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Functional requirement
for

REMOTE DIAGNOSTIC
AND
PREDICTIVE MAINTENANCE

Legend:

Blue text = clause where specific comments is required for taking decision and freezing requirements. Stakeholders are requested to give comment on these clause in specific in addition to comments on other causes.

Red text = Important highlight.

TABLE OF CONTENTS:

1 FOREWORD:

1.1 This specification FRS requires reference to the latest version of following specifications: –

1.	EULYNX	EULYNX standards : selective Docs.for Diagnostic and maintenance.
2.	IRS: S-24	Electric Point Machine
3.	RDSO SPN 153	Subsidiary LED Signal
4.	RDSO SPN 199	Main LED Signal
5.	RDSO SPN 146	Audio Frequency Track Circuit
6.	IRS S 105	Block Proving by Axle Counter using UFSBI
7.	RDSO SPN 175	Solid State Block Proving by Digital Axle Counter
8.	RDSO SPN 176	Multi-section Digital Axle Counter
9.	RDSO/SPN/177	Single section Digital Axle Counter
10.	IRS: S-99	Data Logger System.
11.		Integrated Power Supply
12.	IRS: :S 63	PVC insulated underground unscreened cable for Railway signaling
13.	IRS: S 76	PVC insulated indoor cables for Railway signaling
14.	RDSO/SPN/144	Safety and reliability requirement of electronic signalling equipment.
15.	RDSO/SPN/197	Code of Practice for Earthing and Bonding System for SignallingEquipments.
16.	EN 50121*	Railway Applications - Characteristics of Rail-way Systems thataffect EMC behaviour
17.	ISO 9001	Quality Systems- model for quality assurance in design, development, production, installation and serving.

Note:

1. * Equivalent Recognized International standards may also be agreed subject to their acceptability in a foreign Railway for same application. The supplier shall submit a copy of the same for verification.

2. Whenever, reference to any specification appears in this document, it shall be taken as a reference to the latest version of that specification.

1.2 **ABBREVIATIONS :**

SNO.	Abbreviation	Expanded Form
1.	IoT	Internet of Things
2.	AI	Artificial Intelligence
3.	ML	Machine Leaning
4.	ABS	Automatic Block Signalling
5.	IBS	Intermediate Block Signalling
6.	I/O	Input/output
7.	CCIP	Control Cum Indication Panel
8.	MTBF	Mean Time Between Failure
9.	MTBWSF	Mean Time Between Wrong Side Failure
10.	MTTR	Mean Time to Repair
11.	PCB	Printed Circuit Board
12.	RDSO	Research Designs and Standards Organisation
13.	EI	Electronic Interlocking
14.	OFC	Optical Fiber Cable
15.	IPS	Integrated Power Supply
16.	AFTC	Audio Frequency Track Circuit
17.	DAC	Digital Axle Counter
18.	SEM	Signal Engineering Manual
19.	MSDAC	Muti Section Digital Axle Counter
20.	UFSBI	Universal Failsafe Block Interface
21.	LED	Light Emitting Diode
22.	SM	Station Master
23.	RTC	Real Time Clock
24.	BOM	Bill of Material
25.	FOM	Fiber Optic Modem
26.	OS	Operating System
27.	ROM	Read Only Memory
28.	STR	Schedule of Technical Requirements
29.	LCD	Liquid Crystal Display
30.	RE	Railway Electrification
31.	QA	Quality Assurance
32.	QAP	Quality Assurance Program
33.	MTTR	Mean Time To Repair
34.	PF contact	Potential Free contact
35.	OPC-UA	Open Platform Communications – Unified Architecture
36.	LoRa	Long Range communication (a wireless Technology)
37.	IRNSS	Indian Regional Navigation Satellite System

1. **SCOPE:**

This document contains the functional requirement for Remote Diagnostic and Predictive Maintenance System forIndian Railway Signalling equipment using IoT based data acquisition systems and Machine learning/Artificial Intelligence.

To ensure that the Specification is not restrictive to propriety systems, the functional requirements have been laid down and device specific details are avoided to keep scope of widely available systems without any propriety hardware and protocols. Hence, the scope of this specification is to standardize the requirements for ensuring conformity and interoperability such that data being collected on any platform/IoT device shall be utilized for machine learning/AI based data processing in the system.

Note: This Functional requirement is released for development of Specification for Remote diagnostic and predictive maintenance system. Development of system together with initial trials &further improvisation based on the experience will be done in the course of time.

2 SYSTEM REQUIREMENT:

2.1 The objective of providing Remote Diagnostic and Preventive Maintenance system is to assist maintenance team in taking appropriate maintenance action in advance to prevent the failure of signalling gears. At functional level the system is broadly divided into two categories:

2.2 **Remote Diagnostic:** of equipment to reduce MTTR and providing aid to maintenance staff in rectifying the signal failures. This is achieved by automated analysis of parameters of Signal gears collected remotely using IoT devices. The system shall be able to give probable cause of failure to aid the maintenance staff for early restoration reducing MTTR.

2.3 **Predictive Maintenance:**Facilitating predictive maintenance by advance computing of Big data using Machine Learning and Artificial Intelligence. Thedata of all the stations shall be continuously analysed by system for developing the supervised and unsupervised machine learning. The system shall be able to send automatic alerts for Signalling gears which are likely to fail based on the system learning. This will assist the maintenance staff to take necessary action to eliminate failure before it occur.

3 SYSTEM ARCHITECTURE:

The system consists of the following:

3.1 Data acquisition for parameters of Signallingequipments using additional sensors and/or inbuilt diagnostic ports of the equipment. Details in Section-5.

3.2 Transfer of raw data from site using IoT devices to local server at station. Details in Section-6.

3.3 The local server is complemented by Edge computing device to generate first level fault and diagnostic information based on the realtime data.

