Railway Safety Audio Alert System
(Camera-Based Detection of Obstacles and Signal Aspects)

Functional Requirement Specification (FRS)

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List of amendments

S. No	Amendment Date	Revision	Details
1.	29 December 2025	1.1	Amendments based on the meeting of Railway Board - Elect. (Dev.) Directorate and CRIS along with Russian Railways held on 23rd December 2025
2.	05 January 2026	1.2	Amendments based on the meeting of Railway Board - Elect. (Dev.) Directorate and CRIS along with Russian Railways held on 30rd December 2025
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8.	13 February 2026	1.8	Amendments based on MOM dated 12.02.2026
9.	18 February 2026	1.9	Annexure -4 added based on the meeting of Railway Board - Elect. (Dev.) Directorate and CRIS along with Russian Railways held on 17th Feb 2026

10.	03 March 2026	1.10	Amendments based on MOM dated 27.02.2026
11.	06 March 2026	1.11	Amendments based on MOM dated 03.03.2026
12.	16 March 2026	1.12	Amendments based on MOM dated 10.03.2026
13.	23 March 2026	1.13	Amendments based on MOM dated 17.03.2026
14.	31 March 2026	1.14	Amendments based on MOM dated 24.03.2026
15.	06 April 2026	1.15	Amendments based on MOM dated 31.03.2026
16.	14 April 2026	1.16	Amendments based on MOM dated 07.04.2026
17.	12 May 2026	1.16	Amendments based on the meeting of Railway Board - Elect. (Dev.) Directorate and CRIS along with Russian Railways held on 12th May 2026
18.	12 May 2026	1.17	Distance Measurement Accuracy validation system added as annexure-5 based on the meeting of Railway Board - Elect. (Dev.) Directorate and CRIS along with Russian Railways held on 12.05.2026.
19.	27 May 2026	1.18	Logging and Data Recording system incorporated as annexure-6 based on the meeting of Railway Board - Elect. (Dev.) Directorate and CRIS along with Russian Railways held on 26.05.2026.
20.	1 Jun 2026	1.19	Annexure-4 updated — Operating System (Debian GNU/Linux 11, custom build) added to computation unit configuration.

Contents

1. Introduction

Train drivers capabilities to detect obstacles and recognize railway signals are inherently limited due to human factors. Additionally, train drivers may become tired or distracted, which may result in missing signals or failing to detect obstacles. Modern technologies based on sensors, computers, and artificial intelligence enable the detection of obstacles and recognition of signals ahead of train drivers. The implementation of such technologies on locomotives will significantly improve railway traffic safety.

This technical specification defines the functional and technical requirements for Railway Safety Audio Alert System - Camera-Based Detection of Obstacles and Signal Aspects. The specification covers the basic features and operational requirements of the system. The usage of these specifications shall be limited to POC only.

2. Objectives and Scope of the specification

This document specifies the functional requirements for Railway Safety Audio Alert System - Camera-Based Detection of Obstacles and Signal Aspects (RSAAS or System) for Indian Railways.

This document has been prepared to define the requirements for the development of the System, which shall be capable of warning the Locomotive Driver about obstacles and infringing objects (as specified in this document) from a specified distances, in order to prevent collisions or mitigate their consequences.

3. Terminology / Abbreviations

Sr No.	Term		Definition
1	RSAAS	—	Railway Safety Audio Alert System - Camera-Based Detection of Obstacles and Signal Aspects
2	IR	—	Indian Railway
3	CRIS	—	Centre for Railway Information Systems
4	NETD	—	Noise Equivalent Temperature Difference
5	VIS	—	Visual Inertial System
6	MTBF	—	Mean Time Between Failures
7	BOM	—	Bill Of Material
8	POC	—	Proof of Concept
9	GNSS	—	Global Navigation Satellite System (GPS, GLONASS, Galileo, BeiDou)
10	RTK	—	Real-Time Kinematic — differential correction technique using carrier-phase measurements for centimetre-level positioning
11	Base station	—	Stationary GNSS receiver at a known location; computes and transmits correction data

12	Rover	—	Mobile GNSS receiver that applies corrections from the base to reach centimetre accuracy
13	RTK-fix	—	Carrier-phase ambiguities resolved; accuracy 2–5 cm
14	RTK-float	—	Ambiguities not fully resolved; accuracy 10–50 cm; not accepted for validation
15	carrSol	—	Carrier solution indicator: 0 = no fix, 1 = float, 2 = fix
16	RTCM 3.x	—	Standard format for GNSS differential correction messages
17	NTRIP	—	Protocol for sending RTK corrections over the internet
18	PPS	—	Pulse Per Second — timing signal from a GNSS receiver, used for clock synchronisation
19	UBX	—	u-blox proprietary binary protocol for GNSS data
20	RINEX	—	Receiver Independent Exchange Format — open file format for GNSS observations
21	Baseline	—	Distance between base and rover; RTK accuracy degrades as baseline grows
22	FRS	—	Functional Requirement Specification — CRIS/2026/RSAAS/FRS/001

4. Scope of Supply

4.1. The proposed RSAAS for one loco shall contain following major components which are within the scope of supply of the vendor:

4.1.1. Sensor Module - 2 Sets (One set mounted at either end of the Loco). Each Sensor Module shall include 3 Optical Cameras and 1 Thermal Imaging Camera as detailed in Annexure- 3 (the sensor suite composition may be augmented by the Vendor).

4.1.2. Computation Module (may be integrated with other modules). It must be capable to meet all functional requirements as per section 5 and computation unit configuration as per Annexure-4

4.1.3. Audio Alert Module - 2 units (One module installed in each cab of the Loco).

4.1.4. Display Module (optional, at supplier’s discretion; may be combined with the Audio Alert Module).

4.1.5. Navigation Module (may be integrated with other modules).

4.1.6. 5G/LTE modem (optional, at supplier’s discretion; may be integrated with other modules).

4.1.7. Required cables and interfacing equipment.

4.1.8. Hardware for mounting and cabling.

4.1.9. DC-DC Converter, as applicable to the type of locomotive (Input supply 110V for Electric Loco or 72 V for Diesel Loco).

5. Functional requirements

5.1. The system shall pre-warn the locomotive driver, well in advance, about any obstacle and/or aspect of signal (in accordance with the requirements specified in the Section 5) so as to give him/her an audio warning for each console (two consoles in each locomotive) enabling him/her to timely apply brakes so as to stop the train well short of the obstacle and/or to timely control the train as per the aspect of the signal.

5.2. Each working side of the locomotive will have one set of equipment consisting of all the necessary cameras/antennas/sensors for monitoring the track ahead in the direction of motion.

5.3. The system shall detect the following types of objects:

5.3.1. Humans

5.3.1.1. Humans of approximate size not less than 1.7 m (height) x 0.4 m (width) shall be detected at a distance of not less than 1000 m.

5.3.1.2. For humans with lower size the range of detection shall be the function of object height according to the next equation: $range(h) = 1000 * \frac{h}{1.7},\ if\ 0.7 \leq h \leq\ 1.7$, where h – height of object (minimum object height for detection: 0.7 m).

5.3.1.3. Bikes and motorbikes with a rider of approximate size not less than 1.7 m (height) x 0.6 m (width) shall be detected at a distance of not less than 1000 m.

5.3.2. Railway car–sized object

5.3.2.1. Railway car–sized object of approximate size not less than 4 m (height) x 2.9 m (width) shall be detected at a distance of not less than 1000 m.

5.3.2.2. For Railway car–sized object with lower size the range of detection shall be the function of object height according to the next equation: $range(h) = 1000 * \frac{h}{4},\ if\ 1.2 \leq h \leq\ 4$, where h – height of object (minimum object height for detection: 1.2 m).

5.3.3. Road vehicles

5.3.3.1. Road vehicles of approximate size not less than 1,5 m (height) x 1,9 m (width) shall be detected at a distance of not less than 1000 m.

5.3.3.2. For road vehicles with lower size the range of detection shall be the function of object height according to the next equation: $range(h) = 1000 * \frac{h}{1{,}5},\ if\ 1.2 \leq h \leq\ i$, where h – height of object (minimum object height for detection: 1.2 m).

5.3.4. Red railway signals (Red Aspects), Single Yellow signals (Yellow Aspects), Double Yellow signals (Double Yellow Aspects) and

Green signals (Green Aspects) shall be detected not less than 1000 m.

5.3.5. Cow–sized animal (optionally, if the Zonal Railways provides a properly collected and annotated dataset containing at least 10,000 images of cow–sized animals located within the danger zone or in its immediate vicinity)

5.3.5.1. Cows–sized animal of approximate size not less than 1.4 m (height) x 0.8 m (width) shall be detected at a distance of not less than 1000 m.

5.3.5.2. For cow–sized animal with lower size the range of detection shall be the function of object height according to the next equation: $range(h) = 1000 * \frac{h}{1.4},\ if\ 0.7 \leq h \leq\ 1.4$, where h – height of object (minimum object height for detection: 0.7 m).

