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DRAFT

Executive Summary

This document covers deliverable D8.2 “Validation of SIA” of SIA project. This deliverable describes the results of the SIA system validation in the testing operational scenarios provided by the end users involved in the project. The testing scenarios used for the validation are described in deliverable D8.1 [16], and the validation tests have been carried out within the scope of Task T8.2 “Qualification and Validation of SIA functionality” during the last year of the project, concluding by the end of August 2021.

After the introduction and an architecture overview reminder, the document describes the individual validation of the different SIA subsystems and the four SIA services (iCatMon, iPantMon, iRailMon and iWheelMon) in the corresponding applicable testing scenarios. The subsystems had been already tested with lab data in controlled scenarios during their development, as justified in previous SIA deliverables of WP3 to WP7. This deliverable describes how the subsystems and the integrated SIA system and services have been tested in real operational scenarios with real field data, and their functional requirements have been thus fully validated.

Unfortunately, it should be taken into consideration that due to the restrictions imposed by the COVID-19 pandemic, the nine months testing period has been significantly reduced even though the six months project extension.

Nevertheless, when analysing the results achieved during the tests and compiled in this document, the full SIA system and its 4 services have been successfully validated reaching TRL of 7.

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Abbreviations and acronyms

Acronym	Description
ABA	Axel Box Acceleration
CDM	Component Degradation Models
CEIT	ASOCIACION CENTRO TECNOLOGICO CEIT (SIA coordinator)
CMMS	Computerized maintenance management system
DH	Data Hub
DOW	Description of work
DLR	DEUTSCHES ZENTRUM FUER LUFT – UND RAUMFAHRT EV (SIA partner)
EGNSS	European Global Navigation Satellite System
EUSPA	EU Agency for the Space Program
FGC	Ferrocarrils de la Generalitat de Catalunya (SIA partner)
GIS	Geographical Information System
GMV NSL	GMV Nottingham Science Limited (SIA partner)
GNSS	Global Navigation Satellite System
IM	Infrastructure Manager
INGECONTROL	INGENIERIA Y CONTROL ELECTRONICO S.A. (SIA partner)
IT	Information Technologies
KPI	Key Performance Indicator
MQTT	Message Queuing Telemetry Transport
OBB	OBB-Infrastruktur AG (SIA partner)
PANT	Pantograph-to-catenary
POS	Positioning
RCF	Rolling Contact Fatigue
SFTP	Secure File Transfer Protocol
SISTEPLANT	CMMS provider at VIAS
TELICE	TELEFONOS LINEAS Y CENTRALES S.A. (SIA partner)
TOC	Train Operating Companies
UI	User Interface
VIAS	VIAS Y CONSTRUCCIONES S.A. (SIA partner)
VP	Visualisation Platform
WP	Work Package

1 Introduction

1.1 SIA Overview

The SIA project (System for vehicle-infrastructure Interaction Assets health status monitoring) has the objective of developing four ready-to-use new services (iWheelMon, iRailMon, iPantMon and iCatMon) to provide prognostic information about the health status of the railway's most demanding assets in terms of maintenance costs (wheel, rail, pantograph and catenary).

1.2 Purpose and Scope of this Document

The main purpose of this document is to validate the SIA system detailing and reporting the results of the tests of the developed system. These tests have been carried out in different real operational environments described in D8.1 [16].

As each scenario covers a different set of functionalities provided by SIA, the different components and services of SIA system, described in Chapter 2, have been tested independently and as a whole in their corresponding scenarios to completely validate SIA requirements. VIAS scenario was intended to validate the integration of the SIA system and its functionalities prior the major tests in FGC and OBB scenarios. FGC scenario has been used to qualify SIA_PANT onboard equipment and iCatMon and iPantMon services, while OBB scenario assesses SIA_ABA onboard equipment and iWheelMon and iRailMon services. SIA_POS, SIA_DH, SIA_CDM and SIA_VP are common to all scenarios.

This deliverable is the final output of WP8 "Test setup preparation and validation" and has been led by INGECONTROL with contributions from all partners including technology providers CEIT, DLR and GMV NSL, and end users FGC, VIAS, TELICE and OBB.

1.3 Intended Audience and Distribution

This is a public deliverable, but the reader should be aware that not all details are disclosed here. For further information see other SIA deliverables compiled in References section of this document.

1.4 Structure of the Document

This document starts with an introduction and the SIA architecture overview. Then, it is divided in six chapters describing the testing results and validation of the different components of SIA system: SIA_POS, SIA_ABA, SIA_PANT, SIA_DH, SIA_CDM and SIA_VP. Then internally each chapter is divided describing separately the scenarios addressed.

Afterwards, the fulfilment of the requirements of the four SIA Services constituting the SIA system as a whole is justified, and the document ends with the conclusions.

2 SIA Architecture Overview

According to the deliverable D2.2 [2], and in order to fulfil the requirements defined in D2.1 [1], the following sub-systems have been defined for the SIA system:

- Pantograph/catenary interaction assessment subsystem (SIA_PANT)
- Wheel/rail interaction assessment subsystem (SIA_ABA)
- Positioning subsystem (SIA_POS)
- Data Hub (SIA_DH)
- Component Degradation modelling and algorithms (SIA_CDM)
- Visualisation Platform (SIA_VP)

2.1 Architecture Description

As a visual representation of the above subsystems, the following diagram was created to define the overall architecture and the associated interfaces of the SIA system.

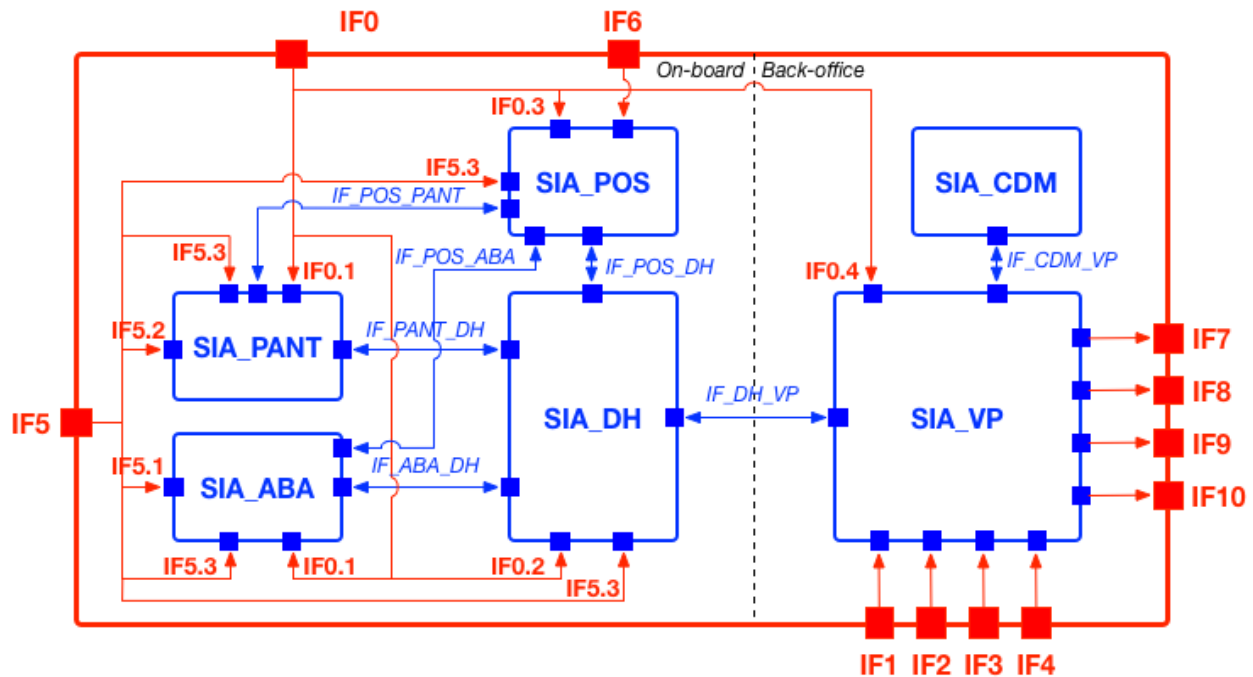


Figure 2-1. SIA Architecture

With this architecture, SIA will provide four services with characteristics defined below:

- *iWheelMon*, which is intended for TOCs and integrated operators, will provide real time information about the status of the wheels (e.g. the presence of wheel flats) and prognostic health status information within a certain time frame such as predicted wear, RCF and

polygonization, and maintenance recommendations for meeting ISO 1005-8 [3] and TOC specific requirements.

- *iPantMon*, which is intended for TOCs and integrated operators, will provide real time information about the status of the pantograph (e.g. if there is incorrect vertical damping forces of upper arm) and prognostic health status information in a certain time frame such as wearing of contact stripes, and maintenance recommendations for meeting EN 50405 [4] and TOC specific requirements.

- *iRailMon*, which is intended for IMs and maintenance subcontractors, will provide real time information about the status of the rail (e.g. broken rail) and prognostic health status information in a certain time frame such as squats, corrugation, wear and RCF, and maintenance recommendations according to ISO 5003:2016 [5] and IM specific maintenance requirements.

- *iCatMon*, which is intended for IMs and maintenance subcontractors, will provide real time information about the catenary status (e.g. wearing of cable) and prognostic health status information in a certain time frame such as inclination of the mooring balance with respect to the rail, break of the automatic regulation pulley, wear of cables, and maintenance recommendations for meeting EN50119 [6].

These services will be delivered by the different sub-systems of the SIA system according to the next table.

SIA Subsystems	SIA Services			
	<i>iWheelMon</i>	<i>iPantMon</i>	<i>iRailMon</i>	<i>iCatMon</i>
SIA_PANT		√		√
SIA_ABA	√		√	
SIA_DH	√	√	√	√
SIA_POS			√	√
SIA_VP	√	√	√	√
SIA_CDM	√	√	√	√

Table 2-1. SIA services mapped to sub-systems

3 SIA_POS Test results

The SIA Positioning System (SIA_POS) has been initially validated in the lab environment, with some initial results shown reported in deliverable D3.2 [8]. This chapter contains the validation results of SIA_POS with the results obtained in the relevant validation scenarios, as described in deliverable D8.1. For validation, the SIA Positioning System has been tested in three different rail environments with our consortium rail operators, VIAS, OBB and FGC.

As described in [8], to identify the evolution of failures in the infrastructure, accurate positioning and time stamping that synchronizes measurements from sensing nodes within the vehicle is essential. To fulfil this requirement, the main functionality of SIA_POS is to provide high accuracy positioning in the railway environment. This document also defines the performance requirements for the SIA_POS subsystem as documented in D2.1 [1]. Therefore, for the above mentioned validation scenarios real time SIA_POS data has been validated against the performance requirements described in Table 3-1. In addition to this, it also covers the benefits of Galileo being collected and utilised in the SIA_POS results.

Req_ID	Description	Source
POS_PF_001	SIA must guarantee its functionality with a train velocity up to 100 km/h.	SIA_PF_001
POS_PF_006	The accuracy requirements of the positioning subsystem shall comply with sub-20m horizontal positioning for the localization of failures on infrastructures assets.	SIA_PF_006
Internal	Availability: The POS sub-system shall be capable of providing a position 100% of the time in the railway environment for monitoring purposes.	Internal

Table 3-1. SIA_POS Performance Requirements

3.1 Key Performance Indicators

The rail test campaign results are analysed in terms of the following Key Performance Indicators (KPIs):

- Horizontal (2D) positioning accuracy in meters
- Horizontal (2D) positioning accuracy with reference to speed
- Availability of position solution (as a percentage of total test duration)

3.2 SIA_POS Test Results (OBB Validation Scenario)

The SIA-POS system was tested in the following scenarios whilst it was installed in the OBB locomotive:

- Static tests in the workshop
- Functional check under electrification
- Tests in the workshop
- Tests in the track

3.2.1 Static tests in the workshop

In this activity, a few basic tests were carried out whilst the locomotive was in a static position. These tests were carried out mainly to verify that the installation of the system has been correctly completed and according to the description in Deliverable D8.1. The test results applicable to SIA_POS (extracted from those described in D8.1) are summarized in Table 3-2.

Test ID	Test Description	Passed? (Y/N)	Comments
OBB_W_001	Visual inspection of the system: <ul style="list-style-type: none"> • Antenna is correctly fixed on the top of the test train. • Wires enter the equipment cabinet without tension • Connections of the system are ok 	Y	Visual inspection is validated by OBB personnel: <ul style="list-style-type: none"> • Antennas are correctly fixed to the magnetic plate on the roof of test locomotive • Wires from roof to equipment cabinet are properly placed without harmful tensions • All connections of the system are good (electrical continuity is provided) and reliable
OBB_W_002	SIA-POS unit placed on the train in a suitable secure manner	Y	SIA equipment is firmly fixed on a platform and placed in train cabinet.
OBB_W_003	On the SIA-POS unit is an arrow that indicates the direction of travel. Check that arrow must be pointing towards the direction the train will move in so the IMU is orientated correctly.	Y	Checked

Test ID	Test Description	Passed? (Y/N)	Comments
OBB_W_004	Connect the SIA_POS via antenna cable	Y	Checked
OBB_W_005	Power supply cable connect properly into supply connector of SIA_POS	Y	The positive cable MUST be aligned with + (LEFT) and the negative cable MUST be aligned with the – (RIGHT) symbol.
OBB_W_006	Check that the input power supply should be between 9 and 36 Volts.	Y	Required power is supplying to the SIA_POS
OBB_W_007	Check Ethernet cable of SIA_POS is connected for internet connection.	Y	Ethernet connection was proper and provides SIA_POS with internet access.
OBB_W_008	measure the 3-D offset (lever arm) from the centre of the IMU sensor to the GNSS antenna	Y	Lever arm offset has been measured by OBB

Table 3-2. SIA POS OBB Static Tests in Workshop Results

3.2.2 Functionality checks under electrification

These tests have been completed to check the functionality of the SIA_POS system at deployment, when the train is electrified. The tests results applicable to SIA_POS (extracted from those described in D8.1) are summarized in Table 3-3 below:

Test ID	Test Description	Passed? (Y/N)	Comments
OBB_W_009	Power up the SIA_POS and check that the start-up process is successful (LEDs change to Green).	Y	All LEDs changed into green
OBB_W_010	Use real time software to log GNSS, IMU, IONEX and RTCM data	Y	Checked via connecting SIA_POS unit via team-viewer
OBB_W_011	Use Novatel Application Suite (NAS) software to log data from SPAN	Y	Manually start NAS software via team-viewer.

Table 3-3. SIA POS OBB Functionality check under Electrification Test Results

3.2.3 Test In the workshop

Once the equipment's performance under electrification has been verified, a few basic cross-checking activities were carried out in the workshop before starting the tests in the track as follows.

Test ID	Test Description	Passed? (Y/N)	Comments
OBB_W_012	Configuration parameters can be received by: <ul style="list-style-type: none"> SIA_POS 	Y	
OBB_W_013	Following information related to EGNSS can be received and processed by SIA: <ul style="list-style-type: none"> GNSS signals Inertial signals 	Y	Checked via connecting SIA_POS unit via team-viewer
OBB_W_014	Following information related to EGNSS can be received by SPAN: <ul style="list-style-type: none"> GNSS signals Inertial signals 	Y	Checked via connecting SIA_POS unit via team-viewer

Table 3-4. SIA POS OBB Tests in the Workshop Test Results

3.2.4 Tests on the track

Once the equipment's performance has been verified whilst in the workshop, the tests in the track were performed as follows.

Test ID	Test Description	Passed? (Y/N)	Comments
OBB_T_001	Configuration parameters can be received by: <ul style="list-style-type: none"> SIA_POS 	Y	
OBB_T_002	Following information related to EGNSS can be received and processed by SIA: <ul style="list-style-type: none"> GNSS signals Inertial signals 	Y	Checked via connecting SIA_POS unit via team-viewer
OBB_T_003	Configured parameters can be logged by	Y	Connected SIA_POS unit

Test ID	Test Description	Passed? (Y/N)	Comments
	SPAN.		via team-viewer. Checked in D drive, all selected parameters start logging and saved in designated directory (D) of SIA_POS Unit.

Table 3-5. SIA POS OBB Tests on the Track Results

3.2.5 Validation test results

3.2.5.1 Reference trajectory

As described in D8.1, the first SIA_POS unit (an interim version) was used for the OBB real time test. This unit was equipped with a GNSS Inertial Measurement System (Novatel SPAN). The reference trajectory for the OBB campaign was therefore generated from the Septentrio GNSS receiver and IMU with comparison to the SPAN Inertial Unit (Novatel PwrPak 7D E2). During the real time data collection the SPAN was continuously logging the best positioning solution (BESTPOS configuration), this config provides the best available combined GNSS and Inertial Navigation System position computed by the receiver. Figure 3-1 represents the reference trajectory obtained by SPAN vs GNSS+IMU Unit.

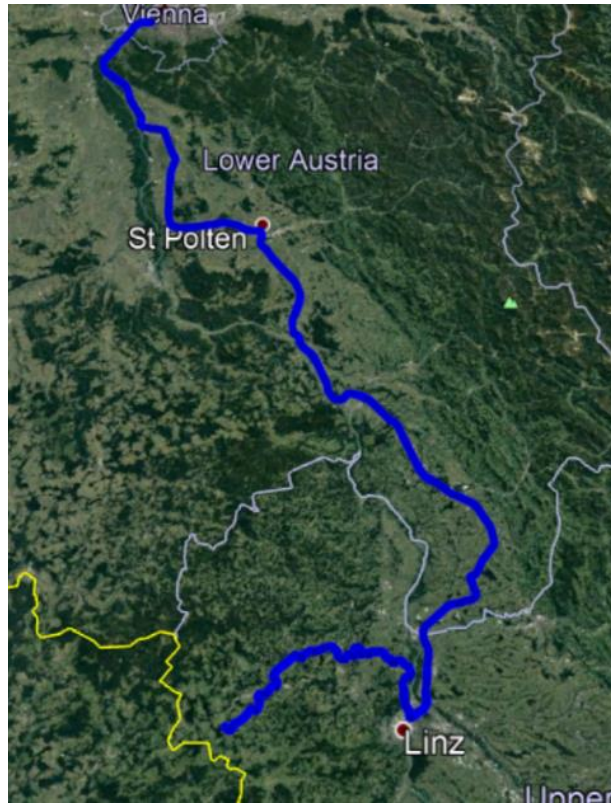


Figure 3-1. Reference trajectory obtained by SPAN + IMU Unit

3.2.5.2 Positioning performance analysis results

From the real time online data, the positioning results from each epoch are compared against a reference position to compute the horizontal errors and generate statistics in post process. The data analysis and statistics are based on the whole data set, which includes durations when the train is dynamic as well static in rail stations.

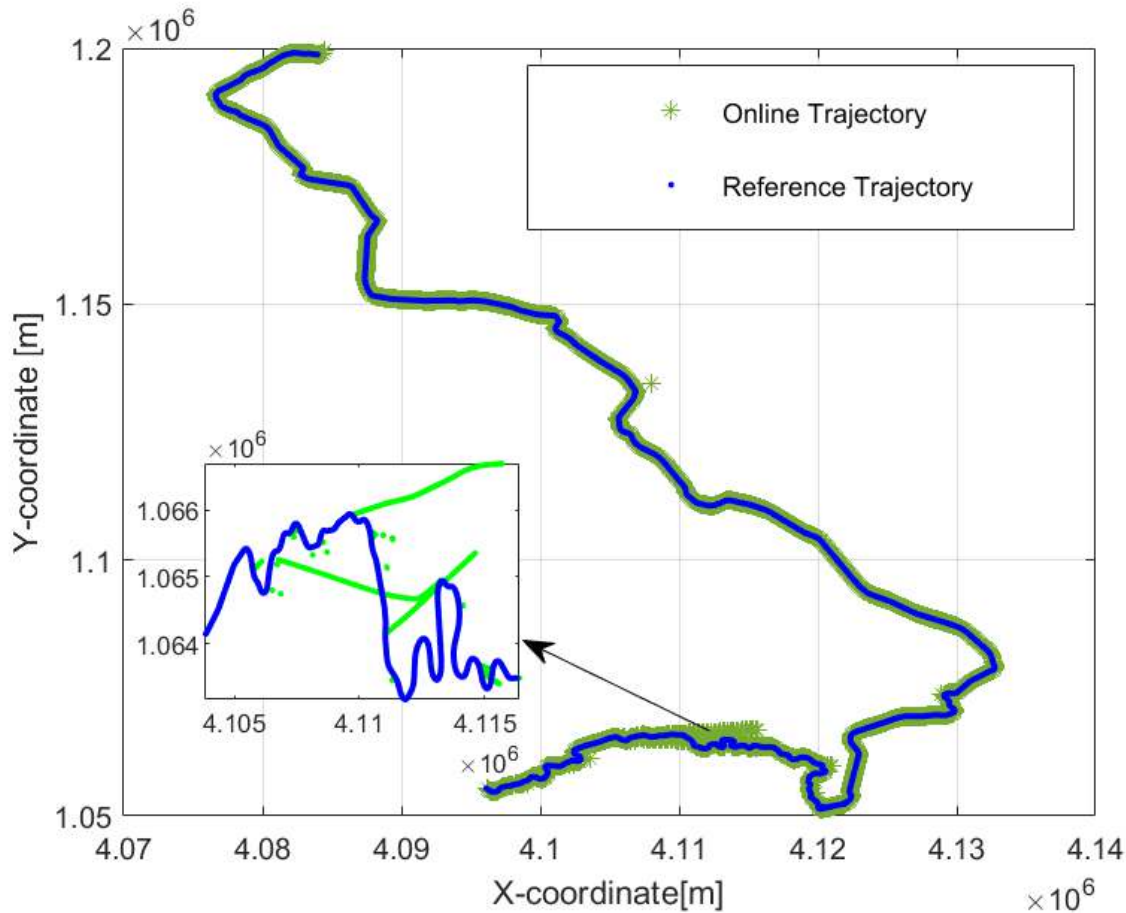


Figure 3-2. Real time and Reference Trajectory

Figure 3-2 shows the scatter plot of XY coordinates from the real time solution (in green) along with reference trajectory (in blue) from the testing with OBB. The scatter plot shows that the real time solution shows close correlation with reference trajectory. However, there is an area where some divergence in the real time solution was observed with respect to the reference trajectory. Figure 3-2 highlights a section (zoomed in) where the real time solution shows divergence from the reference trajectory. In order to find out the reason behind this divergence during the online data collection, horizontal position error with regards to the XY coordinates obtained from the real time solution has been plotted in Figure 3-3. This is only for the selected period when the divergence was observed. Figure 3-3 shows that the horizontal position error reached up-to 1000km during the online analysis. Figure 3-4 shows the number of locked satellites for the same duration. This shows that during the real-time solution when the position error was high the number of locked satellites was 0 and afterward less than 5. This clearly shows that the position accuracy was decreased in the real time solution due to unavailability/a lower number of GNSS signals.

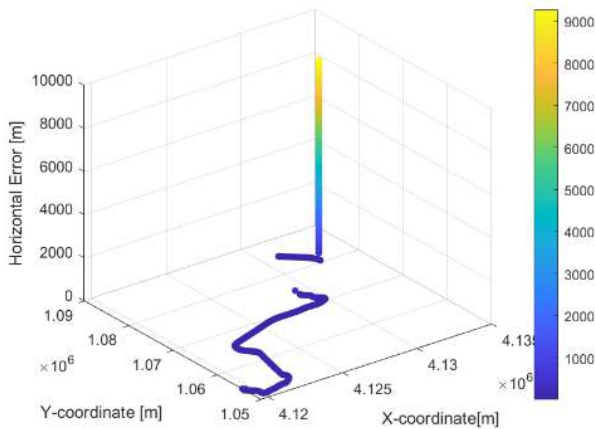


Figure 3-3. Horizontal error wrt XY coordinate of Selected trajectory

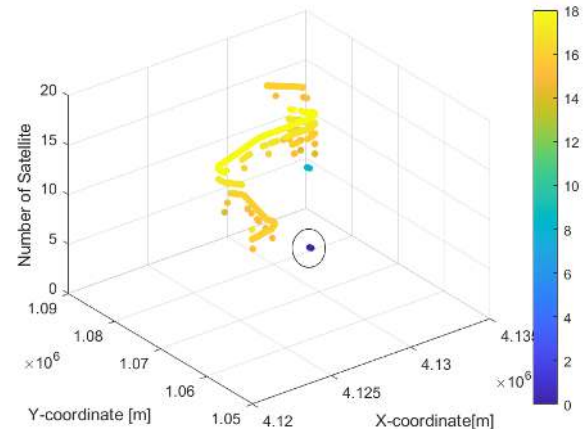


Figure 3-4. Number of locked satellite wrt XY coordinate for selected trajectory

Percentage	50%	68%	95%
Horizontal Position Error [m]	0.66	0.90	2.05
Mean Number of Satellites	15		
Solution Availability	100%		

Table 3-6. Statistical analysis of horizontal error obtained from GNSS in real time during the OBB test campaign

Overall the results for the day of testing that was completed on the 21st of June 2021 with OBB are tabulated in Table 3-6. This table shows the statistical analysis of horizontal error obtained for the GNSS real time solution for the OBB campaign. The results show the 50%, 68% and 95% of horizontal error, for the overall data set. During the online analysis 95% of the time the accuracy of 2.05m was observed, while 68% of the time an accuracy of 90cm was obtained. Furthermore, 50% of the time the real time solution gives an accuracy of 66cm. The analysed results show that an average number of 15 satellites were used whilst 100% of the solution was available during the test period.

3.2.5.3 The benefits of E-GNSS

To see the impact of E-GNSS on the positioning solution, the logged real time data has been re-processed and analysed using GPS only observations. Using the same reference trajectory, the horizontal error was computed for a GPS only solution and tabulated in Table 3-7, the analysed results show that with GPS alone 95% of the time, an accuracy of 2.75m was observed, whilst 1.0m and 77cm of accuracy was obtained during 68% and 50% of the time period respectively.

However while comparing GPS only results with GPS+Galileo positioning performance, it was clearly seen that the GPS+Galileo solution shows an improvement of 25% in 95% of position accuracy.

Probability	50%	68%	95%
Horizontal Position Error [m]	0.77	1.00	2.74
Percentage of improvement in GPS+Galileo solution in comparison to GPS only	14.28%	9.99%	25.18%
Mean Number of Satellites	9		
Solution Availability	100%		

Table 3-7. Statistical analysis of horizontal error obtained from a GPS only post processed data solution from the OBB test campaign

3.2.5.4 Position performance with high train velocity

One of the main requirements of the SIA-POS subsystem is to guarantee its functionality with a train velocity of up to 100 km/h.

For this purpose, the temporal variation of horizontal error is plotted where the color represents the corresponding velocity as display in Figure 3-5. Similarly, Figure 3-6 shows the temporal variation of horizontal error where the color represents the locked number of satellites. Figure 3-5 shows that when the velocity is increased and reaches more than 100km/hour (27.7m/s) most of the time the horizontal error was less than 5m. In a few instances, the results show that the horizontal error was increased due to a lower number of locked satellites or a loss of GNSS signal as shown in Figure 3-6.

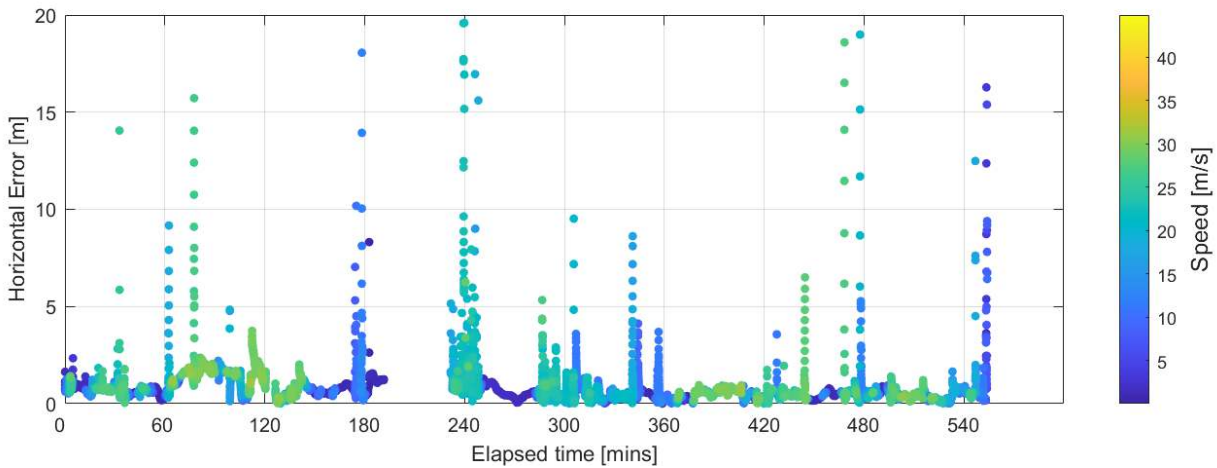


Figure 3-5. Temporal variation of horizontal error with corresponding velocity shown in colour

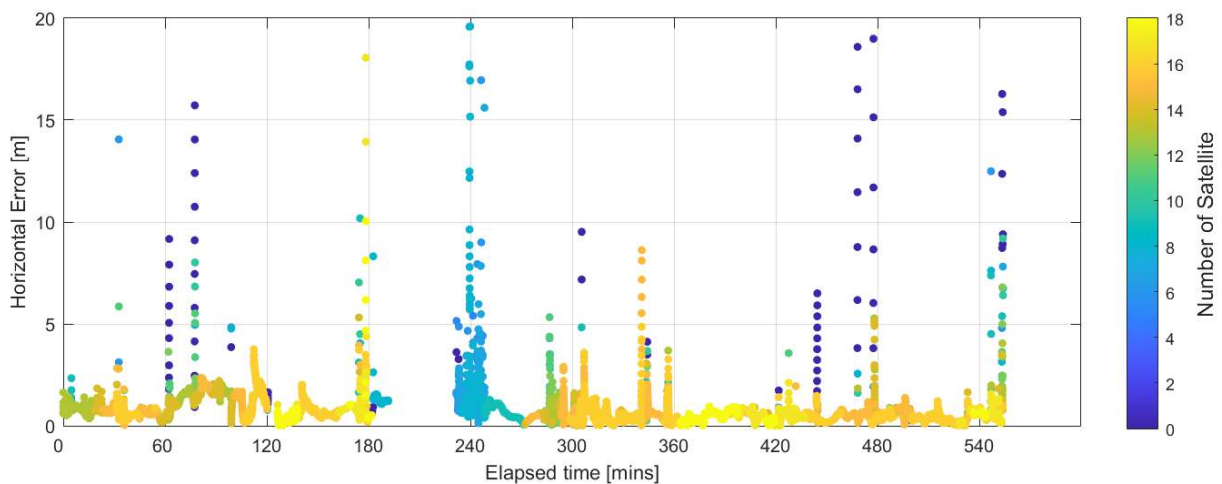


Figure 3-6. Temporal variation of horizontal error with corresponding number of locked satellite show via colour.

A statistical analysis of horizontal error was measured for the epochs where velocity was greater than 20m/s, this is displayed in Table 3-8. The results show that when the train was dynamic and the train speed was greater than 20m/s, the probability of getting a position accuracy of 2.12m is 95% probable, whilst 50% and 68% of the time SIA_POS gives an accuracy of 91cm and 1.5m respectively.

