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Deliverable D 9.1
Design Specification for the Target Signalling Systems

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Report contributors		
Name	Beneficiary Short Name	Details of contribution
Sener Ingenieria Y Sistemas S.A.	SENER	All sections
Technische Universitat Berlin	TUB	Reviewed
Università degli Studi di Roma La Sapienza	DICEA	Reviewed
Witt Industrieelektronik Gmbh	WITT	Feasibility Analysis
Ab Lietuvos Gelezinkeliai	LiRa	Reviewed

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Executive Summary

Presenting the identification of the target signaling systems and specifications of the data acquisition process for different types of data.

Abbreviations and acronyms

Abbreviation / Acronyms	Description
FDI	Fault Detection and Isolation
LED	Light-Emitting Diode
ROM	Read Only Memory
DC	Direct Current
AC	Alternating Current
SAM	Maintenance Support System
PC	Personal Computer
PLC	Programmable Logic Controllers
PV	Photovoltaic
MOM	Message Oriented Middleware
SCADA	Supervisory Control And Data Acquisition

1. Background

Monitoring the conditions of railway asset is essential for ensuring the railway safety. Condition monitoring can be a part of the well-established area of Fault Detection and Isolation (or Identification). Condition monitoring is mainly applicable to system that deteriorate in time. The aim of condition monitoring is to detect and isolate deterioration before it causes a failure.

A condition monitoring system is usually used to provide a diagnosis of failure for maintenance, in situations where the measured features exceed some predetermined thresholds or show a specific deviation from normal conditions. On the other hand, the data acquired can be used as a prognosis for predicting future failures and the remaining useful life.

There are many assets in the railway around the world (points, track circuits, signals...). Efficient and timely maintenance interventions are essential to ensure trains operate to the published timetable without delays or interruptions to service.

The challenge therefore is being able to monitor key assets with real time information that will support:

- right time interventions
- changes in the existing maintenance regimes
- re-design of an asset.

Monitoring as it was traditionally known is reinvented to satisfy needs and more demanding safety and production quality policies. Modern monitoring processes should include not only the ability to receive data about the critical points of the process or chain of services, but also the possibility of predicting possible problems that could endanger the functioning of a system or even the physical integrity of the system or the people around him.

2. Objective/Aim

The objective of this work package is to design and propose a set of acquisition and data collection schemes for safety-critical systems. These schemes must be developed for the trackside signalling systems only.

These set of monitoring, inspection and data collection systems shall not thread the safety critical functionalities of the "under inspection" equipment. The proposed solution will be a modular hardware and software platform capable to be integrated within the equipment to be monitored.

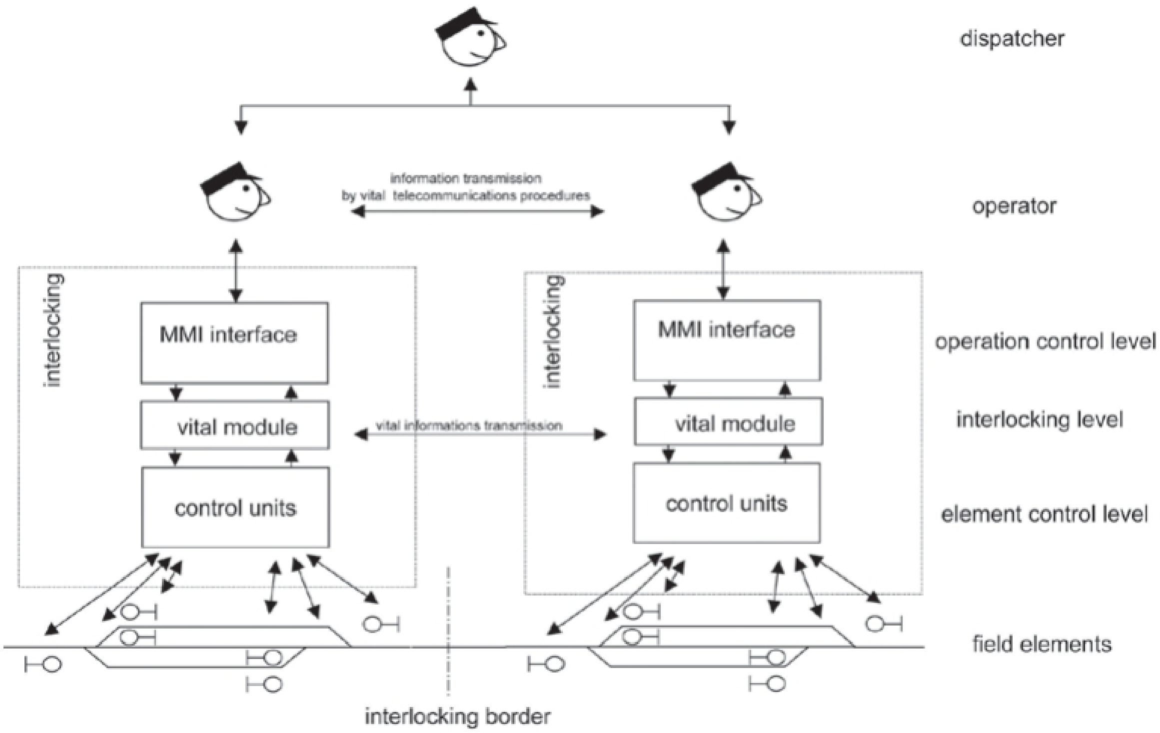
This report presents the results of *Task 9.1 Design Specifications and Acquisition Methodologies*, which aims to

- identify the target signaling systems to be monitored.
- formulate the overall data acquisition concept and setup the high-level system architecture
- identify the specific data acquisition methods from the field elements

3. Target fail-safe systems

The functional structure of the railway control system, as it has been developed and practically proved over the years is shown in the next figure. The fail-safe data collection system to be developed consider the interlocking system, in particular the interlocking level, the element control level and field elements.

- The interlocking level includes the vital functions to interlock signals, routes, movable track elements, block applications with each other.
- The element control level includes functions of commanding, power and information transmission to and from the field elements.
- Field elements are the signal devices distributed in the field such as signals, point machines, track circle, axle counter and level crossing.

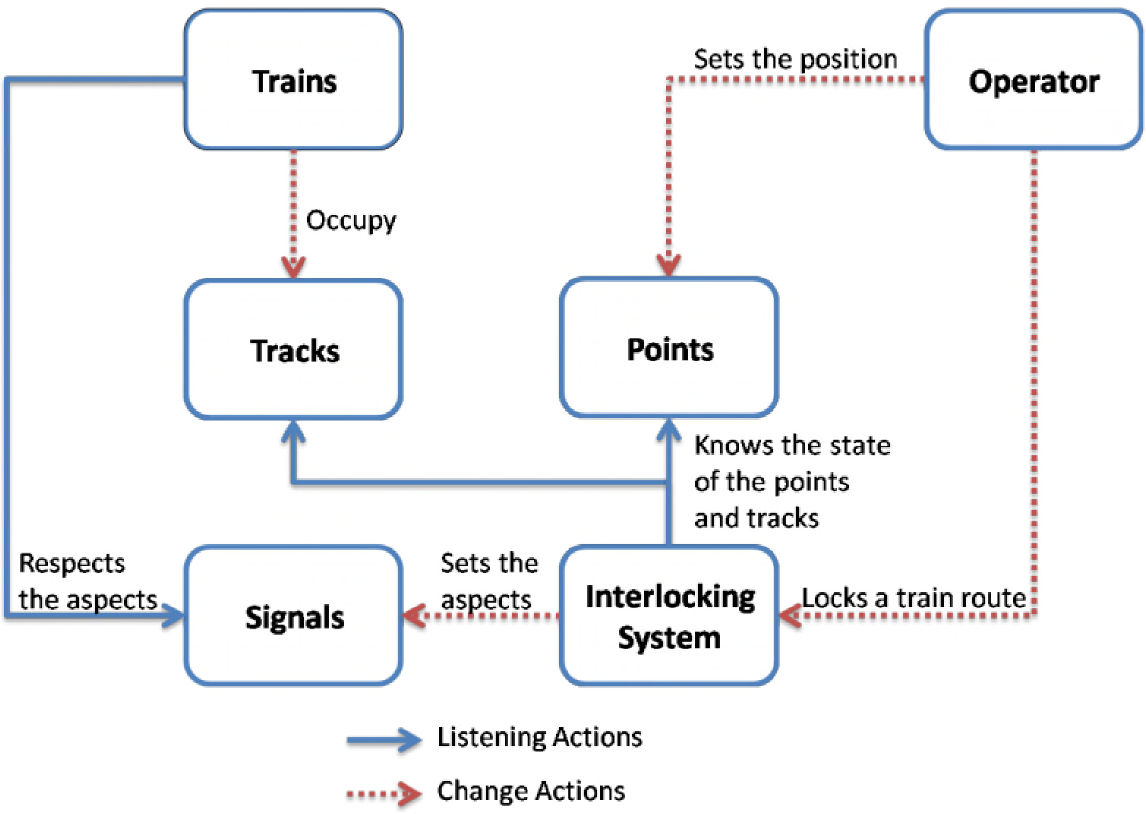


3.1 Interlockings

As digital signals, the data and logs obtained by the electronic interlocks can be monitored.