5.3.6. All dimensions are specified in the plane perpendicular to the direction of loco motion.

5.3.7. All distances are specified under normal visibility conditions on straight visible track sections.

5.3.8. All distances are specified along the direction of loco motion.

5.3.9. Objects may be occluded up to 25% of their total area.

5.4. The System shall generate an audio alert signal indicating the presence of objects, specified in Section 5.1 at the specified distances Section 5.3, when such objects are within the danger zone. The system should be able to identify whether the object is on the same track or not (in accordance with Section 5.15). The danger zone is defined as a distance of 2.5 m on each side of the track centerline along which the loco is moving. The distance is measured in the plane perpendicular to the direction of loco motion. The error in determining the presence of an object within the danger zone shall not exceed ±0.2 m in the transverse plane when the object is at a distance less than 100 m, shall not exceed ±0.5 m when the object is at a distance from 100 m to 500 m and shall not exceed ±0.7 m when the object is at a distance more than 500 m.

5.5. For Signal Aspects (Red Aspects, Yellow Aspects, Double Yellow Aspects and Green Aspects) detection (and corresponding alerting) shall be provided for the nearest signal ahead in the direction of locomotive movement along the current track, assuming straight-line travel on the same track branch without consideration of potential lane changes to any other parallel or adjacent tracks. System shall detect signals located directly above the current track or at a distance of up to 5 m to the left or to the right of the current track center (for determining signal localization and its spatial orientation relative to the track, the System shall utilize data from the Fog Pass Device or from the Fog Pass Signal Asset Database, depending on the selected integration architecture – see Section 5.18). If, according to Fog

Pass system data, a Signal is expected ahead along the path of travel (in accordance with the accuracy of the Navigation Module and the Fog Pass system data), but the RSAAS is unable to detect the Signal or its Aspect, an audio alert signal cconsistent with the alert parameters for the Red Aspect shall be generated to notify the Loco Pilot of this event.

5.6. The System shall generate an audio alert signal when an object is detected in the danger zone or Signal Aspect (Red Aspect, Yellow Aspect, Double Yellow Aspect or Green Aspect) is identified (in accordance with the requirements specified in Section 5). The system shall generate distinct audio alert signals corresponding to different signal aspects, namely Green, Double Yellow, Yellow, and Red, with Red having the highest priority. The signal type and generation logic may be adjusted (changed) during the development and trial stages upon mutual agreement between the Railways/CRIS and the Vendor.

5.7. The audio alert warning of object presence in the danger zone shall automatically be deactivated at zero speed (0 km/h) and activated during motion (if any object, in accordance with Section 5 requirements, is present in the danger zone).

5.8. The distance to object measurement accuracy shall be within ±10% or ±1 m (the greater value applies).

5.9. The system shall have an anti-blooming mechanism to prevent obscuring of information due to the bright source (headlight of passing locomotive or any other blooming effect). This functionality may be realized through software-level algorithms or integrated image signal processing.

5.10. The range of object detection depends on Meteorological visibility. If Meteorological visibility less than 2000 m, then the range of detection, specified in Section 5.1, shall be multiplied by coefficient $K_{MR}(vis) = \frac{vis}{2000}$, where vis – meteorological visibility.

5.11. The detection ranges given in Section 5.3 may be reduced on curved track sections with a curve radius (Cu) of less than 8000 meters. For such sections, the effective detection distance ($Distance$) shall be calculated using specific formulas based on the radius of curvature (Cu) of the track, defined by the following two ranges:

5.11.1. For a curve radius of less than 2000 meters ($\boldsymbol{Cu \leq 2000\ m}$), the maximum detection distance shall be calculated using a formula: $\boldsymbol{Distance(Cu) = Cu * 0.25}$, but not less than 200 meters.

5.11.2. For a curve radius from 2000 meters up to 8000 meters ($\boldsymbol{2000 < Cu < 8000\ m}$), the maximum detection distance shall be calculated using a formula: $\boldsymbol{Distance(Cu) = Cu * 0.125}$, but not less than 500 meters.

5.12. If the current operating conditions correspond to multiple visibility limitation conditions (see sections 5.10, and 5.11), all applicable coefficients and limitations shall be applied.

5.13. Detection range in degraded visual environments (adverse weather conditions) of the obstacle and Signal Aspect:

(A) Weather Condition	(B) Train Speed (kmph)	(C) Normal Visibility, m.	(D) Obstacle detection range, m.	(E) Signal Aspect detection range, m.
Clear	Upto 160	Horizon Limited	1000	1000
Mild Fog	Upto 160	300	500	550
Dense Fog	Upto 95	100	250	280
Extreme Fog	Upto 20	5	30	40

5.13.1. Train speed ranges given at column (B) are indicative, specific speed(s) will depend upon the conditions and visibility prevailing at the time of field trials in dynamic condition.

5.13.2. Normal Visibility at column (C) should be referred as naked eye visibility of a person with normal vision for static trials and dynamic condition.

5.13.3. To validate the above functional requirement, trials will be conducted in the real field condition and parameters will be recorded. The Trials will be carried out across the regime at different points according to the prevailing foggy condition and the corresponding values for column (D) and (E) of above table shall also be recorded.

5.13.4. However, the trials in each fog regime shall be conducted up to the lowest achievable Normal visibility towards the lower limit of the respective range of fog regime (Column C).

5.13.5. Vendor has to arrange for necessary measuring and test equipment for functional trials.

5.14. Precise data regarding the reduction in visibility range for objects and signal aspects under adverse operating conditions (see sections 5.9, and 5.11) shall be evaluated based on the results of field trials under actual operational conditions.

5.15. The System shall detect objects along the current track, assuming straight-line travel on the same track branch without consideration of potential lane changes to any other parallel or adjacent tracks. Note: Optionally, if the Zonal Railways provides information about the state of railway turnouts

(through integration with a system providing such information), this information will be incorporated in the System's logic.

5.16. The system shall operate at speeds up to 160 km/h.

5.17. The number of false positives shall be not more than 3 per 100 passed km (detections and alerts meeting the requirements specified in Section 5 shall be considered correct). The number of false negatives shall be zero (the validation criteria for correct system reaction are detailed in Section 14.4).

5.18. Integration with the Fog Pass system shall be established for signal location data for determining Red Aspects, Yellow Aspects, Double Yellow Aspects and Green Aspects localization and its spatial orientation relative to the track as per the functionality broadly based on the Fog Pilot Assistance System for Safety (FogPASS) Specification number: RDSO/SPN/201/2010, Version-2.0. The specific integration methodologies — involving either the direct utilization of data from the Fog Pass Device or the Fog Pass Signal Asset Database — shall be mutually agreed upon between the Zonal Railways/CRIS and the Vendor. The Zonal Railways/CRIS shall be responsible for providing all requisite information necessary for the execution of these works, including but not limited to: comprehensive API documentation, Interface Control Protocols, Data Formats and communication standards, related technical specifications for system interoperability. In subsequent phases of the project, the Fog Pass system shall be integrated into the RSAAS architecture. The definition of the scope of work, including all technical and commercial terms, shall be subjected to separate negotiations between the Vendor and the Zonal Railways/CRIS .

5.19. System sensitivity

5.19.1. In case a thermal imaging camera is used, the Noise Equivalent Temperature Difference (NETD) of the system should be lower or equal to 45 mk in the full operating temperature range. If the recommended NETD is not used, Vendor may furnish the NETD for selected camera with justification to meet the functional requirement with their offer for their design appraisal

6. Environmental condition

6.1. Atmospheric temperature – from -20ºC to + 50ºC for devices mounted inside the locomotive, and from -20ºC to +75ºC for devices mounted outside the locomotive.

6.2. Humidity: 20 – 95 %, with extended operation possible up to 100% in specific environmental conditions (fog, dew).

6.3. Altitude – up to 1800 m above mean sea level.

6.4. Rainfall – Very heavy in certain areas.

6.5. Atmospheric Conditions – Extremely dusty and desert terrain in certain areas. The dust content in air may reach a high value of 1.6 mg / m^3. In

many iron ore and coal mine areas, the dust concentration is very high affecting the filter & air ventilation system.

6.6. Coastal area – Humid & salt laden atmosphere with maximum pH value of 8.5, sulphate of 7 mg per liter, maximum concentration of chlorine 6 mg per liters and maximum conductivity of 130 micro siemens/cm.

6.7. Vibration – The equipment, system and their mounting arrangement shall be designed to withstand satisfactorily the vibration and shocks encountered in service as specified in IEC 61373.

6.8. Wind speed – High wind speed in certain areas, with wind pressure reaching 150 kg/m3.

6.9. The unit shall meet the requirements of RDSO specification no. ELRS/SPEC/SI/0015/ Rev 1-October 2001 for "Reliability of Assurance specification for Electronic components for use in rolling stocks."

6.10. Rolling Stock: EN 50155:2007 / IEC 60571 or latest compliance (shock, vibration, temperature, EMC).

7. Technical Requirement

7.1. The system should be user friendly as well as hands free to the extent possible.

7.2. The System shall be powered from the locomotive's nominal 110V DC battery supply. System shall be designed to minimize the power requirement. The electromagnetic compatibility inside the locomotive shall be as per IEC-62236. The hardware design shall be highly rugged for external environment and resilient to voltage fluctuations as specified in IEC 60571.

7.3. Hermetic ceiling shall be provided for critical components with minimum IP-54 level for indoor equipments and IP-67 for outdoor equipments as per IEC-60529 standard.

7.4. Every component of the system shall be mounted on locomotive itself. The system shall be self-sufficient and there shall not be any installation on the track side.