Probability	50%	68%	95%
Horizontal Position Error [m]	0.91	1.5	2.12

Table 3-8. Statistical analysis of horizontal error obtained from GNSS real time OBB test campaign data where the velocity >20m/s

Overall the validation test results for the SIA POS subsystem show that the system meets the performance requirements described in Table 3-9:

Req_ID	Description	Passed? Y/N	Comments
POS_PF_001	SIA must guarantee its functionality with a train velocity up to 100 km/h.	Y	
POS_PF_006	The accuracy requirements of the positioning subsystem shall comply with sub-20m horizontal positioning for the localization of failures on infrastructures assets.	Y	
Internal	Availability: The POS sub-system shall be capable of providing position 100% of the time in the railway environment.	Y	

Table 3-9. Validation test results against the performance requirements for SIA POS during the OBB test campaign

3.3 SIA_POS Test Results (VIAS Validation Scenario)

3.3.1 Testing activities

The following tests were carried out with VIAS to validate the integration of SIA components.

Test ID	Test Description	Passed? (Y/N)	Comments
VIAS_T_001	Configuration parameters can be received by: <ul style="list-style-type: none"> SIA_POS 	Y	
VIAS_T_003	Following information related to E-GNSS can be received and processed by SIA:	Y	Checked D drive of SIA POS, all required data

Test ID	Test Description	Passed? (Y/N)	Comments
	<ul style="list-style-type: none"> GNSS signals Inertial signals 		are received and analysed by SIA_POS software.

Table 3-10. SIA POS VIAS Tests Results

3.3.2 Validation test results

This test scenario was carried out from the 24th of March 2020 when all the devices were installed until the 9th of April 2020. The objective of this testing campaign was:

- To validate, in an operational scenario, the integration of the different subsystems (except SIA_ABA) at a functional level
- To collect EGNSS data to validate the algorithms of SIA_POS

During the test campaign the SIA_POS unit was successfully logging the GNSS and IMU data and also generating a positioning solution with the SIA_POS algorithm software. During the testing period it was noticed due to some service issues that the real time correction data was not available and therefore the position computation was without the SSR corrections. This issue was resolved on the 6th of April 2020 and afterwards the positioning solution was correctly generated applying SSR corrections for a PPP solution.

3.3.2.1 Reference trajectory

In order to validate the real time GNSS position performance, a reference trajectory is required. For the FGC test scenario the reference trajectory was obtained from post-processing the Septentrio GNSS data + IMU data using Novatel's Inertial Explorer software. For more precise positioning, precise products (satellite orbits, clocks, ionosphere models) from IGS (The International GNSS service) were used. The reference trajectory computed for the 6th to the 9th of April using the data by the Septentrio receiver + UM7 IMU can be seen in Figure 3-7.



Figure 3-7. Reference trajectory produced by IE Software

3.3.2.2 Position performance analysis results

From the real time solution, the positioning results from each epoch are compared against a reference position to compute the horizontal errors and generate statistics in a post processed way. The data analysis and statistics are based on the whole data set, which includes the duration when the train was dynamic as well as whilst it was static in stations.

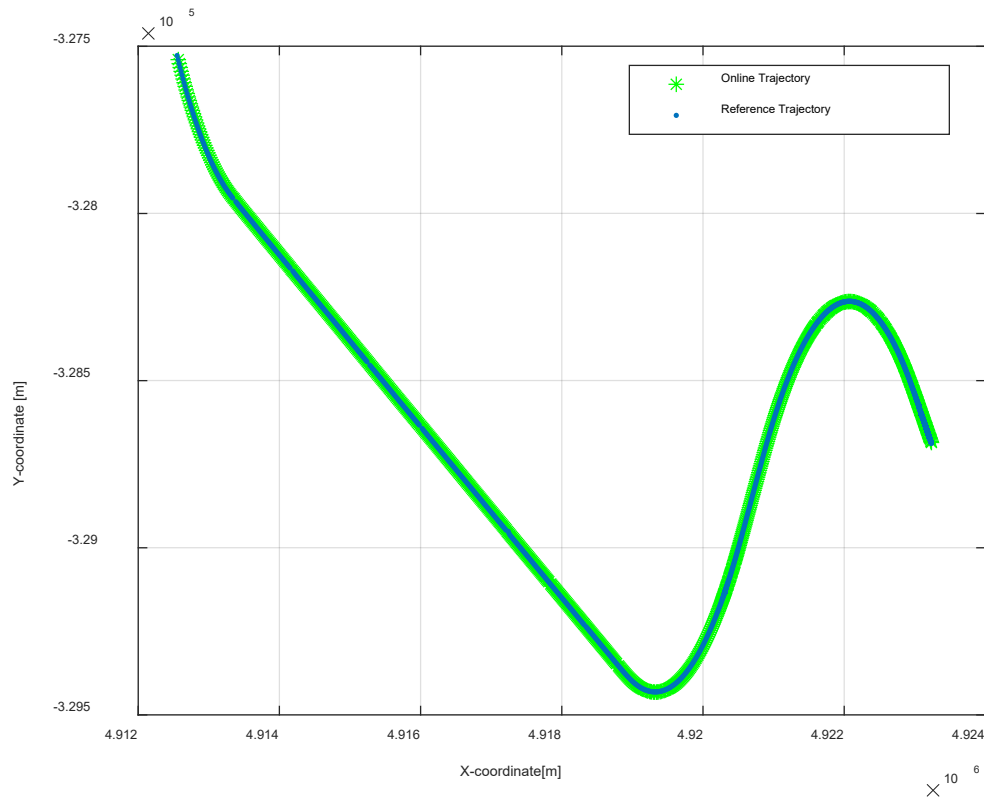


Figure 3-8. Real time vs. Reference Trajectory

Figure 3-8 shows the scatter plot of the XY coordinates from the real time solution (in green) along with the reference trajectory (in blue). The scatter plot shows that the real time solution shows close correlation with the reference trajectory. To quantify the difference between the real time solution and the reference trajectory, a horizontal error has been computed for all available data and its mean, this is tabulated in Table 3-11.

Probability	50%	68%	95%
Horizontal Position Error [m]	0.46	0.58	17.9
Mean Number of Satellite	15		
Solution Availability	100%		

Table 3-11. Statistical analysis of horizontal error obtained from GNSS real time solution during VIAS test campaign data

The results show the 50%, 68% and 95% of horizontal error for the overall data set. For the online solution 95% of the time an accuracy of 18m was observed, while 68% of the time an accuracy of 46cm was observed and finally, 50% of the time an accuracy of 58cm was observed. The analysed results show that an average number of 15 satellites were used whilst 100% of the solution was available during the test period.

3.3.2.3 The benefits of E-GNSS

To see the impact of E-GNSS on the position solution, the real time solution has been re-processed and analysed using GPS only observations. Using the same reference trajectory, the horizontal error was computed for a GPS only solution, this has been tabulated in Table 3-12. The analysed results show that with a GPS only solution, 95% of the time an accuracy of 19m was observed, while accuracies of 61cm and 42cm were obtained 68% and 50% of the time respectively.

While comparing GPS only results with GPS+Galileo positioning performance, it was clearly seen that the GPS+Galileo solution provides a 6% improvement in 95% of position data accuracy.

Probability	50%	68%	95%
Horizontal Position Error [m]	0.42	0.61	19
Percentage of improvement in GPS+Galileo solution in comparison to GPS only	-9.5%	4.9%	6.14%
Mean Number of Satellites	11		
Solution Availability	100%		

Table 3-12. Statistical analysis of horizontal error obtained from GPS only post processed data from the VIAS test campaign

3.4 SIA_POS Test Results (FGC Validation Scenario)

The testing of SIA_POS with FGC comprised of the following activities:

- Static tests in the workshop
- Functional checks under electrification
- Tests in the workshop

- Tests on the track

3.4.1 Static tests in the workshop

In this activity, a few basic tests were carried out whilst the train was static. These tests were completed to verify that the installation of the system was correct and according to the description in deliverable D3.1. The test results applicable to SIA_POS (extracted from those described in D8.1) are summarized in Table 3-13.

Test ID	Test Description	Passed? (Y/N)	Comments
FGC_W_004	Connect the SIA_POS via antenna cable	Y	SIA_POS was properly connected via antenna cable.
FGC_W_005	Power supply cable connect properly into supply connector of SIA_POS	Y	The positive cable was aligned with + (LEFT) and the negative cable was aligned with the – (RIGHT) symbol.
FGC_W_006	Check that the input power supply should be between 9 and 36 Volts.	Y	Required Power was supplied to SIA_POS Unit
FGC_W_007	Check Ethernet cable of SIA_POS is connected for internet connection.	Y	
FGC_W_008	measure the 3-D offset (lever arm) from the centre of the IMU sensor to the GNSS antenna	Y	
FGC_W_009	Power up the SIA_POS and check that the start-up process is successful (LEDs change to Green).	Y	After power up all LED was working accordingly.
FGC_W_010	Use real time software to log GNSS, IMU, IONEX and RTCM data	Y	Once SIA_POS was power-up, all required data was logged in designated directory. Was confirmed by checking the designated directory.

Table 3-13. SIA_POS static tests in the workshop (FGC)

3.4.2 Functionality checks under electrification

These tests were completed to check the functionality of SIA_POS when the unit is installed and connected to antenna and the train is electrified. The test results applicable to SIA_POS (extracted from those described in D8.1) are summarized in Table 3-14.

Test ID	Test Description	Passed? (Y/N)	Comments
FGC_W_014	Power up the SIA_POS and check that the start-up process is successful (LEDs change to Green).	Y	All LEDs changed to Green
FGC_W_015	Use real time software to log GNSS, IMU, IONEX and RTCM data	Y	SIA_POS unit was connected to Team viewer and checked that all the required data are logged.

Table 3-14. SIA_POS functionality checks under electrification in the workshop (FGC)

3.4.3 Tests in the workshop

Once the equipment's performance under electrification was verified, a few basic cross-checking activities were carried out in the workshop before starting the tests on the track as shown in Table 3-15.

Test ID	Test Description	Passed? (Y/N)	Comments
FGC_W_016	Configuration parameters can be received by: <ul style="list-style-type: none"> SIA_POS 	Y	SIA_POs receives configuration parameters
FGC_W_018	Following information related to EGNSS can be received and processed by SIA: <ul style="list-style-type: none"> GNSS signals Inertial signals 	Y	SIA_POS received all required GNSS and inertial signals. Signals are processed by SIA_POS software to generate position solution

Table 3-15. Verification activities in the workshop (FGC)

3.4.4 Tests on the track

Following the static tests in the workshop, the SIA_POS system was tested whilst the train was in motion in the following scenarios:

- A few runs at nominal speed (up to 90km/h) in the validation scenario (as described in D8.1) for one night
- With the train in commercial service in the whole FGC network for 6 days.

Test ID	Test Description	Passed? (Y/N)	Comments
FGC_T_001	Configuration parameters can be received by: <ul style="list-style-type: none"> SIA_POS 	Y	SIA_POs receives configuration parameters
FGC_T_003	Following information related to EGNSS can be received and processed by SIA: <ul style="list-style-type: none"> GNSS signals Inertial signals 	Y	SIA_POS received all required GNSS and inertial signal Signals and processed by SIA_POS software to generate position solution

Table 3-16. Verification activities on the track (FGC)

3.4.5 Validation test results

3.4.5.1 Reference trajectory

In order to validate the real time GNSS positioning performance, a reference trajectory is required. For the FGC test scenario the reference trajectory was obtained from post-processed Septentrio GNSS data + IMU data using Novatel's Inertial Explorer software. For precise positioning precise products (satellite orbits, clocks, ionosphere models) from IGS (The International GNSS Service) were used. A reference trajectory was computed for the 13th of July 2021 using the data provided by the Septentrio receiver and the UM7 IMU which can be seen in Figure 3-9. This was used for the duration test of the campaign for all 6 days.

3.4.5.2 Position performance analysis results

In D3.2 [8], it is mentioned that the real time test for the developed SIA system was performed in one of FGC's main lines, the Barcelona to Vallès (BV) railway line. The BV line has metro services inside Barcelona city and has commuter services between Barcelona and surrounding areas. It has 53 km of double track with international gauge. Most of the track area of the BV line is underground as it is inside Barcelona city. Because of the underground route, the possibility of the loss of GNSS signals is extremely high. Therefore it is interesting to show results in such a harsh GNSS environment.

The real time solution is shown in Figure 3-9, the trajectory looks smooth but a few epoch show a big divergence from the original train track. Figure 3-10 shows a closer zoomed in look of the trajectory as the train enters the underground track.

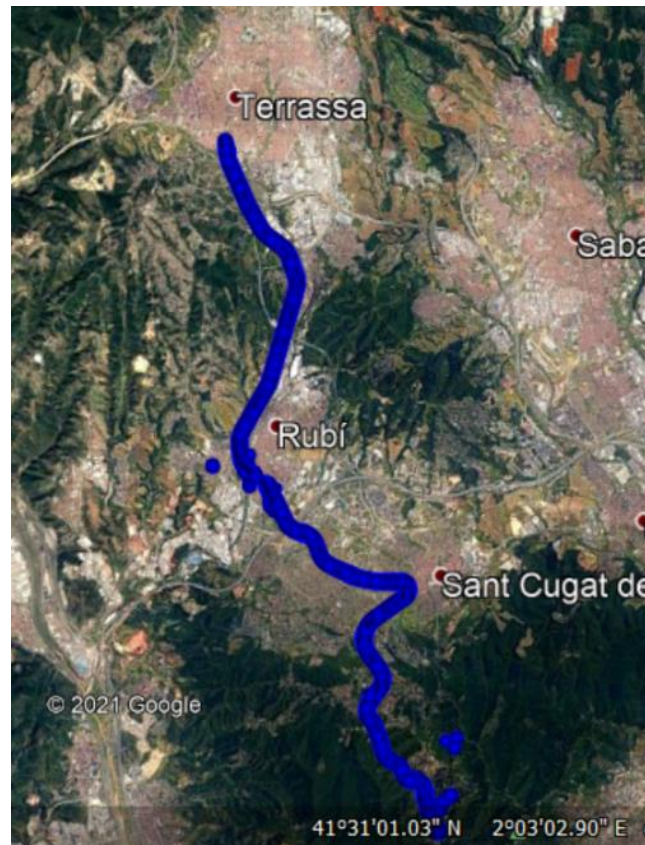


Figure 3-9. Real time solution for the 13th of July 2021 during the FGC test campaign

Train enters the underground track



Figure 3-10 Real time solution when the train enters the underground track

The above figure shows that when train enters the underground track afterwards a big divergence is present. This clearly indicates that the position performance is degraded. Figure 3-11 also highlights the area where the train comes out from the underground track. The results show that just after coming out of the underground, the trajectory is again suitable.

Train comes out from the underground track



Figure 3-11. Real time solution when train comes out from the underground track

In order to see the effect of this on the GNSS signal and the positioning performance, data was selected whilst the train was underground and just before and after it. Figure 3-12 shows the number of locked satellites with regards to the XY coordinates. Figure 3-12 shows that before the train enters the underground track the number of locked satellites is between 10 and 15, but in the area where the train is underground, the SIA_POS unit lost GNSS and the number of locked satellites was 0. It also shows that once the train comes out from the underground, the GNSS signal was restored and again the locked number of satellites reached up to 15.

In order to see the effect of the underground route on position performance, the horizontal error with reference to the XY coordinates for the selected area is illustrated in Figure 3-13. Figure 3-13 shows that for the duration that the train was underground the position error was very high and reached more than 40 m. Also, once the train comes out from the underground route, the horizontal error shows improvement.

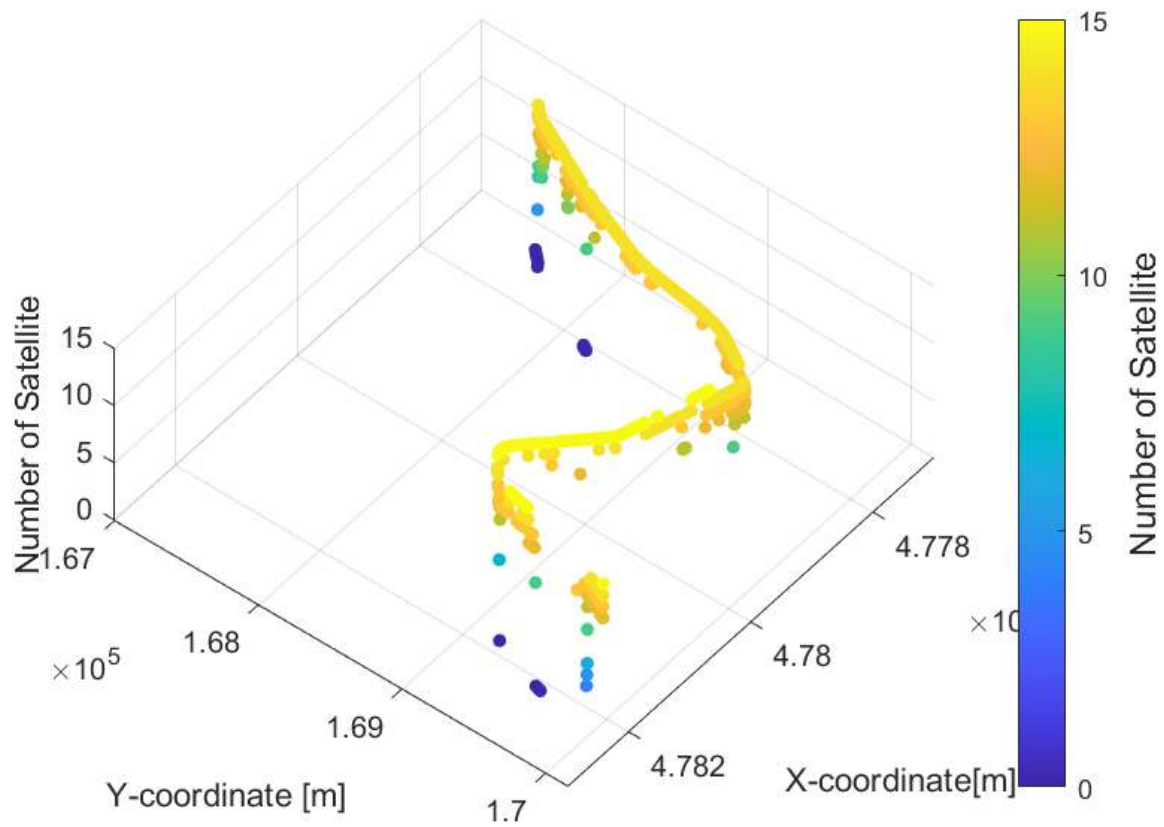


Figure 3-12. Number of locked satellites wrt XY coordinates for the selected trajectory, the colour scale shows the number of locked satellites

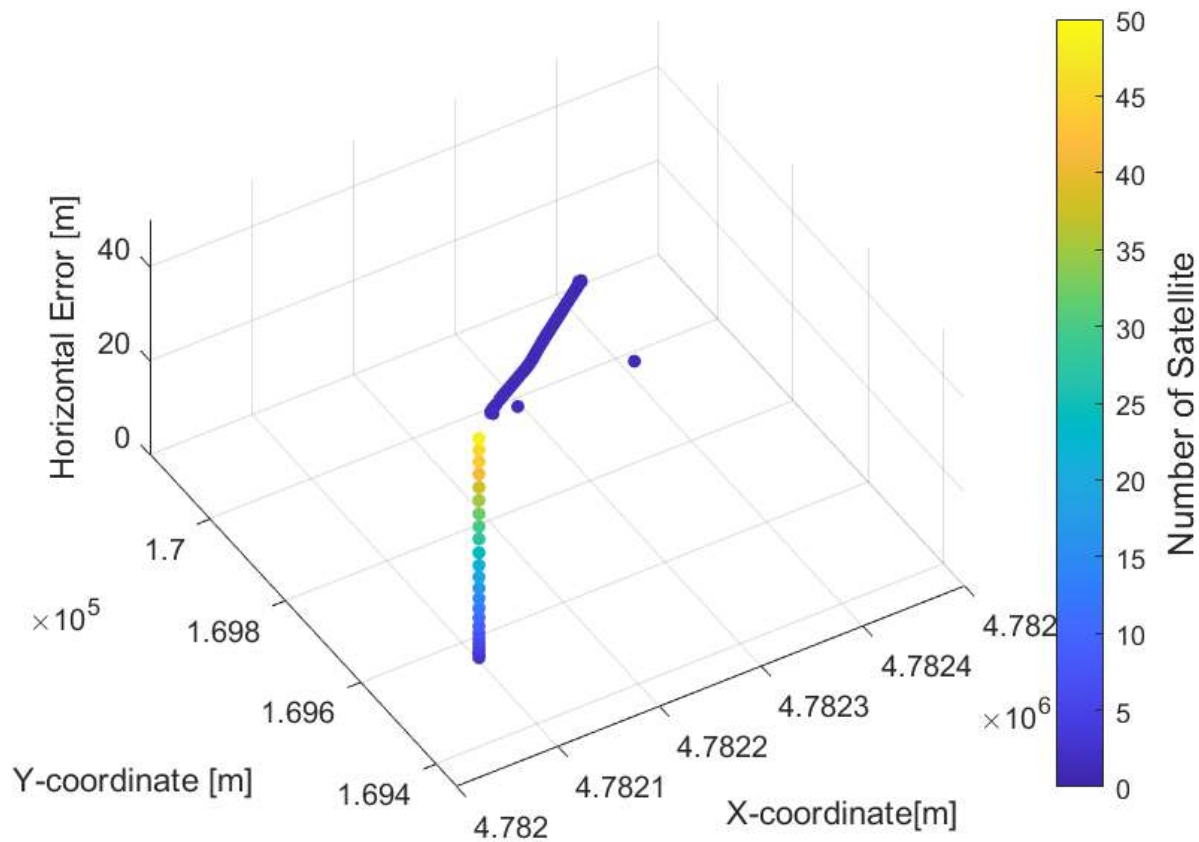


Figure 3-13. Horizontal error wrt XY coordinate for the selected trajectory, the colour scale shows the magnitude of horizontal error

Due to the analysis above, the validation of SIA POS in the FGC test scenario was very challenging. Because the route was mostly underground, all real time logged data was divided into two categories:

- Open sky track (GNSS available) and minimum number of 6 satellites are available
- Underground track (GNSS signal may lost or less)

The position performance has been measured for the open sky environment as in the underground most of the time the position performance was very poor.

For the performance analysis, the position results from each epoch are compared against a reference position to compute the horizontal errors and generate statistics. Each day of data has been analysed to compute the horizontal error. As mentioned above, the data was divided into two categories, the divide was done on the basis of reference trajectory map. The time where reference trajectory track shows that the train is underground the time was noted and then the data is separated to analyse performance without an open sky.

The position performance statistics have been computed for the whole data set whilst the train was in an open-sky environment. These statistics have been tabulated in Table 3-17.

Probability	50%	68%	95%
Horizontal Position Error [m]	1.9	3.10	4.36
Mean Number of Satellites	12		
Solution Availability	100%		

Table 3-17 Statistical analysis of horizontal error obtained from the GNSS real time solution for the FGC test campaign data

The results show the 50%, 68% and 95% of horizontal error for the overall data set. In the FGC open sky scenario, an accuracy of 4.36 m was observed 95% of the time. Whilst 68% of the time an accuracy of 3.1m was observed and 50% of the time the online solution gave us an accuracy of 1.9m. This is however the average accuracy based on when the train was dynamic as well as static.

However, if we talk about the overall accuracy, for the FGC scenario it was very poor and it was hard to maintain the accuracy of 20m for the whole duration of the test. Because the track was mostly underground, the accuracy was degraded very quickly.

3.4.5.3 The benefits of E-GNSS

To see the impact of E-GNSS on the position solution, the logged real time data has been re-processed and analysed using GPS only observations. Using the same reference trajectory, the horizontal error was computed for a GPS only solution (only for an open sky environment and a minimum number of 6 satellites), this analysis is tabulated in Table 3-18. The analysed results show that with GPS alone 95% of the time an accuracy of 4.79m was observed, while accuracies of 3.80m and 1.93 m were obtained 68% and 50% of the time respectively.

While comparing GPS only horizontal accuracy with GPS+Galileo position performance, it was clearly seen that the GPS+Galileo solution shows a 9% improvement in 95% of the position accuracy.

Probability	50%	68%	95%
Horizontal Position Error [m]	1.93	3.80	4.79

Percentage of improvement in GPS+Galileo in comparison to GPS only	1.5%	18.1%	9.0%
Mean Number of Satellites	8		
Solution Availability	100%		

Table 3-18 Statistical analysis of horizontal error obtained from GPS only post processed data from the FGC test campaign

3.4.5.4 Position performance with high train velocity

During the FGC real time tests, when the velocity of the train was on or around 100km/h, the SIA_POS system was able to provide positioning solution. However, the system wasn't able to maintain the position accuracy of 20m for the whole duration due to the underground route. Overall validation test results against the performance requirement described in Table 3-19:

Req_ID	Description	Passed? Y/N	Comments
POS_PF_001	SIA must guarantee its functionality with a train velocity up to 100 km/h.	N	The real time solution was maintained when speed was up-to 100 Km/h, however the system wasn't able to maintain the position accuracy of 20m.
POS_PF_003	Availability: The POS sub-system shall be capable of providing position 100% of the time in the railway environment.	Y	
POS_PF_005	The accuracy requirements of the positioning subsystem shall comply with sub-20m horizontal positioning for the localization of failures on infrastructures assets.	Partially	Fulfilled only in open sky environment.

Table 3-19. Validation test results against the performance requirement for FGC test campaign

4 SIA_ABA Test results

This section summarizes tests performed for the SIA_ABA subsystem and relevant insights. Whereas details of the specific design can be found in Deliverable 4.1 [10], the presentation here is more condensed.

SIA_ABA comprises the hardware and software to collect and process axle-box acceleration (ABA) data that contains information about the vehicle wheels and the railway track surfaces. This information is extracted using different analysis algorithms.

The SIA_ABA module comprises different hardware components. Most important are the ABA sensors, that is, analog accelerometers that measure three-dimensional accelerations at the axle-box. Two ABA sensors have been employed in the pilot operation on an OBB in-service vehicle since November 2020. A single ABA sensor was employed in an initial campaign on an OBB measurement vehicle in June 2019. The SIA_ABA architecture is flexible so that further ABA sensors can be added.

The ABA sensors need to be mounted on the wheelsets, which is a challenging environment in terms of vibrations, shocks, dirt, water, etc. Hence, robust custom mounting options have been designed and manufactured. Cables and connectors have been chosen to provide the required protection. Details on this, including requirements derived from the overall SIA requirements in Deliverable 2.1 [1], can be found in Deliverable 4.1 [10].

The ABA sensors provide an analog output signal that is sampled by an analog-to-digital converter (ADC) at kHz rates. A module to configure the sampling rates, message sizes, ADC channels to read, etc. and to read the sensor data has been implemented in the software framework ROS. The ROS module outputs ROS messages that contain ABA data of a defined length at a defined rate, for example, 1024 samples for 6 ADC channels every second. Details on the actual configuration are not revealed here. Further ROS modules have been developed to provide online processing of the ABA data, for example, to monitor if ABA features exceed certain thresholds. Furthermore, a module to generate events from the ABA data and communicate those events to the software framework of the SIA data hub (Chapter 6) has been implemented.

4.1 Lab tests

Prototypic sensor units comprising ABA sensors, ADC, and processing hardware have been designed and implemented. Commercially available components suitable for the harsh railway environment have been chosen.

Hardware testing routines were performed in the lab to ensure the correct configuration of the sensor set-up in terms of rates and message sizes before mounting on any rail vehicle.

Software tests were performed on the developed ROS modules using the rosbag recording and replay functionalities of ROS. The software development of SIA_ABA was carried out

collaboratively among a group of researchers. Documentation, coding, and testing were carried out in a DLR gitlab repository.

4.2 First OBB tests

A first prototype of a SIA system including SIA_ABA functionality was field-tested on a two-week measurement campaign in June 2019.

The SIA system including a magnetically mounted GNSS antenna and one ABA sensor was installed on an OBB measurement train. Prior to installation DLR and OBB visited the vehicle and discussed the installation details. The beginning and end of the campaign were executed in the presence of DLR employees and the OBB vehicle staff to ensure correct operation. The system was configured to record autonomously beforehand, though, so that no interaction during the campaign was needed. The correct functionalities in terms of ABA and position data recording were monitored remotely by accessing the prototype through the mobile network.

The campaign could show successful testing of

- the autonomous operation of the system including the recording of ABA and GNSS data,
- the robustness of the system and sensor installation at the axle-box in actual use with vehicle speeds above 100 km/h,
- the feasibility of remote monitoring of SIA_ABA.

All campaign data were recorded as rosbag files and subsequently used for the continued analysis and development of SIA_ABA and the ABA data analysis algorithms.

4.3 OBB Pilot operation

Following the initial campaign, the installation of a SIA pilot system including the full SIA_ABA functionality (two ABA sensors, a rail-certified PC shared by SIA_ABA and SIA_DH, ROS modules for online analysis and event generation) on an OBB in-service train was prepared.

Due to the impact of the Corona pandemic and limited access to the OBB workshop the installation had to be delayed until October 2020, when access to an OBB vehicle could be granted. Prior to the installation a DLR visit to the OBB workshop was conducted in September 2020. The installation in a confined part, not accessible to the train passengers, was decided. Mounting options for the ABA sensors, cables, and the sensor unit inside the vehicle were discussed. As final adjustments the sensor unit in a railway-suitable enclosure was equipped with fire-proof ventilation grids.

The sensor units and components for on-site assembly were prepared and shipped by DLR. The actual installation was performed by OBB staff during scheduled maintenance of the OBB train in October 2020. Participation by DLR was not possible due to traveling restrictions. Therefore, detailed installation instructions were prepared by DLR.

The pilot operation could verify:

- the full functionality of SIA_ABA according to the specifications,
- the continuous recording of ABA and positioning data for later analysis by DLR,
- the robust operation of the system over the entire pilot operation from November 2020 until the end of the project in August 2021.

5 SIA_PANT Test results

SIA_PANT has been initially validated in the lab, with the results already reported in deliverable D4.1 [10]. This chapter contains the validation results of SIA_PANT with the results obtained in the relevant validation scenarios, as described in deliverable D8.1 [16]:

- SIA_PANT test results (VIAS validation scenario)
- SIA_PANT test results (FGC validation scenario)
- D4.1

5.1 SIA_PANT test results (VIAS validation scenario)

Table 6-1 compiles the results of the tests that are relevant for SIA_PANT in the validation scenario of VIAS (see deliverable D8.1 for details about the system installation and description of tests). It must be noticed that, in this case, the sensors are not installed in a pantograph (as the maintenance vehicle is not electric), but only accelerometers are installed in the bogie of the unit for functional checks only.

Test_ID	Test Description	Passed? (Y/N)	Comments
VIAS_T_001	Configuration parameters can be received by SIA_PANT	Y	SIA_PANT receives configuration parameters (via SIA_DH)
VIAS_T_002	Following information related to Ambient can be received and processed by SIA_PANT: <ul style="list-style-type: none"> • Wheel-Rail contact, i.e. physical magnitudes (e.g. accelerations) 	Y	Signals that represent the relevant ambient for SIA_PANT are properly acquired by SIA: <ul style="list-style-type: none"> • Acceleration signals are properly acquired by SIA_PANT
VIAS_T_005	IF_POS_PANT: Timing related information can be sent by SIA_POS and received by SIA_PANT	N/A	Timing related information is received by SIA_DH
VIAS_T_006	IF_PANT_DH: Sensor information can be transmitted by SIA_PANT and received by SIA_DH	Y	Acceleration signals are properly streamed by SIA_PANT and received by SIA_DH

Table 5-1. Tests in the track (VIAS scenario)

5.2 SIA_PANT test results (FGC validation scenario)

The testing of SIA_PANT in the scenario of FGC comprised the following activities:

- Static tests in the workshop
- Functional check under electrification
- Tests in the workshop
- Tests in the track

5.2.1 Static tests in the workshop

In this activity, a few basic tests were carried out in static condition. They were used mainly to verify that the installation of the system is correct and according to the description of deliverable D4.1. The tests results applicable to SIA_PANT (extracted from those described in D8.1) are summarized in Table 5-2.