A railway interlocking is an arrangement of signal apparatus that prevents conflicting movements through an arrangement of tracks such as junctions or crossings. The signalling appliances and tracks are sometimes collectively referred to as an interlocking plant. An interlocking is designed so that it is impossible to display a signal to proceed unless the route to be used is proven safe.

Modern interlockings (those installed since the late 1980s) are generally solid state, where the wired networks of relays are replaced by software logic running on special-purpose control hardware. The fact that the logic is implemented by software rather than hard-wired circuitry greatly facilitates the ability to make modifications when needed by reprogramming rather than rewiring. In many implementations, this vital logic is stored as firmware or in ROM that cannot be easily altered to both resist unsafe modification and meet regulatory safety testing requirements.



The following physical objects are controlled by an interlocking system:

- Signals.
- Point machine
- level crossing

An interlocking system knows the state of:

- Track sections. When a track circuit (a linear track circuit or a point) is occupied (by a train or due to some other physical reason), the associated track relay will be dropped and the interlocking system can therefore know that the track circuit is occupied.
- Buttons. When an operator wants to authorize a train to enter or exit the station, he or she has to lock a specific train route. The operator can push buttons for initiating such processes. However, an interlocking system is only allowed to lock a given train route when it is considered as being safe, e.g. conflicting train routes are not supposed to be locked at the same time.
- Points. For each point, there are two point relays. Thanks to them, an interlocking system knows the position of a given point.

The electronic interlockings use different modules in order to manage the data from track circuits, points, signals... These modules are the following:

- Module for power and control signals: This module is used for power and checking of the bulbs of the signals, conventional lamps, LED diodes or as alphanumeric. This module is programmable so that it is controlled by current detection if the signal is ON, OFF, or with an incidence (fused bulb, derivations…) The module can give fixed or intermittent outputs and acts as a final power stage for the lighting of the signals, checking the fused bulbs.
- Module of security entries for the verification of elements: This module is used to receive the information and validate each entry from the different trackside elements, except the signals, such as points, track circuits, axle counters, level crossings… It consists of DC input cards and active redundancy in the corresponding part of the vital logic.
- Module of security outputs for the control of elements: This module is used for the sending of vital outputs for the control of field elements except signals, such as points, electric locks, and relations with level crossings… The electronic part of this module consists of DC output cards and active redundancy in the corresponding part of the vital logic.
- Point control module: This group of units are used for the control of deviations equipped with electric or electrohydraulic points, depending on the characteristics thereof and the number of associated points. It will be composed of DC input cards that receive the information from the safety output module for the control of the field elements and the DC output cards that act on the relays or the galvanically isolated contactors. The module includes the electromechanical interface necessary to tackle the point. For the deviations equipped with multiple drives, this module includes the additional relay equipment for the synchronization and control of the sequential movement of the motors.

The input values are safely and logically processed in the interlocking process modules.

3.2 Signals

Signals are used to control the railway traffic. There are several kinds of signals. Some signals are used for shunting while other signals are used for controlling the ordinary traffic on the rails.

- Stop. The train must stop in front of the signal. The stop aspect will be indicated by a red light, sometimes combined with a yellow light.
- Drive. The train is allowed to pass the given signal, but the train driver must expect to stop at the next signal. The drive aspect is indicated by a green light, sometimes combined with a yellow light.
- Drive through. The train is allowed to pass the given signal and it should expect drive or drive through at the next signal. The drive through aspect is either indicated by two green lights or a blinking green light.

There are several signal types indicating the role of the signal. For instance, entrance signals control the entry of a station by displaying the appropriate aspect and exit signals control the exit of a station.

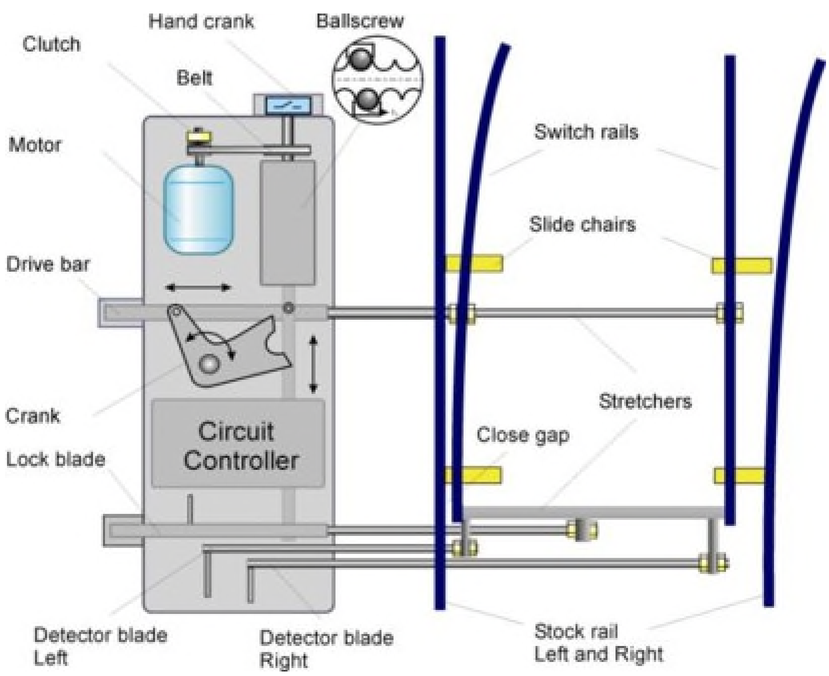
The typical electric maintenance of the signals is the next:

ID	Maintenance Operation	Periodicity
1	Check the ground connection of all signals and all distribution boxes	Annual
2	Checking bulbs and replacing fused bulbs.	Quarterly

3.3 Point machines

The point machine is a device for moving and securing point blades from a source of power, usually electric.

The point machine is a safety relevant component, ensuring safe passage of railway vehicles over moveable elements at points, crossings and derailers.



Modern point machines have an electric motor and gears to convert the rotational motion of the motor into the linear motion required to switch the points. The gear assembly also provides required transmission ratio so that it can generate necessary force to move switch blades. The machine performs following functions:

- Moving switch blades.
- Locking the blades
- Detection and proving the position of blades.

A Point machine moves the switch blade in the following procedure:

(1) Transmit the signal to turn over the point machine from the signal box to the point machine

(2) Short-circuit the indication relay (which indicates whether the point machine is in 'Normal' position or 'Reverse' position)

(3) Complete the electrical circuit to move the motor
(4) Unlock the point machine with the locking mechanism
(5) Move the drive rod until the switch blade is fully moved
(6) Lock the point machine with the locking mechanism
(7) Break the electrical circuit to move the motor and complete indication circuit
(8) Indication relay operates and the signal indicating the position of the point machine is transmitted from the point machine to the signal box.