7.5. Multispectral Camera (Including VIS Camera) should be installed at suitable location Mounting arrangement of camera shall be such that clear view is available and it is robust to sustain and isolate jerk and vibration experienced while locomotive running.

7.6. System components shall be installed on the locomotive jointly by representatives of the Vendor and the Zonal Railways/Nominated Loco sheds. The schedule and timeline for allocating locomotives for system component installation shall be pre-agreed between the Zonal Railways/Nominated Loco sheds and the Vendor. Nominated Loco

sheds for conducting POC shall be communicated to the successful bidder.

7.7. Proper vibration isolation technology should be provided for the system at physical level.

7.8. Video stabilization algorithms to stabilize real lime videos may be provided, if required.

7.9. Device must work in all types of weathers encountered in India, including rain, fog conditions, etc., as mentioned in section 6.

7.10. The system must record Camera recordings in clear video format for post-event analysis. The storage capacity must be sufficient to store at least 15 days of video. Industrial grade Solid state drive should be used for storing the data.

7.11. In addition to the video recording requirements specified above, the System shall incorporate a comprehensive logging and data recording subsystem for recording sensor data, perception outputs, alerts, navigation information and system health parameters. The logging subsystem shall support operational monitoring, fault diagnosis, performance assessment and offline analysis. Detailed requirements of the logging subsystem are specified in **Annexure-6**.

7.12. The video so stored as above must be in a format that can be copied to a portable Hard Disk (USB) or a USB flash drive, or to a connected laptop using the software installed on it. The final solution is determined by the Vendor and approved by the Zonal Railways/CRIS. The quality of the transferred video must be as clear as the original video.

7.13. The system shall run built in self-test on power up, and could give warning to the driver if the system fails and is not functioning as expected.

7.14. If the system device fails, then it should give a positive indication to the driver/loco pilot that the system has become inoperative/ unreliable/ defective. This should be an act of positive alarm to the driver. Such alarm/warming should be acknowledged by the driver through a positive act of acknowledgement.

7.15. Power up time shall be less than 2 minutes.

7.16. The overall dimension and weight of the equipment should be able to be accommodated in the space available in the driving cab of both diesel and electric locomotives, without causing any inconvenience to the driver in having clear view ahead and discharging his functions.

7.17. The components installed at the locomotive's exterior shall not infringe the maximum moving dimension The Drawing indicating maximum moving dimension of loco is attached at Annexure-2.

7.18. Anti-pilferage and vandal proof mechanism should be provided for external equipment.

7.19. Connectors used with RSAAS should be compliant to MIL standard or equivalent.

8. Life cycle management

The equipment supplier shall ensure that the lifecycle requirements of the equipment be met as detailed in the paragraphs below

8.1. Expected life

8.1.1. The expected life of the equipment shall be 12 years or more.

8.2. Support during lifetime

8.2.1. The equipment manufacturer shall ensure that the following support is available on demand during the equipment lifetime:

8.2.1.1. Service/spares support for the equipment

8.2.1.2. Options for comprehensive maintenance contract

8.2.1.3. Modifications in equipment design to meet new requirements or to improve reliability

8.2.2. The options for demanding these support services shall be reserved by the Indian Railways and the equipment manufacturer shall provide the same on demand.

8.2.3. Note. Cost of the services shall be determined through a mutually acceptable process between the manufacturer and the users on the Indian Railways

8.3. End of equipment life management

8.3.1. The equipment manufacturer shall provide options to upgrade/refurbish equipment at the end of life of the equipment when requested by the Indian Railways.

9. Safety requirements

9.1. The equipment shall meet all statutory and regulatory criteria required for public safety. The device must be safe in all respects to humans- both to locomotive personnel and to trespassers on railway track who are being scanned and imaged.

10. Tests and Trials

10.1. Test and Trials shall be conducted with the system mounted on locomotive.

10.2. Tests and Trials shall be conducted in accordance with Annexure 1.

11. Training

11.1. The Vendor shall conduct training for the Railway staff on system operation. The number of Zonal Railway staff to be trained and the timing of the training shall be agreed upon between the Vendor and the Zonal Railways/CRIS.

12. Warranty

12.1. The complete system with controls shall be warranted for satisfactory and trouble-free operation in conformity with the "Special Condition of Tender" All aspects of workmanship and design shall be covered by this warranty. The supplier shall immediately provide arrangement for rectification of failures reported under warranty.

12.2. Warranty period of any equipment of the system may be extended as per mutual agreement between purchaser and supplier if the equipment has undergone major design modifications during the warranty period.

13. Documents

13.1. The following documents shall be provided by the Vendor:

13.1.1. Functional Requirement Specification

13.1.2. Operating Manual

13.1.3. Maintenance Manual

13.1.4. Documentation for the Overall System:

13.1.4.1. Bill of Materials (BOM) / System Specification

13.1.4.2. Installation Drawing

13.1.4.3. Installation Manual

13.1.4.4. Connection Diagram and List of Components

13.1.5. Documentation for Components and Sub-assemblies (where applicable, to be determined by the Supplier)

13.1.5.1. Sub-assembly Bill of Materials (BOM)

13.1.5.2. Assembly Drawings

13.1.5.3. Detail Drawings

13.1.5.4. Circuit Diagram (Schematic) and List of Components

13.1.5.5. Wiring Diagram and List of Components

13.1.6. Design documentation for the fabrication of test obstacles.

13.1.7. **Installation Drawings:**

The successful Vendor shall prepare and submit detailed installation drawings/Schematic for locomotive, clearly indicating the exact mounting/fitment locations of all RSAAS components including, but not limited to, cameras, computation unit, audio alert system, display

unit (if provided), power supply arrangements, MCBs/fuses, connectors, cable routing/layout, junction boxes, mounting brackets and all other associated installation hardware/accessories.

The installation drawings/schematics shall also include details of suitable protection cages/enclosures, mounting structures and cable termination/interfacing arrangements for all onboard equipment.

14. Annexure 1. Assessment of compliance with the specified requirements

14.1. Assessment shall be conducted both at the test facility and under real operating conditions.

14.2. Assessment at the test facility

14.2.1. Prior to the start of testing, following objects shall be prepared

14.2.1.1. Human dummy/mock-up of approximate size not less than 1.7 m (height) x 0.4 m (width).

14.2.1.2. Human dummy/mock-up of approximate size not less than 0.7 m (height) x 0.4 m (width).

14.2.1.3. Bike or motorbike with a rider dummy/mock-up of approximate size not less than 1.7 m (height) x 0.6 m (width).

14.2.1.4. Railway car dummy/mock-up of approximate size not less than 4 m (height) x 2.9 m (width).

14.2.1.5. Road vehicle dummy/mock-up of approximate size not less than 1.5 m (height) x 1.9 m (width).

14.2.1.6. Cow dummy/mock-up (optionally) of approximate size not less than 1.4 m (height) x 0.8 m (width).

14.2.1.7. Cow dummy/mock-up (optionally) of approximate size not less than 0.7 m (height).

14.2.1.8. A railway signal with the capability to activate and deactivate a Red aspect, Yellow Aspect, Double Yellow Aspect and Green Aspect (if such signal is not available at the test site).

14.2.2. Test dummies shall be built in accordance with Design documentation (Section 13.1.6) and in conformity with the requirements in section 5.

14.2.3. Testing shall be performed for the objects listed in Section 14.2.1.

14.2.4. Testing shall be performed by a committee including representatives from both the Zonal Railways/CRIS and Vendor. Test results shall be documented in a test report.

14.2.5. Testing of the system characteristics specified in Section 5 shall be conducted under both static and dynamic conditions on a straight track section (radius of curvature not less than 8000 meters), with a minimum length of 1100 m, under normal lighting conditions and meteorological visibility (greater than 2,000 m).

14.2.6. Test success for each object shall be evaluated in accordance with Section 14.4. In case of disagreement among committee members regarding test results, verification with the corresponding object type may be repeated. Additionally, analysis of test results based on System logs recorded during testing is acceptable (in this case, the Vendor's representatives shall be provided access to the System to retrieve the logs).

14.2.7. Static testing

14.2.7.1. Before starting testing, the Vendor's representative must activate the audio warning function at 0 km/h speed.

14.2.7.2. Before starting testing, the loco shall move forward and travel at least 3 meters in the direction of the objects to activate the sensor block directed toward the objects.

14.2.7.3. During static testing, objects shall be placed within the danger zone defined in Section 5.4, at a distance not exceeding 1000 m from the loco equipped with the System.

14.2.7.4. During static testing, Railway Signal shall be placed in according with zones defined in Section 5.5, at a distance not exceeding 1000 m from the loco equipped with the System. Signal must be pre-configured in the Fog Pass system (see Section 5.5) (alternatively, the Vendor may utilize simulated data).

14.2.7.5. According to the test results, the table below should be filled in.

	Fact of detection/measured distance			
Dummies	250 m	500 m	750 m	1000 m
Human dummy			*Detected/ 730**	*Detected/ 940**
Child dummy				*Not detected**
Bike with a rider				
Railway Car				
Road vehicle				
Cow				
Signal				

**example*

14.2.8. Dynamic testing

14.2.8.1. Before dynamic testing, objects shall be placed within the danger zone defined in Section 5.4, in the direction of movement, at a distance at least 1100 m from the loco equipped with the System.