Test_ID	Test Description	passed? (Y/N)	Comments
FGC_W_001	Visual inspection SIA_PANT subsystem after installation	Y	Visual inspection is validated by FGC personnel with the pantograph disassembled: <ul style="list-style-type: none"> • Base unit of SIA_PANT is properly fixed to the base frame of the pantograph • Sensors are firmly attached to their position • Wires are correctly routed from sensors to base unit
FGC_W_003	Free movement of the pantograph is not affected by the installation of SIA_PANT, including the cables <ul style="list-style-type: none"> • Option 1: pantograph disassembled • Option 2: pantograph already on the roof 	Y	Pantograph's movement is ok after the installation of SIA_PANT: <ul style="list-style-type: none"> • With pantograph disassembled • With the pantograph installed

Table 5-2. Static tests in the workshop (FGC scenario)

5.2.2 Functionality check under electrification

This activity aims at checking the functionality of SIA_PANT when the pantograph is deployed and the train is electrified. The tests results applicable to SIA_PANT (extracted from those described in D8.1) are summarized in Table 5-3.

Test_ID	Test Description	passed? (Y/N)	Comments
FGC_W_011	Visual inspection of the system (SIA_PANT) once the pantograph is contacting the catenary and the system is electrified. Performance looks normal.	Y	Pantograph is installed in the train and electrification is powered-on in the workshop. Then, the pantograph is deployed, and it contacts the OHL. By visual inspection, the performance of the system looks normal.
FGC_W_012	SIA_PANT is streaming data (connection via tablet)	Y	SIA_PANT is streaming data under electrification. Signals are correctly acquired and no significant noise is observed. Streaming is received by SIA_DH correctly.
FGC_W_013	SIA equipment is powered-up	Y	SIA_PANT is powered up: <ul style="list-style-type: none"> Switched-on to “stand-by” mode (with on/off switch) Switched-on to “operation” mode (from SIA_DH)

Table 5-3. Functional check under electrification in the workshop (FGC scenario)

5.2.3 Tests in the workshop

Once the equipment's performance under electrification has been verified, a few basic cross-checking activities were carried out in the workshop before starting the tests in the track.

Even though the verification plan described in D2.2 has been materialized in the lab and in field tests using a maintenance vehicle by VIAS, some of the tests were repeated in FGC's workshop, according to Table 5-4.

Test_ID	Test Description	passed? (Y/N)	Comments
FGC_W_016	Configuration parameters can be received by SIA_PANT	Y	SIA_PANT receives configuration parameters (via SIA_DH)
FGC_W_017	Following information related to Ambient can be received and processed by SIA_PANT: <ul style="list-style-type: none"> Catenary-Pantograph contact, i.e. physical magnitudes (e.g. 	Y	Signals that represent the relevant ambient for SIA_PANT (according to the description of D4.1) are properly acquired. All

Test_ID	Test Description	passed? (Y/N)	Comments
	accelerations) that will be processed in order to assess the health status of both catenary and pantograph		channels are working properly, with no significant noise.
FGC_W_020	IF_POS_PANT: Timing related information can be sent by SIA_POS and received by SIA_PANT	N/A	Timing related information is received by SIA_DH.
FGC_W_021	IF_PANT_DH: Sensor information can be transmitted by SIA_PANT and received by SIA_DH	Y	All signals acquired by SIA_PANT are properly streamed and received by SIA_DH.

Table 5-4. Verification activities in the workshop (FGC scenario)

5.2.4 Tests in the track

After static tests in the workshops, SIA_PANT was tested with the train in motion:

- A couple of runs out of the workshop (500m) and back, at 5km/h
- A few runs at nominal speed (up to 90km/h) in the validation scenario (as described in D8.1) for one night
- With the train in commercial service in the whole FGC network, for 6 days.

Test_ID	Test Description	passed? (Y/N)	Comments
FGC_T_001	Configuration parameters can be received by SIA_PANT	Y	SIA_PANT receives configuration parameters (via SIA_DH)
FGC_T_002	Following information related to Ambient can be received and processed by SIA_PANT: <ul style="list-style-type: none"> • Catenary-Pantograph contact, i.e. physical magnitudes (e.g. accelerations) that will be processed in order to assess the health status of both catenary and pantograph 	Y	Signals that represent the relevant ambient for SIA_PANT (according to the description of D4.1) are properly acquired. All channels are working properly, with no significant noise.
FGC_T_005	IF_POS_PANT: Timing related information can be sent by SIA_POS and received by SIA_PANT	N/A	Timing related information is received by SIA_DH.
FGC_T_006	IF_PANT_DH: Sensor information can be	Y	All signals acquired by

Test_ID	Test Description	passed? (Y/N)	Comments
	transmitted by SIA_PANT and received by SIA_DH		SIA_PANT are properly streamed and received by SIA_DH.

Table 5-5. Verification activities in the track (FGC scenario)

6 SIA_DH Test results

SIA_DH has been initially validated in the lab, with the results already reported in deliverable D4.3 [11]. This chapter contains the validation results of SIA_DH with the results obtained in the relevant validation scenarios, as described in deliverable D8.1:

- SIA_DH test results (VIAS validation scenario)
- SIA_DH test results (FGC validation scenario)

6.1 SIA_DH test results (VIAS validation scenario)

Table 6-1 compiles the results of the tests that are relevant for SIA_DH in the validation scenario of VIAS (see deliverable D8.1 for details about the system installation and description of tests).

Test_ID	Test Description	passed? (Y/N)	Comments
VIAS_T_001	Configuration parameters can be received by SIA_DH	Y	SIA_DH receives configuration parameters and can configure SIA_PANT
VIAS_T_002	Following information related to Ambient can be received and processed by SIA_PANT: <ul style="list-style-type: none"> • Electric power supply 	Y	SIA system is connected to 72VDC. The power supply unit provides SIA_DH with 24VDC with the required protection.
VIAS_T_004	IF_POS_DH: Positioning related information can be sent by SIA_POS and received by SIA_DH	Y	SIA_DH receives positioning information by SIA_POS.
VIAS_T_005	IF_POS_PANT: Timing related information can be sent by SIA_POS and received by SIA_PANT	Y	Timing related information is received by SIA_DH, which is used to synchronize the different signals of the sensors of SIA_PANT in the generation of files.
VIAS_T_006	IF_PANT_DH: Sensor information can be transmitted by SIA_PANT and received by SIA_DH	Y	All signals acquired by SIA_PANT are properly streamed and received by SIA_DH.
VIAS_T_007	IF_DH_VP: Generated data in SIA_DH can be transmitted and received by SIA_VP	Y	Communication with SIA_VP is successful: <ul style="list-style-type: none"> • Data can be sent by

Test_ID	Test Description	passed? (Y/N)	Comments
			SIA_DH to SIA_VP using SFTP Events are properly generated and sent by SIA_DH to SIA_VP using MQTT

Table 6-1. Tests in the track (VIAS scenario)

6.2 SIA_DH test results (FGC validation scenario)

The testing of SIA_DH in the scenario of FGC comprised the following activities:

- Static tests in the workshop
- Functional check under electrification
- Tests in the workshop
- Tests in the track

6.2.1 Static tests in the workshop

In this activity, a few basic tests were carried out in static condition. They were used mainly to verify that the installation of the system is correct and according to the description of deliverable D4.1. The tests results applicable to SIA_PANT (extracted from those described in D8.1) are summarized in Table 6-2.

Test_ID	Test Description	passed? (Y/N)	Comments
FGC_W_002	Visual inspection of the system: <ul style="list-style-type: none"> • Antennas are correctly fixed • Wiring of antennas to the electric box is correct • Wires enter the equipment cabinet without tension • Connections of the system are ok • SIA equipment is correctly fixed in the open frame rack • Open frame rack is correctly fixed in the equipment cabinet 	Y	Visual inspection is validated by FGC personnel: <ul style="list-style-type: none"> • Antennas are correctly fixed to the extension plate on the roof • Wiring of antennas to the electric box is conducted by a corrugated pipe, which is sealed for better water proofing • Wires from roof to equipment cabinet are properly placed without harmful tensions • All connections of the system are good (electrical continuity is provided) and reliable • SIA equipment is firmly fixed in the open frame rack. It does not interfere with the operation of other systems and the

Test_ID	Test Description	passed? (Y/N)	Comments
			doors of the cabinet close properly <ul style="list-style-type: none"> SIA_DH's enclosure is properly fixed (racked) in the open frame rack
FGC_W_007	Check Ethernet cable of SIA_POS is connected for internet connection.	Y	SIA_DH is connected to SIA_POS via Ethernet connection and provides SIA_POS with internet access.

Table 6-2. Static tests in the workshop (FGC scenario)

6.2.2 Functionality check under electrification

This activity aims at checking the functionality of SIA_DH when the pantograph is deployed and the train is electrified. The test results applicable to SIA_DH (extracted from those described in D8.1) are summarized in Table 6-3.

Test_ID	Test Description	passed? (Y/N)	Comments
FGC_W_012	SIA_PANT is streaming data (connection via tablet)	Y	SIA_PANT is streaming data under electrification. Signals are correctly acquired and no significant noise is observed. Streaming is received by SIA_DH correctly.
FGC_W_013	SIA equipment is powered-up	Y	<ul style="list-style-type: none"> SIA DH is receiving 24VDC from the power supply unit

Table 6-3. Functional check under electrification in the workshop (FGC scenario)

6.2.3 Tests in the workshop

Once the equipment's performance under electrification has been verified, a few basic cross-checking activities were carried out in the workshop before starting the tests in the track.

Even though the verification plan described in D2.2 has been materialized in the lab and in field tests using a maintenance vehicle by VIAS, some of the tests were repeated in FGC's workshop, according to Table 6-4.

Test_ID	Test Description	passed? (Y/N)	Comments
FGC_W_016	Configuration parameters can be received by SIA_DH	Y	SIA_DH receives configuration parameters and can configure

Test_ID	Test Description	passed? (Y/N)	Comments
			SIA_PANT
FGC_W_017	Following information related to Ambient can be received and processed by SIA_PANT: <ul style="list-style-type: none"> Electric power supply 	Y	SIA system is connected to 72VDC. The power supply unit provides SIA_DH with 24VDC with the required protection.
FGC_W_019	IF_POS_DH: Positioning related information can be sent by SIA_POS and received by SIA_DH	Y	SIA_DH receives positioning information by SIA_POS.
FGC_W_020	IF_POS_PANT: Timing related information can be sent by SIA_POS and received by SIA_PANT	Y	Timing related information is received by SIA_DH, which is used to synchronize the different signals of the sensors of SIA_PANT in the generation of files.
FGC_W_021	IF_PANT_DH: Sensor information can be transmitted by SIA_PANT and received by SIA_DH	Y	All signals acquired by SIA_PANT are properly streamed and received by SIA_DH.
FGC_W_022	IF_DH_VP: Generated data in SIA_DH can be transmitted and received by SIA_VP	Y	Communication with SIA_VP is successful: <ul style="list-style-type: none"> Data can be sent by SIA_DH to SIA_VP using SFTP Events are properly generated and sent by SIA_DH to SIA_VP using MQTT

Table 6-4. Verification activities in the workshop (FGC scenario)

6.2.4 Tests in the track

After static tests in the workshops, SIA_DH was tested with the train in motion:

- A couple of runs out of the workshop (500m) and back, at 5km/h
- A few runs at nominal speed (up to 90km/h) in the validation scenario (as described in D8.1) for one night
- With the train in commercial service in the whole FGC network, for 6 days.

Test_ID	Test Description	passed? (Y/N)	Comments
FGC_T_001	Configuration parameters can be received by SIA_DH	Y	SIA_DH receives configuration parameters and can configure SIA_PANT
FGC_T_002	Following information related to Ambient can be received and processed by SIA_PANT: <ul style="list-style-type: none"> Electric power supply 	Y	SIA system is connected to 72VDC. The power supply unit provides SIA_DH with 24VDC with the required protection.
FGC_T_004	IF_POS_DH: Positioning related information can be sent by SIA_POS and received by SIA_DH	Y	SIA_DH receives positioning information by SIA_POS.
FGC_T_005	IF_POS_PANT: Timing related information can be sent by SIA_POS and received by SIA_PANT	Y	Timing related information is received by SIA_DH, which is used to synchronize the different signals of the sensors of SIA_PANT in the generation of files.
FGC_T_006	IF_PANT_DH: Sensor information can be transmitted by SIA_PANT and received by SIA_DH	Y	All signals acquired by SIA_PANT are properly streamed and received by SIA_DH.
FGC_T_007	IF_DH_VP: Generated data in SIA_DH can be transmitted and received by SIA_VP	Y	Communication with SIA_VP is successful: <ul style="list-style-type: none"> Data can be sent by SIA_DH to SIA_VP using SFTP Events are properly generated and sent by SIA_DH to SIA_VP using MQTT

Table 6-5. Tests in the track (FGC scenario)

7 SIA_CDM Test results

As described in deliverable D2.2, SIA_CDM is the subsystem in charge of processing the algorithms necessary to transform the signals from sensors (from SIA_ABA and SIA_PANT subsystems) into health related KPIs, as described in depth in deliverables D5.4 [12] and D5.5 [13].

In this chapter, the use cases defined in deliverable D2.1 are presented and validated with field data. The use cases list is the following:

- Use Case #1. Contact wire wear
- Use Case #2. Contact wire height and stagger
- Use Case #3. Contact strip wear (normal / asymmetric)
- Use Case #4. Wheel flats and polygonization wear
- Use Case #5. Rail Corrugation
- Use Case #6. Short-wave irregularities

7.1 Use Case #1. Contact wire wear

Contact wire wear estimation is done by the calculation of the ratio between the original section and the worn area of the wire. The threshold for its overhaul is fixed at 80% of the original cross section. However, the worn process is a slow phenomenon that takes decades, and therefore its validation cannot be assessed with field data in short campaigns. However, the validation of this use case has been carried out with the simulation framework that was developed to assess the pantograph-catenary interaction, and has been already described in deliverable D5.4.

7.2 Use Case #2. Contact wire height and stagger

For the generation of contact wire height and stagger, the FGC validation scenario has been used. Data has been collected across FGC's network. However, a representative section between Rubí and Hospital-General stations has been selected, where benchmark measurements have been taken by tCat® equipment. The following plots show the KPIs extracted by SIA_CDM for this use case.

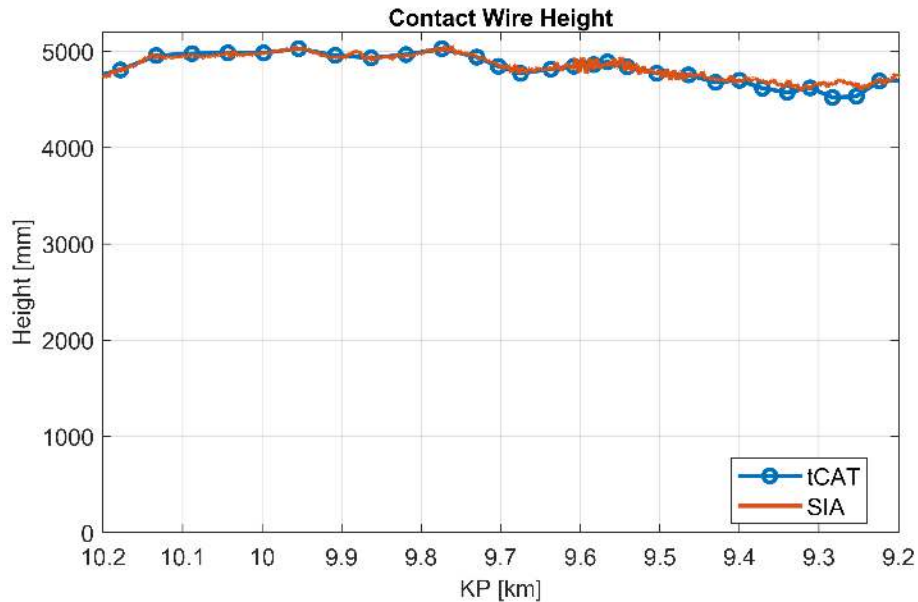


Figure 7-1. Overhead line height

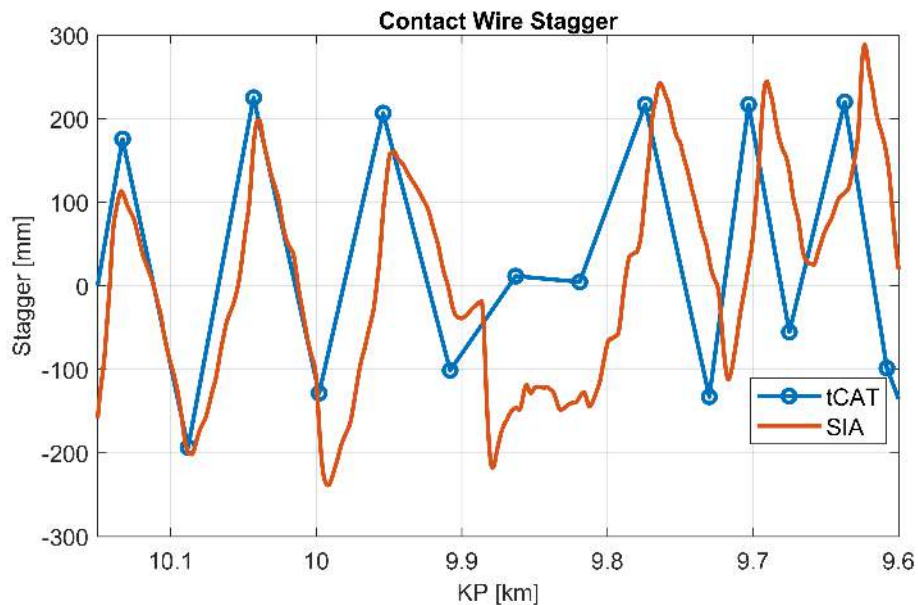


Figure 7-2. Overhead line stagger

7.3 Use Case #3. Contact strip wear (normal / asymmetric)

The wearing of the pantograph's contact strips is not that slow as the wearing of the contact wire. The assessment methodology was described in deliverable D5.4. However, its validation with

field data is not possible given the short time available for field tests, as no degradation of the strips happens in the matter of a few days.

However, alternative KPIs were introduced and described in deliverable D5.4 to assess the dynamic interaction between the pantograph and the catenary, that were indeed analyzed with field data. These parameters are the contact force (Figure 4), the evolution of the contact point's height (Figure 5) and the apparition of shocks (Figure 6), as depicted in the following figures, also extracted from the FGC validation scenario.

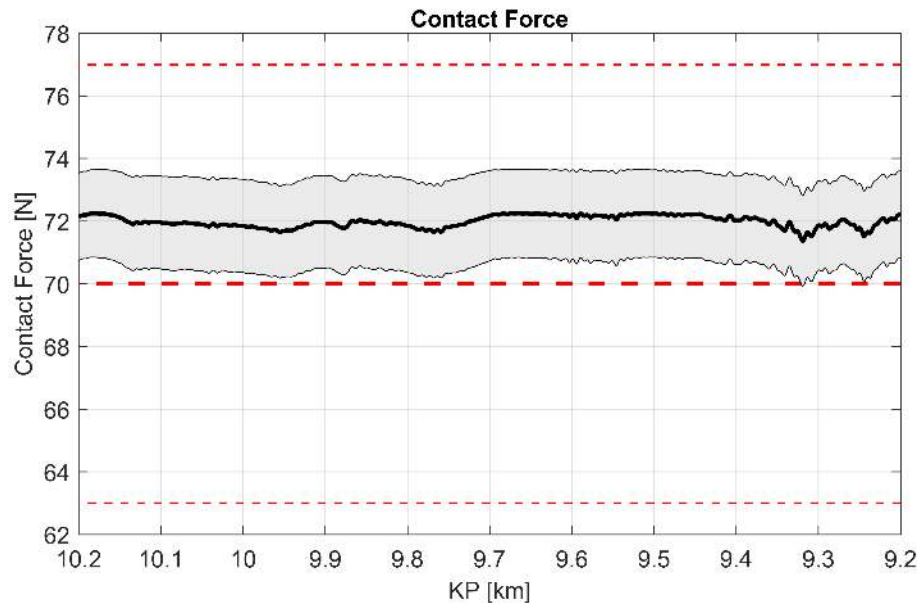


Figure 7-3. Estimated contact force

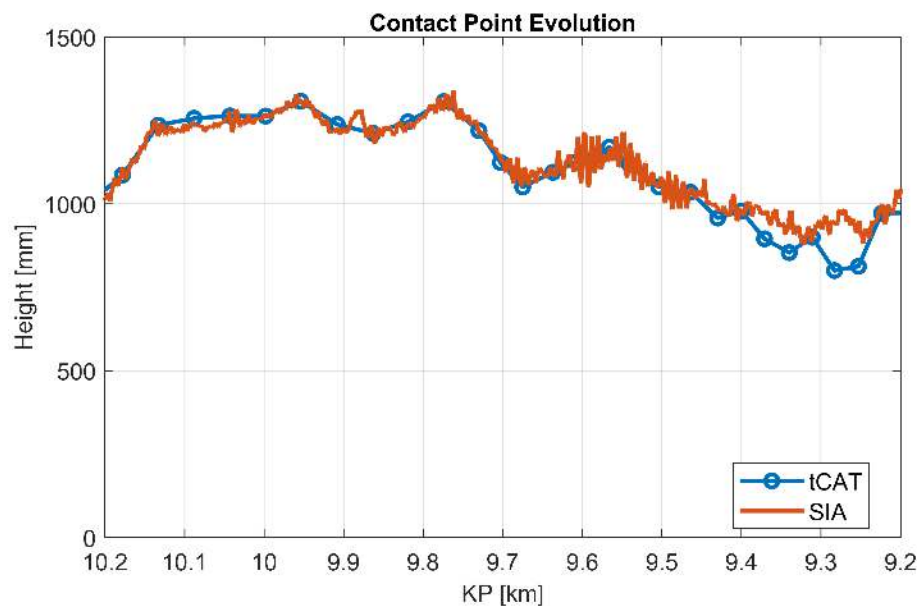


Figure 7-4. Evolution of the contact point

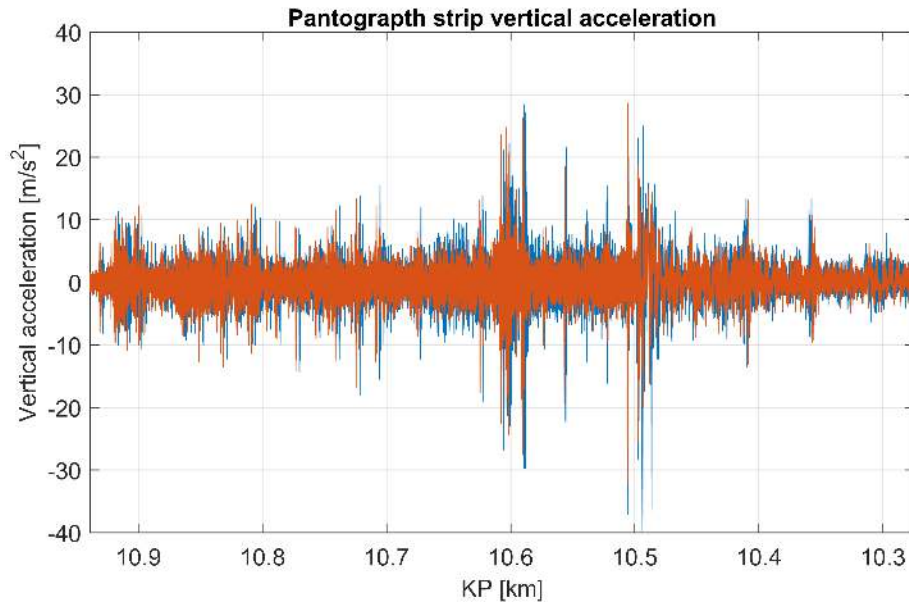


Figure 7-5. Apparition of shocks

7.4 Use Case #4. Wheel flats and polygonization wear

The wheel wear is monitored by applying cepstrum analysis to the vertical component of the ABA data. Two wheel health status indicators can be extracted through this kind of analysis, namely the wheel diameter and an out-of-roundness indicator (OORI). The wheel diameter provides information on the abrasion of the wheel. In contrast, the OORI indicates sudden changes of the roundness of the wheel, as occurs with wheel flats. For further information on the feature extraction see deliverable D5.4 [12] and [17].

The nominal new wheel diameter of the wheels of the equipped wagon in the validation scenario is 0.84 m. We assume that the wheel diameter of this kind of wheel reduces by 0.06 m throughout the lifespan of a wheel, so that the wheel diameter at end-of life is 0.78 m. Therefore, we define diameter of 0.78 m as the threshold of intervention. In Figure 7-6 the estimated wheel diameter is shown for seven different journeys between December 2020 and April 2021. It can be seen that the diameter is well above the threshold of 0.78 m. Figure 7-7 shows the corresponding OORI for the same journeys. As aforementioned, the OORI can be used to detect sudden changes related to wheel flats. In order to determine an absolute threshold of intervention, more empirical studies including data from defected wheels would be necessary. However, the trend of the OORI can be analysed to detect suddenly or continuously emerging wheel defects. The OORI observed during the campaign (Figure 7-7) reveal a normal condition of the wheel. A wheel out-of-roundness defect, such as a wheel flat, would result in a sudden increase of the OORI of several orders of magnitude.

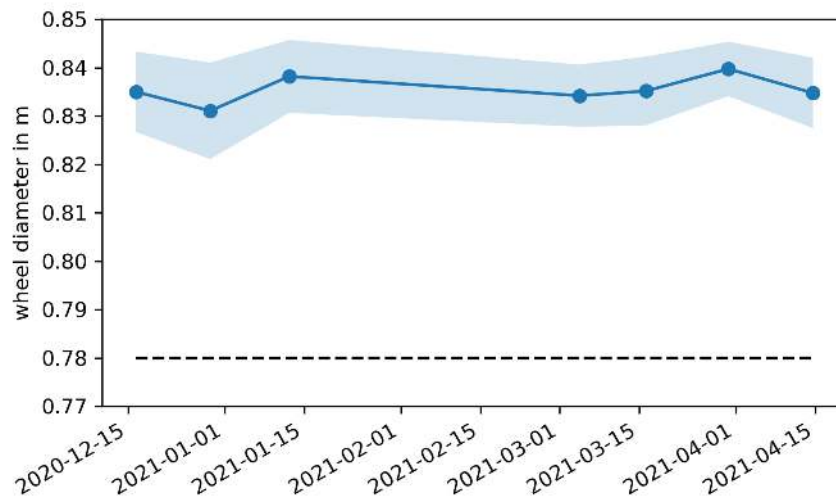


Figure 7-6. Estimated wheel diameter per journey, dots show the mean value and the filled area the standard deviation per journey, dashed line indicates possible threshold of intervention.

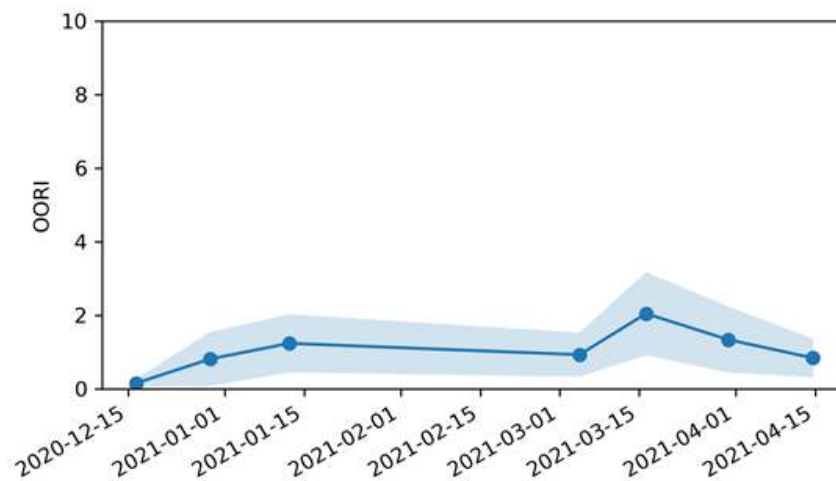


Figure 7-7. Out of roundness indicator (OORI) per journey, dots show the mean value and the filled area indicates the standard deviation per journey.

7.5 Use Case #5. Rail Corrugation

The longitudinal level is the standard physical parameter to assess vertical track irregularities. According to deliverable D5.4 [12] short pitch corrugation can be detected by analysing the longitudinal rail level in the wavelength range of 30-100 mm. A relative measure of the longitudinal level can be directly recovered from the ABA data. To reconstruct an absolute measure of the longitudinal level, calibration by means of ground truth data is required that was

not available for the validation scenario. In Figure 7-8 the longitudinal level in the wavelength range 30-100 mm is shown. The values are averaged over four runs over the same track section to increase the reliability of the analysis. It is assumed that all values are in an acceptable range, since no corrugation defects are known for this track segment.

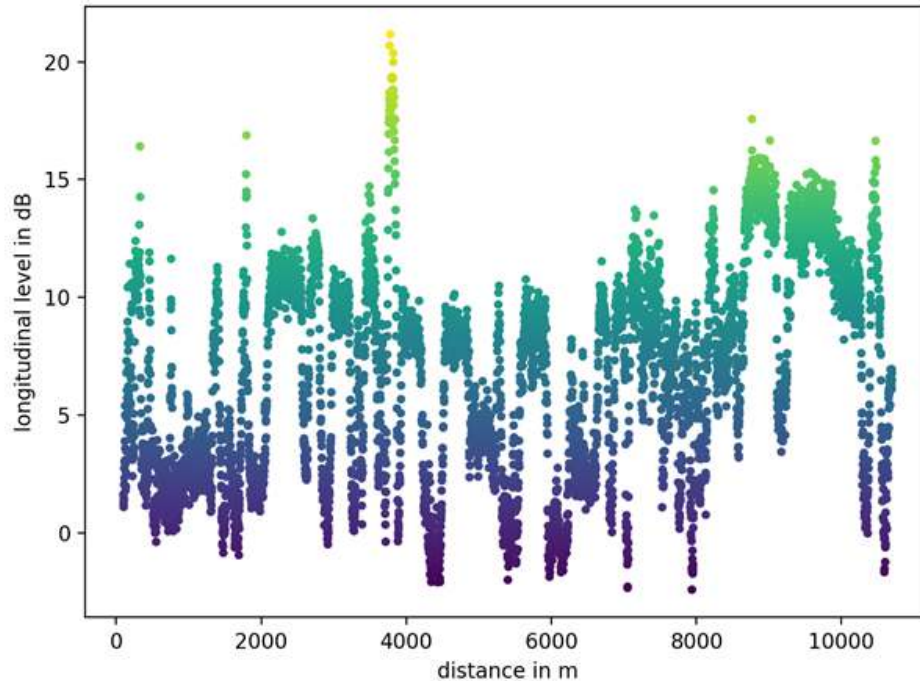


Figure 7-8. Longitudinal level (30-100 mm) averaged over four runs of the same track section.

7.6 Use Case #6. Short-wave irregularities

Similarly to corrugation, short-wave irregularities can be detected via the longitudinal level. Squats and other rolling contact fatigue phenomena that fall into the category of short-wave irregularities have a dominant wavelength range between 10 and 30 mm. Figure 7-9 shows the corresponding longitudinal levels. It is assumed that all values are in an acceptable range, since no short-wave defects are known for this track segment.