3.3.1.1 Electro - Hydraulic

The typical electric maintenance of the electro-hydraulic points is the next:

ID	Maintenance Operation	Periodicity
Engine		
1	Verification of the existence of indication of dangerous current indication.	Anual
2	Check the implementation of the ground of the electric drive of the point.	Anual
3	Check the correct position of the drive.	Anual
4	Checking the operation of the electrical disconnection/connection through the crank and that is correctly engaged.	Anual

3.3.1.2 Electromechanical

The typical electric maintenance of the electromechanical points is the next:

ID	Maintenance Operation	Periodicity
Engine		

1	Check the ground of the electric point.	Anual
2	Check the correct position of the blades.	Anual
3	Check that current cut-of and blocking device is working correctly.	Anual
4	Measure the value of the engine current in the movement from normal to inverted position and vice versa, registering the values.	Anual

3.4 Axle Counters

An axle counter is a device on a railway that detects the passing of a train between two points on a track. A counting head (or "detection point") is installed at each end of the section, and as each train axle passes the counting head at the start of the section, a counter increments. A detection point comprises two independent sensors, so the device can detect the direction and speed of a train by the order and time in which the sensors are passed. As the train passes a similar counting head at the end of the section, the system compares count at the end of the section with that recorded at the beginning. If the two counts are the same, the section is presumed to be clear for a second train.

This is carried out by safety-critical centrally located computers, called "evaluators", with the detection points located at the required sites in the field. The detection points are either connected to the evaluator via dedicated copper cable or via a telecommunications transmission system. That allows the detection points to be located significant distances from the evaluator, and is useful when using centralised interlocking equipment, but less so when signalling equipment is situated beside the line in equipment cabinets.

The typical electric maintenance of the axle counters is the next:

ID	Maintenance Operation	Periodicity
1	Functional inspection of the entire system.	Anual
2	General checks.	Anual
3	Checks and cleaning in the Central Unit.	Anual

4	Checks in the Road Units.	Anual
6	Review of detector heads.	Anual
7	Pedals cable review.	Anual

3.5 Track Circuits

The track circuit is a device in the track used for track vacancy proving.

The basic principle behind the track circuit lies in the connection of the two rails by the wheels and axle of locomotives and rolling stock to short out an electrical circuit. This circuit is monitored by electrical equipment to detect the absence of the trains. Since this is a safety appliance, fail-safe operation is crucial; therefore the circuit is designed to indicate the presence of a train when failures occur. On the other hand, false occupancy readings are disruptive to railway operations and are to be minimized.

Track circuits allow railway signaling systems to operate semi-automatically, by displaying signals for trains to slow down or stop in the presence of occupied track ahead of them. They help prevent dispatchers and operators from causing accidents, both by informing them of track occupancy and by preventing signals from displaying unsafe indications.

Remote Condition Monitoring (RCM) is the process of monitoring a number of parameters in a device, in order to identify any significant changes which may indicate that a fault is developing.

In the case of track circuits, a common form of RCM is to constantly measure the current levels at the track circuit receiver for free and occupied segments. Unfortunately, this cannot guarantee a preventative approach, because the relationship between the Track Circuit parameters along the track and the current value at the receiver and transmitter ends is not linear. This means that they are not good indicators of a potential failure.

To be defined as comprehensive and effective, each measurement session should be able to detect and assess the quality of the following parameters:

- Icc (shunt current) levels for each relevant frequency
- transversal elements (electrical joints)
- compensating capacitors, if present, along the track
- data transmission modulation and verification for both pointwise and continuously transmitted data.

3.5.1.1 50 Hz

The typical electric maintenance of the 50 Hz track circuit is the next:

ID	Maintenance Operation	Periodicity
	Electrical measurements	
1	Tension measurement and shunting on the supply side.	Anual
2	Measurement of voltages and shunting of the relay side.	Anual
3	Measures in fasimeter.	Anual

3.5.1.2 Audio-Frequency

The maintenance of the audio-frequency track circuits depends on the manufacturer. The typical maintenance for the Siemens track circuits is shown below:

ID	Maintenance Operation	Periodicity
	FS-3000	
1	Checking the voltage level of the tuning units.	Anual
2	Checking the status of the transceiver LEDs.	Anual
3	Checking the status of the LEDs of the power supply.	Anual
4	Checking the voltage level of the transceiver monitor.	Anual
5	Checking the voltage level at different points in the track circuit.	Anual
6	Check and control of the connections to ground.	Anual
	FTGS	
1	Checking the disconnection threshold voltages	Anual
2	Checking the reception voltages at the measuring points I5 / II8 and E1 / E2.	Anual
3	Test of the short-circuit supervisor between wires, according to the adjustment instructions.	Anual
4	Check and control of the connections to ground.	Anual

3.6 Level crossing

A level crossing is an intersection where a railway line crosses a road. Level crossing safety systems are a field element being responsible for the reliable safeguarding of crossroads of road and rail traffic. It usually consists of a control system, road signals, train signals, barrier driver, train detection system, axle sensor, sound signal, etc.

4. Acquisition methodology and high-level system architecture

In one region, the central interlocking system monitors and controls the distributed field elements. The developed data collection system **A4R_SYSTEM** for diagnosis will also consist of a central manager system and the distributed data acquisition nodes for reading data from the field elements, technical rooms and the electronic interlocking system. The whole system is modular and scalable by adding / removing the acquisition nodes. Depending on the types of the monitored systems and the needs for diagnosis, the acquisition nodes could contain the sensors to measure the key parameters in case that the monitored systems are analog systems and do not have data interface. In case that the monitored systems are the digital systems that provide interface for read digital parameters or log files, the acquisition nodes are the converter proxy to translate the obtained data into a common language and forward these data.

A digital system is any device intended for the generation, transmission, processing or storage of digital signals. In addition, a digital system is a combination of devices designed to manipulate physical quantities or information that are represented in digital form (discrete values).

A system is analog when the magnitudes of the signal are represented by continuous variables. An analog system contains devices that manipulate physical quantities represented in analog form. In this kind of systems, quantities vary over a continuous range of values.

4.1 High-level system architecture

Figure 1 shows the overall high-level architecture of the A4R data collection system (A4R_SYSTEM) for one region. A4R_SYSTEM can be scalable for multiple interlocking systems.

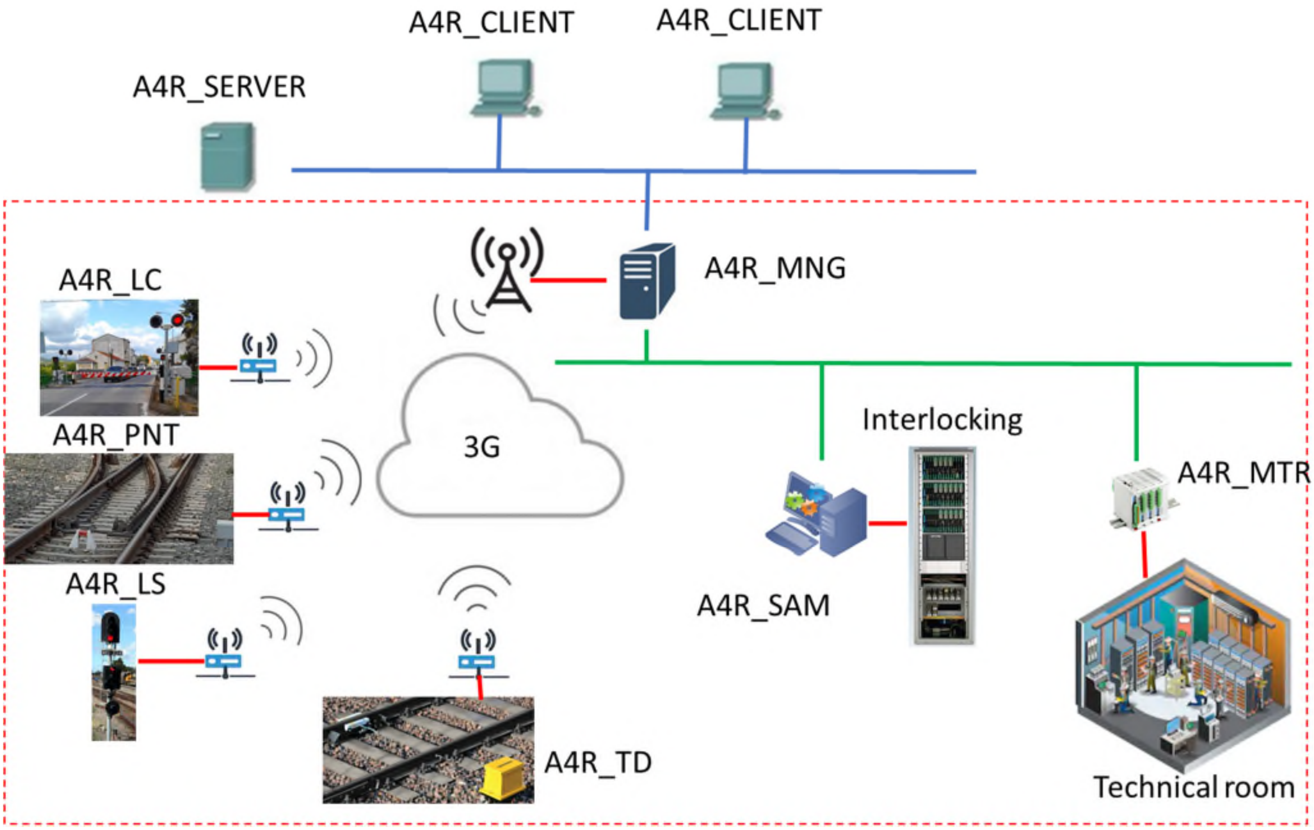


Figure 1 High-level system architecture of the A4R data collection system (A4R_SYSTEM)