14.2.8.2. Before dynamic testing, Railway Signal shall be placed in according with zones defined in Section 5.5, in the direction of movement, at a distance at least 1100 m from the loco equipped with the System. Signal must be pre-configured in the Fog Pass system (see Section 5.5) (alternatively, the Vendor may utilize simulated data).

14.2.8.3. Before testing with each object, the loco shall return to the initial position at a distance of at least 1100 m from the installed test object or Railway Signal.

14.2.8.4. Tests shall be conducted under various visibility conditions (the final list of conditions and scenarios shall depend on the climatic conditions prevailing at the location of dynamic testing)

- Day lighting/clear visibility
- Night lighting/clear visibility
- Day lighting/mild, dense, extreme fog
- Night lighting/mild, dense, extreme fog

14.2.8.5 The indicators of visibility and illumination should be measured using special equipment (transmissometer, luxometer).

14.2.8.6 According to the test results, the table below should be filled in for different conditions, including day, night, fog.

Dynamic testing		
Data		Notes
Visibility measured by a transmissometer, meters		
Lighting measured by a luxometer, lux		
	Detection distance	
Human dummy		
Child dummy		
Bike with a rider		
Railway Car		
Road vehicle		
Cow		
Signal (red aspect)		
Signal (yellow aspect)		
Signal (double yellow aspect)		
Signal (green aspect)		

14.3. Real operating conditions testing

14.3.1. Testing under real operating conditions shall be conducted as part of normal train operations. The timing and schedule of such testing shall be pre-agreed between Zonal Railways/CRIS and Vendor representatives.

14.3.2. In case of System operational issues detected during testing, a record of such event with the time and, if possible, a brief description shall be entered into the test log. This log shall be provided daily to the Vendor's representatives.

14.3.3. The Vendor shall develop and provide a "Loco Pilot's Log Instruction" detailing the procedure for manual recording of System events. In case of any System operational issues detected during testing, the client's personnel (e.g., Loco Pilot) shall record such events in a Test Log in accordance with said Instruction.

14.3.4. The Vendor shall submit a weekly summary report on the System's performance to the Zonal Railways/CRIS. The report shall be prepared based on analysis of system logs, manual recording logs and test records (logs).

14.3.5. The Vendor's report shall contain statistical data on how many false positives occurred per 100 km.

14.3.6. The Vendor's representatives shall be provided access to the System to retrieve the logs.

14.3.7. The Vendor's report shall contain the next statistical data

The description of a trip	*Start point – destination point*	
	Per a trip	Per 100 km
False positive detections per a trip/ 100km		
Real obstacle detections		
Correct signal detection/recognition		

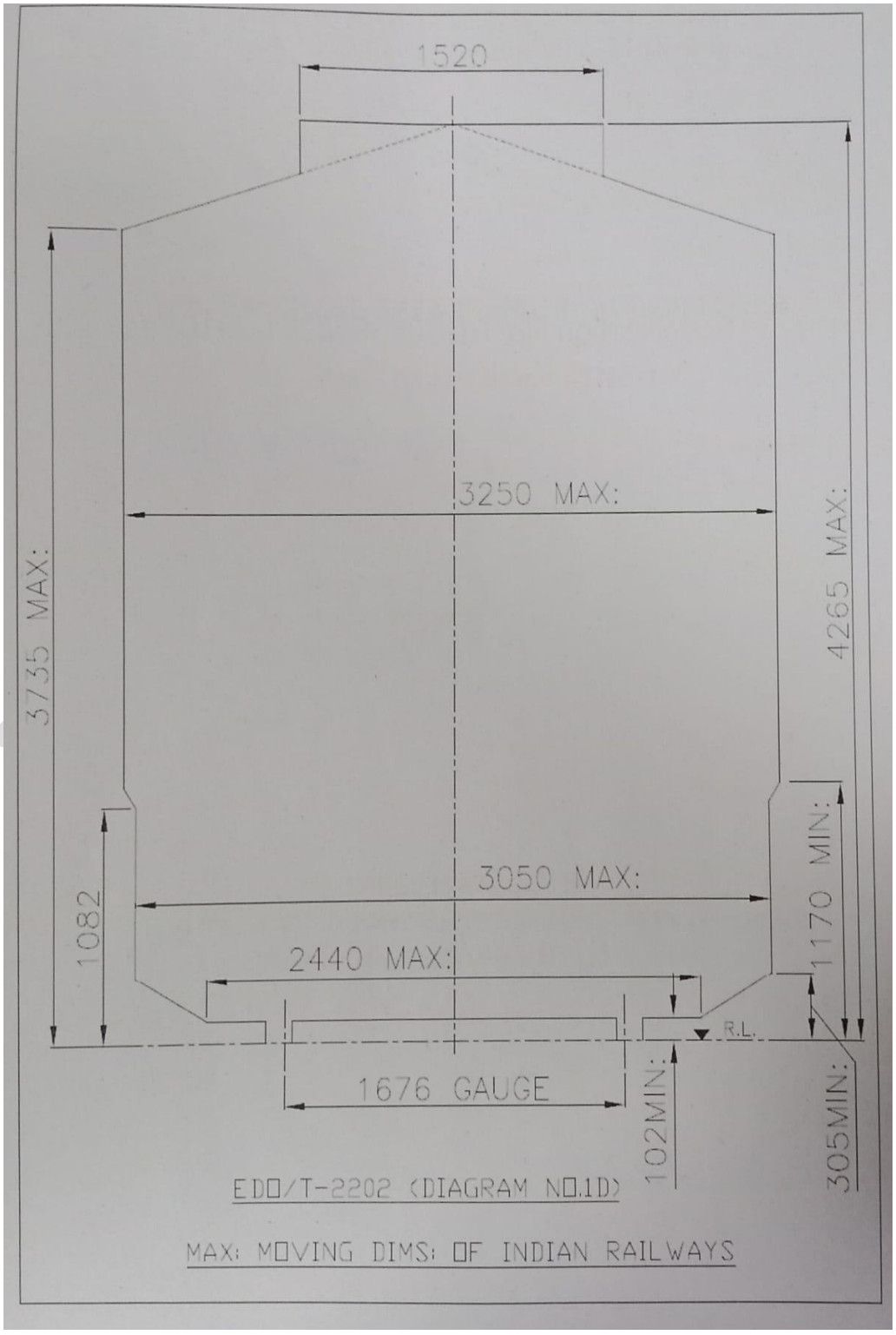
14.3.8. The System's overall performance assessment and statistical data shall be formulated based on the Vendor's reports and their thorough examination. The resulting test protocol shall be agreed upon by representatives of the Vendor and the Zonal Railways/CRIS.

14.4. The System reaction shall be considered correct and successful if the corresponding audio alert is generated for at least 90% of the period during which the object is present in the danger zone or the Signal Aspect is within the sensor's line of sight (in accordance with the requirements specified in the Section 5).

Note:

Test Setup: Testing of the RSAAS shall be conducted in accordance with the test setup scheme detailed in Annexure-5. The setup shall facilitate conduct of testing at the designated test facility, as well as static, dynamic and real operating condition trials for evaluation of obstacle detection, signal aspect detection, alert generation, distance estimation and overall system performance. Any additional instrumentation, test equipment or arrangements required for recording, monitoring, and analysis of trial results during the Proof of Concept (PoC) trials shall be arranged by the Vendor.

Annexure 2. Maximum moving dimension of loco



15. Annexure-3 Sensor Configuration

The requirements specified in this section are preliminary and may be modified by the Vendor. The equipment offered by the Vendor shall meet or better the specifications indicated in this section.

Preliminary sensor configuration (Optical Camera and Thermal Imaging Camera) for the RSAAS project

Optical Camera

- Resolution: 3840H*2160V
- Frame Rate: 3840*2160@30fps
- Sensor OMNIVISION: 8.3MP OX08B40 RGGB or similar
- ISP: GW5300
- Output data: YUV422@8bit
- Serializer MAXIM MAX9295A
- Sensor Type : Rolling Shutter
- Operating temp. range: -20°C to +70°C
- Dimensions : 40mm*40mm*23mm

The recommended sensor configuration includes 3 Optical Cameras per Sensor Module, each equipped with a fixed-focal or varifocal lens covering the following focal lengths: 20 mm, 40 mm, and 75 mm. Varifocal lenses whose zoom range includes the specified focal length values are preferred, as they allow field adjustment of the Field of View during installation and commissioning.

Thermal Imaging Camera

- Sensor: Uncooled Vanadium Oxide (VOx) microbolometer, 1280 x 1024 pixels, 12 µm pitch.
- Spectral Range: Long-wave infrared (LWIR), 8 to 14 µm.
- Sensitivity (NETD): ≤ 40 mK @ 25°C.
- Frame Rate: 30 Hz.
- Field of View (H x V): 17.5° x 14° (±10%).
- Image Functions: Automatic/Manual NUC, Digital Zoom (1-8x), Digital Noise Reduction.
- Interfaces: Gigabit Ethernet (video/data)
- Power Supply: 6 – 24 VDC (12 VDC nominal).
- Power Consumption: ≤ 3.5 W (without heater), up to 45 W (with heater).
- Protection Class: IP65.
- Operating Temperature: -20°C to +70°C
- Dimensions (W x H x D): 90 mm × 82.5 mm × 146 mm (±2 mm).