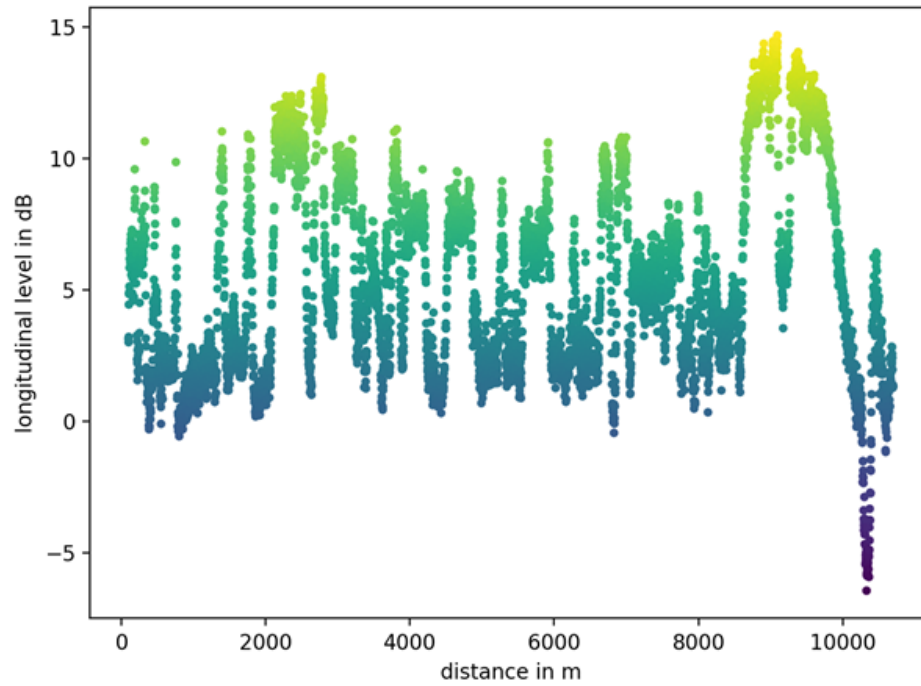


Figure 7-9. Longitudinal level (10-30 mm) averaged over four runs of the same track section.

8 SIA_VP Test results

Chapter 8 shows how SIA_VP displays the results obtained during the different field tests carried out in WP8 by SIA partners. Each of the next subsections compiles different screenshots describing how the information generated in each testing scenario is displayed in SIA_VP.

These scenarios with the monitoring systems used to validate the SIA Services are reflected in next table:

Scenario	Monitoring system			SIA Service			
	SIA_ABA	SIA_PANT	tCat®	iRailMon	iWheelMon	iPantMon	iCatMon
VIAS				X	X		
FGC		X	X			X	X
OBB	X			X	X		

Table 8-1. Scenarios and systems used to validate SIA Services

Overall, this section displays similar information to deliverable D6.1-D6.2 [14], but using real data obtained during field testing. The validation of SIA_VP functional requirements for the 4 SIA services is assessed in Chapter 9.

8.1 VIAS validation scenario

In order to test SIA system integration while the OBB and FGC test setups were being prepared, SIA partners carried out a short testing campaign hosted by VIAS. This setup was assembled near Madrid in the high-speed railway line Madrid-Seville (Spain) as described in Chapter 6 of Deliverable D8.1 [16].

Data collected during VIAS testing affect iRailMon and iWheelMon SIA services. So, to check the testing results, we need to log-in SIA_VP and access iRailMon and iWheelMon services clicking on the corresponding icons:

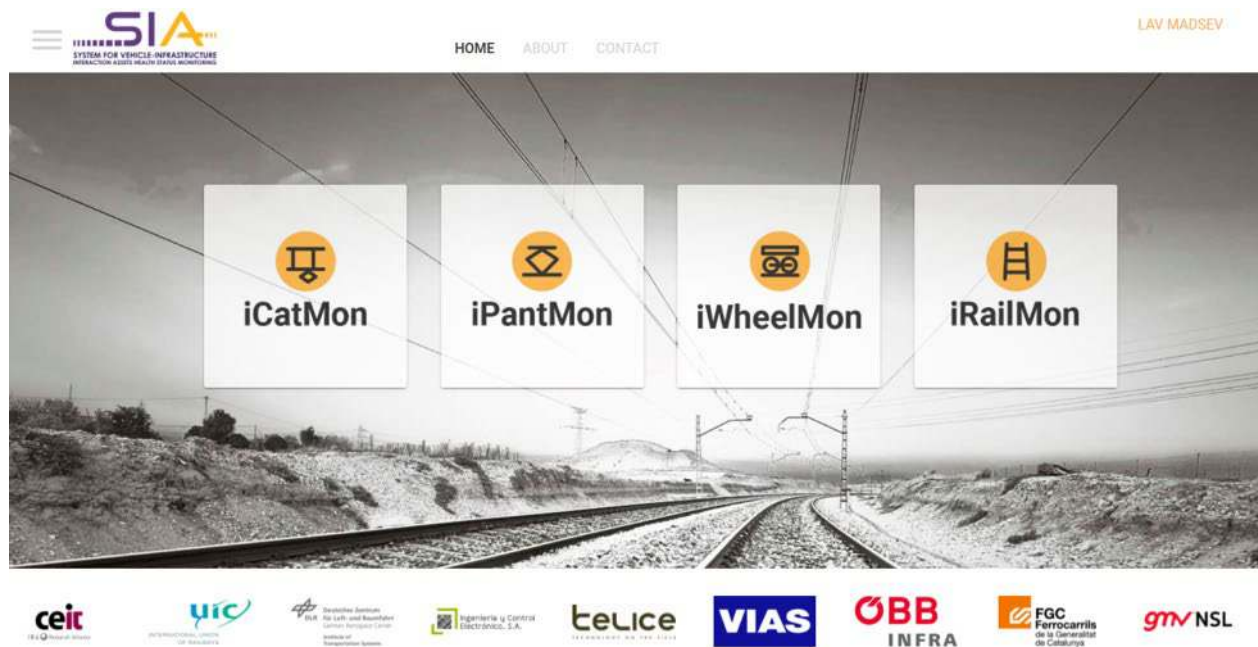


Figure 8-1. SIA Home page

If we go to the configuration menu, we can create a new online inspection (type=Monitoring) associated to the Rail Head component, and with 4 associated failure mode KPIs which in this case correspond to the parameters (accelerations) the onboard equipment monitors:

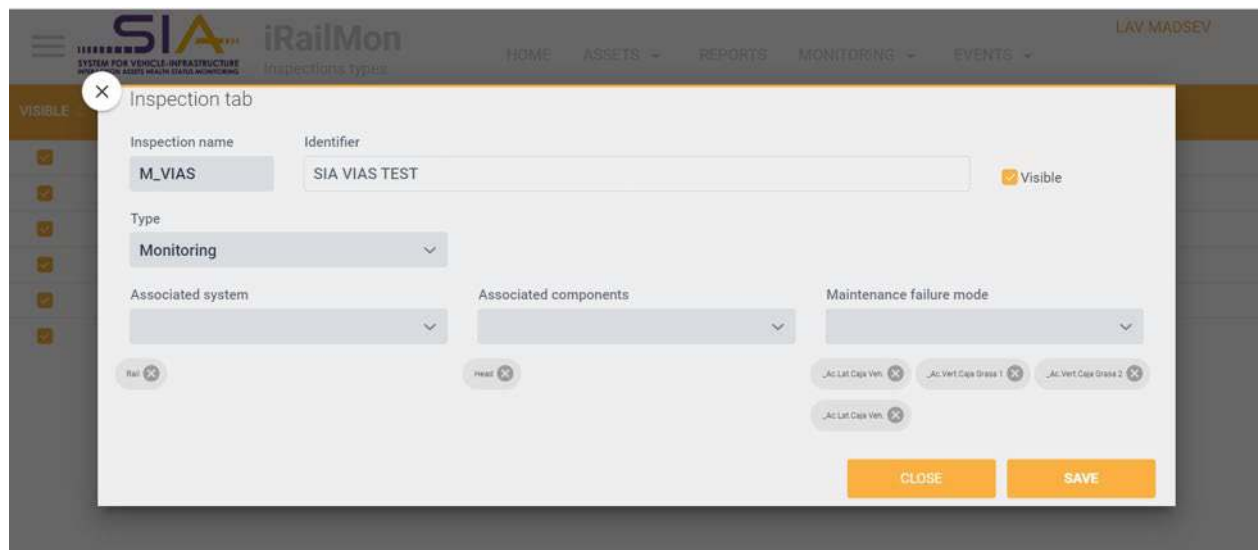
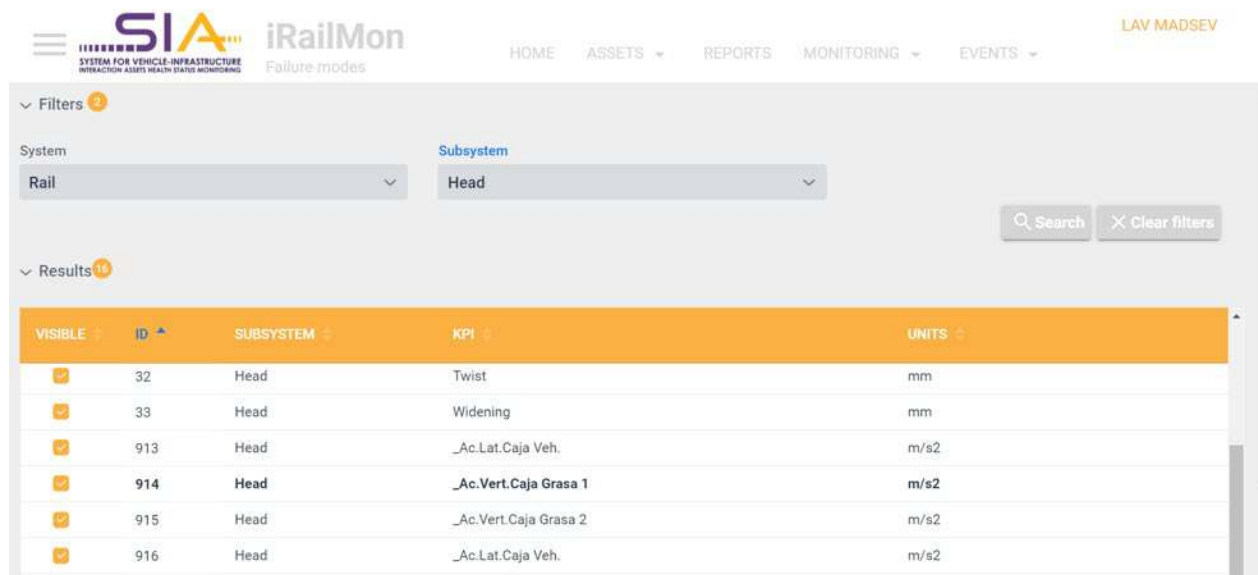


Figure 8-2. iRailMon inspection management tab

Those failure mode parameters have been created before using the configuration menu too, and their thresholds are set too:



Filters 2

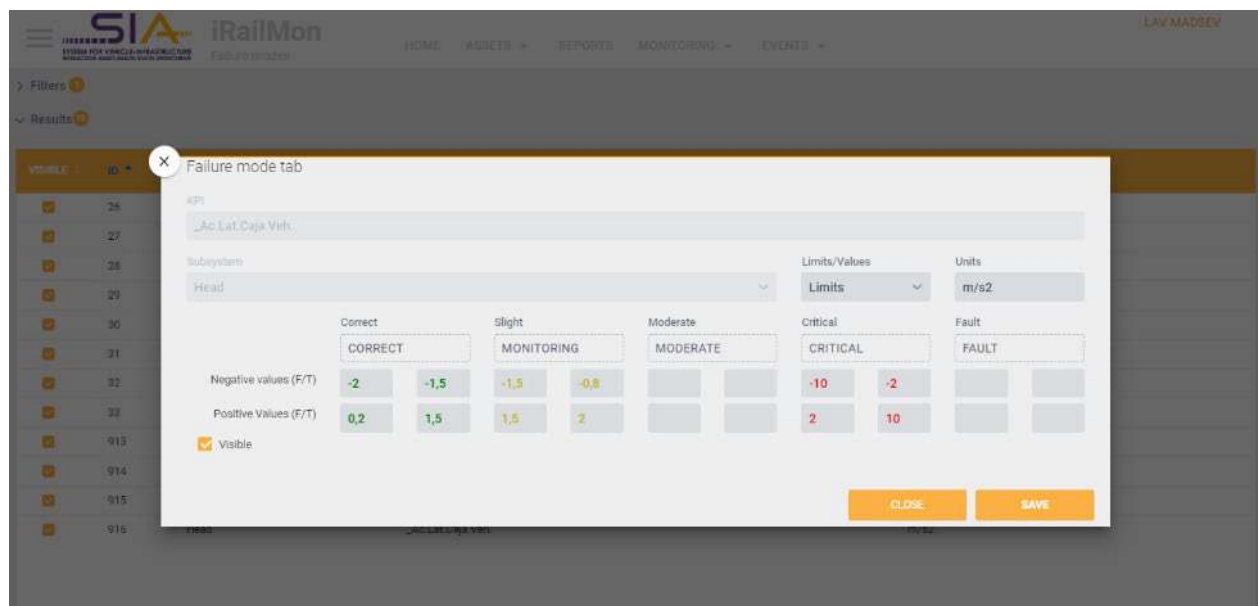
System: Rail Subsystem: Head

Search Clear filters

Results 16

VISIBLE	ID	SUBSYSTEM	KPI	UNITS
<input checked="" type="checkbox"/>	32	Head	Twist	mm
<input checked="" type="checkbox"/>	33	Head	Widening	mm
<input checked="" type="checkbox"/>	913	Head	_Ac.Lat.Caja Veh.	m/s2
<input checked="" type="checkbox"/>	914	Head	_Ac.Vert.Caja Grasa 1	m/s2
<input checked="" type="checkbox"/>	915	Head	_Ac.Vert.Caja Grasa 2	m/s2
<input checked="" type="checkbox"/>	916	Head	_Ac.Lat.Caja Veh.	m/s2

Figure 8-3. iRailMon failure modes list



Failure mode tab

KPI: _Ac.Lat.Caja Veh.

Subsystem: Head

Limits/Values: Limits Units: m/s2

	Correct	Slight	Moderate	Critical	Fault
Negative values (F/T)	-2	-1,5	-1,5	-0,8	-10
Positive Values (F/T)	0,2	1,5	1,5	2	10

☒ Visible

Close Save

Figure 8-4. iRailMon failure mode administration pop-up window

Once configured the system and created the GIS model in the Database, users can start using the system. In the Assets section, they can check the whole line zooming in and out, and moving over the map (Figure 8-5).

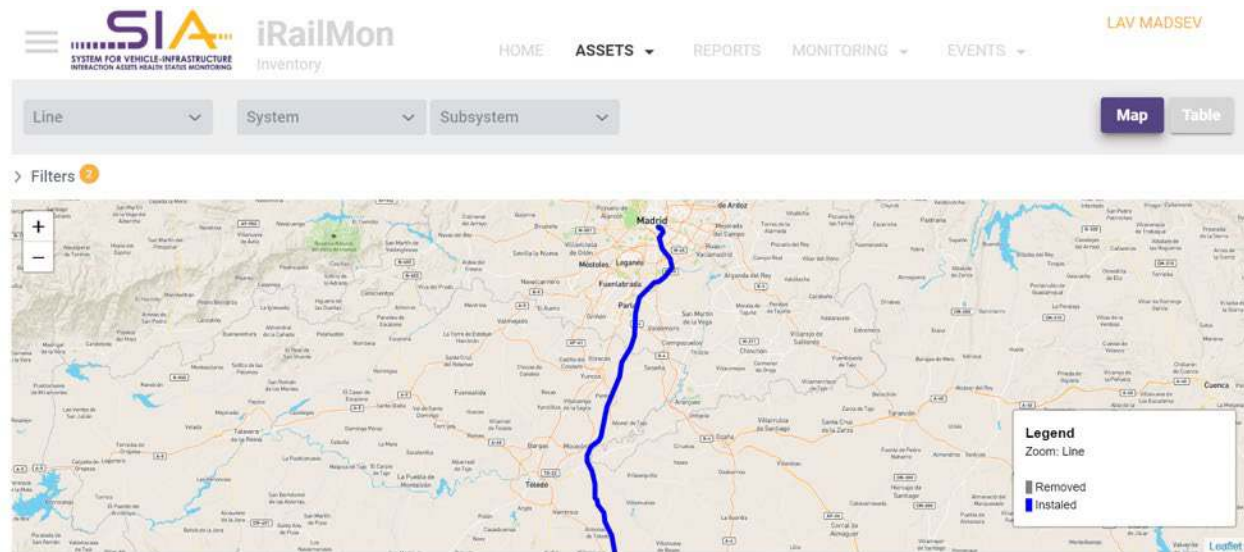


Figure 8-5. iRailMon assets inventory map view

Clicking on a point on the line, they can see the component (Rail) and location in UTM coordinates as in Figure 8-6:

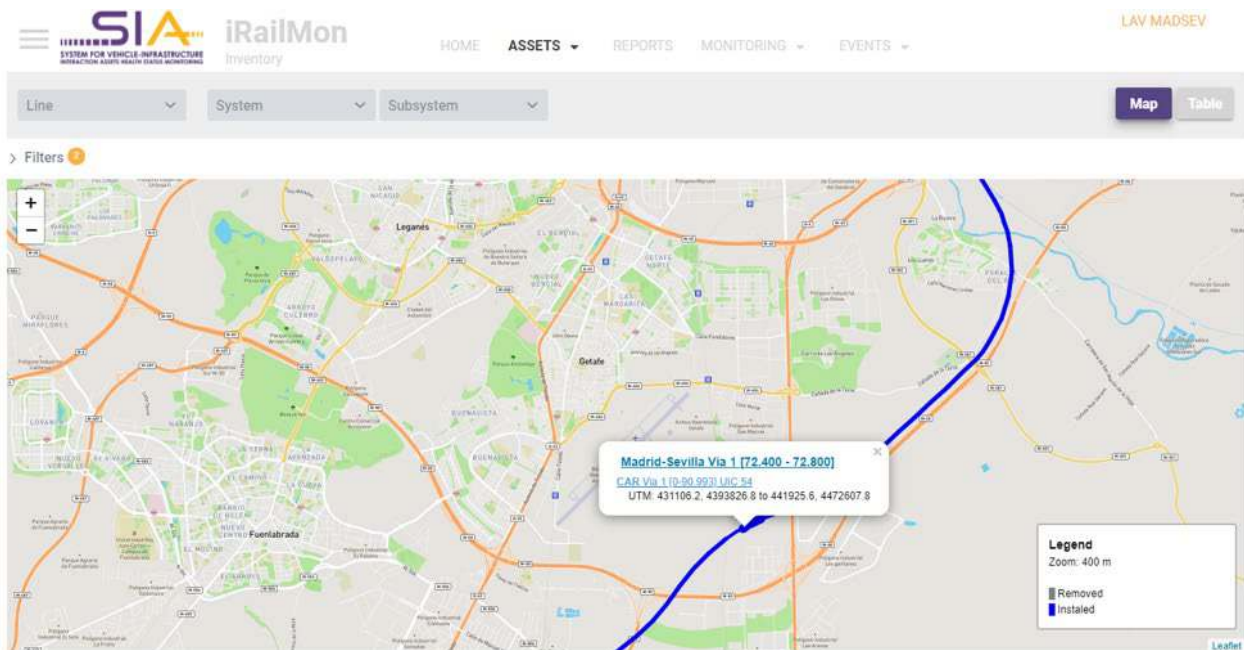


Figure 8-6. iRailMon assets inventory map representation with details after zooming in

Once again, clicking on the asset displayed in the tab in the previous image, the corresponding asset tab is displayed with all the component information:

Figure 8-7. iRailMon asset tab

Then, going to the Monitoring section in the Menu, user can access to the data collected by the onboard equipment of SIA VIAS TEST online inspection during the tests and calculated KPIs placed over the line shown in a map (Figure 8-8). If the 4 monitored parameters are within acceptable thresholds, they are displayed in green, otherwise they are highlighted in their corresponding colour based on the configured status. A Maintenance recommendation is suggested based on the KPIs status.

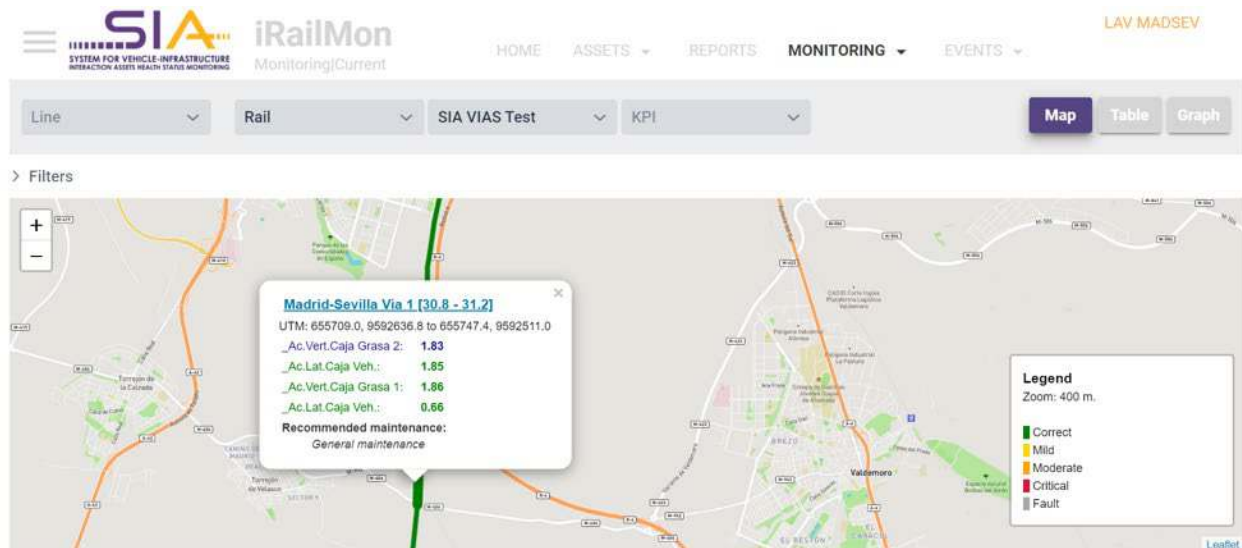


Figure 8-8. iRailMon monitoring values displayed in map

In the previous image, we could see an average of the KPIs over a particular section, but if we zoom-in enough, individual measures will be displayed:

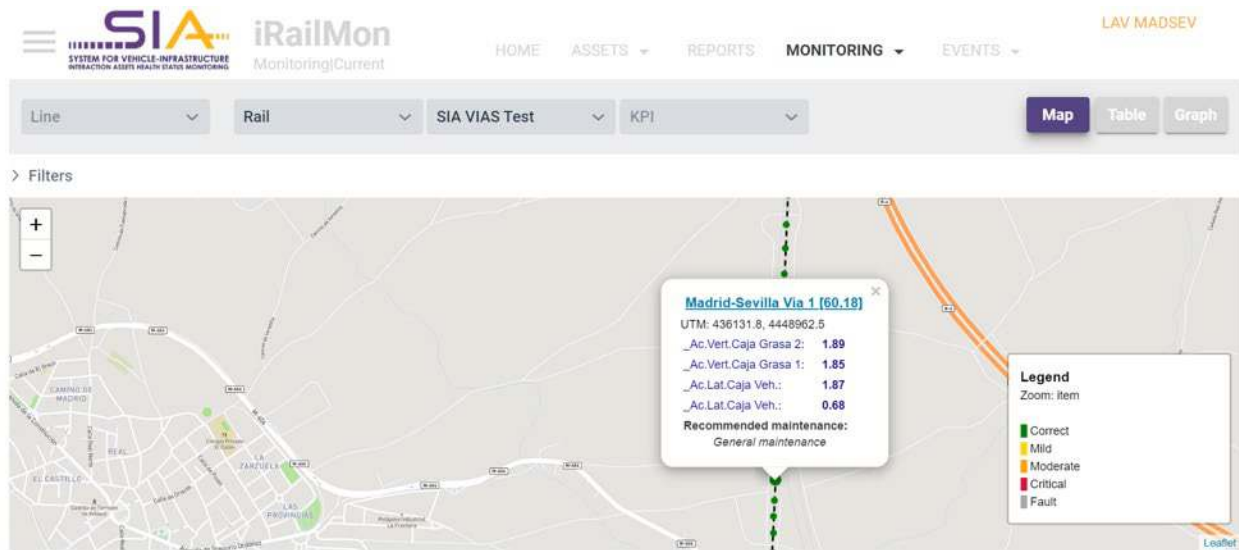


Figure 8-9. iRailMon individual monitoring values displayed in map with maximum zoom

The system also offers a graphic mode (Figure 8-10) to analyse the data using charts apart from the mapping view:



Figure 8-10. iRailMon monitoring values displayed in charts

Finally, also a Table view mode displaying the individual measurements collected by the onboard sensors:

SIA

SYSTEM FOR VEHICLE-INFRASTRUCTURE
INTERACTION, ASSETS HEALTH STATUS MONITORING

iRailMon

Monitoring(Current)

HOME

ASSETS

REPORTS

MONITORING

EVENTS

LAV MADSEV

Line

Rail

SIA VIAS Test

KPI

Map

Table

Graph

Filters

Results

Export

DATE		LOCATION		ASSET		VALUES				
DAY	HOUR	LINE	TRACK	KP INI	KP END	NAME	DESCRIP...	KPI	VALUE	STATE
24/03/2021	23:18	MD-SV	Via 1	39.795		CAR	UIC 54	_Ac.Vert.Ca...	1.852257	Correct
24/03/2021	23:18	MD-SV	Via 1	39.795		CAR	UIC 54	_Ac.Lat.Caj...	0.658119	Correct
24/03/2021	23:18	MD-SV	Via 1	40.025		CAR	UIC 54	_Ac.Lat.Caj...	1.921854	Correct
24/03/2021	23:18	MD-SV	Via 1	40.025		CAR	UIC 54	_Ac.Vert.Ca...	1.882782	Correct
24/03/2021	23:18	MD-SV	Via 1	40.025		CAR	UIC 54	_Ac.Lat.Caj...	0.663003	Correct
24/03/2021	23:18	MD-SV	Via 1	40.23		CAR	UIC 54	_Ac.Lat.Caj...	1.811964	Correct

Figure 8-11. iRailMon monitoring values displayed in table mode

In the Reports menu option, iRailMon displays data of other auscultation systems that users may upload to SIA as shown in D7.1 [15], not related to SIA onboard equipment. The information is displayed in maps, tables and charts similarly to what has just been described for Monitoring Menu. In this case we have linked automatically SIA to VIAS maintenance application (SISTEPLANT) using webservices to import to SIA new inspections. As VIAS only records measured values out of limits, that's why all the measurement points are highlighted in red in Figure 8-12 and with an immediate Maintenance recommendation:

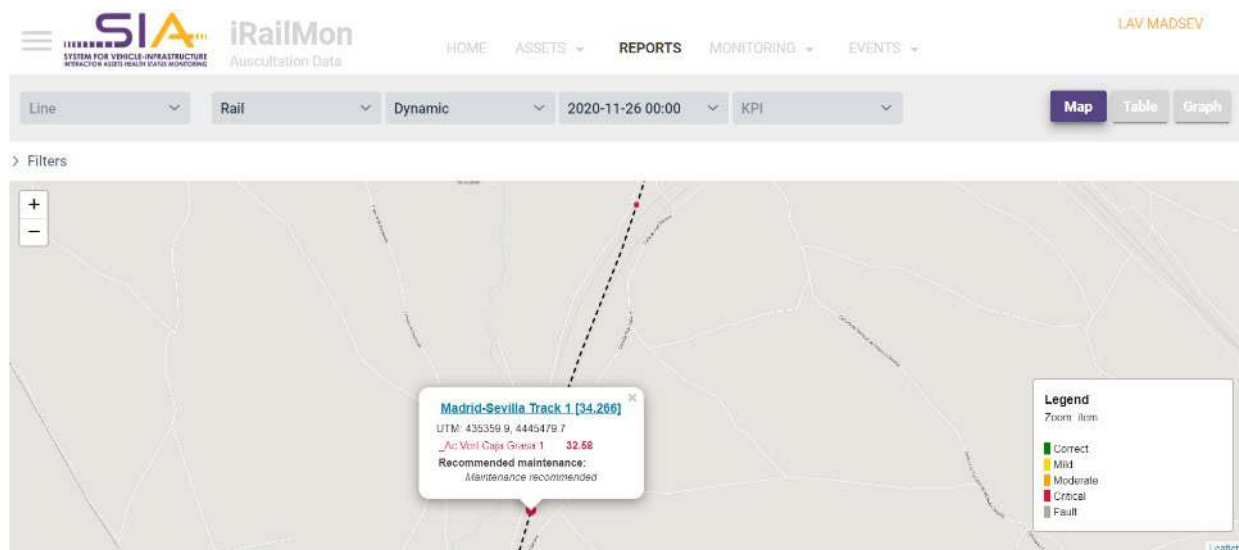


Figure 8-12. External auscultation report displayed in iRailMon Reports

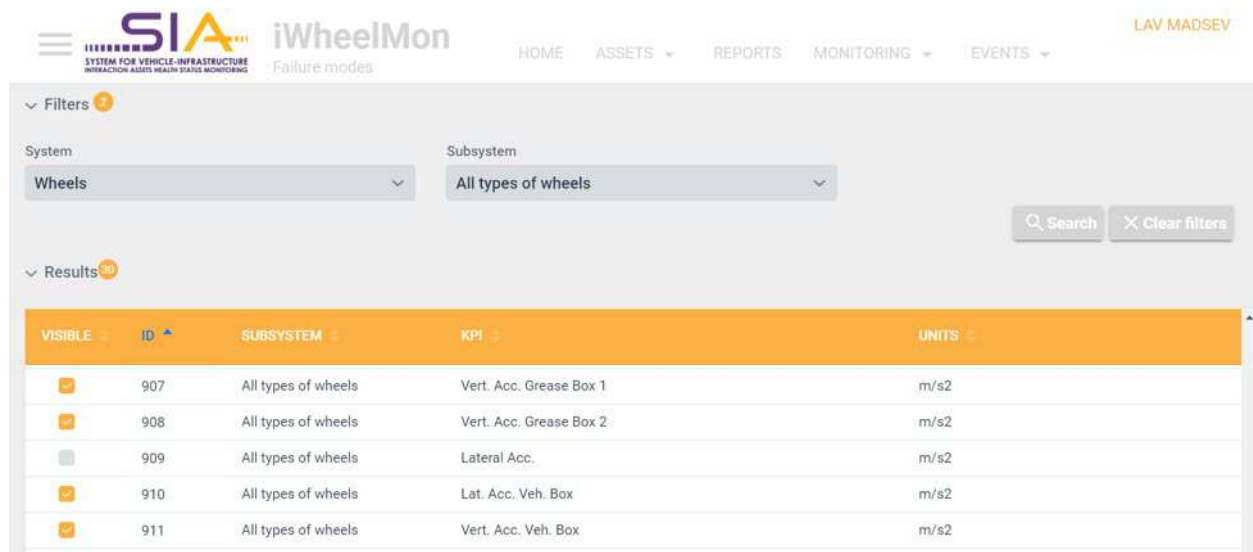
We can also switch to iWheelMon to check the results of the testing, as data collected by onboard sensors in this test can be used to assess health status of wheels as well as of rail. Then, in the Assets menu, instead of showing a map of the line as in iRailMon, the users can see vehicles and their components in table view mode. In this case we have a locomotive and its wheelset, where the onboard sensors were installed:



LINE	TRACK	KP IN	KP END	NAME	SUBSYST.	COMPON.	UNITS	IDENTIFIER
MD-SV	Via 1	0		VEH_1	Vehicle	Locomotive ...	1	VEH_1
MD-SV	Via 1	0		VEH_1.AL...	Wheelset		1	Wheel 1

Figure 8-13. iWheelMon assets inventory table

In iWheelMon configuration section, administrator users have the ability to configure different KPIs, thresholds, failure modes and maintenance actions different to those we have used in iRailMon, specific to iWheelMon, if needed.