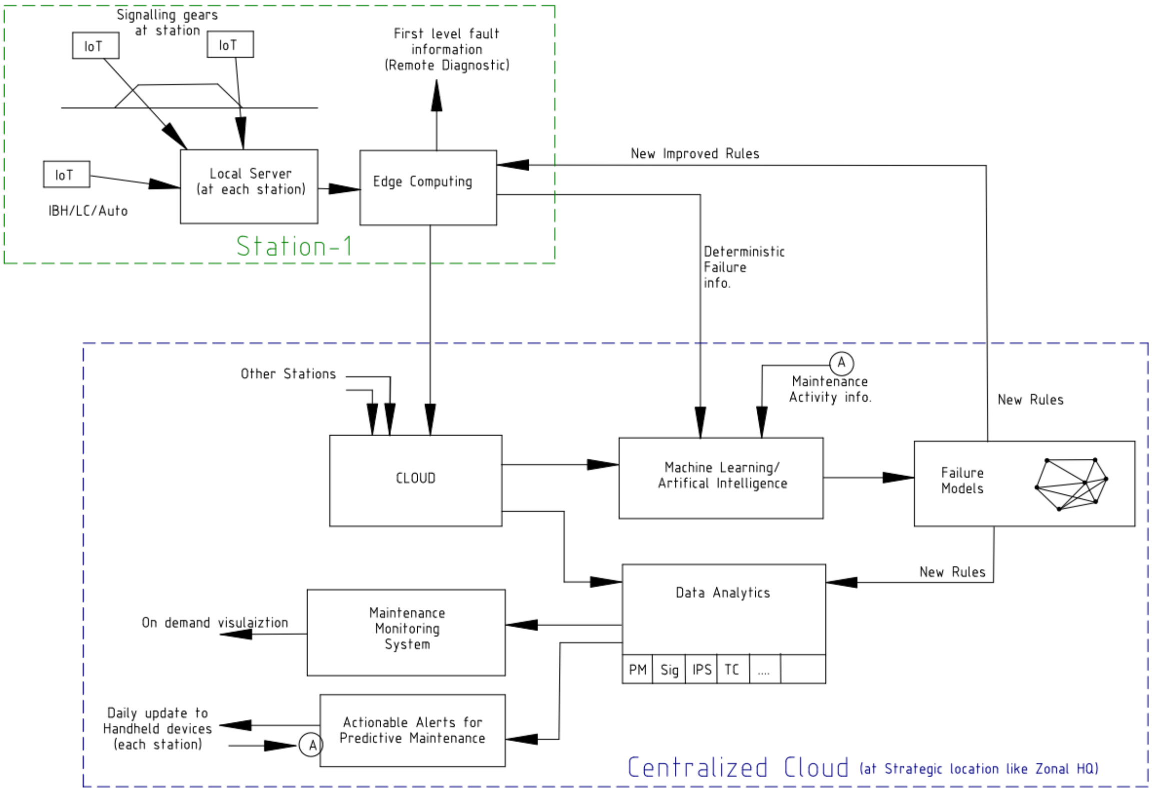

Figure-1 : System Architecture

3.4 The data from local servers at every station will be sent to centralized cloud.This data complemented by historical data and trends will be processed using advance computing through data analytics (Artificial Intelligence / Machine Learning) to anticipate any issues or failures before they occur.

3.5 Remote monitoring: An automated alert mechanism will send information to Signal Control of concerned Division and the concerned maintenance staff over sms/mobile app.

3.6 Predictive Maintenance: Mobile app should also be developed which shall be having realtime update on each station gears. The maintenance staff of particular station will be having the handheld device where at the start of each day he can see which gears need the specific attention for maintenance.

For critical faults, the sms or automated voice calls may be provided once machine learning is stable and alerts are quite accurate (upto> 60%).

The system architecture is depicted broadly in the Figure-1. As Signalling assets are distributed at more than 6000 stations, the decentralization of computing is necessary to handle the requirement for which edge computing at every station is proposed. However, the machine learning need to be centralized for complete Indian Railways so as to use the data from every station as well as streamlining the efforts for machine learning techniques. Hence, the need for one platform is proposed for AI techniques.

4 DATA ACQUISITION:

4.1 The data from each signalling gear at the station shall be collected on realtime basis using the inbuilt diagnostic ports of the signalling gears and/or the external sensors.

4.2 General requirements for external sensors:

4.2.1 For measuring the currents non-intrusive sensor shall be used.Voltage sensor shall also be preferably non-intrusive. In case of non suitability/non availability ofnon intrusive sensor for voltage, sensors having High impedance and galvanic isolation can also be considered with minimum withstand voltage of 2.5KV for 60 sec.

Note: Feasibility of non-intrusive voltage sensor to be explored. In case non-intrusive voltage sensor is not feasible and galvanic connection to monitor voltage is unavoidable, then proper plan to demonstrate that EMI noise/surge is not transferred from monitoring probe to delicate equipment power supply like Axle counters etc to be given.

4.2.2 The accuracy of sensors should be such that it will not cause noise in the data being used for machine learning. Proper accuracy and stability of sensors is very important for end goal of predictive maintenance.If the raw data is noisy and not reflecting true value of ~~site~~field gear, the machine learning will be inaccurate.

4.2.3 Most of the sensors would be transducers converting current, voltage, vibration, etc to very weak electrical signals. Hence, proper safeguard against EMI effects on the stability and accuracy of readings should be taken.Protection arrangement for sensors against surges coming from lightening/power line/ OHE shall be made. Appropriate signal processing technique and filtering shall be used to remove unwanted signals.

For example, in the RE area, the induce voltage is dynamic varying due to change in OHE current during presence or absence of train. Hence, the length of cables/wires from transducer/sensor to IoT device shall be such that induced voltage are within limit to ensure desired accuracy of stable readings.

Further, the transducer/sensor wires should not run parallel to dynamic current carrying conductors which may alter the readings of the sensors.

> *Note: "SEM para 22.6.2.1 The induced voltage in the* ***underground-*** *Unscreened cable shall be reckoned as 116 volts/km on single line and 95 volts/km on Double Line."This is when the catenary current is maximum i.e. 600Amp per catenary.*
>
> *This comes to* ***around 100mV (AC) per meter*** *which can disturb accuracy of sensor very badly. Furthermore this induced voltage is variable due to varying catenary current (upto Zero) as per number trains and their locations in the feeder section. So calibration will not help due to variable noise. This variable voltage should be tackled by suitable installation practices (use of twisted pair, etc).*
>
> *This specific requirement is very important for consistent and accurate reading and the correct machine learning for AI model.– Neccesary scheme need to be included in specification to deal with this.*
>
> *-Due to above reason, feasibility of monitoring the Signals****at Signal post itself****, Points"at point machine enclosure" in place of Location Boxes shall also be explored and suitable clauses in specification may be incorporated accordingly.*

4.2.4 Proper rated sensors shall be used as per parameter monitoring range of gear type to be monitored. Since the machine learning will depend on the variation of data to capture health signature, the least count of sensor for each category of equipment would be different. ~~Details of sensors and their accuracy should also be brought out on specification~~. For initial trial accuracy of sensors may be kept as 2%.

4.3 OUTDOOR GEARS AND THEIR TENTATIVE PARAMETERS TO BE MONITORED

4.3.1 Signals

The following data shall be recorded for each aspect of Signal:

i) AC Current.

ii) AC Voltage.

iii) Illumination of aspect(optional)

iii) Status of local signal control/detection relays at Location boxes.