- Weight: ≤ 1.3 kg (without cable).
- Reliability: MTBF 100,000 hours.

Note:-The input supply shall be taken from locomotive which is 110V DC +/- 35V in electric locomotives

The recommended lens focal length for the Thermal Imaging Camera is 100 mm. A varifocal lens whose zoom range includes the specified focal length value is preferred.

16. Annexure-4 Computation unit configuration

The requirements specified in this section are preliminary and may be modified by the Vendor. The equipment offered by the Vendor shall meet or better the specifications indicated in this section.

Computation Unit shall have following:

1. Industrial Edge AI Computing Unit (Rugged Enclosure Included)
2. CPU support: Intel® Xeon® E and Intel® 14th GenCore or similar
3. GPU support: NVIDIA® RTX A6000 or similar, with dedicated GPU bracket
4. Multi-Camera Frame Grabber / Capture Card
5. Networking Module (miniPCIe or Equivalent)
6. PoE+ Ethernet Adapter (PCIe-Based or Equivalent)
7. Memory: up to 128 GB DDR4 (ECC/non-ECC)
8. Storage SSD (2 TB)
9. Storage SSD (1 TB)

1. Industrial Edge AI Computing Unit (Rugged Enclosure/chassis : Neousys Nuvo-8108GC-QD or similar Included) :

- Functional Role: Industrial grade edge AI computing unit (with rugged enclosure as a part of the Computing Unit) for real-time multi-camera video ingestion, processing, AI inference, storage, and network transmission in rugged field environments.
- Operating temperature: −25°C to +60°C (rugged operation, per vendor spec)
- Reliability / ruggedness: vibration 3 Grms (5–500 Hz, 3 axes) and shock per MIL-STD-810G; humidity 10–90% non-condensing

2. CPU support: Intel® Xeon® E and Intel® 14th GenCore or similar

- Cores / threads: 8 Cores / 16 threads
- Base / turbo: 3.40 GHz / up to 5.00 GHz
- Cache / TDP: 16 MB cache; 80 W TDP
- Operating temperature (thermal limits): Tcase ~73°C, T-junction ~ 100°C or better
- Reliability angle (platform-level): server/workstation-class CPU family used with ECC-capable platforms (ECC enablement depends on system configuration)

3. GPU Support : NVIDIA RTX A6000 or similar, with dedicated GPU bracket

- Architecture: NVIDIA Ampere (pro RTX) or similar
- VRAM: 48 GB GDDR6, ECC supported
- Memory interface / bandwidth: 384-bit / 768 GB/s
- Operating environment (ambient): 0°C to +50°C (short-term up to +55°C), humidity 5–85% operational
- Reliability: MTBF reported as >800,000 hours

4. Multi-Camera Frame Grabber / Capture Card - CCG3-8H (CoaxCapture GMSL Video Capture Card Gen2) or similar

- Function: multi-camera capture (variant supports 8 camera inputs)
- Supported camera resolution: 1–8 MP; bit depth includes YUV422 (8-bit) and RAW (8/12/16-bit)
- Operating temperature: −20°C to +70°C; storage −40°C to +80°C
- Humidity: 5–90% RH non-condensing (operating)
- Reliability: MTBF: 5 years (as specified in datasheet)

5. Networking Module (miniPCIe) — Innodisk EMPL-G201-W2 (mPCIe to Dual GbE LAN Module or similar)

- Interface: PCI Express 2.0 x1 (miniPCIe); 2× GbE (RJ45)
- Power: max 1.485 W (3.3 V, 450 mA)
- Operating temperature: −40°C to +85°C (Wide Temp, W/T); storage −55°C to +95°C
- Reliability / ruggedness: vibration 5G (7–2000 Hz), shock 50G @0.5 ms

6. PoE+ Ethernet Adapter (PCIe-Based or Equivalent) - Neousys PCIe-PoE312M (M12 X-coded) or similar

-
- Ports / NIC: 4× GbE via Intel® I350 (server-grade), supports IEEE 1588
- PoE: IEEE 802.3at (PoE+), up to 25.5 W per port
- Operating temperature: 0°C to +55°C with airflow
- Reliability note: rugged surveillance/edge card positioning

7. Memory 2 × 32 GB Kingston KSM26SED8/32ME or similar

- Type / form factor: DDR4-2666 ECC SO-DIMM (260-pin)
- Capacity / rank: 32 GB, 2Rx8
- Operating temperature: 0°C to +85°C
- Storage temperature: −55°C to +100°C
- Reliability feature: ECC (single-bit error correction)

8. Storage SSD (2 TB) — Innodisk mSATA 3TE7, 2TB or similar

- Form factor / interface: mSATA (MO-300), SATA III 6.0 Gb/s
- Capacity: up to 2TB (order option exists for 2TB)
- Performance (max): Sequential R/W 550 / 510 MB/s
- Endurance: P/E 3,000, TBW (max) 2,400 TB
- Operating temperature: Standard 0 - 70°C, Industrial −40 to 85°C
- Reliability: MTBF > 3,000,000 hours

9. Storage SSD (1 TB) — Innodisk M.2 (P80) 4TG2-P, 1TB (PN: DGM28-01TDP1KCCEF / wide-temp option DGM28-01TDP1KWCEFH) or similar

- Form factor / interface: M.2 2280 (M-Key), PCIe Gen4 x4, NVMe 1.4
- Flash: 3D TLC, LDPC ECC
- Performance (max): Seq Read/Write 6950 / 4700 MB/s
- Endurance: TBW (Max.) 8444 TB, P/E 3000
- Operating temperature: Standard 0 - 70°C, Industrial (Wide Temp) −40 to 85°C
- Storage temperature: −40 to 85°C
- Reliability / rugged: MTBF > 3,000,000 hours, Vibration 20G (7–2000Hz), Shock 1500G @0.5ms

10. Operating System — Debian GNU/Linux 11 (custom build) or similar

- Type: 64-bit Linux distribution based on Debian GNU/Linux 11 (“bullseye”), customized and built by the Vendor for the target hardware.
- Configuration: tailored to support storage and network services, with drivers for the GPU, frame grabber and network modules specified above.
- Deployment: installed on the internal SSD and configured for unattended startup, automatic launch of the RSAAS application services and execution of the power-up self-test.

Note:

1. All equipment shall be industrial-grade and suitable for 24×7 continuous operation.
2. OEM must provide environmental compliance certificates.
3. MTBF documentation shall be submitted where available.
4. All components must be mutually compatible and validated by the bidder.

17. Annexure 5. Distance Measurement Accuracy validation system

Introduction

1.1 Purpose

This document describes a validation system that checks how accurately the RSAAS measures distances to obstacles. The RSAAS detects obstacles and railway signal aspects with onboard cameras and warns the locomotive driver through audio alerts. To test it, we need an independent way of measuring the actual distance to a test obstacle and comparing it with what the RSAAS reports. High-precision GNSS positioning gives us that independent measurement.

1.2. Scope

The validation system covers the Proof of Concept phase and acceptance testing. Its only function is producing a reference distance between the locomotive and a test obstacle, accurate to a few centimetres, which is then compared against the RSAAS reading for the same obstacle.
All obstacle types from the FRS are included: human (1.7 m × 0.4 m), child (0.7 m × 0.4 m), bicycle or motorcycle with rider (1.7 m × 0.6 m), railway car-sized object (4.0 m × 2.9 m), road vehicle (1.5 m × 1.9 m), and cow-sized animal (1.4 m × 0.8 m).

2. Operating Principle

2.1. The Problem

RSAAS testing demands a ground-truth distance from the locomotive to the test obstacle, and that ground truth must be far more accurate than the RSAAS tolerance itself. Consumer-grade GNSS (smartphone-level) lands at 3–5 m, which is useless here. RTK GNSS closes the gap, delivering 2–5 cm.

2.2. How It Works

A geodetic GNSS base station goes up at a fixed point near the test obstacle. A GNSS rover goes on the locomotive. The base station receives satellite signals, computes correction data that cancel out atmospheric and orbital errors, and transmits those corrections to the rover over a radio link. Once the rover applies the corrections, it knows its position relative to the base within a few centimetres.

The base station sits at a known point near the obstacle; the rover sits on the locomotive. The computed distance between them is the ground truth that gets compared to the RSAAS output.

3. System Description

3.1. Architecture

Two connected components:
Ground segment (base station). A geodetic GNSS receiver on a survey tripod, with a GNSS antenna and a UHF radio modem. It sits at a fixed, surveyed position at or near the obstacle, receives satellite signals, computes RTK corrections, and broadcasts them.
Locomotive segment (rover). A second geodetic GNSS receiver mounted on the locomotive, paired with a receiving modem. It picks up corrections from the base, applies them, and writes the corrected position to a log file 5–10 times per second.