VISIBLE	ID	SUBSYSTEM	KPI	UNITS
<input checked="" type="checkbox"/>	907	All types of wheels	Vert. Acc. Grease Box 1	m/s2
<input checked="" type="checkbox"/>	908	All types of wheels	Vert. Acc. Grease Box 2	m/s2
<input type="checkbox"/>	909	All types of wheels	Lateral Acc.	m/s2
<input checked="" type="checkbox"/>	910	All types of wheels	Lat. Acc. Veh. Box	m/s2
<input checked="" type="checkbox"/>	911	All types of wheels	Vert. Acc. Veh. Box	m/s2

Figure 8-14. iWheelMon failure modes configuration

Then in the rest of menu options users can check the measured parameters/KPIs in a similar way as exposed before in iRailMon:

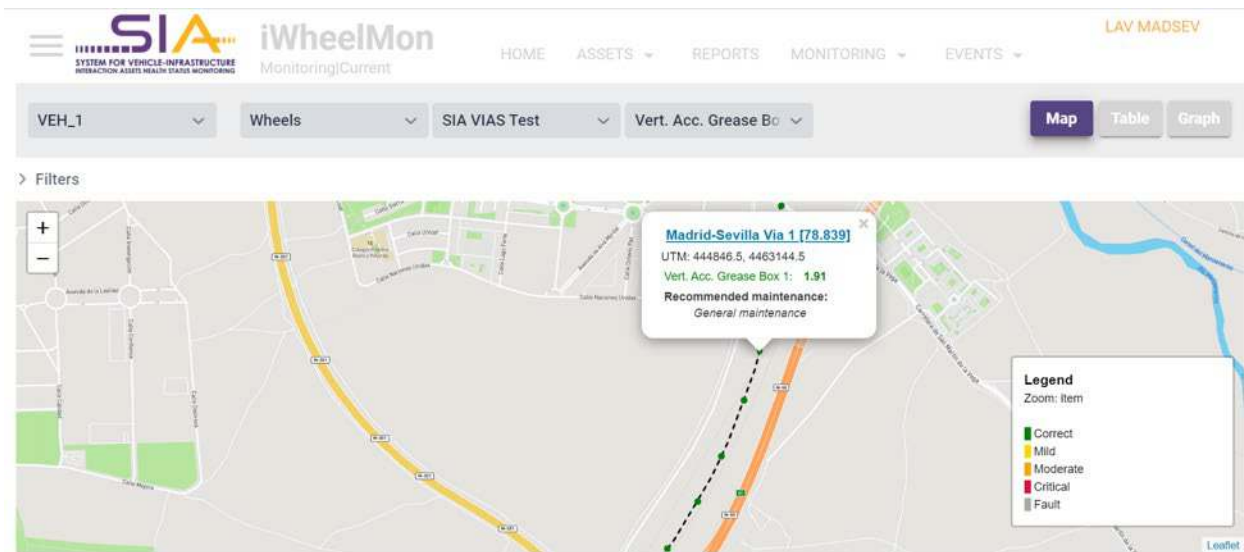


Figure 8-15. iWheelMon monitoring values and KPIs displayed in map mode

If we set tighter thresholds in the configuration to raise a mild warning on one of the KPIs, we can see that the system recommends a different maintenance action based on the new asset status. Maintenance recommendations in the system are sample ones not provided by an IM.

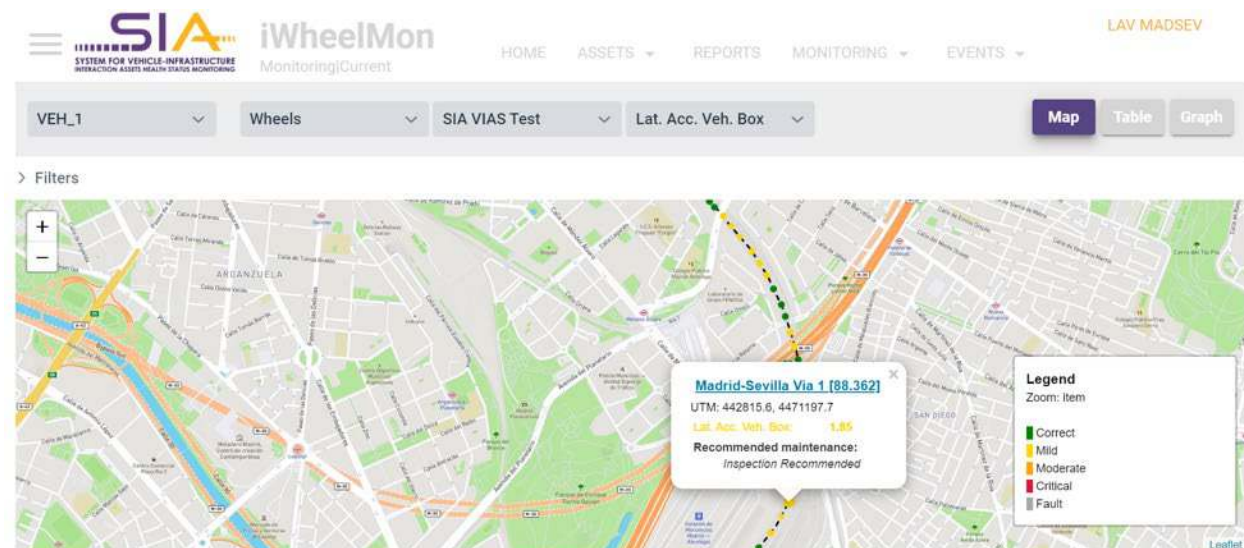


Figure 8-16. iWheelMon maintenance recommendations in Monitoring screen

Finally, in iWheelMon Reports menu option, external auscultation inspections reports can be uploaded to SIA. In this case, as previously explained in this scenario for iRailMon, SIA has been automatically linked using webservices to import auscultation reports from VIAS CMMS application (SISTEPLANT). As VIAS only records out of limits measurements, all points in Figure 8-17 are highlighted with warning colours.

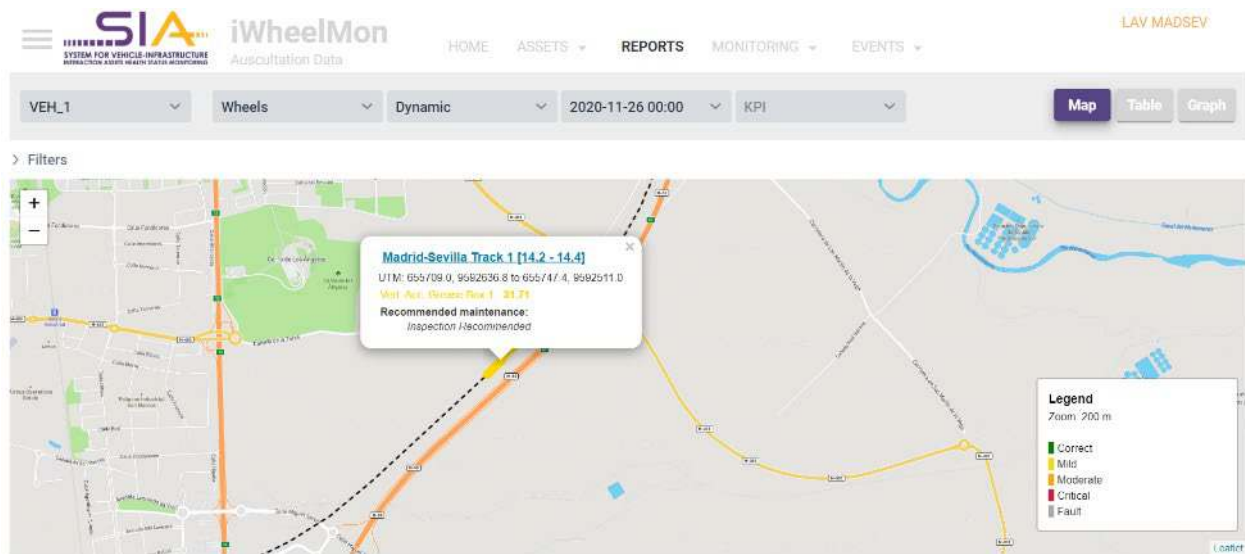


Figure 8-17. External auscultation report displayed in iWheelMon Reports

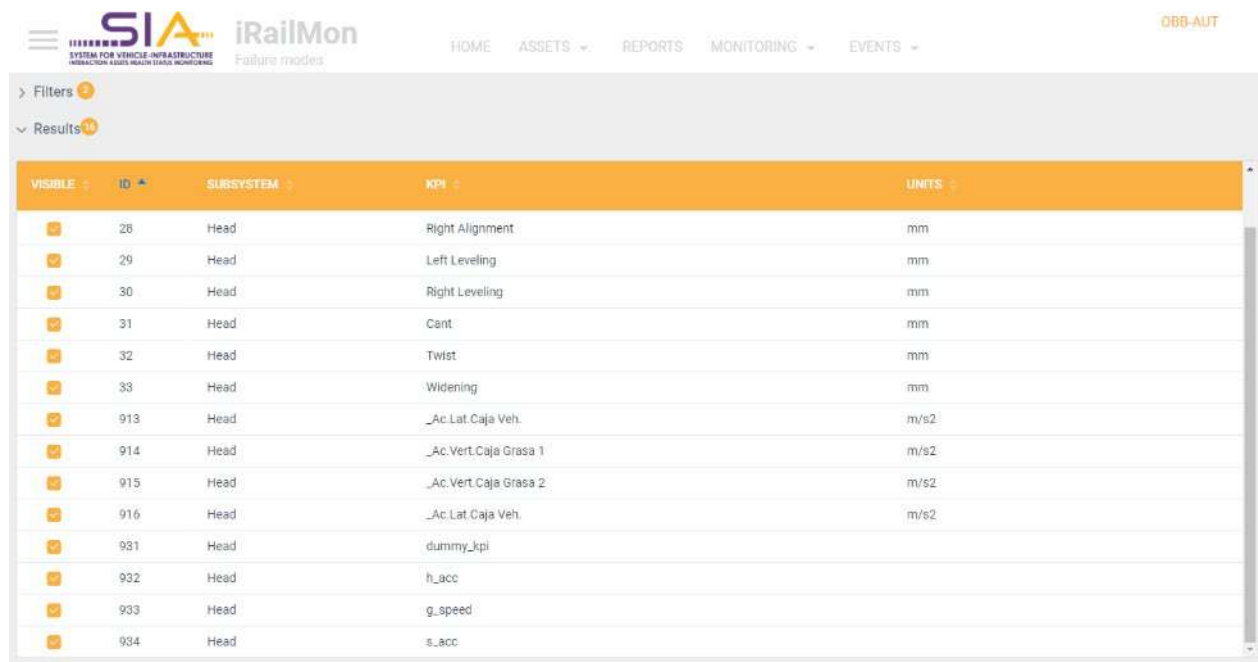
8.2 OBB validation scenario

Field tests in OBB network correspond to SIA_ABA onboard measurement equipment to provide data for iRailMon and iWheelMon SIA services. The test set up is described in Chapter 5 of deliverable D8.1. Authorized users can create in iRailMon Configuration a new online Monitoring inspection associated to rail head which we call MONITORING SIA_ABA. It has associated field measurements and KPIs as Maintenance failure modes.

The screenshot shows the iRailMon Configuration interface. A table lists existing inspections with columns for VISIBLE, ID, TYPE, NAME, and DESCRIPTION. A modal window titled 'Inspection tab' is open, allowing the creation of a new inspection. The 'Inspection name' is 'MONO' and the 'Identifier' is 'MONITORING SIA_ABA'. The 'Type' is set to 'Monitoring'. The 'Associated system' is empty, and the 'Associated components' is also empty. The 'Maintenance failure mode' is set to 'Correct'. There are buttons for 'Close' and 'Save' at the bottom of the modal.

Figure 8-18. Creation of SIA_ABA inspection using SIA configuration in iRailMon

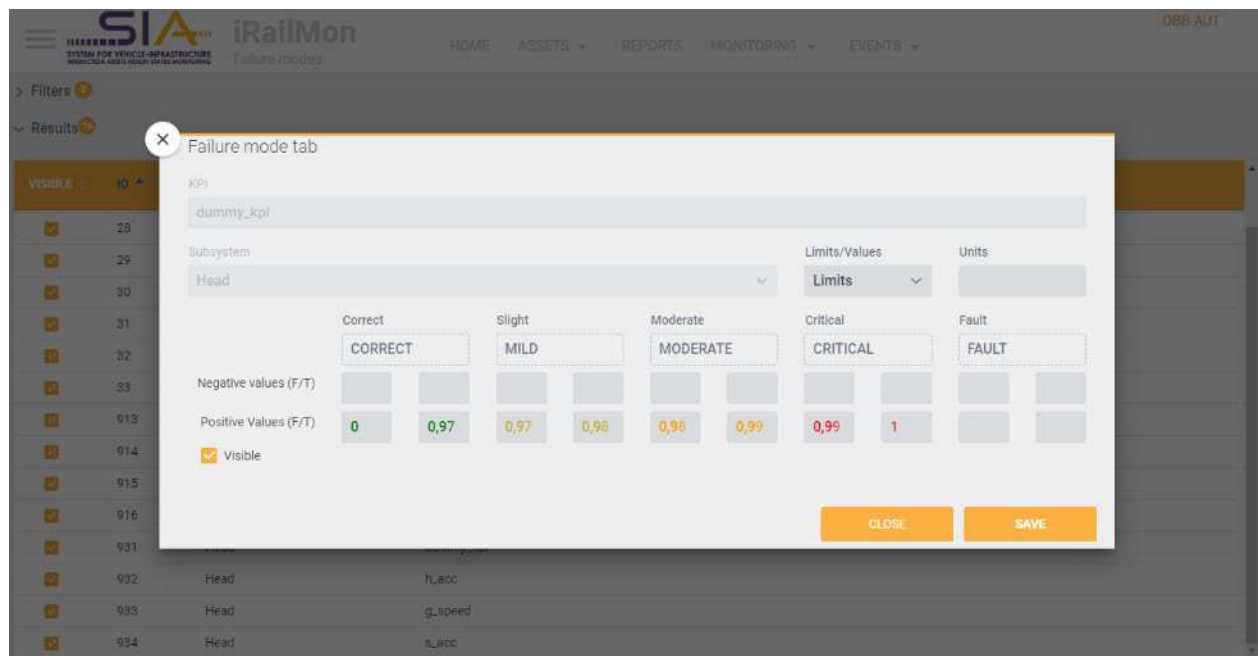
In Configuration we can configure thresholds for KPIs and raw field measurements as well.



The screenshot shows the iRailMon configuration interface. At the top, there is a navigation bar with the SIA logo, the text 'iRailMon Failure modes', and menu items: HOME, ASSETS, REPORTS, MONITORING, and EVENTS. Below the navigation bar, there is a 'Filters' section and a 'Results' section. The 'Results' section displays a table with the following columns: VISIBLE, ID, SUBSYSTEM, KPI, and UNITS. The table contains 15 rows of data, each representing a KPI configuration.

VISIBLE	ID	SUBSYSTEM	KPI	UNITS
<input checked="" type="checkbox"/>	28	Head	Right Alignment	mm
<input checked="" type="checkbox"/>	29	Head	Left Leveling	mm
<input checked="" type="checkbox"/>	30	Head	Right Leveling	mm
<input checked="" type="checkbox"/>	31	Head	Cant	mm
<input checked="" type="checkbox"/>	32	Head	Twist	mm
<input checked="" type="checkbox"/>	33	Head	Widening	mm
<input checked="" type="checkbox"/>	913	Head	_Ac.Lat.Caja Veh.	m/s2
<input checked="" type="checkbox"/>	914	Head	_Ac.Vert.Caja Grasa 1	m/s2
<input checked="" type="checkbox"/>	915	Head	_Ac.Vert.Caja Grasa 2	m/s2
<input checked="" type="checkbox"/>	916	Head	_Ac.Lat.Caja Veh.	m/s2
<input checked="" type="checkbox"/>	931	Head	dummy_kpi	
<input checked="" type="checkbox"/>	932	Head	h_acc	
<input checked="" type="checkbox"/>	933	Head	g_speed	
<input checked="" type="checkbox"/>	934	Head	s_acc	

Figure 8-19. Creation of SIA_ABA monitoring parameters and KPIs using failure modes configuration in iRailMon



The screenshot shows the iRailMon configuration interface with a 'Failure mode tab' dialog box open. The dialog box has a title bar with a close button (X) and the text 'Failure mode tab'. Inside the dialog, there is a 'KPI' field with the value 'dummy_kpi' and a 'Subsystem' dropdown menu with the value 'Head'. Below these fields, there is a 'Limits/Values' section with a 'Limits' dropdown menu. The 'Limits' dropdown menu is open, showing five options: CORRECT, MILD, MODERATE, CRITICAL, and FAULT. Each option has a corresponding input field for 'Negative values (F/T)' and 'Positive Values (F/T)'. The 'Positive Values (F/T)' field for 'CORRECT' is set to 0, and for 'MILD' it is set to 0.97. The 'Positive Values (F/T)' field for 'MODERATE' is set to 0.96, and for 'CRITICAL' it is set to 0.99. The 'Positive Values (F/T)' field for 'FAULT' is set to 1. There is also a 'Visible' checkbox which is checked. At the bottom of the dialog, there are 'CLOSE' and 'SAVE' buttons.

Figure 8-20. Setting SIA_ABA parameters thresholds in iRailMon

Once the system is configured and the georeferenced assets loaded, we can access to the user interfaces to check the data and information collected during testing campaign.

First, in iRailMon Assets Inventory users can check the line where the tests have been carried out. It is a railway track going from Linz to the Czech border. As shown in D6.1-D6.2 users can click on any point of the track to get assets information.

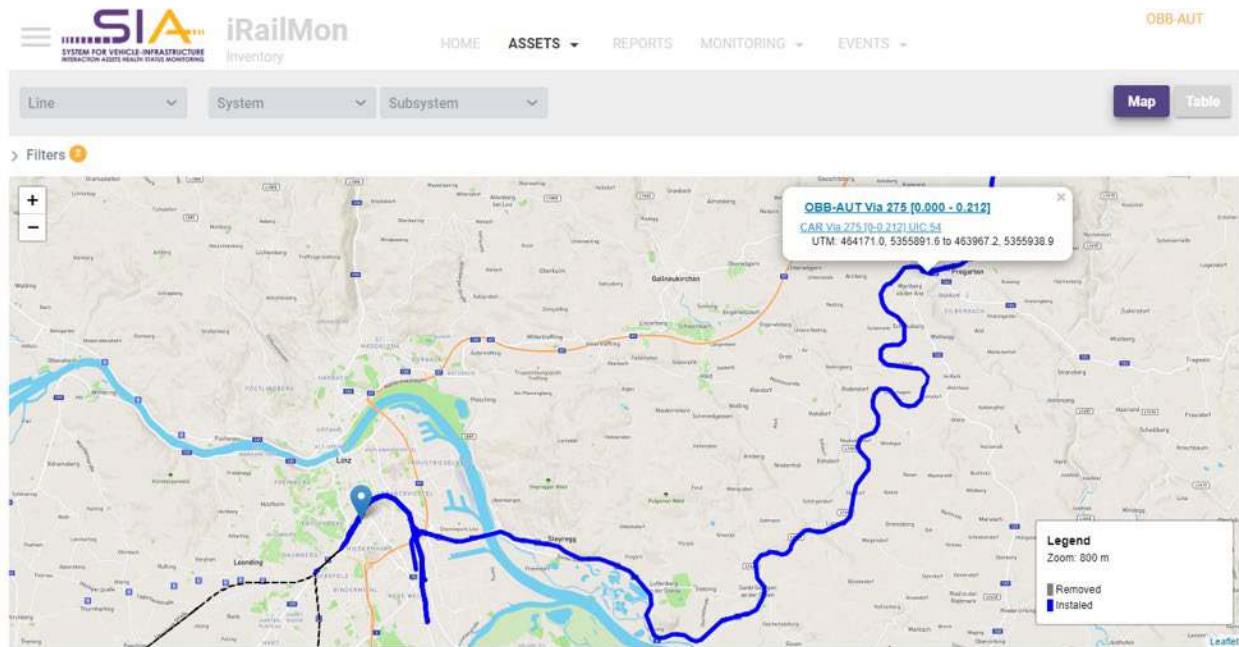


Figure 8-21. iRailMon assets inventory displayed in a map

In Monitoring menu section, users can access to raw data collected during the campaign and calculated KPIs selecting the type of inspection. In “Current” menu option they will see the latest data in the system. In the Map view the data are displayed georeferenced with different zoom levels reaching to individual measurement points supported by colours to highlight assets status. Maintenance recommendations are also displayed here.

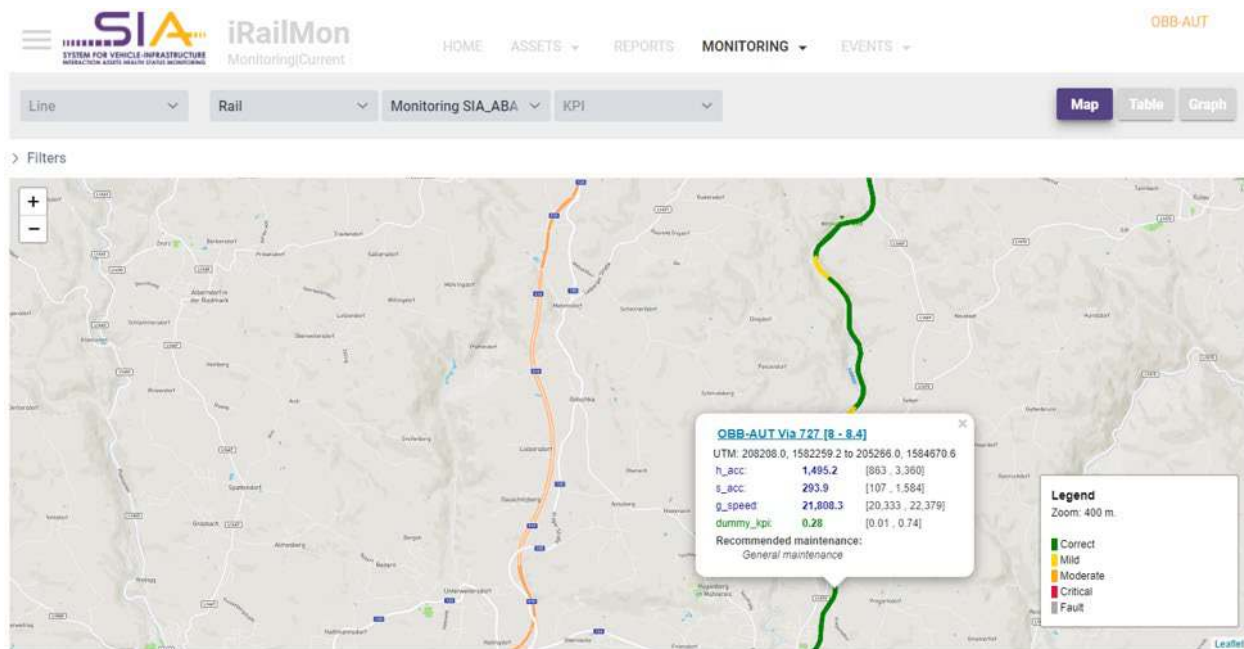


Figure 8-22. SIA_ABA measures and KPIs displayed in iRailMon Monitoring screen

As aforementioned, zooming in we can see the individual values on the map. If we click on a place with a warning on any of the values, recommended maintenance changes based on the configuration of the system. The recommended actions currently displayed by the system are only samples to demonstrate functionality. Real maintenance measures and recommendations in an operational system must come from IM expert knowledge.

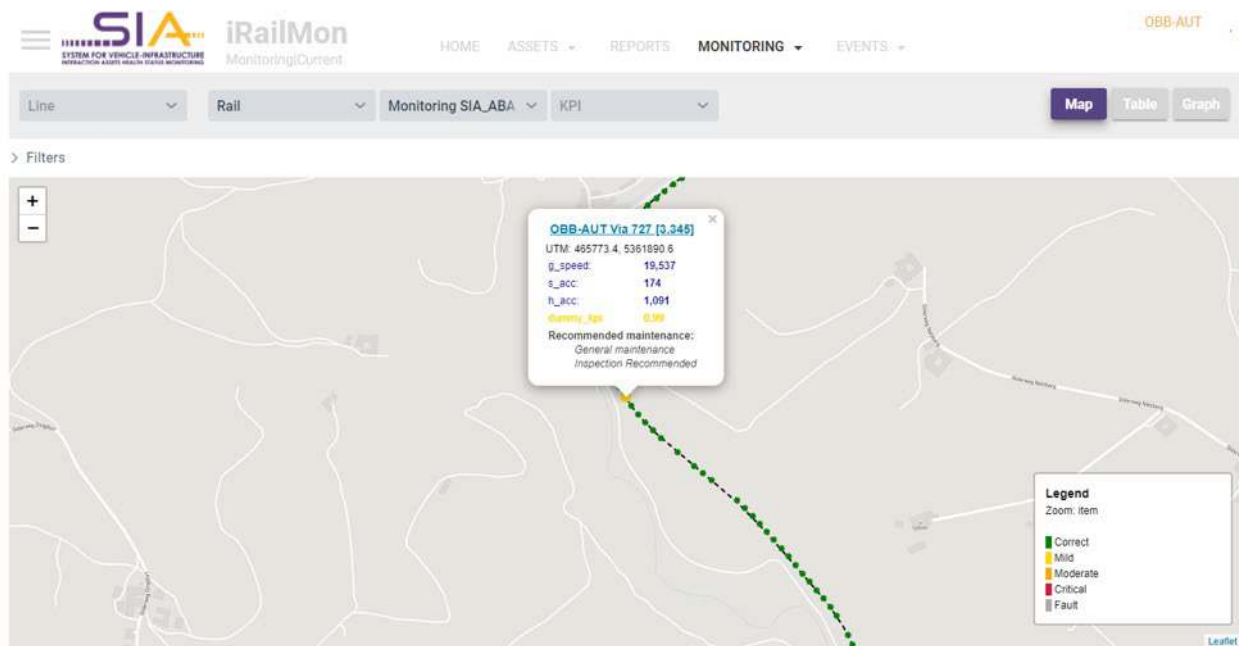


Figure 8-23. iRailMon SIA_ABA individual measurement points and maintenance recommendations zooming in the map representation

The system also displays the data in table mode and in chart mode, as shown in VIAS scenario as well.

SIA™

SYSTEM FOR VEHICLE INFRASTRUCTURE

INTERACTION WITH RAILWAYS DATA ACQUISITION

iRailMon

MonitoringCurrent

HOME

ASSETS

REPORTS

MONITORING

EVENTS

Line

Rail

Monitoring SIA_ABA

KPI

Map

Table

Graph

> Filters

< Results

Export

DATE		LOCATION			ASSET		VALUES			
DAY	HOUR	LINE	TRACK	KPI IN	KPI END	NAME	DESCRIPTION	KPI	VALUE	STATE
16/03/2021	17:26	AU	Track 5140	0.004		CAR	UIC 54 (Track 5140)	s_acc	138	
16/03/2021	17:26	AU	Track 5140	0.004		CAR	UIC 54 (Track 5140)	dummy_kpi	0.8603793	Correct
16/03/2021	17:26	AU	Track 5140	0.004		CAR	UIC 54 (Track 5140)	h_acc	713	Correct
16/03/2021	17:26	AU	Track 5140	0.004		CAR	UIC 54 (Track 5140)	g_speed	11212	Correct
16/03/2021	17:26	AU	Track 3361	0.005		CAR	UIC 54 (Track 3361)	s_acc	131	
16/03/2021	17:26	AU	Track 3361	0.005		CAR	UIC 54 (Track 3361)	dummy_kpi	0.28807098	Correct
16/03/2021	17:26	AU	Track 3361	0.005		CAR	UIC 54 (Track 3361)	h_acc	713	Correct
16/03/2021	17:26	AU	Track 3361	0.005		CAR	UIC 54 (Track 3361)	g_speed	10910	Correct
16/03/2021	17:26	AU	Track 727	0.006		CAR	UIC 54 (Track 727)	s_acc	131	
16/03/2021	17:26	AU	Track 727	0.006		CAR	UIC 54 (Track 727)	h_acc	720	Correct
16/03/2021	17:26	AU	Track 727	0.006		CAR	UIC 54 (Track 727)	dummy_kpi	0.69861275	Correct
16/03/2021	17:26	AU	Track 727	0.006		CAR	UIC 54 (Track 727)	g_speed	10916	Correct
16/03/2021	17:17	AU	Track 3768	0.011		CAR	UIC 54 (Track 3768)	s_acc	122	
16/03/2021	17:17	AU	Track 3768	0.011		CAR	UIC 54 (Track 3768)	dummy_kpi	0.51095384	Correct

Figure 8-24. iRailMon SIA_ABA individual measures in table view mode

In the menu section Events, online notifications of possible issues generated by onboard equipment and immediately sent to SIA_VP are displayed to the network operators, who can act on them immediately if needed.

SIA

SYSTEM FOR VEHICLE INFRASTRUCTURE

MONITORING ASSETS AND EVENTS FOR THE RAILWAY

iRailMon

Events | Current

HOME

ASSETS

REPORTS

MONITORING

EVENTS

OBB-AUT

Line

ABA_2_axis_0_low_peak

New

Table

Map

> Filters

< Results

Export

DATE		LOCATION			VEHICLE				
DAY	HOUR	LINE	TRACK	KP	NAME	DESCRIPTION	VALUE	STATE	
17/03/2021	13:59	AU	Via 5519	0.228	VEH_1	Locomotive Alsto...	1.0601661	ABA_2_axis_0_l...	New
17/03/2021	13:59	AU	Via 5519	0.216	VEH_1	Locomotive Alsto...	1.0629299	ABA_2_axis_0_l...	New
17/03/2021	13:48	AU	Via 5519	0.204	VEH_1	Locomotive Alsto...	1.0631605	ABA_2_axis_0_l...	New
17/03/2021	12:58	AU	Via 5519	0.192	VEH_1	Locomotive Alsto...	1.0631206	ABA_2_axis_0_l...	Read
17/03/2021	12:50	AU	Via 5519	0.18	VEH_1	Locomotive Alsto...	1.0471723	ABA_2_axis_0_l...	Read
17/03/2021	07:30	AU	Via 5519	0.168	VEH_1	Locomotive Alsto...	1.0664741	ABA_2_axis_0_l...	In progress
17/03/2021	07:11	AU	Via 5519	0.156	VEH_1	Locomotive Alsto...	1.0481536	ABA_2_axis_0_l...	In progress
17/03/2021	06:48	AU	Via 5519	0.144	VEH_1	Locomotive Alsto...	1.0407497	ABA_2_axis_0_l...	New

Figure 8-25. iRailMon online events raised by SIA_ABA displayed in Events menu option

And double-clicking on any of the events, it is positioned on the map.