4.3.2 Points:

The following data shall be recorded for each end of the Point:
i) DC operating Current.
ii) DC operating Voltage.
iii) Vibration.
iv) Movement of point machine slides (Drive, lock & Detector).

4.3.3 DC Track Circuits:
The following data shall be recorded for each Track Circuit:
i) DC feed end and relay end voltage.
ii) DC feed end and relay end current.
iii) Track relay position.
iv) ~~Track charger potential free contact (or output voltage where PF contact is not available).~~ Input Voltage & output current of Track feed battery charger,
v) Voltage & charging /discharging current of battery.

4.3.4 Presently the external sensors are required to be provided for monitoring the health of Points, Signals and DC Track circuits as these are yet not inbuilt on Indian Railways. The details of nominal voltage/current range for the Signal, Points and DC track circuits and other information is given in Annexure-1 for ready reference.

4.3.5 Axle Counters (SSDAC, MSDAC etc):
Input Voltage, current and status of vital relays and Diagnostic data from Diagnostic port of Axle counter evaluator shall be captured. This shall be based on recommendation of different OEMs of Axle counters of different makes.

4.3.6 AFTC:Voltage, current, frequency data of EJB installed in field and Diagnostic data from Diagnostic port of AFTC evaluator shall be captured. This shall be based on recommendation of different OEMs of AFTC of different makes.

4.3.7 Level Crossing Gates:
The following data shall be recorded for each Boom:
i) AC/DC operating Current of Electrical Lifting Barrier.*
ii) AC/DC operating Voltage of Electrical Lifting Barrier.*
iii) Status of open close position for each boom.
iv) Locking status of gate.

Note*: Voltage and current signature of motor shall be recorded by capturing data at the rate of 20ms during operation of ELB.

4.4 **<u>INDOOR Gears AND THEIR TENTATIVE PARAMETERS TO BE MONITORED :</u>**

Note – Some equipment data like status of relays, IPS PF contacts, etcis already available in existing Data loggers installed in relay room. The same data shall be used to avoid redundant wiring to each relay. The interface to Data Logger needs to be developed for taking data from serial port. Protocols information of Data Logger is available in Specification IRS: S-99.

4.4.1 Relays:

Status (pickup or drop) of each relay in the relay room shall be recorded through datalogger.

4.4.2 Electronic Interlocking:

Data from Diagnostic port of Electronic Interlocking.

4.4.3 Integrated Power Supply(IPS) / Battery Charger:

The following shall be monitored:

i) All voltage outputs

ii) Health of IPS modules from potential free contacts

iii) Availability of standby input power supplies from Auto-changeover system of IPS.

4.4.4 Surge Protection Devices:

The potential free contacts of SPD devices where available shall be monitored. Care should be taken to keep sensor wiring from SPD such that (electrically) dirty cable in SPD box is not in parallel to sensor wires.

4.4.5 OFC Cable:

Monitoring of Dark Fibre for monitoring the health of OFC cable, especially those not under NMS monitoring (like OFC for distributed EI, EI to ASM room, etc). The dark fibre of the cable shall be used to detect the following:

i) OFC cut and Geographical Location of Cut.

ii) dBLoss / Degradation.

4.4.6 All Networking switches/dc-dc convertors and other devices having potential free contacts for monitoring.

4.4.7 Fuse Auto changeover system:

Status of main and standby fuse.

4.4.8 Battery:

The health of battery to be monitored by using time proven techniques available in other industries using IoT. – Industry experts for suggestion and comments

Note: The IPS battery set consists of 55 Numbers of individual 2V Lead Acid cells connected in series for 110V DC backup. Whether monitoring of each cell is recommended or there is any established technique to monitor health using overall Voltage/Current. Any other established technique (which does not require to monitor each cell) available for monitoring of battery health may also be deployed. (comment regarding availability of such system may be provided)

4.4.9 Earth Leakage Detector (ELD):
Status of earth leakage from the ELD to be monitored.

4.4.10 Cables:
The use of coordinated data shall be made by the machine learning to monitor the voltage drop analysis for checking the health of signalling and power cables. Hence, existing data collected from voltage in IPS room, Voltage in field, ELD data etc will serve for the health of cables.

4.4.11 Block Instruments:
Line current and selective data for different types of Block Instruments using non-intrusive sensors.

4.4.12 UFSBI:
Relay status and Potential free contacts of UFSBI modem, Data from Diagnostic port, etc shall be monitored.

Note: The information already being logged in conventional Data logger shall be used.

4.4.13 Ambient Temperature and humidity of Battery room, relay room, power room, IoT devices location, etc shall be recorded. The temperature data may help in machine learning algorithms to model the environmental effects.

4.4.14 Any other equipment not in above list or any additional parameter of above listed equipment as found suitable for better predictive maintenance will be incorporated. However, to avoid unnecessary wiring for monitoring, it is recommendatory to monitor only required gears and parameters

4.5 Due to issue of proprietary protocols in signaling equipments, which is causing issues in interfacing various electronic signaling equipments, Indian Railways is working for uniform protocols like EULYNX.

In this regard following will be followed:

(i) OEM of equipment will provide protocol of his system. In future only EULYNX std shall be followed by all OEM.

(ii) OEM of RMPM system has to follow EULYNX standard.

Note: The EULYNX standards have defined standard information of Maintenance Diagnostic Data for Signal, Points and Track detection devices like what data should be available as diagnostic information in the relevant signalling equipment. EULYNX Release-5 or latest documents should be consulted for protocol and scheme to have uniform design to avoid interoperability between systems of different vendors.

5 IoT device:

5.1 The IoT device shall be software embedded system **preferably COTS (commercially off the shelf)** and will do the basic function of capturing the parameters from the Signalling devices using the sensors and diagnostic ports and transmit the data to Local Server through Gateway at the station.

5.2 For monitoring at IBS/LC/Auto Signalling gears, the IoT device shall be linked to nearest station and its local server.

5.3 It shall work on available 24V DC power of IPSas available at site.

5.4 To ensure that the interoperability between different manufacturers, the standard protocols for communication may be used. The protocols of EULYNX standard for Diagnostic information of Signalling equipment shall be followed.

5.5 It is imperative that the IoT device will continuously monitor the sensors for the parameters depending on scanning interval. Scanning interval to be defined keeping in mind requirement for machine learning & AI and availability of COTS IOT devices. However, device should support scanning interval of 20ms or less, it should be possible to program scanning interval.