The A4R_SYSTEM create a network of capture and concentration of data to be analyzed and stored in a database by means of A4R_SERVER, and visualized through A4R_CLIENT, an interface person-machine that can be consulted remotely from any device with web access.

A4R_MNG receives remote information from multiple data acquisition notes, storing it in A4R_SERVER. In order to manage all the devices in a station, is needed the A4R_MNG capable of collect information from 50 different devices. It takes charge of the concentration of information received from the equipment installed in the different electrical systems. All incoming data is analyzed to determine the status of the assets and generate the corresponding alarms. Users can consult all the information by accessing the A4R_CLIENT client using any web browser of devices such as computers, tablets, mobile phones, etc. The information is presented through highly intuitive and functional screens that offer tools for rapid diagnosis of engine status, analysis through graphics, detailed information in real time, etc.

The acquisition nodes (e.g. A4R_PNT, A4R_LC, etc.) can be installed in any type of field devices (points, LED signals, track circuits, axle counters or level crossings) independently of the manufacturer. The data is transmitted between A4R_xx and A4R_MNG via remote wireless communication such as LoT and mobile network, depending on the local coverage of the network.

The acquisition nodes measure the key parameters related to the operation of trackside assets. The intelligent analysis of the collected data allows the system to identify the deterioration of the conditions before a failure. This provides an important framework in which maintenance tasks can be reprogrammed to improve performance and correct the problem before it results in a stop during service hours.

The following modules carry out the obtaining of information of the electrical devices:

- A4R_LS: Module for the acquisition of information of the light signals.
- A4R_PNT: Module for the acquisition of information of the point machines.
- A4R_LC: Module for the acquisition of information of the level crossings.
- A4R_TD: Module for the acquisition of information of the track circuits and axle counters.

The modules shall be "plug and play" devices and have a great ability to collect and transmit data in a completely transparent way to the system to which are connected. The installation must be simple and non-intrusive.

Apart from the trackside field elements, the centralized electronic interlocking system and the technical rooms contain valuable information for diagnosis. A4R_ SAM collects digital data from the interlocking system, while A4R_ MTR from technical rooms.

4.2 Potential available data

4.2.1 Data from trackside field elements

To analyze the diagnosis related variables for each field element, the Eulynx protocol will be used. It gives an overview which parameters are essential for controlling and diagnosis. These parameters are obtained by A4R_LS/ A4R_PNT/ A4R_LC/A4R_TD. For analog field devices, the parameters are measured by sensors. For digital field devices that provide data interface, the parameters can be directly read, if the protocol is understandable.

EULYNX

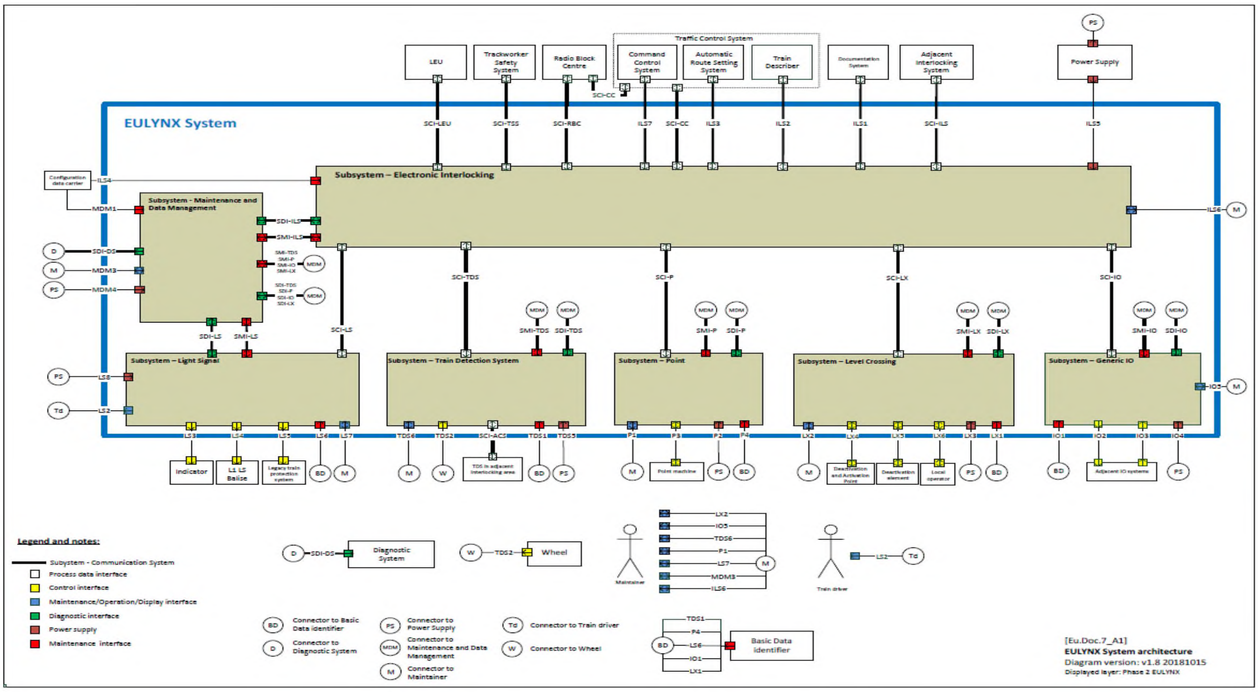
EULYNX is a European initiative in the area of railway signaling, with the aim of reducing the cost and installation time of signalling equipment. Currently, there are 12 members from North and Central Europe, with baseline 1 published in March 2017 and baseline 2 published in December 2017. The project documents lay down a system architecture for interlocking systems, including standard interfaces for the individual interlocking components, that can be used in any of the participating countries. The objective is to turn interlockings into modular systems, where different parts of one interlocking can be supplied by different manufacturers while maintaining the high safety and reliability levels required of a critical railway safety system.

Using the Eunlynx protocol, the system obtain the following characteristics:

- Use a common architecture.
- With a common apportionment of functionalities.

- Define standardized interfaces to connect systems and field elements.
- Closed, safe network based on open standard IT/telecom networks.
- Apply intelligent field elements for enhanced monitoring and diagnoses.