3.2. Equipment

3.2.1. GNSS Receivers

Both units need to be dual-frequency, multi-constellation receivers with RTK:

Parameter	Requirement
Constellations	GPS + GLONASS + Galileo + BeiDou
Frequency bands	L1 + L2 minimum
Horizontal accuracy (RTK-fix)	≤ 2.5 cm + 1 ppm × baseline
Update rate	≥ 5 Hz, 10 Hz recommended
RTK initialisation	< 60 s typical
Correction format	RTCM 3.x
Position output	Raw relative coordinates (N, E, D)
Operating temperature	−20 °C to +70 °C
Ingress protection (outdoor)	≥ IP65

3.2.2. Radio Link

Corrections reach the rover in one of two ways:

- UHF radio modem 400–470 MHz, 5–10 km line-of-sight range, no cellular dependency.
- Cellular modem running NTRIP. Corrections go over 3G/4G/LTE. Useful when the base-to-rover distance exceeds UHF range.

3.2.3. Data Retrieval

Both receivers log continuously. Logs come off via Bluetooth, Wi-Fi, USB, or Ethernet. The rover's position log (timestamped coordinates at 5–10 Hz) is the

primary input. Raw satellite observations in RINEX format should also be saved in case post-processing is needed.

3.3. Obstacle Dummies

Built as per section 14.2.1 and design documentation from Section 13.1.6:

Obstacle type	Height, m	Width, m
Human	1.7	0.4
Child	0.7	0.4
Bicycle / motorcycle with rider	1.7	0.6
Railway car-sized object	4.0	2.9
Road vehicle	1.5	1.9
Cow-sized animal (optional)	1.4	0.8

The base station antenna sits at or next to the dummy. If there is any offset between the antenna position and the dummy's geometric centre, it should be measured and noted before the test.

4. Distance Computation

4.1. Coordinate System

The rover reports its position relative to the base in a local frame:

- N (northing): how far north of the base, in metres.
- E (easting): how far east of the base, in metres.
- D (down): vertical displacement below the base, in metres.

These come straight from the receiver (e.g. relPosN, relPosE, relPosD in the UBX-NAV-RELPOSNED message).

4.2. Straight-Track Distance

On straight sections (curvature radius above 8,000 m, as per Section 5.11), the horizontal distance is:

$$L = \sqrt{(N^2 + E^2)}$$

L — horizontal distance, metres
N — northing of the rover relative to the base (relPosN), metres
E — easting of the rover relative to the base (relPosE), metres

D is excluded deliberately. The RSAAS measures distance in the horizontal plane, so the reference should match.

4.3. Curved-Track Distance

On curves (radius below 8,000 m), a straight line cuts through the arc and understates the along-track distance. The RSAAS reports along-track distance, so the reference must too.

The back-calculation method handles this by accumulating short chord segments between consecutive GNSS fixes:

$$L_p = \sum \sqrt{(\Delta N_i^2 + \Delta E_i^2)}, \quad i = 1 \ldots k$$

L_p — along-track distance, metres
k — number of GNSS intervals between obstacle and locomotive
$\Delta N_i = N_i - N_{i-1}$ — northing change between consecutive fixes
$\Delta E_i = E_i - E_{i-1}$ — easting change between consecutive fixes

At 10 Hz and 60 km/h, each segment spans about 1.67 m. That resolution tracks curves down to 200 m radius without meaningful error. On straight track the sum converges to the Euclidean distance, so the method works everywhere.

4.4. Time Synchronization

Each RSAAS distance reading has a timestamp. The reference distance must belong to the same instant. GNSS data carry GNSS time (UTC); RSAAS data run on the onboard computer's clock. A 100 ms offset at 60 km/h shifts the distance by roughly 1.67 m, which eats most of the RSAAS error budget.

Countermeasures:

- PPS sync: the receiver's Pulse Per Second output locks the computer clock to GNSS time.
- Offset logging: record the gap between GNSS time and system time at session start. Correct all RSAAS timestamps by that offset in post-processing.

4.5. RSAAS Measurement Timestamp

Each RSAAS detection result carries a timestamp. This timestamp shall be the frame acquisition time: the instant at which the camera sensor completed the exposure for the frame from which the detection was derived. The camera driver or frame grabber assigns a hardware timestamp to each frame at the moment of capture. This timestamp propagates unchanged through the processing pipeline and is attached to every detection output derived from that frame.
All distance computations and interpolations in this document use that frame acquisition timestamp as the time of the RSAAS measurement.

4.6. Interpolation between GNSS Fixes

The rover outputs a position at a fixed rate (e.g. 10 Hz). RSAAS measurements may fall between these epochs. Linear interpolation bridges the gap, using the two GNSS fixes that bracket the RSAAS timestamp:

$$N_r = N_0 + (t - t_0) \cdot (N_1 - N_0) / (t_1 - t_0)$$
$$E_r = E_0 + (t - t_0) \cdot (E_1 - E_0) / (t_1 - t_0)$$

t_0, t_1 — timestamps of the two bracketing GNSS fixes ($t_0 < t < t_1$)
N_0, E_0 and N_1, E_1 — rover coordinates at those instants
t — RSAAS measurement timestamp
N_r, E_r — interpolated coordinates at time t

The interpolated coordinates go into the distance formula from 4.2 or 4.3. At 10 Hz the interval is 100 ms; worst-case interpolation error on a 200 m curve at 60

km/h is about 0.17 cm. Any GNSS gap over 2 s invalidates the corresponding RSAAS readings.

5. Accuracy Assessment

5.1. Relative Distance Error

For every RSAAS measurement with a valid reference distance, the relative error is:

$$error = | D_n - D_r | / D_r$$

D_n — distance reported by RSAAS, metres
D_r — reference distance from GNSS, metres

A measurement passes the FRS when:

$$| D_n - D_r | \leq max(0.10 \times D_r , 1.0 \text{ m})$$

The absolute error must stay below 10 % of the true distance or 1 metre, whichever is larger (Section 5.8).

5.1.1. Short-Distance Boundary

Below 2 m both systems approach their resolution limits. If both readings are under 2 m, the error is taken as zero. If the reference is under 2 m but the RSAAS reports more than 2 m, the error is recorded as 1.0 to flag a gross fault.

5.2. GNSS Quality Filter

Only RTK-fix solutions (carrSol = 2) are accepted. RTK-float (carrSol = 1) and standalone fixes (carrSol = 0) are dropped. Timestamp continuity is checked; gaps over 2 s cause the matching RSAAS data to be excluded.

5.3. Summary Statistics

After a test series, the following are computed across all valid measurement pairs:

- Mean absolute error (metres): average of $|D_n - D_r|$.
- Mean relative error (%): average of the per-measurement error values.
- 95th-percentile absolute error (metres): the value below which 95 % of absolute errors fall.
- Error-vs-distance plot: absolute error on the vertical axis, reference distance on the horizontal, with the FRS tolerance band (±10 % or ±1 m) overlaid.

6. Test Procedures

6.1. Setup

Before every session:

1. Set up the base station at the obstacle position: tripod, antenna, radio modem. Power on and wait for satellite lock.
2. Mount the rover on the locomotive with its antenna and receiving modem. Power on, confirm corrections are coming through.
3. Wait for RTK-fix (carrSol = 2), typically 30–60 s.
4. Measure and note any offset between the base antenna and the dummy centre.
5. Synchronise clocks (PPS or offset logging per Section 4.4).
6. Begin GNSS and RSAAS logging.

6.2. Static Tests

As per Section 14.2.7. The locomotive stands still (after an initial 3 m forward move to activate the sensor block). The dummy is placed at 250, 500, 750, and 1,000 m in turn. At each range the RSAAS detection result, the RSAAS-reported distance, and the GNSS reference distance are recorded. Error is computed per Section 5.1.

6.3. Dynamic Tests

As per section 14.2.8. The dummy and base station go at least 1,100 m ahead of the starting position. The locomotive approaches at the agreed speed while the validation system records the reference distance at 5–10 Hz and pairs each value with the RSAAS output. Visibility and illumination are measured with a transmissometer and luxmeter (FRS 14.2.8.5). The specific test conditions depend on the climate at the trial location (FRS 14.2.8.4).

7. Data Management

7.1. Data Collection

GNSS receivers and the RSAAS record independently during the test. The GNSS log carries timestamped relative coordinates (N, E, D) and the carrier solution flag (carrSol) for each epoch. The RSAAS log carries timestamped obstacle type and reported distance. All timestamps reference GNSS time.

7.2. Post-Processing

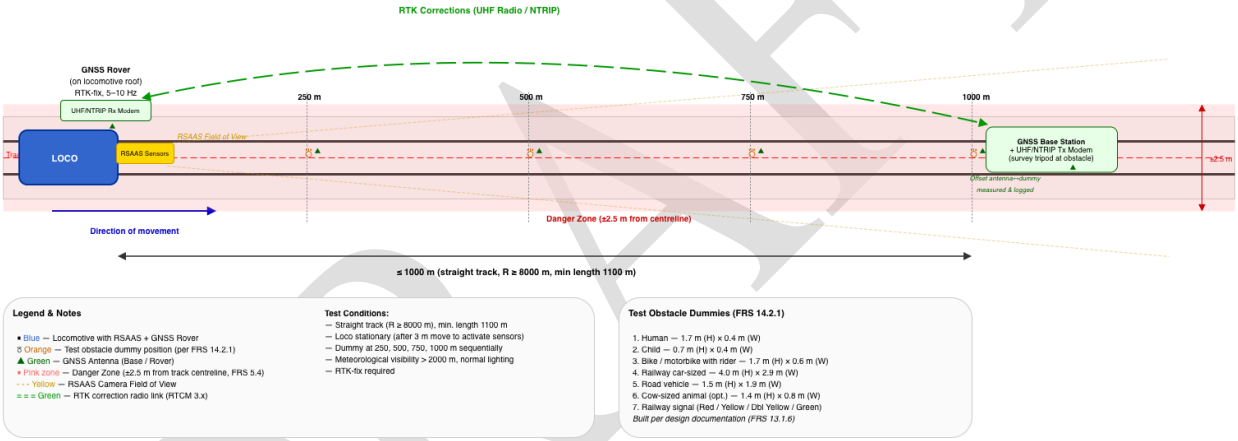
Once the session ends, GNSS and RSAAS logs are pulled and merged offline. Processing runs in four stages: timestamp alignment (applying the offset from Section 4.4 if PPS was not available), coordinate interpolation to RSAAS measurement instants (Section 4.6), reference distance computation (Section 4.2 or 4.3), and per-pair error computation (Section 5.1). The output is a test report with individual error values, aggregate statistics (Section 5.3), and the error-vs-distance plot.