5.6 Further, the data captured by IoT device will be transferred to Local Server. However, if the data is transferred every cycle, there would be two issues: first is the bandwidth requirement for channel and second is the large data (50 packets per second per parameter) which may difficult to handle and will be ignored at processing level at higher stages. Hence, selective methodology is required to be made for each type of device as per general guidelines below:

5.6.1 Some examples for ready reference are as below:

i) Track circuits and Signal Lamp which operates continuously, the operational parameters may be sent conditionally whenever change of reading is more than specific percentage (say 2%) of last sent value.

ii) However for Point machine & ELB motor which operates only for few seconds when operated, the operating current for every scanning cycle will be important to capture its **current signature**. The current signature may help in deciding machine learning to predict cases of less lubrication, friction clutch issue, stone obstruction and gap, Health of motor etc. For such application data will be captured & stored at an interval of 20ms.

5.7 Accordingly, the methodology for sending data from IoT device to server will be laid down for each equipment. **The IoT being embedded system shall be customizable to get the rules changed by the firmware update remotely**.

5.8 For diagnostic purpose provision shall be made that if any sensor or embedded device in field goes down sms alert may be generated. Log of the same shall also be recorded at station server.

6 Network and Communication protocols between subsystems:

6.1 The exchange of information from IoT device to Local server and to Centralized Cloud shall be on standard format for interoperability between different systems.

6.2 The network architecture and communication protocols for Diagnostic data as defined in EULYNX standards shall be followed. These are covered in Annexure-C.

6.3 It is planned for adoption of standard protocols for all Signalling equipment in future. Hence, system need to be compatible for direct interfacing with the diagnostic ports of various equipment like Electronic Interlocking, Axle counters, etc.

6.4 As defined in EULYNX, the **protocols SNMP v2c or OPC-UA** shall be used to transfer diagnostic data from the connected systems (IoT) to the service function Diagnostics collector (Local server/Edge device).

6.5 The time synchronization is an important requirement between various IoT devices for data interpretation in machine learning. This has been taken care in the standard protocol. For master clock, the IRNSS (Indian Regional Navigation Satellite System) clock or SNTP protocol shall be taken for reference.

6.6 The layers of network architecture as per EULYNX standard for the complete Diagnostic system is as shown in figure-2.

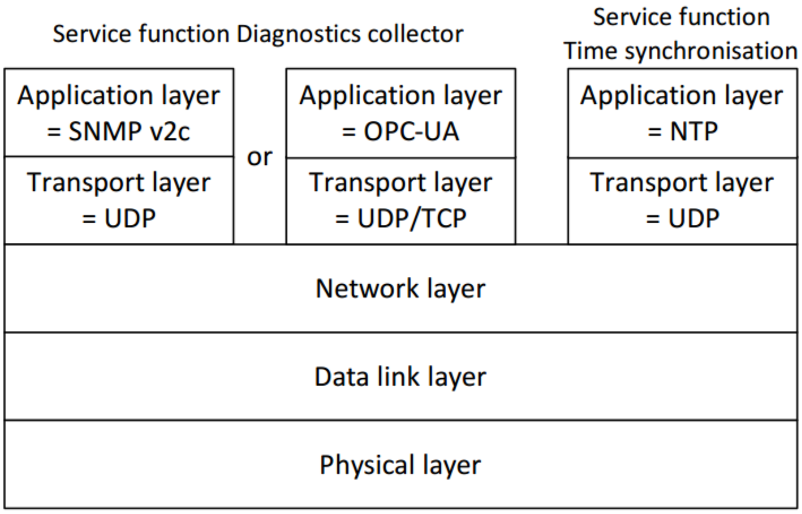

Figure-2: Network Architecture

6.7 At Physical Layer suitable network media shall be used. The EULYNX standard requires OFC and RJ45 (Copper) media which runs along with the equipment. However, on Indian Railways the field devices not having inbuilt diagnostic port shall be connected using IoT devices for which option of wireless media is preferable.

6.8 The following may be the media between various devices.

6.8.1 For communication from IoT device (in station yard near point, signals and other equipments) to Gateway at station–

i) Wireless media onLoRA, Zigbee, NB-IOT or any opensource technology in free band of wireless spectrum.

ii) Optical fiber LC interface [IEC 61754-20](mandatory for outdoor field IoTs)

iii) Copper cable. (RJ45 interfaces [IEC 60603-7])

iv) Wi-Fi communication.

Note: Use of Wireless technology is preferable as laying of additional wires and OFC will make system complex and costly. Further, LoRA, Zigbee, NB-IOT technology seem to work on long distance so it seems suitable for electrically noisy environment (RE area and dynamic variation of line of sight signals due to train movements)having but having lower data rates. The average rate of data from one IoT device will give idea on the suitability of ~~LoRA~~ these wireless technology for Physical layer. Scheme for this has to be worked out with justification.

6.8.2 For communication from outdoor type IoT devices (for field gears like signal, point, track circuits, etc) to Gateway at station, the wireless connectivity is mandatory along with optional Fibre connectivity (Type LC connector).

6.8.3 While for communication from indoor type IoT device (for IPS, Axle counter evaluator, Datalogger, etc) to Gateway at station – RJ45 (copper) and/or LC port (Fiber) may be used. Redundant communication path (wired/wireless) must be kept for reliability.

6.8.4 ~~Communication Scheme to be used~~ For far away field IoT's like for IBH, LC gates wired media like OFC or wireless system like LTE may be used. ~~and wireless to be worked out.~~

6.8.5 For communication from Station to Cloud, existing optical fibre network of Railtelmay be used.~~Option~~For redundancy LTE may~~also~~ be ~~worked out~~.used along with OFC network .

6.9 The details of higher network layers, data packet structure, etc are defined in Annexure-C which has been taken from EULYNX. The EULYNX consortium is working on minor improvement on diagnostic interface *(which is expected in Baseline-3, Release-5 documents).* In this connection, the firmwares of IoT devices and other backend softwares of system shall be designed in such flexible manner to carry out minor update on change of protocol whenever required in developmental stage.

7 Local Server and Edge computing:

7.1 At each station there shall be centralized setup consisting of Gateway to collect the data from various IoT devices and a set of Local server with Edge computing. One integrated unit with capability to work as gateway to collect field data ,edge computing etc can also be used. The basic architecture at station is depicted in Figure-3.

7.2 The Gateway shall have interface to collect data from various media like wireless, OFC and copper. It shall also be able to collect data from conventional Data Logger for indoor relays status.

7.3 The edge computing shall be employed to decentralize the computing and handling the big data and alert mechanism for each station.

7.4 Edge computing shall be done by suitable PC based system.**Industrial grade hardware shall be used for 24x7 operation unmanned functioning**.