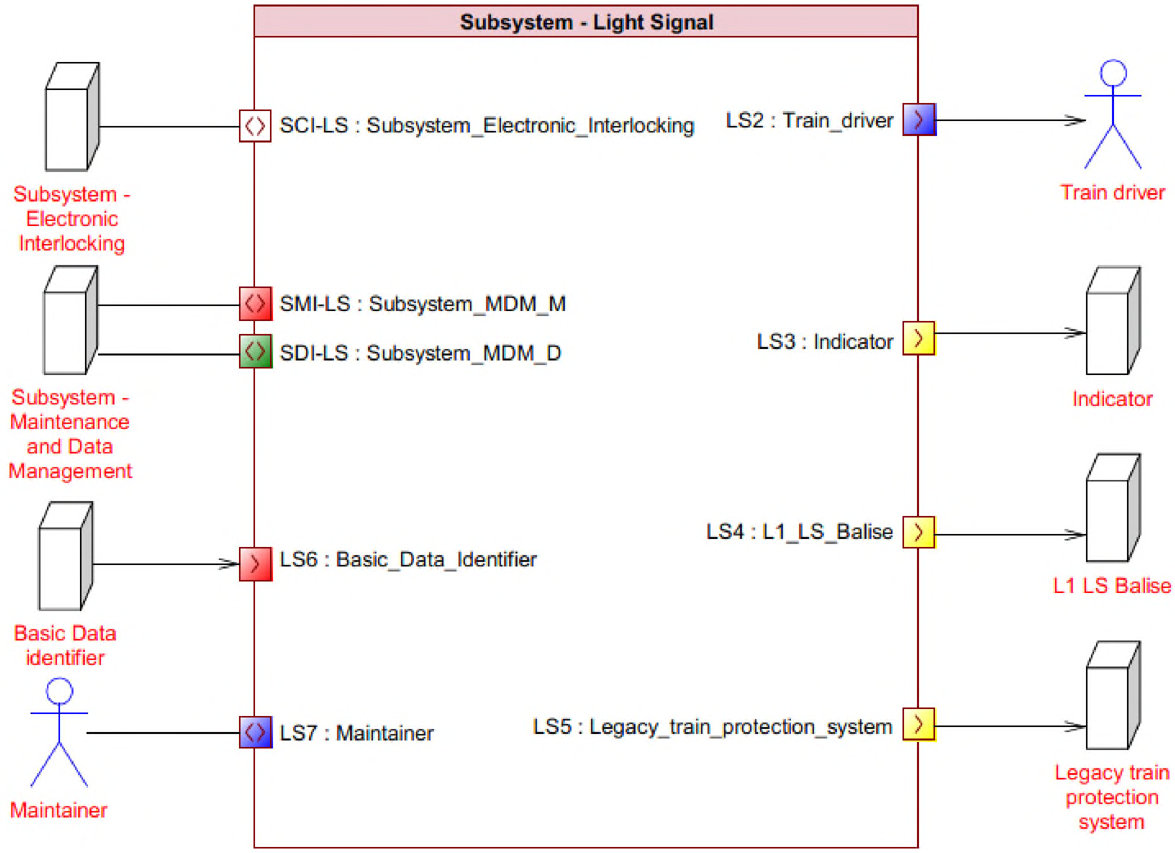
EULYNX aims to reinforce the process of defining and standardising interfaces in the future railway digital control command communication, signalling and automation system. The process of digitization in the railway industry provides a huge opportunity to reduce costs by improving efficiency, streamlining processes and reliability. The major goal is to increase the railway capacity and reliability with a significant reduction in the life-cycle cost of the system.



4.2.1.1 Light signals

The subsystem – Light Signal transmits information to Train driver and Subsystem – Eletronic Interlocking. They are classified into signals at the track (stationary signals) and non-stationary signals.

The subsystem – Light Signal just refers to stationary signals at the track, which can be set and show the visual signal aspect on the basis of a command by Subsystem – Electronic Interlocking or on the basis of a safety-related reaction.



- LS7: The functional Maintenance/Operation/Display interface to the Maintainer. The InformationFlow through the interface is defined by the FlowSpecification "Maintainer".
- SMI-LS: The functional Process Data interface to the Subsystem - Electronic Interlocking (SCI: Standard Communication Interface). The InformationFlow through the interface is defined by the FlowSpecification "Subsystem_Electronic_Interlocking".
- SDI-LS: The functional System Maintenance Interface to the Subsystem - Maintenance and Data Management for the InformationFlow through the interface, which is defined by the FlowSpecification "Subsystem_MDM_M".

Interface SDI-LS (Subsystem – Maintenance and data management)

Colour	Type: Enumeration Colour of the light signal. When an underlying parameter changes, the message shall be generated and transmitted.
CommandedSignalAspects	Type: String Currently commanded Signal Aspect (e.g. if Hp0 has been commanded, CommandedSignalAspects has the value '01FFFFFFFFFFFFFF'). When an underlying parameter changes, the message shall be generated and transmitted.

CurrentSignalAspects	Type: String Currently indicated Signal Aspect (e.g. if Hp0 is indicated, CurrentSignalAspects has the value '01FFFFFFFFFFFF'). When an underlying parameter changes, the message shall be generated and transmitted.
DegenerationGrade	Type: Integer Unit: % When an underlying parameter changes, the message shall be generated and transmitted.
ElectronicFailure	Type: Boolean LED electronics is faulty. When an underlying parameter changes, the message shall be generated and transmitted.
Frequency	Type: Float Unit: Hz Momentarily measured frequency of the Legacy train protection system. When an underlying parameter changes, the message shall be generated and transmitted.
Inductance	Type: Float Unit: H Momentarily measured inductance of the Legacy train protection system. When an underlying parameter changes, the message shall be generated and transmitted.
IsAuxiliaryFilamentLightFailure	Type: Boolean The auxiliary filament is faulty. When an underlying parameter changes, the message shall be generated and transmitted.
IsContactFailure	Type: Boolean The contact of the inductive train control is faulty. When an underlying parameter changes, the message shall be generated and transmitted.
IsDayNightModeChangeNotPossible	Type: Boolean Day/night change: possible/not possible When an underlying parameter changes, the message shall be generated and transmitted.

IsMainFilamentLightFailure	Type: Boolean The main filament is faulty. When an underlying parameter changes, the message shall be generated and transmitted.
IsOutputFailure1	Type: Boolean Error in output channel 1. When an underlying parameter changes, the message shall be generated and transmitted.
IsOutputFailure2	Type: Boolean Error in output channel 2. When an underlying parameter changes, the message shall be generated and transmitted.
IsOutputFailure3	Type: Boolean Error in output channel 3. When an underlying parameter changes, the message shall be generated and transmitted.
IsOutputFailure4	Type: Boolean Error in output channel 4. When an underlying parameter changes, the message shall be generated and transmitted.
IsOutputFailure5	Type: Boolean Error in output channel 5. When an underlying parameter changes, the message shall be generated and transmitted.
IsOutputFailure6	Type: Boolean Error in output channel 6. When an underlying parameter changes, the message shall be generated and transmitted.
IsOutputFailure7	Type: Boolean Error in output channel 7. When an underlying parameter changes, the message shall be generated and transmitted.
IsOutputFailure8	Type: Boolean Error in output channel 8. When an underlying parameter changes, the message shall be generated and transmitted.

IsRepeater	Type: Boolean The signal is a repeater. When an underlying parameter changes, the message shall be generated and transmitted.
IsTestingFacilityFailure	Type: Boolean The testing facility of the signal is faulty. When an underlying parameter changes, the message shall be generated and transmitted.
LampStatus[i]	Type: Enumeration Light point faulty/deactivated/activated/flashing. This message is instanced per light point. It shall be possible to map 1<= light points <= 20. When an underlying parameter changes, the message shall be generated and transmitted.
LightDurationDay	Type: Long Unit: sec Light duration of the light point in the day mode since the last ResetLightDurations. When an underlying parameter changes, the message shall be generated and transmitted.
LightDurationNight	Type: Long Unit: sec Light duration of the light point in the night mode since the last ResetLightDurations. When an underlying parameter changes, the message shall be generated and transmitted.
ModeDayNight	Type: Enumeration Day/night change: Day mode/night mode When an underlying parameter changes, the message shall be generated and transmitted.
NumberOfDefectLEDs	Type: Integer Number of faulty LEDs. When an underlying parameter changes, the message shall be generated and transmitted.

pLightDurationNominal	Type: Long Unit: sec Nominal light duration until the LED shall be replaced according to the manufacturer's service instructions. These messages shall be sent during the establishment of the SDI connection.
pNumberOfLEDs	Type: Integer Number of LEDs installed. The message has to be transmitted with the establishing connection.