7.3. Log Retrieval

GNSS logs come off the receivers over whatever interface the model supports (Bluetooth, USB, Wi-Fi, Ethernet). RSAAS logs come off the onboard storage (Sections 7.10–7.11) via USB or the vendor utility.

8. Glossary

9. Test setup scheme



18. Annexure 6. Logging Subsystem Specification

1. Purpose and Scope

This document specifies the logging subsystem of the Railway Safety Audio Alert System (RSAAS). It defines what data is collected, why it is collected, in which format it is stored, and how it can be retrieved. The logging subsystem serves three consumer roles:

- Software developers — debugging perception, tracking, distance estimation, and alert generation logic during development and field trials.
- Data engineers / ML team — building annotated datasets for model retraining, regression testing, and dataset expansion (new object classes, new operating regions).
- System integrators and maintenance personnel — including Zonal Railways / CRIS staff and Vendor maintenance teams — diagnosing field failures and confirming correct system operation.

Logging is a built-in system function operating in background mode. Access to logs is granted only to authorized users. Logging shall not interfere with real-time obstacle detection or alert generation.

2. Data Available for Logging

The following categories of data produced by the system are available to the logging subsystem. Whether each category is recorded, and at what quality, depends on the log class (see Section 3).

Data category	Description
Optical cameras	3 optical cameras per sensor block, 2 sensor blocks per locomotive (6 streams total — one stream per camera).
Thermal cameras	1 thermal camera per sensor block, 2 sensor blocks per locomotive (2 streams total). Currently the RSAAS sensor suite (FRS Annexure-3) contains only optical and thermal cameras; no lidar or radar. Should additional sensor types be added to the suite by the Vendor in the future, their streams will be logged under the same rules.
Perception outputs	Detections (bounding boxes per frame), tracks of railway tracks (the system's internal representation of the rail lines visible to the machine-vision

	pipeline, used for on-track / off-track classification of detected objects), distance estimates, on-track / off-track classification, confidences, active model version.
Navigation data	GNSS position, heading, speed; expected next signal from the Fog Pass interface.
Alert events	Audio alert generation events: type, target object or signal aspect, distance, beep rate, console identifier, diagnostic information on the audio alert module operation (call setup state, codec, link to the cab ceiling speakers).
Self-diagnostic events	Component health, self-test results at startup, errors, restarts, state transitions.
Platform telemetry	CPU / GPU utilization and temperatures, memory and disk usage, NTP / PTP synchronization state, camera link health, power events.

3. Log Classes

Logs are grouped into four classes by intended use, retention, and data rate. Each class can be enabled, disabled, and configured independently.

Class	Purpose	Quality / rate	Volume order	Default retention
A. Debug recording	Bit-accurate reproduction of an incident or trial run for offline debugging	Full 4K optical + full thermal + all internal messages	≈30 GB/min per loco at maximum quality	Short session only (manual trigger or rolling window)
B. System operation recording	Continuous camera recording required by the FRS for post-event analysis; same recordings also used as a source for ML dataset growth	Reduced resolution / fps, compressed	≈16 GB/h per loco	≥ 15 days rolling (per FRS 7.10)
C. Diagnostic event log	Record of detections, alerts, signal recognitions, and system events	Structured records, no raw imagery	< 1 GB/day	≥ 6 months
D. System log	OS / service health: CPU, GPU, temperatures, restarts, errors	Structured records, periodic samples	< 100 MB/day	≥ 6 months

4. Class A — Debug Recording

4.1. **Purpose**

Debug recording provides software developers with a bit-exact reproduction of the input to the perception stack, plus all internal messages produced by perception, navigation, alert, and diagnostic modules. An incident can then be replayed offline through the same inference pipeline, or through a newer build of it. This is the primary tool for root-cause analysis of false positives, missed detections, and tracker drift.

4.2. **Content**

- Optical cameras: all 3 cameras per sensor block, 2 sensor blocks (6 streams total), full resolution (3840 × 2160), full frame rate (up to 30 fps).
- Thermal cameras: 2 streams (one per sensor block), full resolution (1280 × 1024), full frame rate.
- All internal messages from perception, navigation, alert, and self-diagnostic modules.
- Frame acquisition timestamps assigned by the camera driver at exposure completion (not host wall-clock).

4.3. **Data Rate**

Debug recording produces a very high data rate. At maximum quality (slightly-compressed optical at full 4K @ 30 fps and raw thermal at full resolution and frame rate, on 6 optical and 2 thermal streams) the total stream from one locomotive is on the order of 30 GB per minute. Continuous recording is not the intended mode of use; Class A is operated in one of three modes:

- Manual trigger — operator or developer activates recording for a fixed window (default 10 min).
- Event trigger — recording is started automatically on a configurable event (e.g. diagnostic error, alert generated for a Red Aspect). A pre-roll buffer of N seconds is retained (default 30 s).
- Rolling window — last N minutes are kept on the SSD and overwritten continuously; preserved on event or on manual save.

Class A is intended exclusively for manual debugging sessions performed by the development team. There is no fixed limit on session count or disk consumption — if a one-hour run is needed and it requires a terabyte of space,

the operator is expected to provision the storage accordingly (external disk or larger SSD).

4.4. **Format**

Class A recordings use the system's native internal log format. The format is essentially a direct serialization of the messages that travel on the internal message bus, together with the synchronized camera streams; it preserves every message in the order and timing in which it was produced. A replay tool provided by the Vendor reads this format and feeds the recorded messages back into the inference pipeline for offline debugging.

5. Class B — System Operation Recording

5.1. **Purpose**

Class B is the continuous camera recording of system operation required by Section 7.10: storage capacity sufficient for at least 15 days of video, on industrial-grade solid-state storage, suitable for post-event analysis. Quality is reduced relative to Class A so that the 15-day rolling window fits within the on-board SSD.

> ***Note.*** *The same Class B recordings are also used as the input dataset for ML model retraining and regression testing. Selection of frames for labelling is driven by the events recorded in Class C (Section 6).*

5.2. **Content**

- Optical cameras: down-sampled to 1920 × 1080, 15 fps, all 3 cameras per sensor block, 2 sensor blocks (6 streams total).
- Thermal cameras: native resolution, 15 Hz, both streams, 8-bit normalized.
- Per-frame perception output (detections, railway tracks, distances, model version) recorded alongside the video — useful both for post-event review and for filtering frames for the dataset.
- GNSS position and speed (1 Hz).

5.3. **Data Rate Estimate**

Stream	Resolution	Rate	Bitrate (H.264)	GB / hour

Optical — per single camera (reference)	1920 × 1080	15 fps	~5 Mbps	~2.3
Thermal, both cameras (H.264 8-bit)	1280 × 1024	15 Hz	~5 Mbps	~2.3
Per-frame perception output and GNSS records	—	variable	< 0.5 Mbps	< 0.3
Total per loco			**~35 Mbps**	**~16 GB/h**

At an 8-hour per-day duty cycle, the 15-day on-board footprint is approximately 1.9 TB — fits the 2 TB SSD specified in FRS Annexure-4 with a modest margin. At a 24-hour duty cycle, the same 15-day window grows to approximately 5.7 TB, which exceeds the on-board SSD capacity; in that case periodic off-loading to external storage at the loco shed is required (interval and procedure to be agreed between Zonal Railways and the Vendor). The POC operates under the 8-hour duty-cycle profile.

5.4. Format

- Video: MP4, H.264 high profile, 1-hour segments.
- Per-frame perception output and GNSS samples: one sidecar file per video segment.
- Files are organized by date: /operation/YYYY-MM-DD/<sensor-block>/<camera-id>/*.mp4.

Indicative sidecar JSONL record (one line per processed frame; field set may change during implementation; line breaks below are for readability only):

```
{"ts":"2026-05-24T14:31:05.233Z","seg":"sb1_cam1/14.mp4","frame":1247,
 "detections":[{"cls":"Human","bbox":[1820,940,1880,1140],"dist_m":612.4,
        "lateral_m":1.1,"on_track":true,"conf":0.91,"track_id":42}],
 "model":"rsaas-yolov8-r12"}
```

Indicative GNSS sample line (CSV, 1 Hz; columns subject to change):

```
2026-05-24T14:31:05.000Z,28.61292,77.23073,219.8,128,42.6
# fields: utc, lat, lon, alt_m, heading_deg, speed_kmph
```

6. Class C — Diagnostic Event Log

6.1. Purpose

Class C records semantically meaningful events: when the system detected an object, when it generated an alert, when a signal aspect was recognized, when

a self-diagnostic check failed. This log is the basis for the post-trip summary reports provided to Zonal Railways / CRIS.