7.5 The following is the broad functions of Edge computing device:

7.5.1 Scrutinizing the local data of signalling gears to generate realtime alerts on the "deterministic failures".

For example – A Point has no indication of Normal or reverse for more than 10 second. The system will detect this as failure and using the data of voltage/relay monitoring at relay room, point motor, etc, it should generate an alarm that *"Point No. 101 of Station 'ABC' has failed. Probable reason is – detection contact problem at A end"*

There shall be equipment specific deterministic failure patterns which shall be evolved during development. Systematic and Formal approach is required for writing these rules.

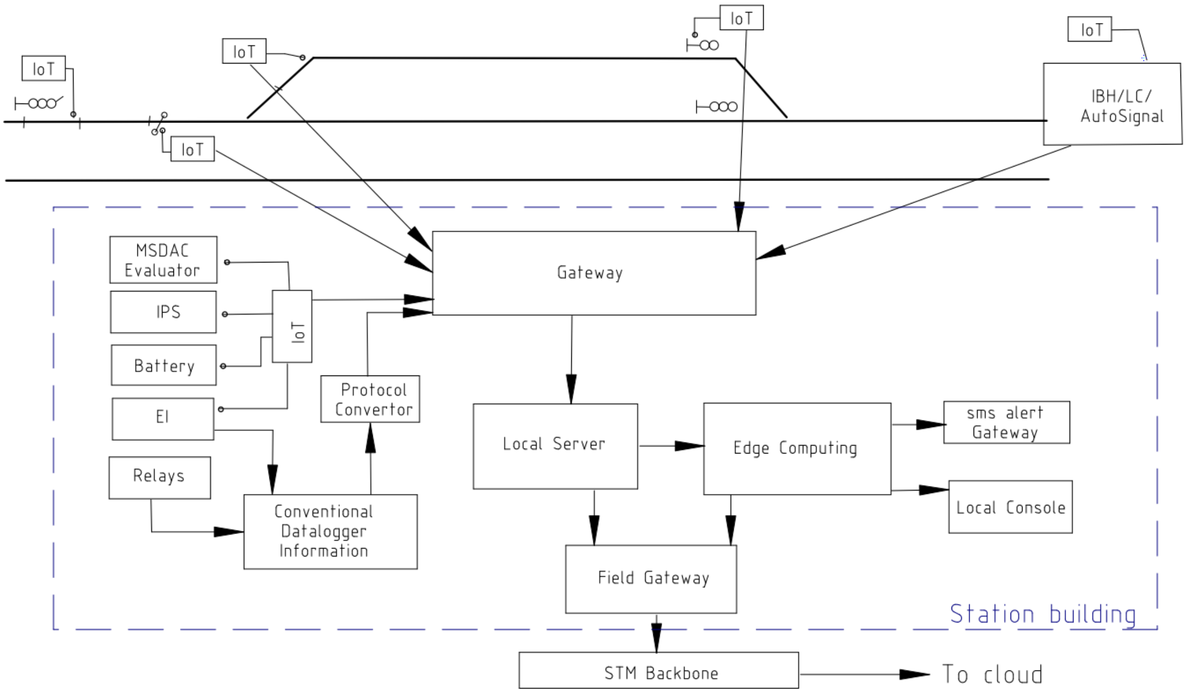

Figure-3 : Arrangement at Station

7.5.2 Sending the alert to maintenance staff through sms using "SMS Alert Gateway" over GPRS/LTE.

7.5.3 This alert shall also be sent to Cloud which shall be used for improving machine learning algorithms using AI techniques.

7.5.4 The edge computing device will update itself by new rules of deterministic failures detection sent by the Cloud based on Machine learning.

7.6 The Local server at each station of suitable size shall be provided. The detail requirement would be evolved during development.

7.7 There shall be a local monitoring maintenance system at each station which shall displayrealtime data and on demand information from local server.

7.8 The complete setup for Local server and edge computing shall be provided Relay room or Maintainer room or any suitable location at the station. However, the local monitoring maintenance system shall be provided in Maintainer room.

8 Field Gateway:

8.1 At each station there shall be field Gateway which filters and pre-processes the data to be sent toand received from Cloud.

8.2 Field gateway will transmit/receive the data to cloud over the STM backbone of Railtel. LTE communication may also be used for redundancy.

9 Power supply requirement at Station:

9.1 The power supply for IoT devices near the outdoor equipments shall be taken from signalling equipment supply with suitable rating fuse. Where power is not existing, 24V DC may be extended from nearby location box.

9.2 The power supply for IoT devices in Indoor i.e. relay room shall be provided from 24V DC of IPS (preferably dedicated module in N+1 configuration).

9.3 The power supply for all other equipments i.e. Gateway, Local server, Edge computing device, etc shall be provided from 230V UPS of good quality. The input to UPS shall be from same source of IPS i.e. selective AT after auto-changeover of IPS. The backup time of UPS to be decided based on the power-cut duration at particular station.

10 Central cloud and Data Analytics:

10.1 For all Zonal Railways, the platform for machine learning and Artificial Intelligence shall be common and open source. In case they are different, the mechanism need to be made to ensure that the learning done in one cloud is shared in compatible manner for use by other clouds.

10.2 For optimum outcome, it is proposed that there shall be integrated single cloud for all stations of Indian Railways. However, if concern for interoperability is proven or single platform is developed, the cloud can be per Zonal Railway or a group of Zonal Railways. A mirror cloud shall be setup for data backup.

The strategic location for cloud and platform will be decided up after gaining experience on trials.

10.3 It is desirable that Cloud and AI shall be based on open source platforms and AI algorithms developed shall be property of Indian Railways. There shall be no propriety of industry partners on the intellectual property so emerged during trials and development of the system.

Note for 11.1 & 11.2: The issue of redundant efforts to develop machine learning and AI analytics need to be seen. Developing AI algorithms and machine learning is a time taking job. The present Specification assumes one single platform to avoid wastage of time and efforts on developing AI machine learning algorithms.