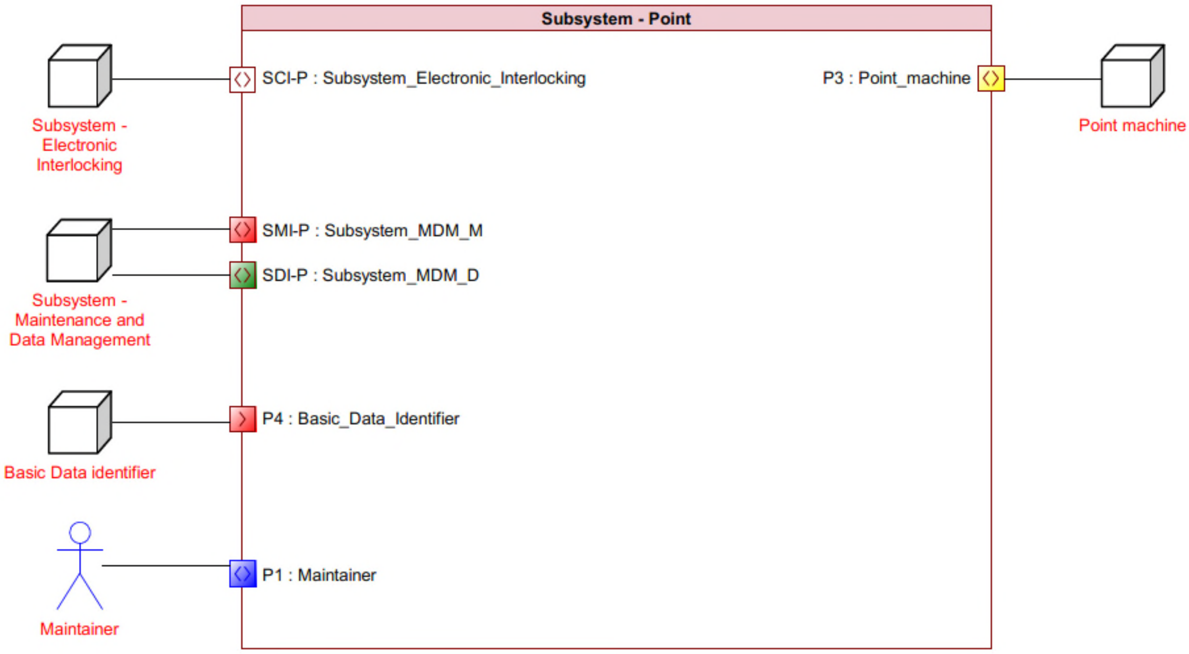
Interface LS7 (Maintainer)

Definition of the InformationFlow (by FlowSpecification) for the visual interface LS7 (Maintainer).

Output_Channel_Legacy_train_protection_systemX	Display of the status of the Output_Channel_Legacy_train_protection_systemX of the Subsystem - Light Signal at the local status display. The status is displayed for every output channel X of the Legacy train protection system.
Output_Channel_IndicatorX	Display of the status of the Output_Channel_IndicatorX of the Subsystem - Light Signal at the local status display. The status is displayed for every output channel X of the Indicator.
Light_Point_Status	Display of the status of the light point at the local status display.

4.2.1.2 Point machines

The Subsystem - Point integrates the moveable elements that may be moved to a different position by a request from the Subsystem - Electronic Interlocking.



- P1: The functional Local Control and Display Interface to the Maintainer. The InformationFlow through the Interface is defined by the FlowSpecification "Maintainer".
- SMI-P: The functional System Maintenance Interface to the Subsystem - Maintenance and Data Management f for the InformationFlow through the Interface, which is defined by the FlowSpecification "Subsystem_MDM_M".
- SDI-P: The functional Diagnostic Interface to the Subsystem - Maintenance and Data Management. The InformationFlow through the Interface is defined by the FlowSpecification "Subsystem_MDM_D".

Interface SDI-P (Subsystem – Maintenance and Data Management)

DriveVoltageFault	Type: Boolean Parameter = {yes, no} Electricity is not switchable. The message shall be transmitted as event triggered. Note: The electricity is not detected.

PointTurnEvent.MotorTurnData[i].CurrentL1Phase	Type: Array of Float Unit: A The course of active current from L1-Phase during the Point Movement is indicated (not the apparent current, which is included in the blind current component). The measured values of the Point Movement shall be given in a continous domain. The time interval between to measured values is defined as PointTurnEvent.SamplingInterval. i is the number of the Point machine (1 = first Point machine). The message shall be transmitted as event triggered after completion of point movement.
PointTurnEvent.MotorTurnData[i].CurrentL2Phase	Type: Array of Float Unit: A The course of active current from L2-Phase during the Point Movement is indicated (not the apparent current, which is included in the blind current component). The measured values of the Point Movement shall be given in a continous domain. The time interval between to measured values is defined as PointTurnEvent.SamplingInterval.
PointTurnEvent.MotorTurnData[i].CurrentL3Phase	Type: Array of Float Unit: A The course of active current from L3-Phase during the Point Movement is indicated (not the apparent current, which is included in the blind current component). The measured values of the Point Movement shall be given in a continous domain. The time interval between to measured values is defined as PointTurnEvent.SamplingInterval. i is the number of the Point machine (1 = first Point machine). The message shall be transmitted as event triggered after completion of point movement.
PointTurnEvent.MotorTurnData[i].DelayStartTime	Type: Float Unit: Seconds Delay of time between the first started Point machine and the considered Point machine. i is the number of the Point machine (1 = first Point machine). The message shall be transmitted as event triggered.

PointTurnEvent.MotorTurnData[i].idSub1	Type: String Functional location of Subsystem - Point (e.g. DB Netz AG TP 1-3 from SAP R/3). If this attribute is not defined, it needs to be filled with Underscore (0x5F). The attribute shall be changeable by updating of Configuration Data. i is the number of the Point machine (1 = first Point machine). The message shall be transmitted as event triggered.
PointTurnEvent.MotorTurnData[i].MotorType	Type: Enumeration Type of Point machine´s motor. i is the number of the Point machine (1 = first Point machine). The message shall be transmitted as event trigerred.
PointTurnEvent.MotorTurnData[i].Power	Type: Array of Float Unit: W The course of active power during the Point Movement is indicated. The measured values of the Point Movement shall be given in a continuous domain. The time interval between measured values is defined as PointTurnEvent.SamplingInterval. i is the number of the Point machine (1 = first Point machine). The message shall be transmitted as event triggered after completion of point movement. Note: This requirement is an alternative realisation for the requirements of Eu.P.1404, Eu.P.1405 and Eu.P.1406 (current measurement of the 3 phases).
PointTurnEvent.Position	Type: Enumeration Direction of Moving Point. The message shall be transmitted as event triggered.
PointTurnEvent.TurnTime	Type: Float Unit: Seconds Time of Moving Point resulting from start of the first moved Point machine until the last switched off Point machine. The message shall be transmitted as event trigerred.

PrincipleOfMeasurement	Type: Enumeration Description how the data of the measurement from electricity (current) or performance (power) are collected. The message shall be transmitted with the establishing connection SDI-P.
PointTurnEvent.SamplingInterval	Type: Float Unit: Seconds Information of time between two measure points for values of electricity or performance from the Moving point curve. The message shall be transmitted with the establishing connection SDI-P. Note: The value shall be between 20ms and 50ms.
StatusPositionLeft	Type: Enumeration Status from detector of the left hand end position. The message shall be transmitted as event triggered.
StatusPositionLeft_PM[i]	Type: Enumeration Information from the additional detector of the left hand end position (producer specific). i is the number of the Point machine or detectors (1 = first Point machine or detector). The message shall be transmitted as event triggered.
StatusPositionRight	Type: Enumeration Status from detector of the right hand end position. The message shall be transmitted as event triggered.
StatusPositionRight_PM[i]	Type: Enumeration Information from the additional detector of the right hand end position (producer specific). i is the number of the Point machine or detectors (1 = first Point machine or detector). The message shall be transmitted as event triggered.

PointTurnEvent.Timeout	Type: Enumeration Status of Timeout from Moving Point. The message shall be transmitted as event triggered.
TrailingStatus_PM[i]	Type: Boolean Information from the Point machine of a trailed point. i is the number of the Point machine (1 = first Point machine). The message shall be transmitted as event triggered.
TurnCounter	Type: Long Counter of Moving point (right and left hand position are counted). The message shall be transmitted as event triggered.

