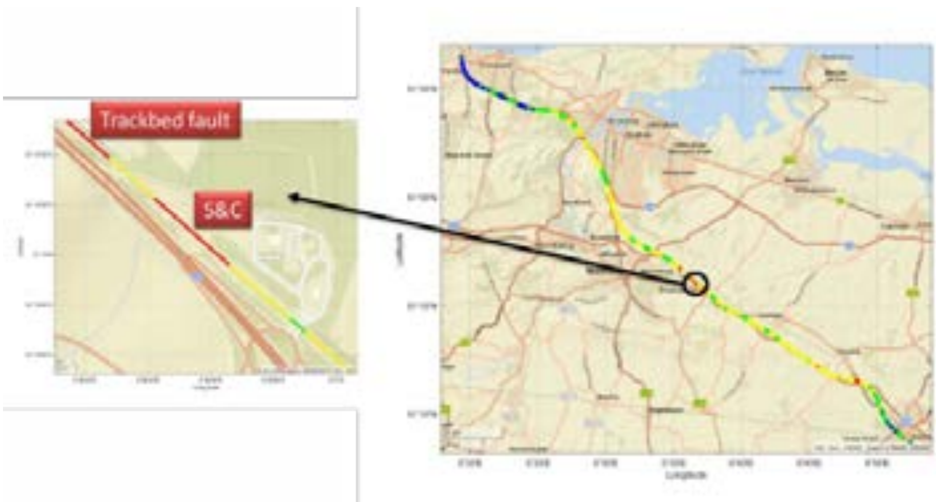

Figure 18: Ride comfort and relation to track information