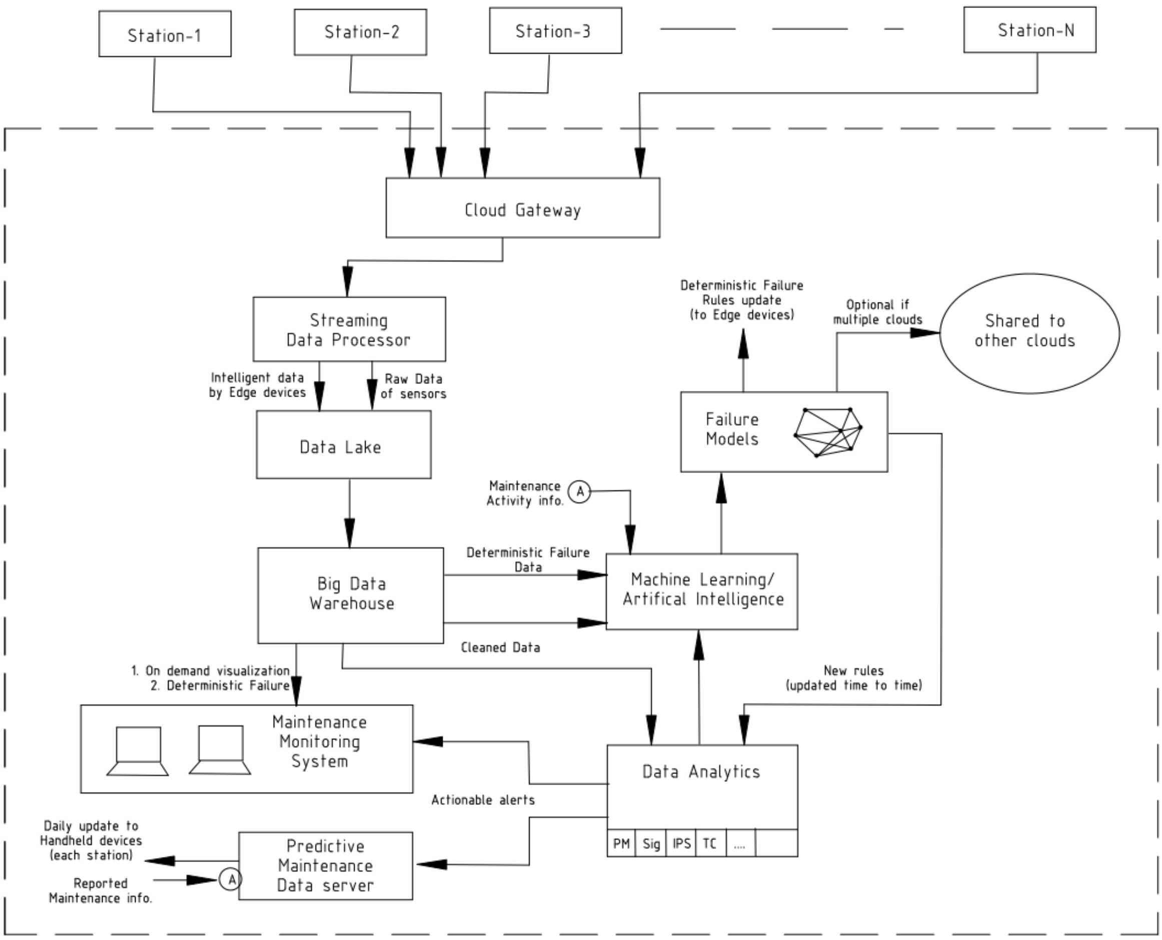

Figure-4 : System Architecture at Cloud level

10.4 The setup in the Centralized Cloud is depicted in Figure-4. There may be minor variation for the architecture. The working of these sub-systems is as follows:

10.4.1 Cloud Gateway:It ensures safe data transmission and provides connectivity to various field gateways from each station. Intermediate Gateways at division level may be used if number of stations are large in number.

10.4.2 Streaming Data processor: The sensor data received through cloud Gateway enters to streaming data processor. Its purpose is to allow continuous flow of data and quickly and efficiently transmit data streams to a data storage.

10.4.3 Data Lake :A data lake stores the data gathered by sensors. It is still raw, so it may be inaccurate, erroneous or contain irrelevant items. It is presented as a number of sets of sensor readings measured at the corresponding time. When the data is needed for insights about equipment's health, it is loaded to a big data warehouse.

10.4.4 Big Data Warehouse: The big data warehouse stores cleansed structured data. It contains various parameters of equipment measured at a particular time and contextual information about equipment like equipment installation details (make, DOI, etc), previous history of maintenance, failure, age, number of operations, etc

10.4.5 Machine Learning / Artificial Intelligence :The data received is used by the AI algorithms to improve the failure models and predictive models. Initially, supervised learning will be done and gradually the learning will be more automated using AI techniques. The failures and maintenance activity data shall also be used for selecting and neglecting the raw data respectively. For example, if deterministic failure is reported by Edge device, the machine learning will analyse deep data screening to relate failure pattern and update its model. While, if maintenance activity is taken where disconnection or forced shutdown of equipment is done, the machine learning algorithm will discard such data to prevent wrong learning.

10.4.6 Data Analytics*: The existing failure models and predictive models are updated time to time by the Machine learning above. The realtime data of signalling gears is analysed with these machine learning models. The ML algorithms are applied to reveal hidden correlations in data sets and detect abnormal data patterns. The recognized data patterns are reflected to generate the predictive health information of signalling equipment.

10.4.7 Maintenance Monitoring System*: It receives the predictive health information from the Data Analytics sub-system as well as has access to historical and live information of signalling gears from Big Data warehouse. It also consists of different terminals for monitoring the data by staff manned 24x7 for assisted maintenance and failure rectification. In addition, there shall be "Preventive maintenance Cloud" which relays the information to all handheld devices for updating the health information of each signalling gear on daily basis. Critical alerts will be sent on realtime basis assisted by automated alert system and manned supervision.

Note – The deterministic failures and critical alerts are sent on realtime basis from station's edge device. While degraded health information for taking up gears for preventive maintenance is sent from Cloud over internet connectivity on handheld device to facilitate maintenance team of particular station for prioritizing predictive maintenance over periodical maintenance. The end goal of the overall system is to make predictive maintenance information self-sufficient and accurate so as to completely remove requirement for periodical maintenance.

***Important Note:** Depending on the experience, the Data Analytics and Maintenance monitoring systems may be decentralized to strategic locations like at every division at later stage of mass deployment.

11 Methodology for Machine learning and AI techniques:

11.1 Machine learning and artificial Intelligence is very vital component of this system. The AI/ ML algorithms should be as per ISO/IEC JTC 1/SC 42 standards or any other latest ISO/IEC standard. The system shall provide predictive maintenance and optimization with the help of advanced analytics, Machine Learning and Data visualization.

11.2 Machine Learning algorithm should be able to suggest and predict defects, device failure and remaining useful life (RUL).. Application should be backed by intelligent health monitoring algorithms for gears using machine leaning algorithms to predict the equipment failure or errors and send SMS alerts to the concerned official's mobile number. It is expected that accuracy of predictive alerts should be better than defined levels with time.