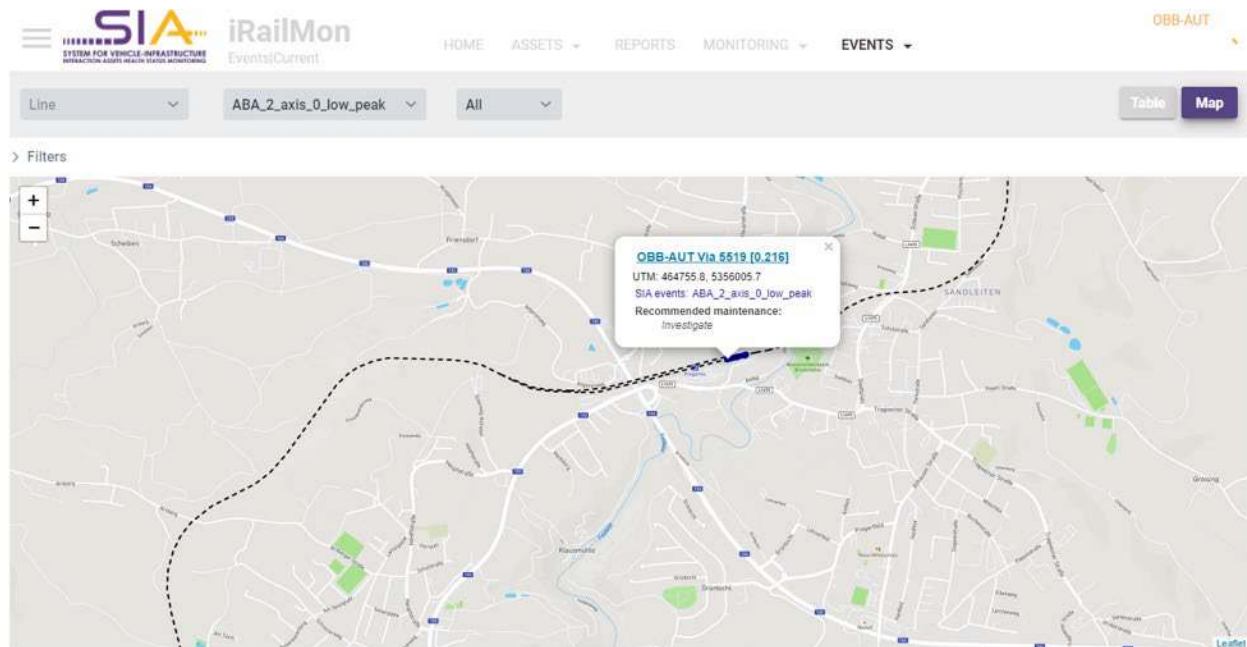


Figure 8-26. iRailMon map positioning of an online event

Similarly, the data collected by SIA_ABA can also be used in iWheelMon to assess the wheelset health status instead of the rails. Authorized users can create a similar inspection in iWheelMon configuration addressing relevant KPIs for the wheelset.

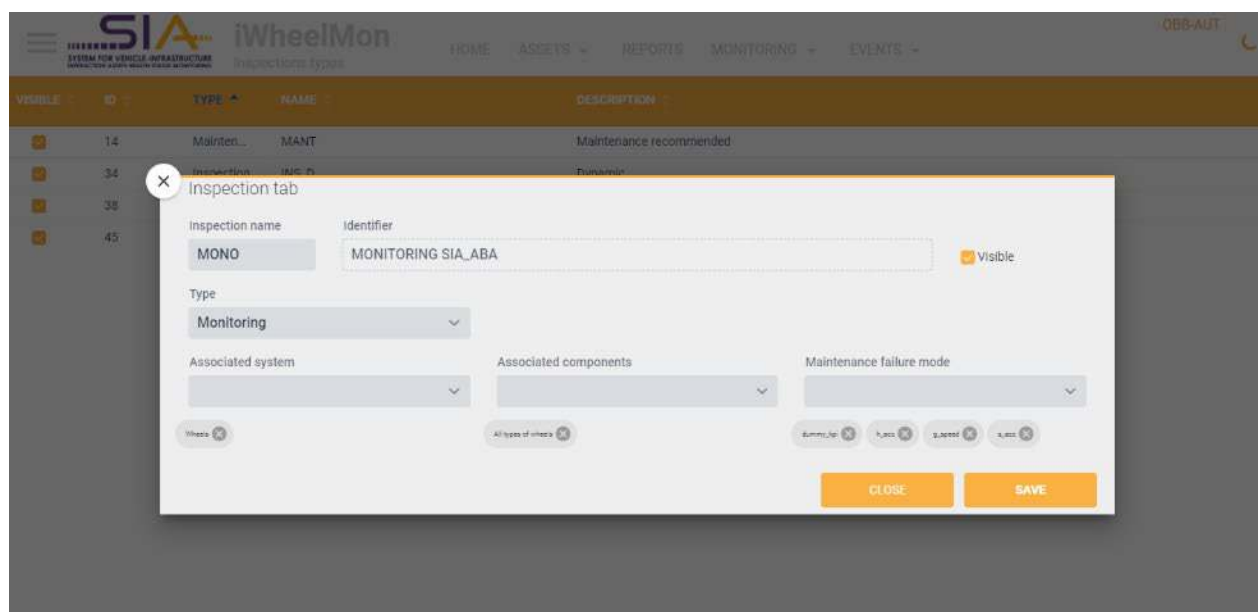


Figure 8-27. iWheelMon SIA_ABA inspection configuration

Raw data and KPIs are also displayed on map, table and charts with maintenance recommendations. In the next figure, configuring very narrow limits we can get a Critical warning requiring an immediate Maintenance recommendation.

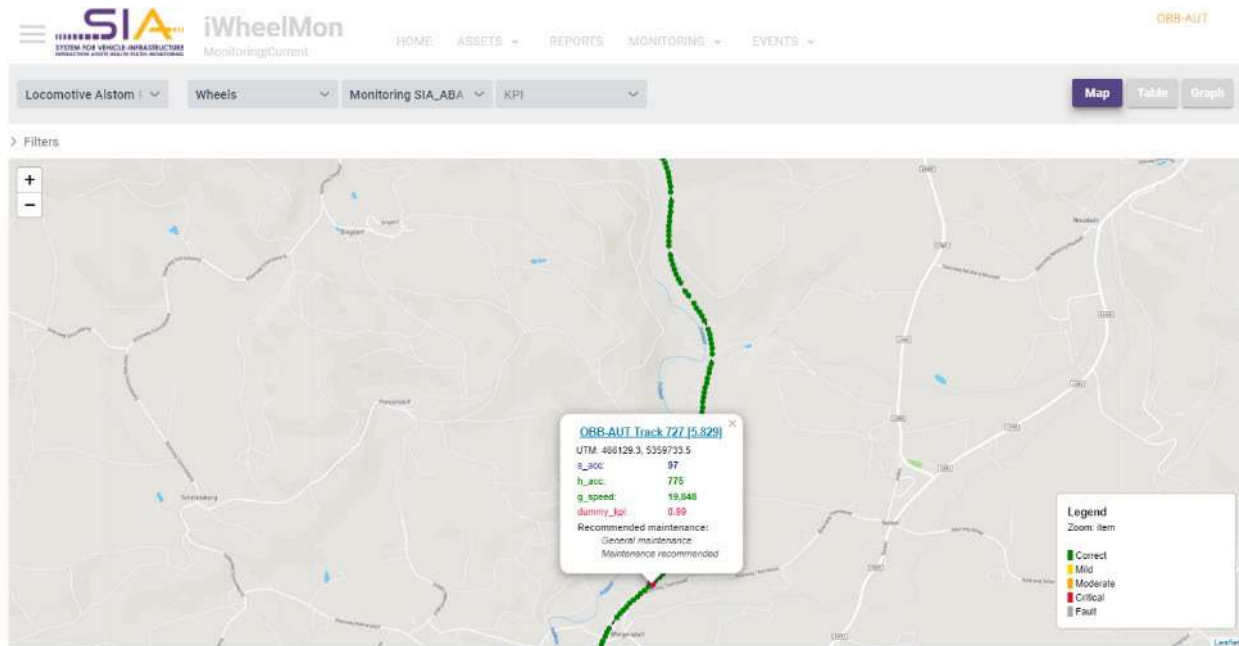


Figure 8-28. iWheelMon monitoring data and maintenance recommendations in Monitoring screen

iWheelMon has its own Events associated to vehicles assets instead of railtracks.

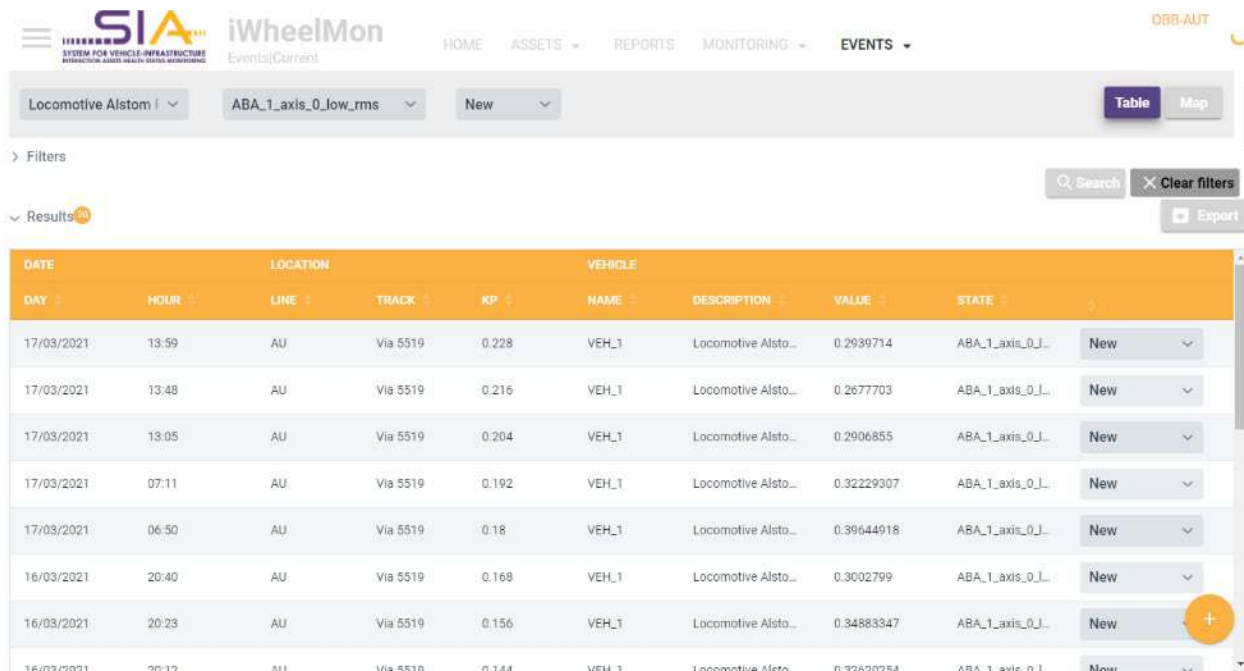


Figure 8-29. iWheelMon online events

8.3 FGC Validation Scenario

Field testing in FGC network correspond to SIA_PANT onboard measurement equipment to provide data for iCatMon and iPantMon SIA services. The test set up is described in Chapter 4 of deliverable D8.1. Additionally, TELICE has carried out an offline catenary inspection using its tCat® system. This test is described in Section 4.3.2 of D8.1 and the results loaded in iCatMon as described in next section 8.3.1.

8.3.1 SIA_PANT testing results representation

As in previous scenarios, authorized users can create in iCatMon Configuration a new online Monitoring inspection associated to the contact wire which we call MONITORING SIA_PANT. It has associated field measurements and KPIs as Maintenance failure modes, whose thresholds can be configured in Failure Mode Tab:

The screenshot displays the 'Inspection tab' in the iCatMon Configuration application. The form includes the following fields and controls:

- Inspection name:** MONF
- Identifier:** SIA_C_MON_FGC
- Inspection description:** Monitoring SIA_PANT
- Visible:** ☒
- Type:** Monitoring (dropdown menu)
- Associated system:** (empty dropdown menu)
- Associated components:** (empty dropdown menu)
- Maintenance failure mode:** (empty dropdown menu)
- Wire:** (button with an 'x' icon)
- Contact wire:** (button with an 'x' icon)
- Acceleration X base:** (button with an 'x' icon)
- Acceleration Y base:** (button with an 'x' icon)
- Acceleration Z base:** (button with an 'x' icon)
- Acceleration X inclinometer:** (button with an 'x' icon)
- Acceleration Y inclinometer:** (button with an 'x' icon)
- Inclinometer Gyroscope X:** (button with an 'x' icon)
- Inclinometer Gyroscope Y:** (button with an 'x' icon)
- Buttons:** CLOSE, SAVE, DELETE

Figure 8-30. Creation of SIA_PANT inspection using iCatMon configuration

Failure mode tab

Identifier: SIA_C_ACC_Y Description: Acceleration Y base

Subsystem: Contact wire Limits/Values: Limits Units:

	Correct	Slight	Moderate	Critical	Fault
Negative values (F/T)	-0,1 0		-0,12 -0,1	-9 -0,12	
Positive Values (F/T)	0 0,1		0,1 0,12	0,12 9	

☒ Visible

Buttons: CLOSE, SAVE, DELETE

Figure 8-31. Setting SIA_PANT parameters thresholds in iCatMon

Once the system is configured and FGC's georeferenced assets loaded, operators can access to the user interfaces to check the data and information collected during testing campaign.

In the case of Assets information, in the corresponding menu screens display the assets in FGC network in table mode or georeferenced in a map with different filtering options.

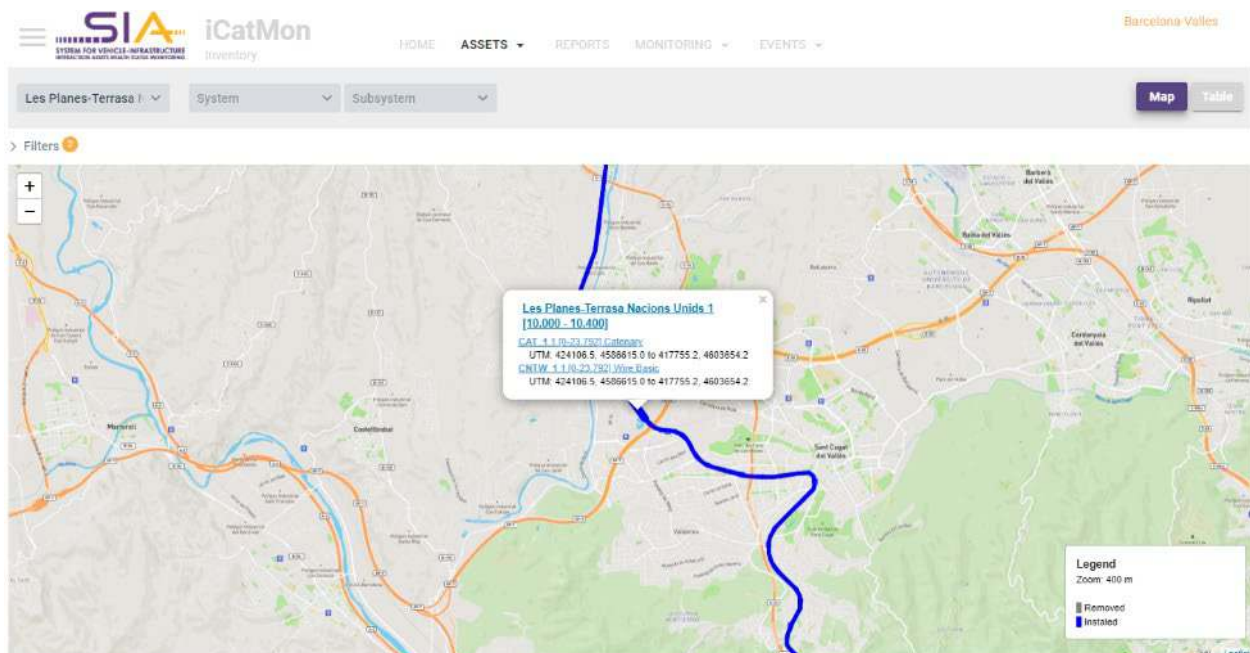


Figure 8-32. Catenary assets displayed in iCatMon

As stated in D8.1, testing campaign in FGC has been carried out switching on SIA_PANT system automatically and remotely to collect data from the sections of interest for the project

between the stations of Rubi and Mirasol. In Monitoring Menu in the Option Current Monitoring, the screen displays the latest data/KPIs in the system. By default, low zoom resolution is displayed, with data aggregated by sections showing minimum, maximum and average values. iCatMon also suggests a recommended maintenance based on the asset status.

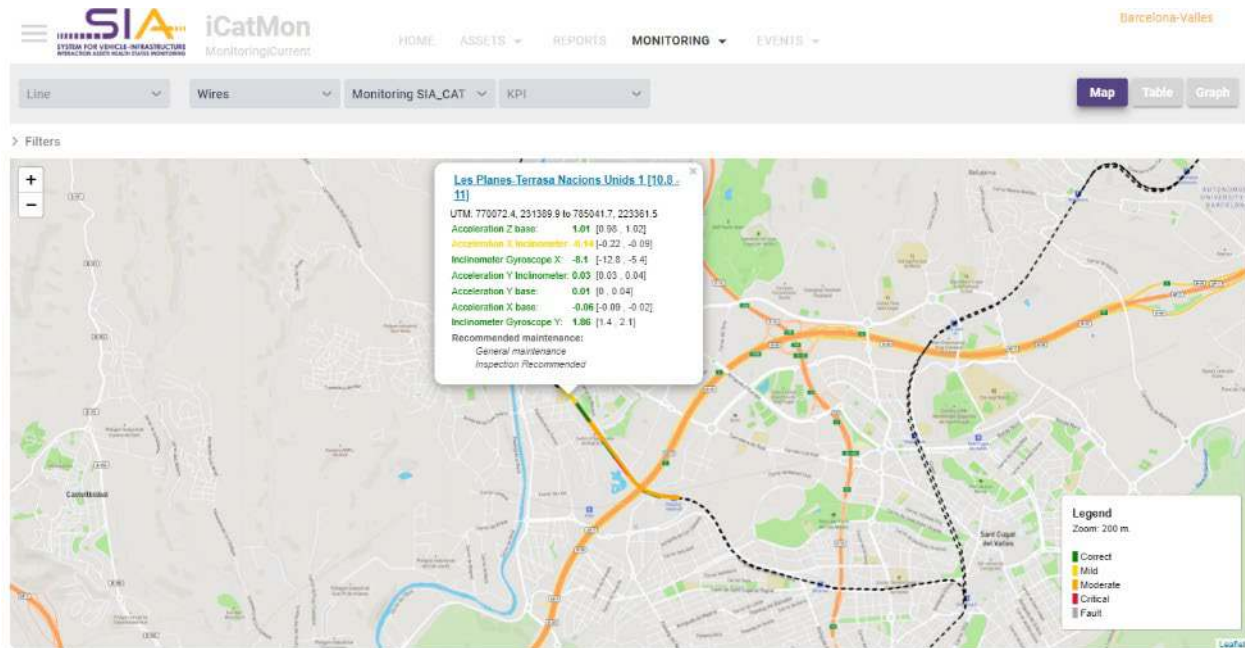


Figure 8-33. iCatMon monitoring information displayed in map representation

As in previous scenarios, zooming in more the screen displays individual measurement points on the track with the values of the parameters.

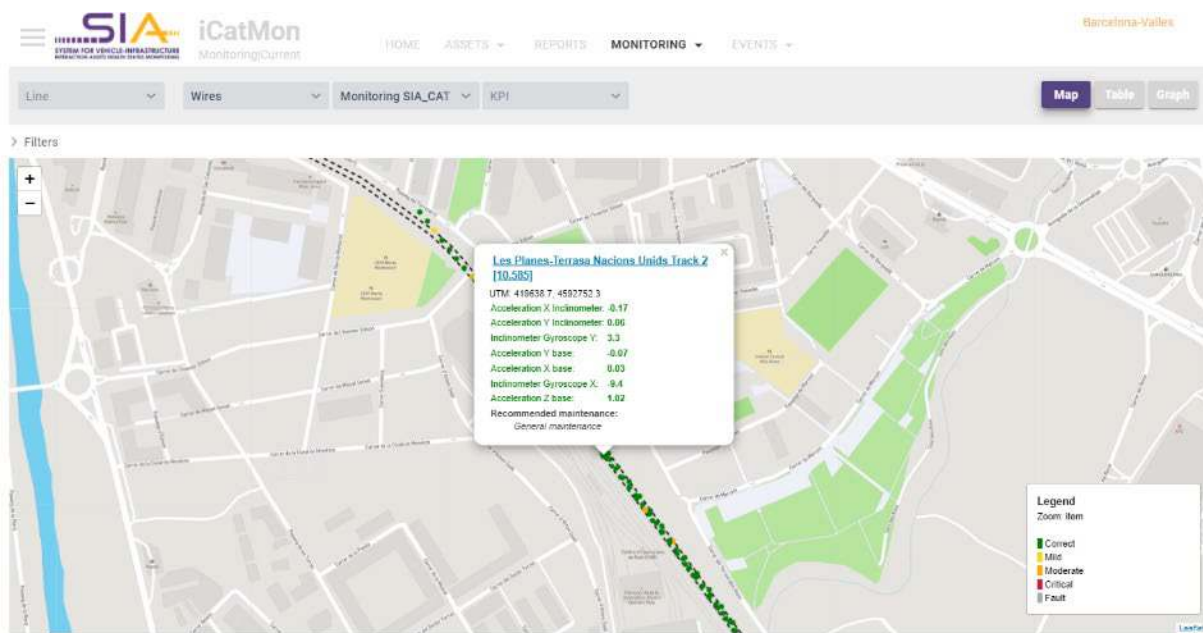


Figure 8-34. iCatMon individual measurements/KPIs georeferenced in a map

Data selected can be also displayed in table and chart views for their analysis.

SIA

SYSTEM FOR VEHICLE INFRASTRUCTURE

INTERACTION AND DATA MONITORING

iCatMon

MonitoringCurrent

HOME

ASSETS

REPORTS

MONITORING

EVENTS

Barcelona-Valles

Line

Wires

Monitoring SIA_CAT

Acceleration X base

Map

Table

Graph

> Filters

< Results

Export

DATE		LOCATION		ASSET		VALUES				
DAY	HOUR	LINE	TRACK	KP (m)	KP END	NAME	DESCRIPTION	KPI	VALUE	STATE
08/07/2021	01:52	LP-NA	Track 1	9.403		CNTW_1	Wire 1 Track 1	Acceleration X b...	-0.015624	Correct
08/07/2021	01:52	LP-NA	Track 1	9.404		CNTW_1	Wire 1 Track 1	Acceleration X b...	-0.003906	Correct
08/07/2021	01:52	LP-NA	Track 1	9.405		CNTW_1	Wire 1 Track 1	Acceleration X b...	-0.011718	Correct
08/07/2021	01:52	LP-NA	Track 1	9.408		CNTW_1	Wire 1 Track 1	Acceleration X b...	-0.007812	Correct
08/07/2021	01:52	LP-NA	Track 1	9.411		CNTW_1	Wire 1 Track 1	Acceleration X b...	-0.011718	Correct
08/07/2021	01:52	LP-NA	Track 1	9.414		CNTW_1	Wire 1 Track 1	Acceleration X b...	-0.015624	Correct
08/07/2021	01:52	LP-NA	Track 1	9.418		CNTW_1	Wire 1 Track 1	Acceleration X b...	-0.003906	Correct
08/07/2021	01:52	LP-NA	Track 1	9.422		CNTW_1	Wire 1 Track 1	Acceleration X b...	-0.011718	Correct
08/07/2021	01:52	LP-NA	Track 1	9.426		CNTW_1	Wire 1 Track 1	Acceleration X b...	-0.011718	Correct
08/07/2021	01:52	LP-NA	Track 1	9.43		CNTW_1	Wire 1 Track 1	Acceleration X b...	-0.007812	Correct
08/07/2021	01:52	LP-NA	Track 1	9.434		CNTW_1	Wire 1 Track 1	Acceleration X b...	-0.015624	Correct
08/07/2021	01:52	LP-NA	Track 1	9.438		CNTW_1	Wire 1 Track 1	Acceleration X b...	-0.007812	Correct
08/07/2021	01:52	LP-NA	Track 1	9.443		CNTW_1	Wire 1 Track 1	Acceleration X b...	-0.015624	Correct
08/07/2021	01:52	LP-NA	Track 1	9.447		CNTW_1	Wire 1 Track 1	Acceleration X b...	-0.007812	Correct

Figure 8-35. iCatMon measured data displayed in table view



Figure 8-36. iCatMon measured data displayed in charts

Also in monitoring Menu, if we select Historical option, SIA_VP displays a similar screen to the Current one we have just shown. Main difference is that there is date selector to select past data in a specific day, week, month or year, instead of the latest ones.

Then, for a specific position in the map, the average, minimum and maximum values in the period will be shown to the user.

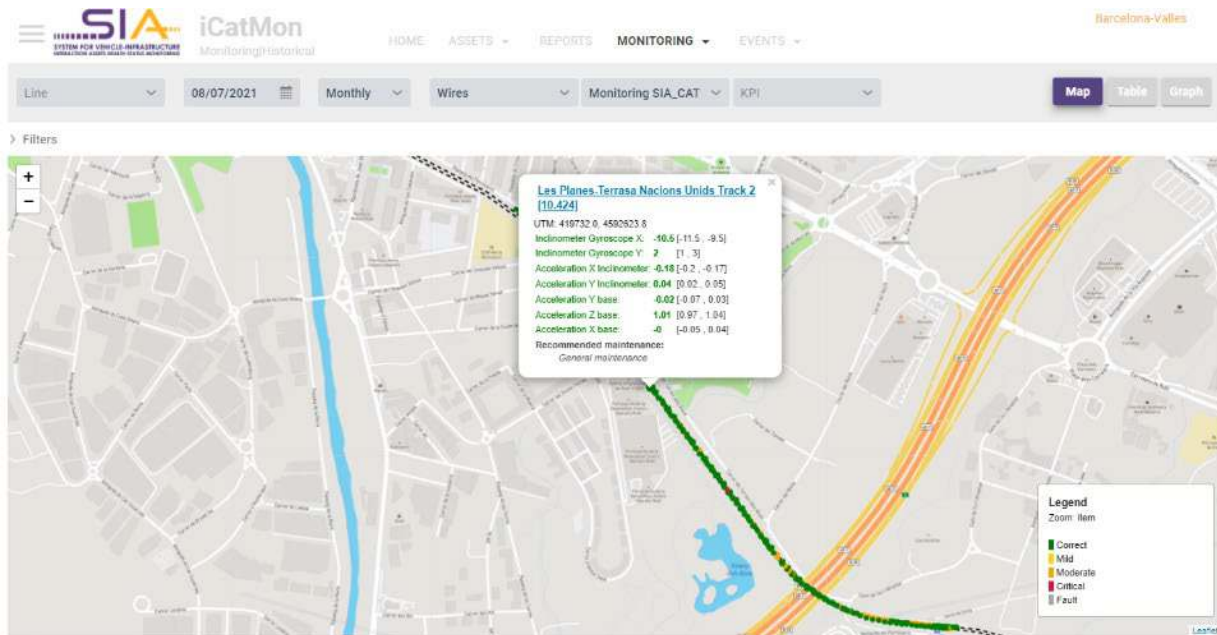


Figure 8-37. iCatMon historical data displayed in a map

As usual in SIA_VP, there is also available the option of displaying the data in table or graphic mode. In the case of the charts, for historical data there is the possibility of doing both a spatial and a time analysis. The spatial analysis is like the one we have already seen in previous examples, but for each position the range of values in the period of analysis is displayed.

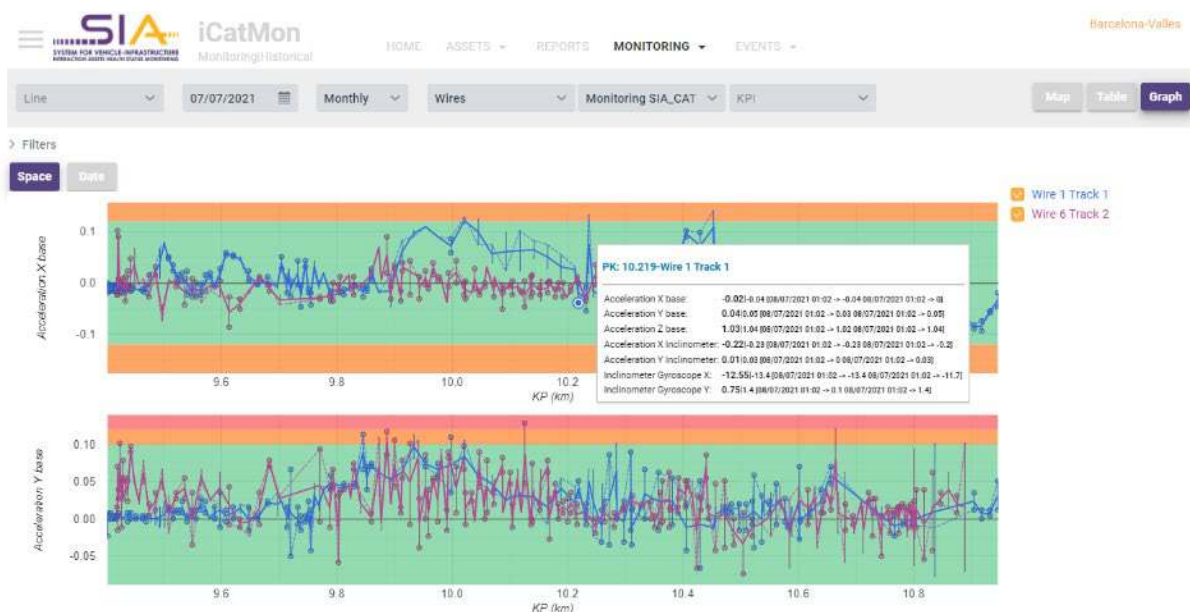


Figure 8-38. iCatMon historical data displayed for spatial analysis in charts

In the case of the asset evolution with time, users can select a period of time and a section of the track (200 m in the example in Figure 8-37), and the system displays the average, maximum and minimum values for all the values measured and calculated each of the occasions a train with SIA_PANT has operated in the area.