6.2. Event Types

Event type	Recorded fields
object_detected	timestamp (frame acquisition time), class (Human / Railway car / Cow / Road vehicle / etc.), bounding box, distance, lateral offset from track centreline, on-track flag, confidence, sensor block, camera id, model version
object_track_update	track id, timestamp, class, distance, speed estimate, in-danger-zone flag. The object_track_update event reports the per-frame state of a tracked object; the railway-tracks representation itself is not duplicated into Class C — it is logged in the system's internal format under perception outputs (see §2 and Class A/B recordings).
signal_expected_not_detected	timestamp, expected signal position (from Fog Pass), fallback alert generated (per FRS 5.5)
alert_generated	timestamp, alert type, beep rate, console id, audio alert module diagnostic state, triggering event reference
alert_acknowledged	timestamp, alert reference
system_state	timestamp, state transition (boot / ready / degraded / fault), self-test results
component_health	timestamp, component id, status, error code, error description

6.3. Format

Class C events are produced by the perception, alert, and self-diagnostic modules and written to disk in the system's native internal log format — the same format used by Class A, but containing only the event messages, without camera streams. This keeps the on-locomotive write path uniform and small.

After retrieval, a post-processing tool provided by the Vendor converts the native log into one or more human-readable representations, selectable by the consumer:

- Plain text log — one event per line, suitable for grep and quick inspection.
- Tabular form — CSV or XLSX, one row per event, suitable for opening in spreadsheet tools.

- JSON Lines — one JSON object per line, suitable for programmatic processing.
- Summary statistics — see Section 6.4.

Indicative Class C events after conversion to JSON Lines (one event per line; field names and layout are illustrative and will be finalized during implementation; line breaks below are for readability only):

```
{"ev":"object_detected","ts":"2026-05-24T14:31:05.233Z","cls":"Human",
 "bbox":[1820,940,1880,1140],"dist_m":612.4,"lateral_m":1.1,
 "on_track":true,"conf":0.91,"sb":1,"cam":1,"model":"rsaas-yolov8-r12"}
{"ev":"object_track_update","ts":"2026-05-24T14:31:05.300Z","track_id":42,
 "cls":"Human","dist_m":605.7,"speed_kmph":1.2,"in_danger_zone":true}
{"ev":"signal_aspect_detected","ts":"2026-05-24T14:31:08.100Z",
 "aspect":"Red","bbox":[1942,612,1968,672],"dist_m":740.2,
 "fogpass_match":"SIG-DLI-04417","conf":0.97,"cam":1}
{"ev":"signal_expected_not_detected","ts":"2026-05-24T14:32:55.880Z",
 "expected_signal":"SIG-DLI-04418","fallback_alert":"red_equivalent"}
{"ev":"alert_generated","ts":"2026-05-24T14:31:05.310Z","type":"obstacle",
 "beep_rate_hz":4.0,"console":"cab_A","audio_state":"streaming",
 "trigger_ref":"object_track_update@2026-05-24T14:31:05.300Z"}
{"ev":"alert_acknowledged","ts":"2026-05-24T14:31:14.022Z",
 "alert_ref":"alert_generated@2026-05-24T14:31:05.310Z"}
{"ev":"system_state","ts":"2026-05-24T08:02:11.000Z",
 "from":"boot","to":"ready","self_test":"passed"}
{"ev":"component_health","ts":"2026-05-24T11:47:00.000Z",
 "component":"thermal_sb2","status":"degraded",
 "error":"GMSL link drop count exceeded threshold","code":"E-CAM-003"}
```

6.4. **Derived Statistics**

The post-processing tool produces the following aggregates from the Class C log over a configurable period (per trip, per day, per 100 km):

- Number of detected objects, broken down by object class (Human, Railway car, Road vehicle, Cow, etc.).
- Number of signal aspect recognitions, broken down by aspect (Red, Yellow, Double Yellow, Green).
- Number of alerts generated, by alert type.
- System uptime, fault count, restart count.

Output of the statistics tool is a small JSON or XLSX file that can be attached directly to project reports.

Indicative summary file (JSON, abbreviated; structure may change):

```
{
 "period": { "from": "2026-05-24", "to": "2026-05-24", "km_with_system_active": 412.7 },
 "loco_id": "LOCO-WAG9-31345",
 "detections_by_class": { "Human": 18, "Railway car": 6, "Cow": 41, "Road vehicle": 9 },
 "signals_by_aspect":   { "Red": 12, "Yellow": 9, "Double Yellow": 4, "Green": 88 },
 "alerts_by_type":      { "obstacle": 74, "signal_red": 12, "signal_yellow": 13 },
```

```
  "system": { "uptime_h": 8.2, "faults": 0, "restarts": 0 }
}
```

7. Class D — System Log

7.1. **Purpose**

Class D records platform-level information independent of the perception pipeline: CPU and GPU utilization, temperatures, memory pressure, disk usage, service restarts, kernel messages, NTP / PTP synchronization status.

7.2. **Content**

- System journal entries for all RSAAS services (forwarded as structured records).
- Periodic sampling (1 Hz default): CPU%, RAM%, GPU%, GPU VRAM, GPU temperature, CPU package temperature, SSD temperature, SSD wear indicator, network link state, NTP/PTP offset.
- Sensor link health: lock state and frame-drop counters per sensor (optical and thermal cameras; any additional sensor types added to the suite by the Vendor in the future are covered by the same field).
- Power events: input voltage excursions reported by the DC-DC converter (where instrumented).

7.3. **Format**

Class D is written directly as JSON Lines (one record per line, daily rotated, gzipped after 24 hours), since it is consumed primarily by maintenance personnel and does not need conversion. Total volume is bounded to < 100 MB/day at default sampling.

Indicative periodic-sample record (1 Hz; fields subject to change):

```
{"ts":"2026-05-24T14:31:05Z","type":"sample","cpu_pct":34,"ram_pct":52,
 "gpu_pct":71,"gpu_vram_mb":18432,"gpu_temp_c":68,"cpu_temp_c":61,
 "ssd_temp_c":47,"ssd_wear_pct":3,"ntp_offset_ms":1.4,"link":"up"}
```

Indicative sensor link health record (emitted on state change):

```
{"ts":"2026-05-24T11:46:58.812Z","type":"sensor_link","sensor":"thermal_sb2",
 "gmsl_lock":"lost","frame_drops_last_min":127}
```

Indicative forwarded service journal entry:

```
{"ts":"2026-05-24T08:02:09.103Z","type":"journal","service":"rsaas-perception",
 "level":"info","msg":"model rsaas-yolov8-r12 loaded, warm-up complete"}
```

8. Timestamping and Synchronization

Every record in every class carries a timestamp. The timestamp of a frame and of any derived detection is the frame acquisition time assigned by the camera driver at the moment the sensor exposure is completed. The host wall-clock is used only for Class D periodic samples and for system journal entries.

Time across components is synchronized via PTP where the network supports it; otherwise NTP. The current sync state and offset are recorded in Class D once per second so post-hoc correction is possible if drift is detected.

All timestamps are stored in UTC.

9. Retention and Rotation

Class	Default retention	Rotation	Eviction policy
A. Debug	Session lifetime	Per session	First to be evicted under free-space pressure (rolling buffer); manually-saved sessions preserved until exported
B. System Operation	≥ 15 days (FRS 7.10)	1-hour segments	Protected within the 15-day window; oldest day removed only after Class A and Class C/D buffers exhausted
C. Diagnostic	≥ 6 months	Daily file, gzipped after 24 h	Oldest gzipped day evicted after Class A rolling buffer is exhausted, before Class B
D. System	≥ 6 months	Daily file, gzipped after 24 h	Same as Class C

When free disk space falls below the configured low watermark, eviction proceeds in the following priority order, from first to last evicted:

- Class A rolling-buffer segments (temporary by definition).
- Class C and Class D gzipped daily files older than the on-board retention floor.
- Oldest Class B day — only when the above two are exhausted and free space is still below the watermark.

Class B days within the FRS-mandated 15-day window are protected from eviction. Class A sessions saved manually by an operator (i.e. not the rolling buffer) and Class C events of the current day are also protected.

10. Retrieval

All logs are retrieved from the on-locomotive computation unit over its Ethernet interface.

- Class B (system operation recording) and Class C (diagnostic event log) are exposed through a dedicated retrieval interface on the unit. Authorized personnel — including Zonal Railways / CRIS representatives and Vendor maintenance staff — connect to this interface and download the recordings and events for a selected date range. The interface returns the recordings at the original quality at which they were captured.
- Class A (debug recording) and Class D (system log) are intended for the development team and are retrieved by the Vendor's developers directly from the unit over the same Ethernet link, using internal tooling. They are not exposed through the routine retrieval interface.

Access to the retrieval interface is governed by an authenticated session. All retrieval operations themselves produce Class C events.