11.3 It is desirable that Cloud and AI shall be based on open source platforms and AI algorithms developed shall be non proprietary.

11.4 During initial development of system, the supervised machine learning will be required and slowly it will switch to unsupervised machine learning.

11.5 The initial development rules include defining the allowable parameter limits. For example, if monitored 24V power supply for and equipment like axle counter of so and so make goes below "x" volt (as per equipment manual), it is likely to fail.

11.6 By monitoring patterns in real time and looking at historical data, the machine learning can identify repeat scenarios which it can then create rules for moving forward. Like in above example, after machine learning, the axle counter parameter limit will be fine-tuned together with information from other parameters like ambient temperature, level of induced voltage in cable etc. This process is an adaptive learning process, meaning that the system will use AI techniques to find pattern in data. The more data and scenarios it collect and encounter, the more it will learn.

11.7 As our machine learning processes identify these patterns, we integrate them as new rules into the proactive workflows to provide the customized rules for each equipment.

11.8 When new gears are added into the system (like new installation at station or by providing IoT device at existing gear), the process starts with the registration and identification of new sensors that come online and get picked up by the system. This process should be automated as gear information is already defined in the data packet it is sending (standard protocol). In short, the new gears information will be updated in IoT device as one time activity and rest of the system (edge computing, cloud, etc) shall identify and automate the predictive maintenance for the gear without further need to feed the information at every stage.

11.9 The non-availability of data due to failure of IoT device or otherwise should not cause false alarms. The health of IoT device should be considered for analysing the data.

11.10 For guidance on development of failure model please refer to the Annexure-D.

12 Alarms message and Maintenance Monitoring Terminals:

12.1 The systems shall generate alarms in best possible manner such that the cause of failure is pin pointed so as to reduce the MTTR.
For example,
"Station ABC, Track circuit 2T failed due to high leakage current of 'x' mA. Feed end current is 'y' while relay end current is 'z'.–
Possible reason – Sleeper shorting – 80% (high probability because the drop is sudden), Low ballast resistance = 10% (low probability as leakage is not gradual), others – 10%."

12.2 The predictive alarms shall contain the detailed information with probability and end of usable life data. One example is as below for general guidance (but not limited to):

Message-Alarm example:
"Station ABC, Point 102A:Need lubrication and if it is not attended for lubrication, the probability of point failure is
5% in next 24 hours
20% in next 1 week
40% in next one month"

12.3 The terminals on maintenance monitoring systems shall display realtime alerts on the screen. Depending on the rate of failure data, suitable number of manned terminals for set of stations shall be provided.

12.3.1 The monitoring terminals shall provide alerts which shall be categorised as Minor, Major, Critical, etc.

12.3.2 The color coding shall be done based on the severity of alert for quick attention.

12.3.3 The alerts information list should be concise. On clicking of the particular alert, the detail technical information of gear fault should come.

12.3.4 Based on the station, the contact information of on duty staff and higher escalation shall also be displayed for relaying the information by telephonic call to the staff concerned. As an example, the maintenance monitoring terminal is displayed above.

13. Performance Evaluation:

13.1 Let us define an experiment from **P** positive instances and **N** negative instances for some condition. The four outcomes can be formulated in a 2×2 *matrix*, as follows:

		True condition	
	Total population	Condition positive	Condition negative
Predicted condition	Predicted condition positive	**True positive**	**False positive**, Type I error
	Predicted condition negative	**False negative**, Type II error	**True negative**
		True positive rate (TPR), Recall, Sensitivity, probability of detection, Power = Σ True positive/Σ Condition positive	False positive rate (FPR), Fall-out, probability of false alarm = Σ False positive/Σ Condition negative
		False negative rate (FNR), Miss rate = Σ False negative/Σ Condition positive	Specificity (SPC), Selectivity, True negative rate (TNR) = Σ True negative/

Accuracy (ACC) = (Σ True positive + Σ True negative)/Σ Total population

13.2.1 System performance will be treated as satisfactory only if Accuracy of prediction is>75% in initial project implementation as Proof of concept (POC).

13.2.2 Further after gaining experience, for regular projects, performance will be treated as satisfactory only if value of Accuracy of prediction is >90% and Miss rate is <4%.

Annexure-A

(Indicative)

A.1 Thefollowing are the parameters to monitor for Signal, Points and Track circuits in outdoor locations.

Note: This list is indicative and based on experience it may be improvised. It is imperative that efforts should be for developing optimum system. Placing unnecessary sensors will make system complex including requirement of extensive wiring in Location boxes.

	Functions	**Status type**
Track Circuit:		
1	Feed end & relay end currents of DC track circuit	Value (Analog)
2	Track circuit feed voltage before feed resistance & choke	Value (Analog)
3	Status of local Track Relay (TR)	Status (Digital)
4	Track charger – Potential free contact	Status (Digital)
Point Machine		
1	Point machine operating current	Value (Analog)
2	Point machine operating voltage	Value (Analog)
3	Point position (Normal/Reverse)	Value (Analog)
4	Vibration	Value (Analog)
5	Movement of slides (drive, lock, detection)	
Signals		
1	Signal lamp Current Note: Individual lamp current for main aspect lamps and groupoflampsincaseofroute&shunt.	Value (Analog)
2	Signal Lamp Voltage	Value (Analog)
3	Local Signal Control repeater relay's status at Location Box (Each aspect)	Status (Digital)
4	Illumination	Value (Analog)

A.2 The details of Voltage and Current ranges of sensors for Point Machine, DC track Circuits and signal lamps are given below:

Signaling Gear	Voltage/ Current Range#	Minimum detectable change (2% of nominal value) (Indicative for initial trials)**
For Point Machine Operating current.	0- 20 Amps DC	**
Point Machine Operating voltage	0- 170V DC	**
Signal lamp current	0-1 Amps AC	**
Track circuit current	0-3 Amps DC	**
Track circuit Feedend voltage	0- 16V DC	**
Track circuit Relay end voltage	0-10 V DC	**
Relay Operating voltage 24V Relays	0- 40V DC	**
Relay Operating voltage 50V Relays	0- 90V DC	**

Nominal values of operating parameters from respective RDSO Specification of equipment may be referred.

** As the Machine learning could be dependent on current and voltage signatures for different types of equipments, the minimum detectable change for each type of equipment will effect the end goal of predicting failures. Reducing minimum detectable change beyond a value would not be economical and may not be required for each and every gear. Hence, this requirement is indicative here and may require change after experience and trials.