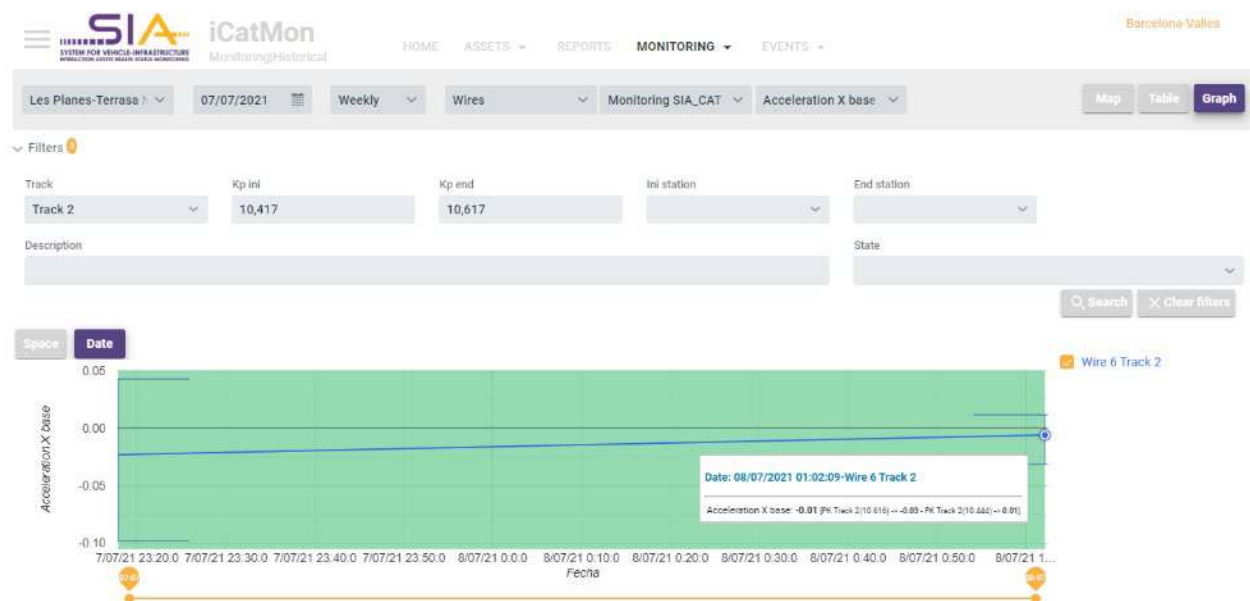


Figure 8-39. iCatMon historical data displayed for time analysis in charts

In iCatMon there is also an Events screen, where events raised online by SIA_PANT are immediately sent to be displayed to the SIA operators.

SIA

SYSTEM FOR INFRASTRUCTURE ANALYSIS

iCatMon

EventsCurrent

HOME

ASSETS

REPORTS

MONITORING

EVENTS

Line

State

New

Table

Map

Filters

Results

Export

DATE		LOCATION			VEHICLE				
DAY	HOUR	LINE	TRACK	KP	NAME	DESCRIPTION	VALUE	STATE	
13/07/2021	16:43	LP-NA	2	10.543	VEH_1	VEH_1	-30.5	Impact	New
13/07/2021	16:43	LP-NA	2	10.543	VEH_1	VEH_1	-28.8	Impact	New
13/07/2021	14:25	LP-NA	2	10.543	VEH_1	VEH_1	-29.3	Impact	New
13/07/2021	12:30	LP-NA	2	10.543	VEH_1	VEH_1	-28.5	Impact	New
13/07/2021	12:30	LP-NA	2	10.543	VEH_1	VEH_1	-28.5	Impact	New
13/07/2021	12:24	LP-NA	2	10.543	VEH_1	VEH_1	-28.9	Impact	New
13/07/2021	12:24	LP-NA	2	10.543	VEH_1	VEH_1	-28.9	Impact	New
13/07/2021	12:24	LP-NA	2	10.543	VEH_1	VEH_1	-28.7	Impact	New
13/07/2021	12:24	LP-NA	2	10.543	VEH_1	VEH_1	-28.7	Impact	New

Figure 8-40. iCatMon events screen

Double-clicking on any of them, SIA_VP positions it on a map with a recommended action.

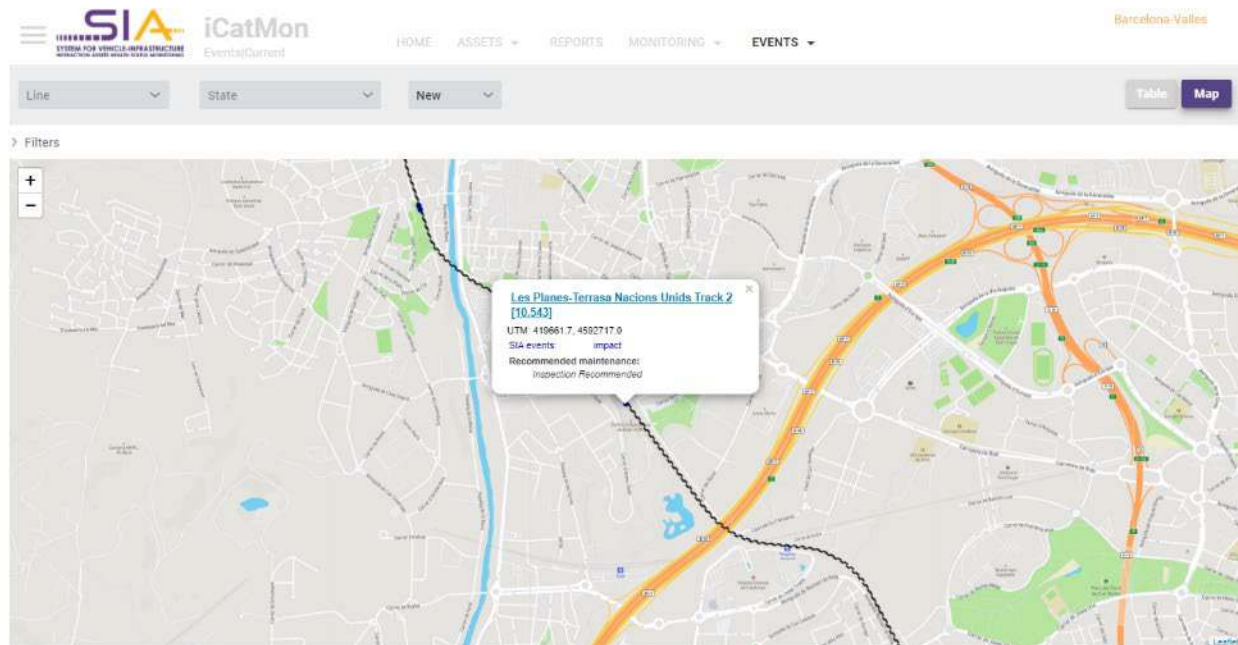


Figure 8-41. iCatMon event positioned in a map with recommended action

Data collected by SIA_PANT are also useful to assess the health status of pantograph additionally to what we have just checked for catenary. So, selecting the iPantMon SIA service in the main menu (Figure 8-1. SIA Home page). Authorized users can create a similar online inspection in iPantMon configuration addressing relevant KPIs for the pantograph, and also create pantograph related assets in the system.

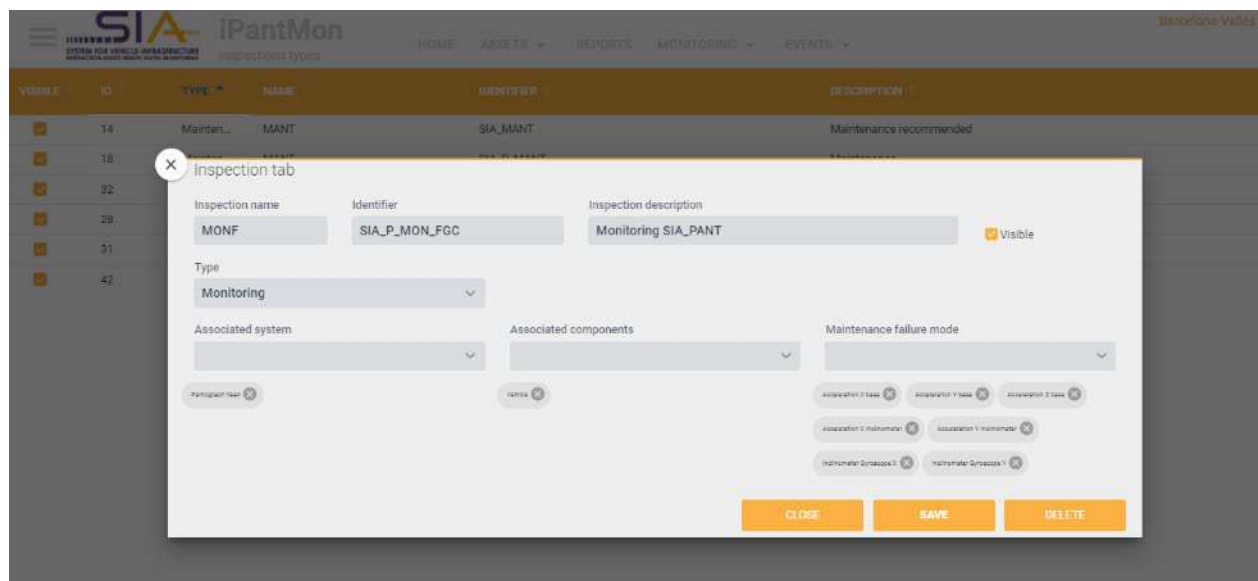
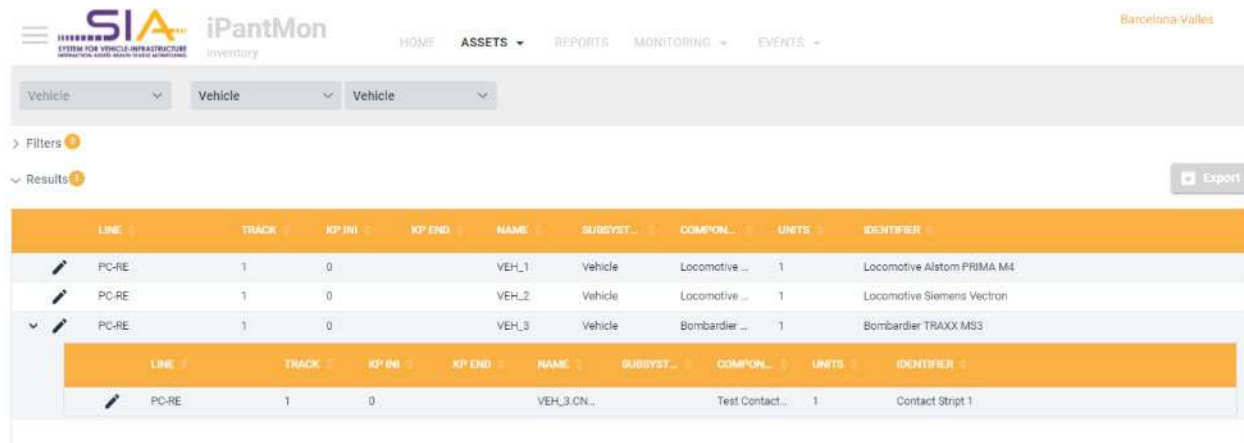


Figure 8-42. iPantMon Inspection configuration module

Once iPantMon is ready to be operational, users can check the assets, which in this case are locomotives with a pantograph and its components (e.g. contact strip). They are only displayed in Table mode as they are not assets fixed to a position.



The screenshot shows the iPantMon interface with the 'ASSETS' tab selected. Below the navigation bar, there are three dropdown menus, all set to 'Vehicle'. A 'Filters' button is visible. The main content area displays a table of assets. The table has columns: LINE, TRACK, KP INI, KP END, NAME, SUBSYSTEM, COMPONENT, UNITS, and IDENTIFIER. The data rows show three locomotives: VEH_1 (Alstom PRIMA M4), VEH_2 (Siemens Vectron), and VEH_3 (Bombardier TRAXX MS3). Below the main table, there is a collapsed section showing a 'Test Contact' component for VEH_3.

LINE	TRACK	KP INI	KP END	NAME	SUBSYSTEM	COMPONENT	UNITS	IDENTIFIER
PC-RE	1	0		VEH_1	Vehicle	Locomotive ...	1	Locomotive Alstom PRIMA M4
PC-RE	1	0		VEH_2	Vehicle	Locomotive ...	1	Locomotive Siemens Vectron
PC-RE	1	0		VEH_3	Vehicle	Bombardier ...	1	Bombardier TRAXX MS3
PC-RE	1	0		VEH_3_CN...		Test Contact...	1	Contact Strip 1

Figure 8-43. iPantMon assets screen

In Monitoring users can check the measurements and KPIs associated to pantograph components selecting the appropriate failure mode previously configured (Monitoring SIA_PANT). Data are displayed in map, table and charts mode for their analysis as seen for iCatMon previously. The system also recommends maintenance activities based on the health status of the assets that data reveal.

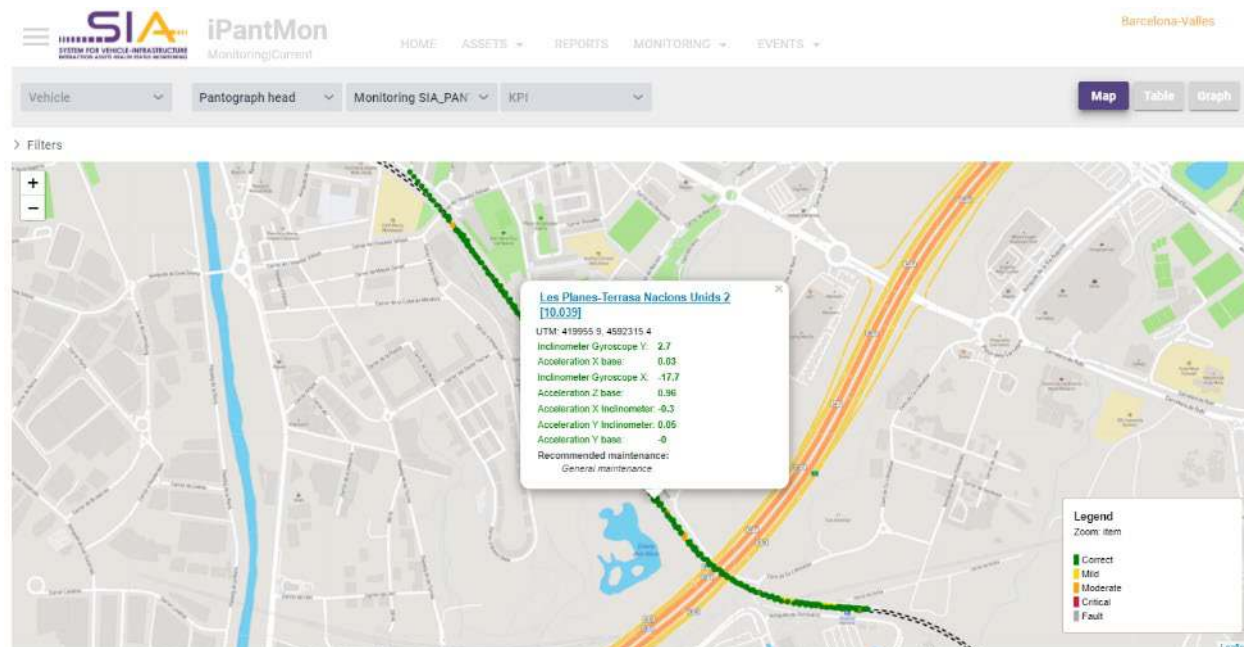


Figure 8-44. SIA_PANT measured values displayed in map in iPantMon

Data can be also displayed in a table mode, with the associated pantograph asset in the vehicle carrying SIA_PANT equipment.

DATE		LOCATION		KPI		ASSET		VALUES		
DAY	HOUR	LINE	TRACK	KPI ID	KPI END	NAME	DESCRIPTION	KPI	VALUE	STATE
08/07/2021	01:52	LP-NA	Track 1	9.403		VEH_3.CNTS...	Contact Stript 1	Inclinometer Gyr...	2.3	Correct
08/07/2021	01:52	LP-NA	Track 1	9.403		VEH_3.CNTS...	Contact Stript 1	Acceleration X b...	-0.015624	Correct
08/07/2021	01:52	LP-NA	Track 1	9.403		VEH_3.CNTS...	Contact Stript 1	Acceleration Z b...	1.011654	Correct
08/07/2021	01:52	LP-NA	Track 1	9.403		VEH_3.CNTS...	Contact Stript 1	Acceleration X in...	-0.3293	Correct
08/07/2021	01:52	LP-NA	Track 1	9.403		VEH_3.CNTS...	Contact Stript 1	Inclinometer Gyr...	-19.2	Correct
08/07/2021	01:52	LP-NA	Track 1	9.403		VEH_3.CNTS...	Contact Stript 1	Acceleration Y in...	0.039775	Correct
08/07/2021	01:52	LP-NA	Track 1	9.403		VEH_3.CNTS...	Contact Stript 1	Acceleration Y b...	0.003906	Correct
08/07/2021	01:52	LP-NA	Track 1	9.404		VEH_3.CNTS...	Contact Stript 1	Acceleration Y in...	0.039775	Correct
08/07/2021	01:52	LP-NA	Track 1	9.404		VEH_3.CNTS...	Contact Stript 1	Inclinometer Gyr...	-19.1	Correct
08/07/2021	01:52	LP-NA	Track 1	9.404		VEH_3.CNTS...	Contact Stript 1	Acceleration X in...	-0.328375	Correct
08/07/2021	01:52	LP-NA	Track 1	9.404		VEH_3.CNTS...	Contact Stript 1	Acceleration X b...	-0.003906	Correct
08/07/2021	01:52	LP-NA	Track 1	9.404		VEH_3.CNTS...	Contact Stript 1	Acceleration Y b...	0	Correct
08/07/2021	01:52	LP-NA	Track 1	9.404		VEH_3.CNTS...	Contact Stript 1	Acceleration Z b...	1.003842	Correct
08/07/2021	01:52	LP-NA	Track 1	9.404		VEH_3.CNTS...	Contact Stript 1	Inclinometer Gyr...	2.3	Correct

Figure 8-45. iPantMon measures associated to rolling stock assets in table mode

Monitoring information can be also displayed in table and graphical mode as in the other SIA services described in previous sections. Historical and predicted values are also available in Monitoring menu with similar functionalities.

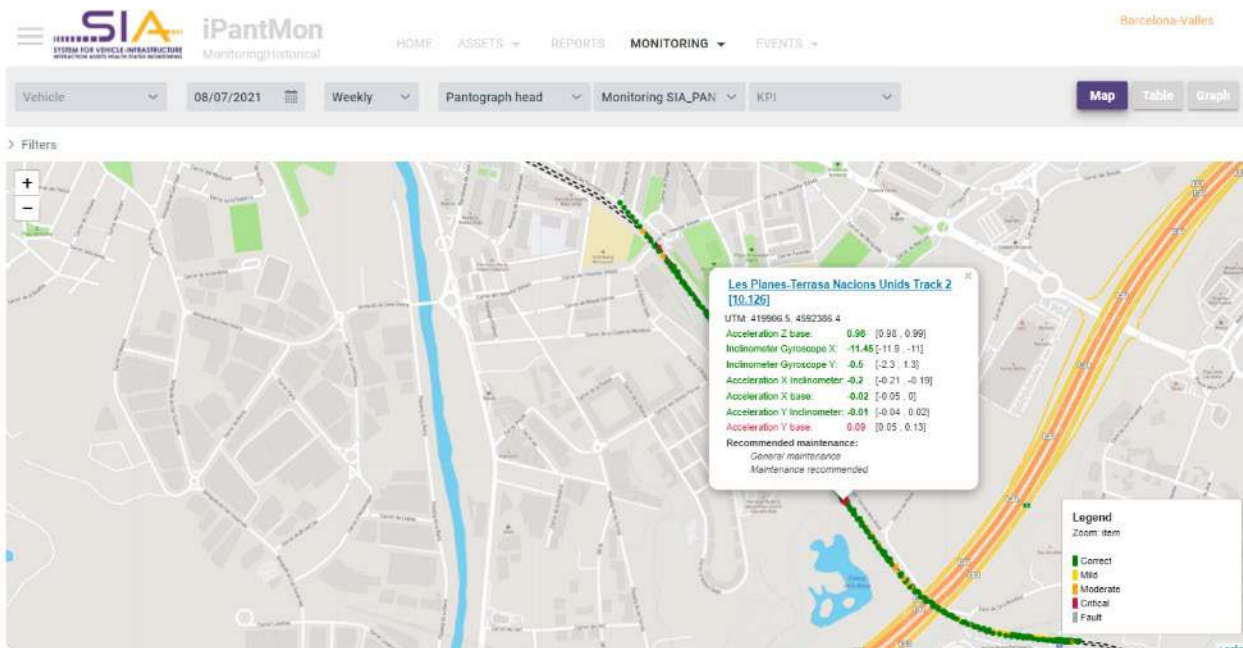


Figure 8-46. iPantMon historical data displayed in map mode

Finally, iPantMon also displays its own online real time Events warning about the pantograph status. Double clicking on each one user will be positioned in the map where the event was

raised.

DATE		LOCATION		VEHICLE		VALUE	STATE
DAY	HOUR	LINE	TRACK	KP	NAME	DESCRIPTION	
13/07/2021	16:43	LP-NA	2	10.543	VEH_1	VEH_1	-30.5 Impact New
13/07/2021	16:43	LP-NA	2	10.543	VEH_1	VEH_1	-28.8 Impact New
13/07/2021	14:25	LP-NA	2	10.543	VEH_1	VEH_1	-29.3 Impact New
13/07/2021	12:30	LP-NA	2	10.543	VEH_1	VEH_1	-28.5 Impact New
13/07/2021	12:30	LP-NA	2	10.543	VEH_1	VEH_1	-28.5 Impact New
13/07/2021	12:24	LP-NA	2	10.543	VEH_1	VEH_1	-28.9 Impact New
13/07/2021	12:24	LP-NA	2	10.543	VEH_1	VEH_1	-28.9 Impact New
13/07/2021	12:24	LP-NA	2	10.543	VEH_1	VEH_1	-28.7 Impact New
13/07/2021	12:24	LP-NA	2	10.543	VEH_1	VEH_1	-28.7 Impact New

Figure 8-47. iPantMon events

8.3.2 tCat® testing results representation

The last testing scenario is related to uploading to SIA platform the results of catenary auscultation carried out with tCat® system in FGC. Similarly to what was described in deliverable D7.1 [15] to upload SIA the tCat® reports or any other inspection, auscultation or maintenance reports, we create in iCatMon an associated type of inspection called “Catenary Inspection TELICE FGC”:

Inspection tab

Inspection name: INSTF Identifier: SIA_A_INSTF Inspection description: Catenary Inspection TELICE FGC ☒ Visible

Type: Inspection

Associated system: Associated components: Maintenance failure mode:

Wires: Contact wire Catenary Height Decentralisation Pole piece

File Format

CLOSE SAVE DELETE

Figure 8-48. tCat® inspection creation using iCatMon inspection configuration

In the same tab authorized users can configure the file format we need to import:

Inspection tab

Wires ☐ Contact wire ☐ Catenary ☐ Height ☐ Decentralisation ☐ Loading gauge ☐

File Format

Format: Thousands sep. Decimal sep. Field Sep Date Form Sheet Row data

Line: Col Row Value Track: Col Row Track KP (ini/end): Col Col Units

Date: Col Row Value

KPI 1: Subsystem Failure mode Cols

KPI 2: Subsystem Failure mode Cols

KPI 3: Subsystem Failure mode Cols

KPI 4: Subsystem Failure mode Cols

Buttons: CLOSE, SAVE, DELETE

Figure 8-49. tCat® file format configuration in iCatMon

Afterwards, going to Reports menu section, in table mode view users can import new tCat® inspection reports clicking the + button on the bottom right of the screen:

Import inspection file

Inspection type

Select value

> File Values

Buttons: CANCEL, IMPORT

Table Data:

DATE	TIME	LINE	WIRE	INSPECTION	KPI	VALUE	STATUS
09/06/2021	00:00	LP-NA	1	9.088	CAT_1	Loading gauge	2987.943
09/06/2021	00:00	LP-NA	1	9.089	CNTW_1	Height	4951.49
09/06/2021	00:00	LP-NA	1	9.13	CNTW_1	Decentralisati	228.353
09/06/2021	00:00	LP-NA	1	9.13	CAT_1	Loading gauge	2987.943

Figure 8-50. tCat® inspection file selection in iCatMon

And new data are displayed in Reports section selecting the type and date of the inspection:

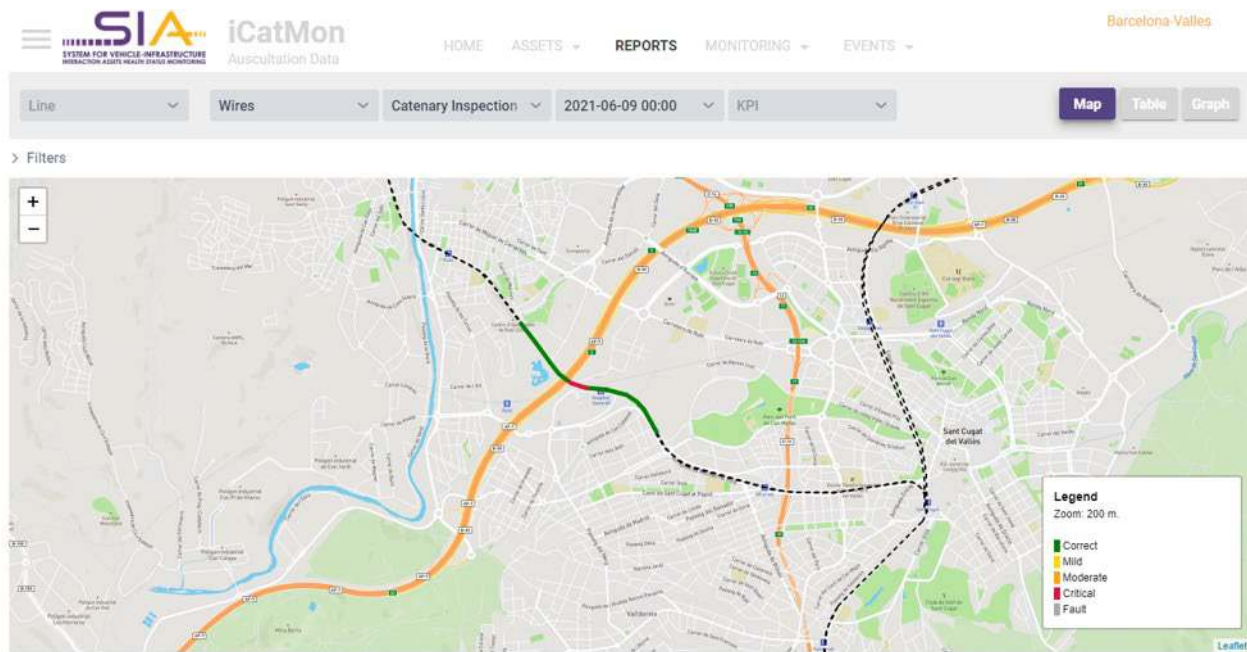


Figure 8-51. New tCat® inspection data displayed in iCatMon Reports map representation

The same way as in previous examples using SIA mapping functionality, we can zoom in to get access to individual measurement points in the map and recommended maintenance actions depending on parameters status:

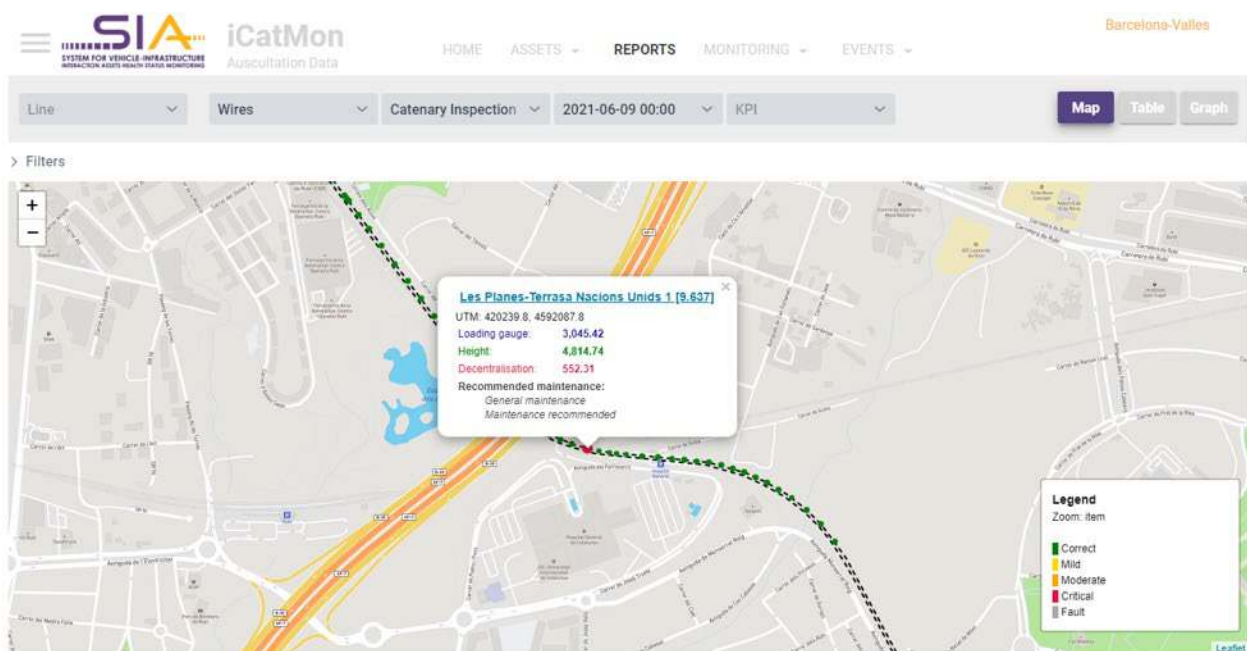


Figure 8-52. Individual measurements displayed after zooming in in iCatMon Reports screen

Users also have the ability to analyse inspection reports of external applications using tables and charts:

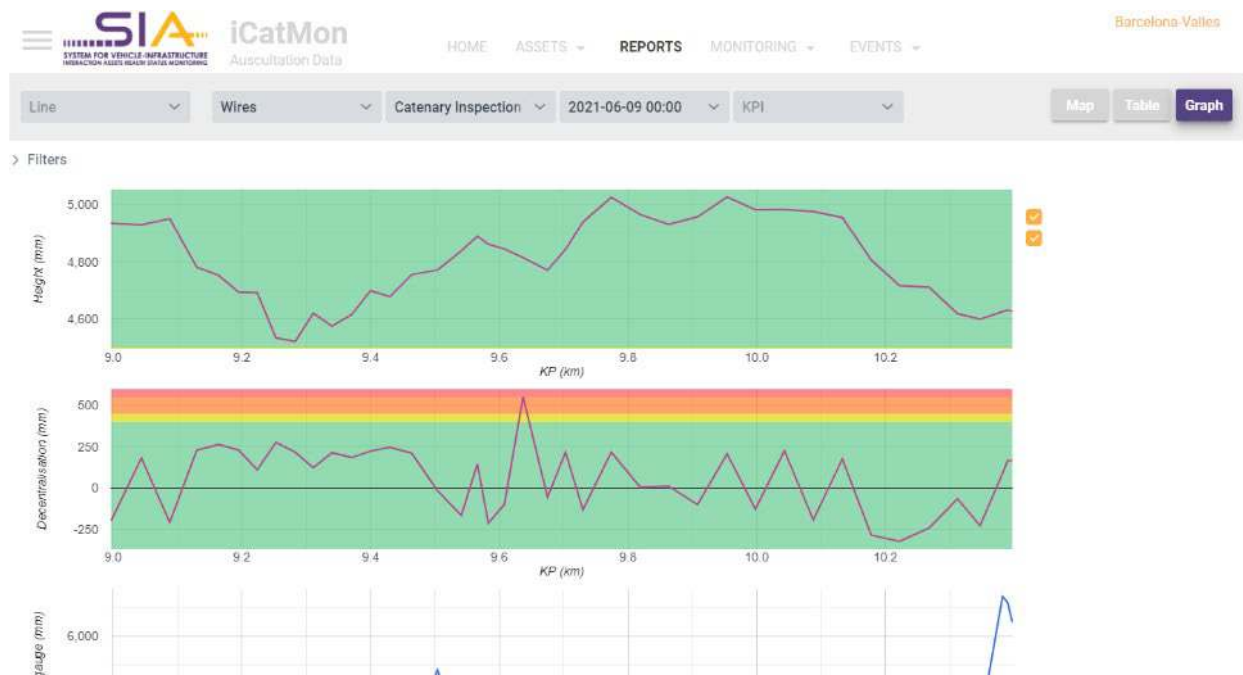


Figure 8-53. iCatMon charts representation of tCat® inspection data

9 SIA Validation

Deliverable D2.1 describes in Chapter 7 the overall SIA Validation Plan, based on test cases checking the fulfillment of SIA functional requirements. Specifically, Section 7.3 in D2.1 included the tables to be used for the validation for each of the four new SIA services in the two testing scenarios at OBB (Scenario 1) and FGC (Scenario 2). In those scenarios the following use cases, also defined in D2.1, have been tested per SIA service:

- iCatMon:
 - **Use case #1:** contact wire wear
 - **Use case #2:** contact wire incorrect height & stagger
- iPantMon:
 - **Use case #3:** contact strip normal wear (normal / asymmetric)
- iWheelMon:
 - **Use case #4:** wheel flats and polygonization wear
- iRailMon:
 - **Use case #5: Rail corrugations**
 - **Use case #6: Short-wave irregularities**

Next sections compile those D2.1 tables filled out with the results obtained in the testing campaign of the SIA project.