A Point Movement starts with the Point machine starting up first (Trigger). The measuring of all Point machines starts when exceeding an appropriate starting value (Electricity). The delay from start of the first starting Point machine is to be specified for each Point machine in the variable PointTurnEvent.MotorTurnData[i].DelayStartTime. The recording of the data ends for each Point machine by stating a continuing undercut of an appropriate minimum value (Electricity). Start and End of the particular measuring procedure of the particular Point machine need to be detected.

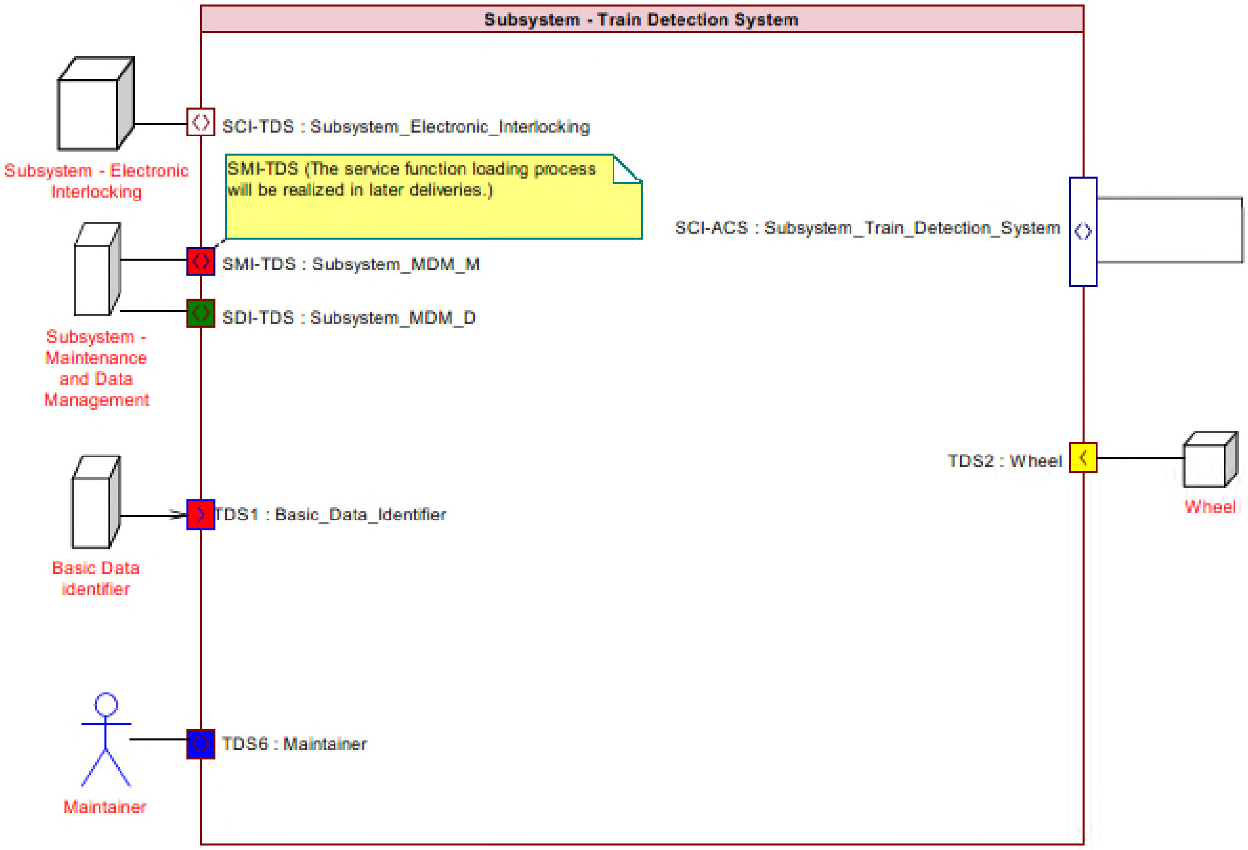
Interface P1 (Maintainer)

Definition of the InformationFlow (by FlowSpecification) for Maintenance/Operation/Display Interface P1 (Maintainer).

Point_Moving	Displays the moving of the point at the local status display.
End_Position_R	Displays the status of the detection of point end position on the right hand.
End_Position_L	Displays the status of the detection of point end position on the left hand.
Point_Trailed	Displays the trailing of the point at the local status display (point trailed or not trailed).

4.2.1.3 Track circuits & Axle counters

The Subsystem - Train Detection System monitors the vacancy and occupancy status of TVP sections. The statuses of the TVP sections are sent to the Subsystem - Electronic Interlocking.



- TDS6: The functional Local Operate and Display interface to the Maintainer. The Information Flow through the interface is defined by the FlowSpecification "Maintainer".
- SMI-TDS: The functional System Maintenance Interface to the Subsystem - Maintenance and Data Management for the InformationFlow through the interface, which is defined by the FlowSpecification "Subsystem_MDM_M".
- SDI-TDS: The functional Diagnostic interface to the Subsystem - Maintenance and Data Management for the InformationFlow through the interface, which is defined by the FlowSpecification "Subsystem_MDM_D".

Interface SDI-TDS (Subsystem – Maintenance and Data Management)

Subsystem_MDM_D	The functional Diagnostic Interface to the Subsystem - Maintenance and Data Management. The InformationFlow through the Interface is defined by the FlowSpecification "SubsystemMDMD".
AxleCounter.DetectionPoint[i].Failure	The message comprises information on whether the Detection Point is failed. The message shall be transmitted as event triggered.

AxleCounter.DetectionPoint[i]. StatusConnectionToACEU	The message comprises the information about the status of the connection between Detection Point and ACEU. The message shall be transmitted as event triggered.
AxleCounter.DetectionPoint[i]. DescriptionOfFailureDueToDetectionPointComponent	The message comprises the description of a failure due to Detection Point component. The message shall be transmitted as event triggered.
AxleCounter.DetectionPoint[i]. FailureDueToDPcomponent	The message comprises information on whether there is a failure due to Detection Point component. The message shall be transmitted as event triggered.
AxleCounter.TrackVacancyProvingSection[i] Status	The message comprises the current status of the TVPS. The message shall be transmitted as event triggered.
AxleCounter.DetectionPoint[i]. DescriptionOfCommunicationInterruptionToACEU	The message comprises the description of the communication interruption between Detection Point and ACEU. The message shall be transmitted event as triggered.
LastStartupReason	The message indicates the reason for the last starting up. The message shall be transmitted as event triggered.
AxleCounter.DetectionPoint[i]. CounterTraversing	The message comprises information on the accumulated amount of traverses of the Detection Point since the last reset or initial startup of the Detection Point. The message shall be transmitted as event triggered.
AxleCounter.DetectionPoint[i]. DriftWarning	The message comprises information on whether the Detection Point reports a drift warning. The message shall be transmitted as event triggered.
AxleCounter.DetectionPoint[i]. Redundancy.IsActive	The message comprises the information whether the redundand Detection Point is active or not.