Annexure-B

Equipment Failure Data for reference (Informative)

The following is the indicative data for frequency of failures of signalling equipments on Indian Railways. The data is for year 2018-19 and indicates the trend of percentage of failures contributed by equipments. This data will help in focussing on the key areas for targeting the predictive maintenance and machine learning to reduce number of Signal failures in absolute terms.

S.No.	Equipment type (in order of failure rate)	% age of Total Failures in 2018-19 over IR[##]
1	**Axle counters:** *In Block Section:* *Reset/UAC/SSAC/BPAC* *UAC/SSDAC/BPAC* *Yard:* *Reset/UAC/SSAC/MSACTC* *UAC/SSDAC/MSDAC/TC*	21.4% *Breakup:* *11.9%* *3.9%* *2.8%* *2.8%*
2	Relay Failure	11.8%
3	Cable	10.7%
4	Track Circuit Failure	9.3%
5	Obstruction in point	7.4%
6	Point M/c	2.1%
7	Lamp fusing	5.3%
8	Lifting Barrier (including ELB) *ELB*	5.1% *3.0%*
9	Point defect (Mechanical) – Engg.	3.7%
10	Fuse blown off	3.7%
11	GJ defect (DC Track Circuit)	3.1%
12	Power Equipment (IPS, Charger, etc)	2.6%
13	Indoor wiring & Dry Soldering	2.5%
14	UFSBI	2.1%

[##] Source: Railway Board's PCDO compilation.

Notes:

1. The above failures are absolute number of failures divided by total numbers of Signal failures. It does not indicate the failure rate per equipment.
2. Other equipmentscontributing less than 2% of total failures are not listed.

Annexure-C
Network layers and Protocol information

(Brief information based on EULYNX standard.)

C.1 For the use of the Standard Diagonostic Interfaces (SDI) the following definitions shall be applied.

a) The higher layers (transport layer and application layer) together form the Standard Diagnostics Interface (SDI), designated as SDI-XX. They are defined in [EULYNX Document No. - Eu.Doc.77].

b) The lower layers (network layer, data link layer and physical layer) are defined by the PoS-Signalling, as defined in [EULYNX Document No. - Eu.Doc.100].

C.2 Lower Network Layers:
The lower layers of the protocol stacks of the standardised interfaces of the EULYNX system are as below:

a) Physical Layer: For the physical layer, the standard [IEEE 802.3] Ethernet protocol over copper RJ45 interfaces [IEC 60603-7] or fiber LC interface [IEC 61754-20] shall be used. For IoT devices, wireless media like LoRa, NB IOT, Zigbee shall be provided for monitoring those equipments which require external sensors like Points, Signals, Track circuits, etc on Indian Railways.
– Note: Requirement for wireless media added in addition to EULYNX standard (where only RJ45 (Cu) and OFC interface is covered) to keep monitoring system simple on existing yards for devices not supporting inbuilt Diagnostic ports.

b) Data link Layer: For the data link layer, the Ethernet [IEEE 802.3] protocol shall be used.

c) Network Layer: For the network layer, both IPv4 [RFC0791] and IPv6 [RFC8200] shall be used.IP addresses and port numbers at the transport layer shall be adjustable.

C.3 The Standard Diagnostic Interface is used for resolving issue of interoperability of various sub-systems for use on Indian Railways. This is as per EULYNX standard.
This interface is telegram based interface and it is composed of Transport Layer and Application layer.

a) Communication requirements
   i) The protocols SNMP v2c or OPC-UA shall be used to transfer diagnostic data from the connected systems (IoT) to the service function Diagnosticscollector (Local Server).
   ii) The service function Diagnostics collector (Local Server) shall support both SNMP and OPC-UA to receive diagnostic data.
   iii) The connected systems (IoT) shall support either SNMP or OPC-UA via HTTPS/SOAP.

C.4 Transport Layer: OPC-UA and SNMP-v2c protocol.

a) Structure of telegrams when using OPC-UA.

i) OPC-UA uses a strict client server model.
ii) The connection shall be encrypted using HTTPS/SOAP.
iii) When establishing the connection, the signature of the connected system (IoT) shall be checked for authenticity and validity by the service function Diagnostics collector (Local Server).

b) Telegram definitions OPC-UA:
   i) The communication between the OPC-UA client and the OPC-UA server is session-oriented.
   ii) For OPC-UA, a "telegram" consists of a communication session in which several OPC-UA-specific messages are exchanged between the client (IoT)and the server.

C.5 Time Synchronization:

a) The service function Time synchronisation shall provide a uniform time base for all connected systems.
b) NTP version 4 shall be used in the Time synchronisation service function and the connected systems to synchronise the time, as described in[NTP].
c) The UDP transport protocol shall be used via port 123 by the sender (Local server) and the receiver (IoTs) to synchronise times.
d) The Time synchronisation service function shall run in "server mode", i.e. it makes the local time available to the connected systems (IoTs).
e) The Time synchronisation service function has access to a precise local time base **(IRNSS clock receiver at every station).**
f) The time stamp of the event is specified in milliseconds since 01.01.1970 00:00:00.000 UTC.

C.6 The technical implementation of the diagnostics interface contains the protocol stack. ***– details shall be incorporated later.***

Annexure-D

(Informative)

D.1 Failure model examples:

D.2 The point's operating current signature (variation of current value with time during operation) can differentiate between various reasons of failures. For example, point failed due to stone obstruction between tongue rail and stock rail will have sudden rise of current after smooth displacement. While it will be different current signature for poor lubrication.

D.3 Similarly, based on particular point's historical data the system can know the displacement of tongue rail . The system can predict if the point has failed due to some obstruction (incomplete movement) by seeing the time length of normal current and point where current increase (obstruction). If current dropped at average time, then movement of tongle rail is full which shows that failure is possibly due to other cause like detection contact failure.

D.4 The health of cable core can be accessed by measuring the voltage at relay room and the voltage reaching the point machine. The drop of large voltage during particular point operation can be used to detect faulty cores in cable.

D.5 The DC track circuit failure identification in case of high leakage current can be predicted based on history of relay end current. If the leakage has increased gradually, it shows the poor ballast resistance due to rain or water-logging. While a sudden leakage current may show sleeper shorting.

D.6 The total number of operations of a relay may be used to assess its life. Automated learning through AI techniques may find a trend in the life of relay in terms of number of operations and duration of cumulative pickup time of relays. Environmental parameters like temperature and humidity may have a relation to failures.

D.7 In case of cable cut, the disconnection is preceded by sudden break and make of cable continuity. The voltage/current monitoring signature of different cores of cable before discontinuity can be used to identify such incident. While sudden break of continuity may imply fuse blown.