9.1 iCatMon

Req_ID	Functionality description	Use case no.	Validation successful (Y/N)	Validation notes
SIA_F1_001	iCatMon allows setting configuration parameters	1, 2	Y	See: <ul style="list-style-type: none"> • Figure 8-2. iRailMon inspection management tab • Figure 8-3. iRailMon failure modes list • Figure 8-4. iRailMon failure mode administration pop-up window
SIA_F1_002	The onboard equipment related to iCatMon allows the initial configuration of the firmware by means of the necessary port(s)	1, 2	Y	<ul style="list-style-type: none"> • SIA_PANT has been configured successfully using a wired port (as described in in D4.1). It also has been successfully re-configured (from SIA_DH) using a wireless link (WiFi). • SIA_POS has been configured by means of a physical (Ethernet) port (as described in D8.1).

Req_ID	Functionality description	Use case no.	Validation successful (Y/N)	Validation notes
				<ul style="list-style-type: none"> SIA_DH has been configured by means of a physical (Ethernet) port (as described in D4.3).
SIA_F2_001	iCatMon allows the introduction of inspection data related to the catenary with the associated electronics forms	1, 2	Y	<p>See:</p> <ul style="list-style-type: none"> Figure 8-48. tCat® inspection creation using iCatMon inspection configuration Figure 8-49. tCat® file format configuration in iCatMon Figure 8-50. tCat® inspection file selection in iCatMon
SIA_F3_001	iCatMon allows the introduction of auscultation data (if any) related to the catenary	1, 2	Y	See section 8.3.2 tCat® testing results representation
SIA_F4_001	iCatMon informs about the historic health status of the catenary, by integrating data from inspections, and auscultations. The historic health status of the catenary is visualized by means of a time representation of its relevant KPIs	1, 2	Y	<p>Map, table and chart representation available with color code to highlight health status and maintenance recommendations. See:</p> <ul style="list-style-type: none"> Figure 8-37. iCatMon historical data displayed in a map Figure 8-38. iCatMon historical data displayed for spatial analysis in charts Figure 8-39. iCatMon historical data displayed for time analysis in charts
SIA_F5_002				
SIA_F5_003				
SIA_F5_004				
SIA_F5_001	iCatMon informs about the current health status of the catenary, by integrating data from historic health status and from onboard systems. The current health status of the catenary is visualized by means of a time representation of its relevant KPIs	1, 2	Y	<p>Map, table and chart representation available with color code to highlight health status and maintenance recommendations. See:</p> <ul style="list-style-type: none"> Figure 8-33. iCatMon monitoring information displayed in map representation Figure 8-34. iCatMon individual measurements/KPIs georeferenced in a map Figure 8-35. iCatMon measured data displayed in table view Figure 8-36. iCatMon measured data displayed in charts
SIA_F5_002				
SIA_F5_003				
SIA_F5_004				
SIA_F6_001	iCatMon visualizes the future (i.e. predicted) status of the overhead contact wire in terms of its wear, height and stagger with their relevant KPIs	1, 2	Y	<p>Due to short time available for real testing it has not been possible to collect enough data to predict degradation and validate it, but D5.5 justifies this predictive functionality by means of a “digital twin” developed in SIA using synthetic data instead of real data. Visual representation in SIA services would be similar to the historical data one but displaying future instead of past time.</p>
SIA_F6_002				
SIA_F6_003				
SIA_F6_004				

Req_ID	Functionality description	Use case no.	Validation successful (Y/N)	Validation notes
SIA_F6_005	iCatMon displays a warning message if a failure related to wear, height and/or stagger of the overhead contact wire is detected	1, 2	Y	See Figure 8-40. iCatMon events screen and also Figure 8-41. iCatMon event positioned in a map with recommended action
SIA_F7_001	iCatMon proposes a set of related maintenance actions recommendations when a failure related to wear, height and/or stagger of the overhead contact wire is detected	1, 2	Y	See: Figure 8-34. iCatMon individual measurements/KPIs georeferenced in a map Figure 8-41. iCatMon event positioned in a map with recommended action

Table 9-1. iCatMon validation requirements

9.2 iPantMon

Req_ID	Functionality description	Use case no.	Validation successful	Validation notes
SIA_F1_001	iPantMon allows setting configuration parameters	3	Y	Similar to iCatMon. See Figure 8-42. iPantMon Inspections configuration module
SIA_F1_002	The onboard equipment related to iPantMon allows the initial configuration of the firmware by means of the necessary port(s)	3	Y	<ul style="list-style-type: none"> SIA_PANT has been configured successfully using a wired port (as described in D4.1). It also has been successfully re-configured (from SIA_DH) using a wireless link (WiFi). SIA_POS has been configured by means of a physical (Ethernet) port (as described in D8.1). SIA_DH has been configured by means of a physical (Ethernet) port (as described in D4.3).
SIA_F2_001	iPantMon allows the introduction of inspection data related to the pantograph with the associated electronics forms	3	Y	iPantMon allows users to create inspection and maintenance reports in a similar fashion to iCatMon (see Chapter 8.3.2). Check also Figure 9-1. iPantMon Inspection configuration screen
SIA_F3_001	iPantMon allows the introduction of auscultation data (if any) related to the pantograph	3	Y	iPantMon allows users to create auscultation reports and upload them to SIA in a similar fashion to iCatMon (see Chapter 8.3.2). There aren't any considered in SIA scenarios.
SIA_F4_001	iPantMon informs about the	3	Y	Similar to iCatMon. See also Figure 8-46.

Req_ID	Functionality description	Use case no.	Validation successful	Validation notes
SIA_F5_002	historic health status of the pantograph, by integrating data from inspections, and auscultations. The historic health status of the pantograph is visualized by means of a time representation of its relevant KPIs			iPantMon historical data displayed in map mode
SIA_F5_003				
SIA_F5_004				
SIA_F5_001	iPantMon informs about the current health status of the pantograph, by integrating data from historic health status and from onboard systems. The current health status of the pantograph is visualized by means of a time representation of its relevant KPIs	3	Y	Similar to iCatMon. See also: <ul style="list-style-type: none"> Figure 8-44. SIA_PANT measured values displayed in map in iPantMon Figure 8-45. iPantMon measures associated to rolling stock assets in table mode
SIA_F5_002				
SIA_F5_003				
SIA_F6_001	iPantMon visualizes the future (i.e. predicted) status of the pantograph in terms of its wear, with the relevant KPIs	3	Y	Due to short time available for real testing it has not been possible to collect enough data to predict degradation and validate it, but D5.5 justifies this predictive functionality by means of a “digital twin” developed in SIA using synthetic data instead of real data. Visual representation in SIA services would be similar to the historical data one but displaying future instead of past time.
SIA_F6_002				
SIA_F6_003				
SIA_F6_004				
SIA_F6_005	iPantMon displays a warning message if a failure related to the wear of the pantograph contact strips is detected	3	Y	Similar to iCatMon. See also Figure 8-47. iPantMon events
SIA_F7_001	iPantMon proposes a set of related maintenance actions recommendations when a failure related to wear of the contact strips is detected	3	Y	Similar to iCatMon. See also: <ul style="list-style-type: none"> Figure 8-44. SIA_PANT measured values displayed in map in iPantMon Figure 8-46. iPantMon historical data displayed in map mode

Table 9-2. iPantMon validation requirements

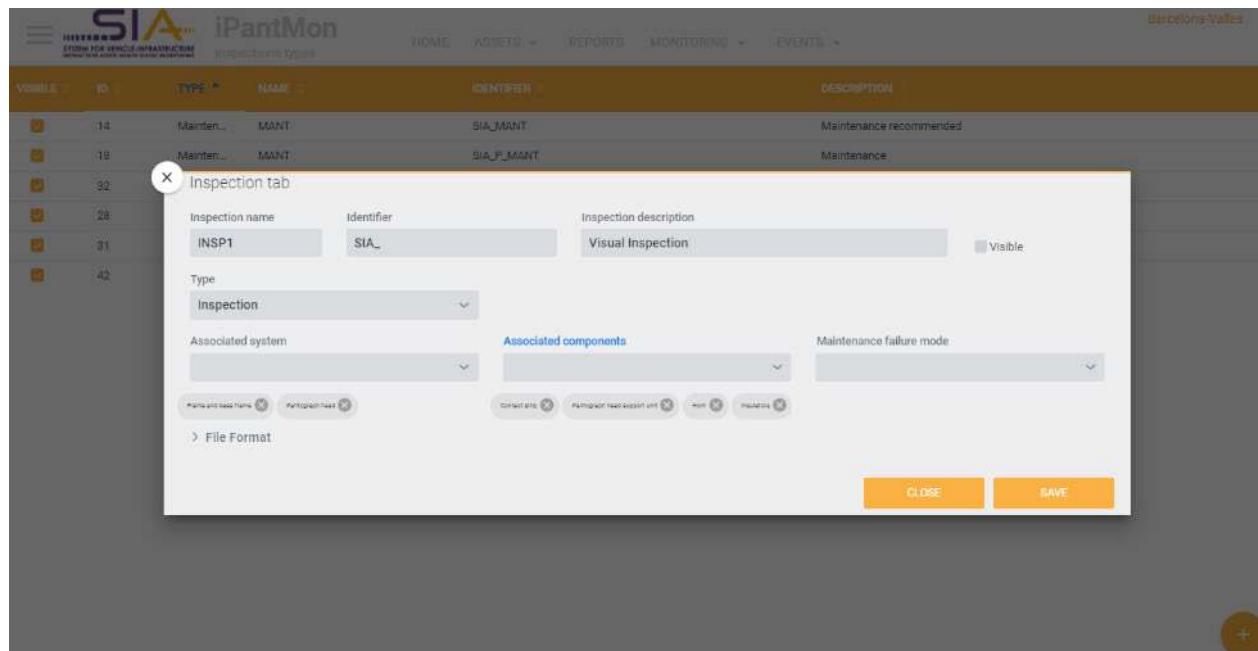


Figure 9-1. iPantMon Inspection configuration screen

9.3 iRailMon

Req_ID	Functionality description	Use case no.	Validation successful	Validation notes
SIA_F1_001	iRailMon allows setting configuration parameters	5,6	Y	<p>Similar to previous services. See also:</p> <ul style="list-style-type: none"> Figure 8-2. iRailMon inspection management tab Figure 8-3. iRailMon failure modes list Figure 8-4. iRailMon failure mode administration pop-up window Figure 8-18. Creation of SIA_ABA inspection using SIA configuration in iRailMon Figure 8-19. Creation of SIA_ABA monitoring parameters and KPIs using failure modes configuration in iRailMon Figure 8-20. Setting SIA_ABA parameters thresholds in iRailMon
SIA_F1_002	The onboard equipment related to iRailMon allows the initial configuration of the firmware by means of the necessary port(s)	5,6	Y	iRailMon is based on ABA data collected by the SIA_ABA subsystem. The configuration of the SIA_ABA subsystem is described in the hardware deliverable D4.1.

Req_ID	Functionality description	Use case no.	Validation successful	Validation notes
SIA_F2_001	iRailMon allows the introduction of inspection data related to the rail with the associated electronics forms	5,6	Y	iRailMon allows users to create inspection and maintenance reports in a similar fashion to iCatMon (see Chapter 8.3.2). Check also Figure 9-2. iRailMon Inspection configuration screen
SIA_F3_001	iRailMon allows the introduction of auscultation data related to the rail	5,6	Y	See Figure 8-12. External auscultation report displayed in iRailMon Reports
SIA_F4_001	iRailMon informs about the historic health status of the rail, by integrating data from inspections, and auscultations. The historic health status of the rail is visualized by means of a time representation of its relevant KPIs	5,6	Y	<p>Similar functionality to the one described for iCatMon with availability to display info in map, charts and table mode. See also:</p> <ul style="list-style-type: none"> Figure 9-3. iRailMon historical data displayed in map mode Figure 9-4. iRailMon historical data displayed in charts
SIA_F4_002				
SIA_F4_003				
SIA_F4_004				
SIA_F5_001	iRailMon informs about the current health status of the rail, by integrating data from historic health status and from onboard systems. The current health status of the rail is visualized by means of a time representation of its relevant KPIs	1, 2	Y	<p>Similar to previous services. See also:</p> <ul style="list-style-type: none"> Figure 8-8. iRailMon monitoring values displayed in map Figure 8-9. iRailMon individual monitoring values displayed in map with maximum zoom Figure 8-10. iRailMon monitoring values displayed in charts Figure 8-11. iRailMon monitoring values displayed in table mode Figure 8-22. SIA_ABA measures and KPIs displayed in iRailMon Monitoring screen Figure 8-23. iRailMon SIA_ABA individual measurement points and maintenance recommendations zooming in in the map representation Figure 8-24. iRailMon SIA_ABA individual measures in table view mode
SIA_F5_002				
SIA_F5_003				
SIA_F6_001	iRailMon visualizes the future (i.e. predicted) status of the rail in terms of the apparition of corrugation and short-wave irregularities, with the relevant KPIs	5,6	Y	<p>Due to short time available for real testing it has not been possible to collect enough data to predict degradation and validate it, but D5.5 justifies this predictive functionality by means of a “digital twin” developed in SIA using synthetic data instead of real data. Visual representation in SIA services would be similar to the historical data one but displaying future instead of past time.</p>
SIA_F6_002				
SIA_F6_003				
SIA_F6_004				

Req_ID	Functionality description	Use case no.	Validation successful	Validation notes
SIA_F6_005	iRailMon displays a warning message if a failure related to corrugation and short-wave defects of the rail is detected	5,6	Y	<p>Similar to previous services. See also:</p> <ul style="list-style-type: none"> Figure 8-25. iRailMon online events raised by SIA_ABA displayed in Events menu option Figure 8-26. iRailMon map positioning of an online event
SIA_F7_001	iRailMon proposes a set of related maintenance actions recommendations when a failure related to corrugation and short-wave defects of the rail is detected	5,6	Y	<p>Similar to previous SIA services. See also:</p> <ul style="list-style-type: none"> Figure 8-23. iRailMon SIA_ABA individual measurement points and maintenance recommendations zooming in in the map representation Figure 8-26. iRailMon map positioning of an online event

Table 9-3. iRailMon validation requirements

The screenshot displays the iRailMon web interface for configuring an inspection. On the left, a sidebar lists existing inspections with their IDs and visibility status. The main panel shows the configuration for a new inspection named 'INS004'. Key fields include the identifier 'SIA_VISUAL_INSP' and the description 'Visual Inspection'. A 'Visible' toggle is set to 'On'. The 'Type' is set to 'Inspection'. There are dropdowns for 'Associated system' and 'Associated components'. A 'Maintenance failure mode' dropdown is also available. Below these, several checkboxes are provided for selecting specific inspection criteria: 'Rail', 'Head', 'Track quality', 'Left Alignment', 'Right Alignment', 'Left Loading', and 'Right Loading'. At the bottom left, there is a 'File Format' link, and at the bottom right, there are 'CLOSE' and 'SAVE' buttons.

Figure 9-2. iRailMon Inspection configuration screen

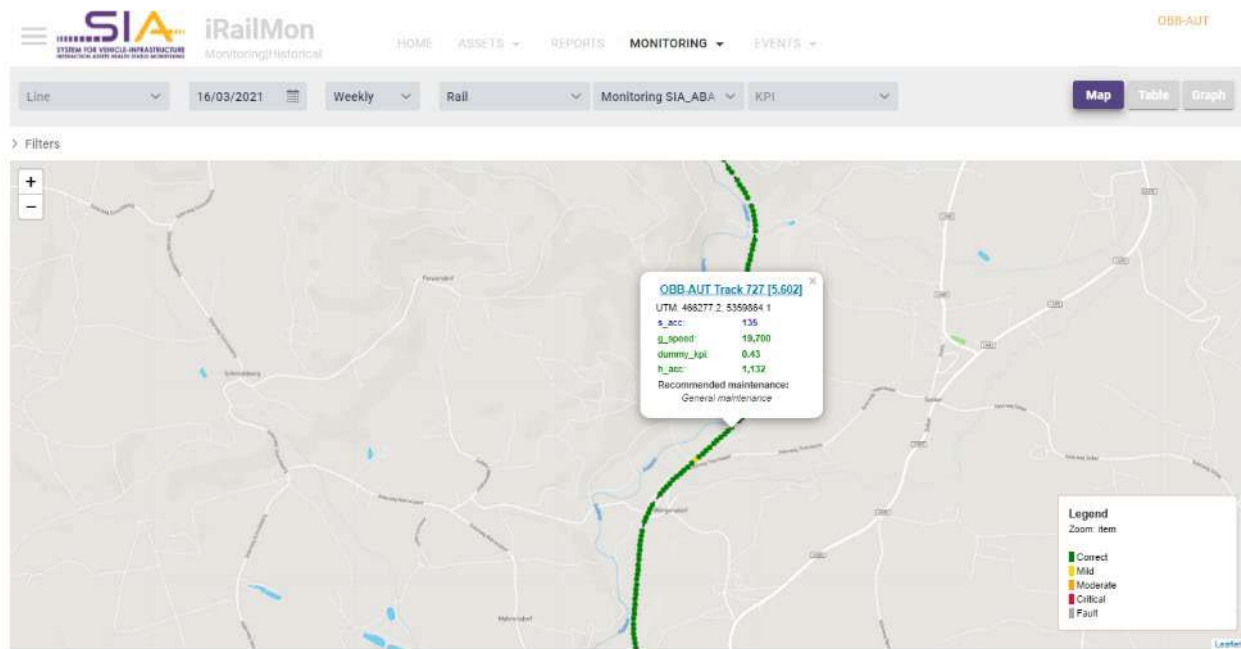


Figure 9-3. iRailMon historical data displayed in map mode



Figure 9-4. iRailMon historical data displayed in charts

9.4 iWheelMon

Req_ID	Functionality description	Use case no.	Validation successful	Validation notes
SIA_F1_001	iWheelMon allows setting configuration parameters	4	Y	Similar to previous services. See also Figure 8-25. iWheelMon SIA_ABA inspection configuration
SIA_F1_002	The onboard equipment related to iWheelMon allows the initial configuration of the firmware by means of the necessary port(s)	4	Y	iWheelMon is based on ABA data collected by the SIA_ABA subsystem. The configuration of the SIA_ABA subsystem is described in the hardware deliverable D4.1.
SIA_F2_001	iWheelMon allows the introduction of inspection data related to the wheelset with the associated electronics forms	4	Y	iWheelMon allows users to create inspection and maintenance reports in a similar fashion to iCatMon (see Chapter 8.3.2). Check also Figure 9-5. iWheelMon Inspection configuration screen
SIA_F3_001	iWheelMon allows the introduction of auscultation data (if any) related to the wheelset	4	Y	iWheelMon allows users to create auscultation reports and upload them to SIA in a similar fashion to iCatMon (see Chapter 8.3.2) or iRailMon. There aren't any considered in SIA scenarios.
SIA_F4_001	iWheelMon informs about the historic health status of the wheelset, by integrating data from inspections, and auscultations. The historic health status of the wheelset is visualized by means of a time representation of its relevant KPIs	4	Y	<p>Similar functionality to the one described for the other SIA services with availability to display info in map, charts and table mode. See also:</p> <ul style="list-style-type: none"> Figure 9-6. iWheelMon historical data grouped by sections displayed in map mode Figure 9-7. iWheelMon historical data displayed in charts
SIA_F5_002				
SIA_F5_003				
SIA_F5_004				
SIA_F5_001	iWheelMon informs about the current health status of the wheelset, by integrating data from historic health status and from onboard systems. The current health status of the wheelset is visualized by means of a time representation of its relevant KPIs	4	Y	<p>Similar to previous services. See also:</p> <ul style="list-style-type: none"> Figure 8-15. iWheelMon monitoring values and KPIs displayed in map mode Figure 8-28. iWheelMon monitoring data and maintenance recommendations in Monitoring screen
SIA_F5_002				
SIA_F5_003				
SIA_F6_001	iWheelMon visualizes the future (i.e. predicted) status of the wheelset in terms of the apparition of wheel flats and polygonization wear, with the relevant KPIs	4	Y	<p>Due to short time available for real testing it has not been possible to collect enough data to predict degradation and validate it, but D5.5 justifies this predictive functionality by means of a "digital twin" developed in SIA using synthetic data instead of real data. Visual representation in SIA services would be similar to the historical data one but displaying future instead of past time.</p>
SIA_F6_002				
SIA_F6_003				
SIA_F6_004				

Req_ID	Functionality description	Use case no.	Validation successful	Validation notes
SIA_F6_005	iWheelMon displays a warning message if a failure related to wheel flats and polygonization wear of the wheelset is detected	4	Y	Similar to previous services. See also Figure 8-29. iWheelMon online events
SIA_F7_001	iWheelMon proposes a set of related maintenance actions recommendations when a failure related to wheel flats and polygonization wear of the wheelset is detected	4	Y	Similar to previous services. See also: <ul style="list-style-type: none"> Figure 8-16. iWheelMon maintenance recommendations in Monitoring screen Figure 8-28. iWheelMon monitoring data and maintenance recommendations in Monitoring screen

Table 9-4. iWheelMon validation requirements

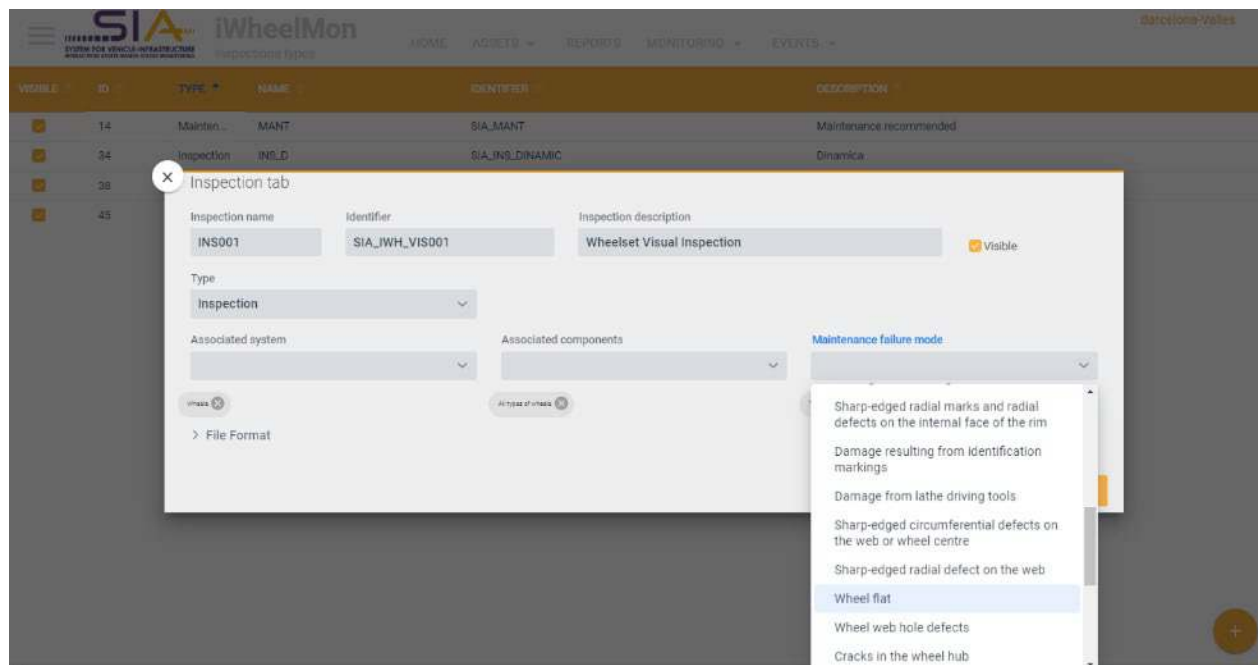


Figure 9-5. iWheelMon Inspection configuration screen

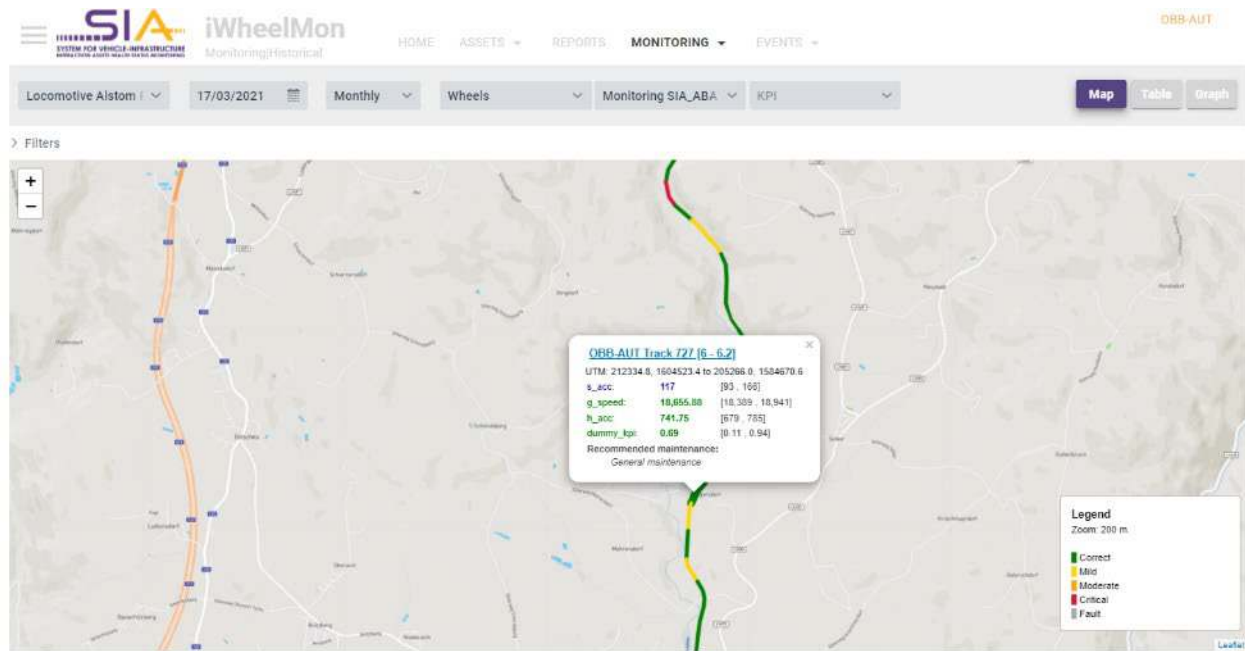


Figure 9-6. iWheelMon historical data grouped by sections displayed in map mode



Figure 9-7. iWheelMon historical data displayed in charts

10 Conclusions

The aim of this document has been to provide an overview and results of the validation activities of the SIA system carried out in real operational demonstration scenarios in WP8. The testing process and results achieved in the different scenarios described in Deliverable D8.1 have been presented for each SIA subsystem validating that data collection, georeferentiation, transformation, transmission and visualization meets the requirements established at the beginning of the project. Specifically, partners have performed the SIA Validation Plan designed in Chapter 7 of Deliverable D2.1 to check that the four services (iCatMon, iPantMon, iRailMon and iWheelMon) delivered fulfill SIA functional requirements.

There have been important deviations in test setup preparation and SIA validation in WP8 from the project work programme/Annex I (DOW). Unfortunately, the pandemic outbreak happened right when SIA testing preparations started, so even though the project was granted a six month extension, the nine months validation campaign has been shorter, but the results achieved have been enough to grant at least a TRL 7 for all SIA subsystems and the four SIA services.

The main conclusions and achievements drawn from the validation process are summarised below:

- Positioning improves by 9% thanks to the use of Galileo with an availability of 100%, although further improvements are required to guarantee a position accuracy of 20m for trains with velocity up to 100 km/h.
- Onboard measurement equipment SIA_ABA and SIA_PANT have been tested in different scenarios to show their accuracy and their operational availability with different configurations in a cost-effective way.
- SIA is a pluggable modular system, flexible for the adoption by end users. Each subsystem has been validated independently, increasing reliability and ensuring errors are not propagated unnoticed to other modules.
- Partners have implemented field data post-processing algorithms to generate relevant KPIs for the defects SIA pretends to mitigate.
- Degradation forecasting algorithms have been also developed, although not tested in real scenarios for lack of enough data due to time constraints imposed by the pandemic.
- SIA services are interoperable with other IT systems as shown in D7.1 and tCat® testing in this document.
- SIA Visualization platform provides for the four SIA services open-source friendly user interfaces for system configuration, assets monitoring, data analytics and real time warnings.

Overall, the consortium believes the functional and technical objectives of SIA have been mostly achieved as described in this document, and SIA system is ready to support IMs and TOCs

through condition based & predictive maintenance in reducing their maintenance costs and increasing the availability of assets. Next steps to create a fully commercial product are assessed in Deliverable D9.2 “Development and delivery of the exploitation plan” [18].

11 References

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- [2] D2.2. SIA deliverable: SIA Architecture (approved version SIA_Architecture_and_Verification_Plan_v4.0)
- [3] ISO 1005-8. Railway rolling stock material
- [4] EN50405. Railway applications. Current collection systems. Pantographs, testing methods for contact strips
- [5] ISO 5003:2016. Flat bottom (Vignole) railway rails 43 kg/m and above
- [6] EN50119. Railway applications - Fixed installations - Electric traction overhead contact lines
- [7] D3.1. SIA deliverable: Justification of the selection of the EGNOS and Galileo based receiver HW platform (latest version SIA_Deliverable_D3.1_v4.0)
- [8] D3.2. SIA deliverable: Positioning algorithms based on multisensory inputs (latest version SIA_Deliverable_D3.2_Positioning algorithms based on multisensory inputs_v4.0)
- [9] D3.3. SIA deliverable: Verification environment for the positioning algorithms (latest version SIA_Deliverable_D3.3_v4.0)
- [10] D4.1. SIA deliverable: Wheel to rail and pantograph to catenary sensing nodes (latest version SIA_Deliverable_D4.1_Wheel to rail and pantograph to catenary sensing nodes_5.0)
- [11] D4.3. SIA deliverable: On-board data integration platform and train-track communication hub (latest version SIA_Deliverable_D4.3_On-board data integration platform and train-track communication hub_4.0)
- [12] D5.4. SIA deliverable: Linking of physical parameters with component health status (latest version SIA_D5.4_Linking of physical parameters with component health status_v5.0)
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- [17] Baasch B, Heusel J, Roth M, Neumann T. Train Wheel Condition Monitoring via Cepstral Analysis of Axle Box Accelerations. Applied Sciences. 2021; 11(4):1432. <https://doi.org/10.3390/app11041432>
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