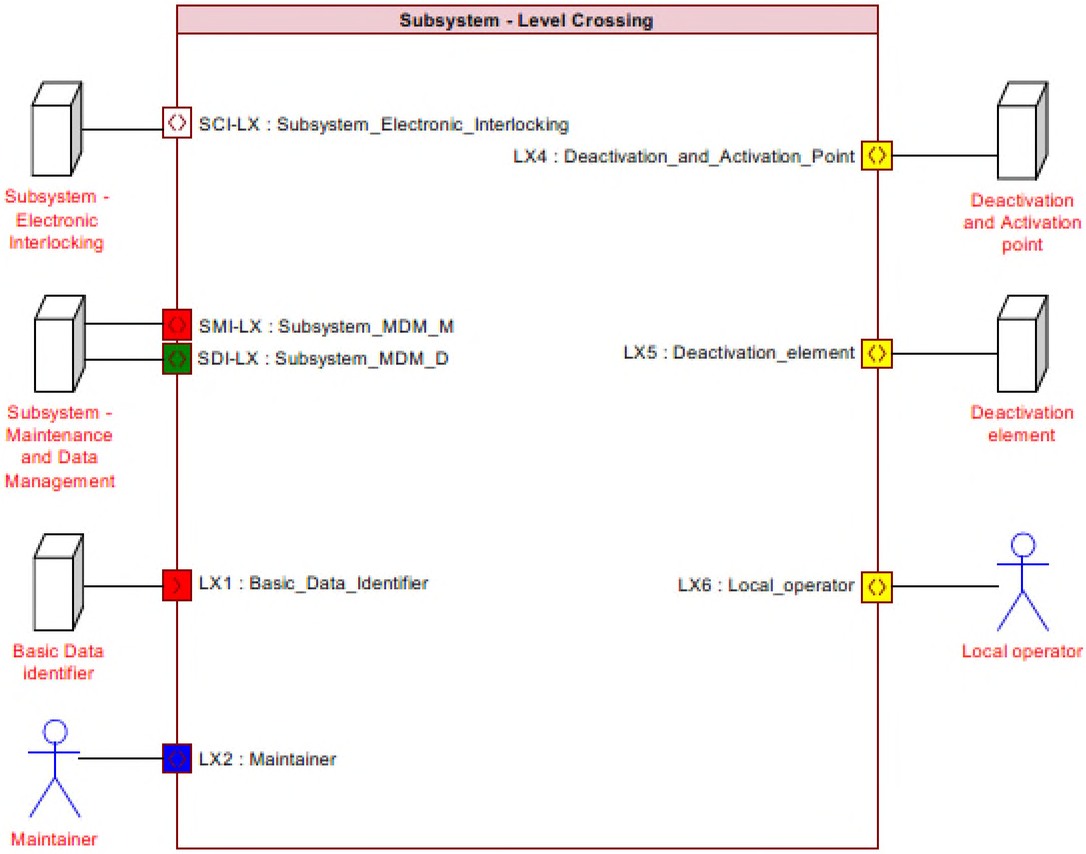
	The message shall be transmitted as event triggered.
AxleCounter.DetectionPoint[i]. SensorsOfTheDPareTriggered	The message comprises information on whether the sensors of the Detection Point are triggered. The message shall be transmitted as event triggered.
AxleCounter.TrackVacancyProvingSection[i] AxleCountBeforeTriggered	The message comprises the filling level of a TVPS receiving a FC or DRFC command. The message shall be transmitted as event triggered.
AxleCounter.TrackVacancyProvingSection[i] isDRFCtriggered	The message comprises the information, that a DRFC command has been executed. The message shall be transmitted as event triggered.
AxleCounter.TrackVacancyProvingSection[i] isFC-Ctriggered	The message comprises the information, that a FC-C command has been executed. The message shall be transmitted as event triggered.
AxleCounter.TrackVacancyProvingSection[i] isFC-P-Afailed	The message comprises the information, that a FC-P-A command has not been executed successfully and the reason. The message shall be transmitted as event triggered.
AxleCounter.TrackVacancyProvingSection[i] isFC-P-Atriggered	The message comprises the information, that a FC-P-A command has been executed. The message shall be transmitted as event triggered.
AxleCounter.TrackVacancyProvingSection[i] isFC-Pfailed	The message comprises the information, that a FC-P command has not been executed successfully and the reason. The message shall be transmitted as event triggered.
AxleCounter.TrackVacancyProvingSection[i] isFC-Ptriggered	The message comprises the information, that a FC-P command has been executed. The message shall be transmitted as event triggered.

AxleCounter.TrackVacancyProvingSection[i] isFC-Utriggered	The message comprises the information, that a FC-U command has been executed. The message shall be transmitted as event triggered.
AxleCounter.TrackVacancyProvingSection[i] isFC_rejected	The message comprises the information, that a FC-command has been rejected. The message shall be transmitted as event triggered.
AxleCounter.TrackVacancyProvingSection[i] NegativeFillingLevel	The message comprises the information, that the TVPS detected a negative filling level. The message shall be transmitted as event triggered.
AxleCounter.TrackVacancyProvingSection[i] Redundancy.IsActive	The message comprises the information whether the redundancy of the TVPS is active. The message shall be transmitted as event triggered.
CounterInvalidMessages	The message comprises the number of invalid transfer telegrams. The message shall be transmitted as event triggered.
DescriptionOfFailureDueToACEUComponent	The message indicates the description of failure due to ACEU component. The message shall be transmitted as event triggered.
Device.Controller[i]. Redundancy.IsActive	The message comprises information on whether the redundancy of the Device Controller channel is active. The message shall be transmitted as event triggered.
Device.IpConnectionPoint.Connection[i]. Redundancy.IsActive	The message comprises information on whether the redundant connection is active. The message shall be transmitted as event triggered.
Device[i].Redundancy.IsActive	The message comprises information on whether the redundancy of the device is active. The message shall be transmitted as event triggered.

4.2.1.4 Level crossing systems

The Subsystem - Level Crossing shall provide the technical interfaces shown in the "Subsystem - Level Crossing - Functional Subsystem Context". Each interface shall allow the connection to the corresponding actors shown in the quantities defined in the multiplicities.

The Level Crossing protection facility is not modelled as an actor with an interface to the Subsystem - Level Crossing. The Level Crossing protection facility is an internal part of the Subsystem - Level Crossing and shall be specified by national requirements.



- LX2: The functional Local Control and Display interface to the Maintainer. The InformationFlow through the interface is defined by the FlowSpecification "Maintainer".
- SMI-LX: The functional System Maintenance interface to the Subsystem - Maintenance and Data Management for the InformationFlow through the interface is defined by the FlowSpecification "Subsystem_MDM_M".
- SDI-LX: The functional Diagnostic interface to the Subsystem - Maintenance and Data Management for the InformationFlow through the interface, which is defined by the FlowSpecification "Subsystem_MDM_D".

Interface SDI-LX (Subsystem – Maintenance and Data Management)

LevelCrossing.LevelCrossingProtectionFacility Barrier[i].Status	The message comprises the status of a determined Barrier. The message shall be transmitted as event triggered.
LevelCrossing.LevelCrossingProtectionFacility. ObstacleDetector[i].Obstacle	The message comprises the detection of an Obstacle of a determined Obstacle detector. The message shall be transmitted as event triggered.
LevelCrossing.LevelCrossingProtectionFacility ObstacleDetector[i].Status	The message comprises the critical or nor- critical fault of a determined Obstacle detector. The message shall be transmitted as event triggered.
LevelCrossing.LevelCrossingProtectionFacility RoadLight[i].Lamps[j].Status	The message comprises the status of a determined Road Light for the road protection is whether switched on or off. The message shall be transmitted as event triggered.
LevelCrossing.LevelCrossingProtectionFacility BarrierMachineMotor.Control	The message comprises the status of the Barrier Machine Motor. The message shall be transmitted as event triggered.
LevelCrossing.LevelCrossingProtectionFacility BarrierMachineMotor.Current	The message comprises the status of the Barrier Machine Motor for moving the Barrier. The message shall be transmitted as event triggered.
LevelCrossing.LevelCrossingProtectionFacility BarrierMovementEvent.SamplingInterval	The message comprises the status of the Barrier Movement Event. The message shall be transmitted as event triggered.

LevelCrossing.LevelCrossingProtectionFacility BarrierMachinePedestalDoorsClosed	The message comprises the status of the Barrier Machine Pedestal Doors Closed. The message shall be transmitted as event triggered.
LevelCrossing.PrimaryPowerSource.Status	The message comprises whether the primary power source faild. The message shall be transmitted as event triggered.
LevelCrossing.PowerSupply	The message comprises the status of the Power supply. The message shall be transmitted as event triggered.
LevelCrossing.ObservationFacility[i].Status	The message comprises whether the facility to observe the Level Crossing is switched on. The message shall be transmitted as event triggered.
LevelCrossing.FloodLight[i].Status	The message comprises whether the Flood Light is switched on. The message shall be transmitted as event triggered.
LevelCrossing.AutoMovement.Status	The message comprises the status of the Auto Raise. The message shall be transmitted as event triggered.

4.2.2 Data from interlocking systems

Nowadays all the electronic interlockings have a Maintenance Support System (SAM) that allows scheduled maintenance to be carried out.

The SAM equipment consists of a rack mounted PC that acts as a central data store for the system. It logs all messages that are passed between the various part of the interlocking system. It also stores the configuration for each of the processor units. This is used to check that each unit is correctly configured and to update the configuration if necessary. It also allows the technicians access to the all logged data and allows controls to be applied.

The problem is that each manufacturer has its own protocol between interlocking and SAM, and its own name of alarms and data management. There should be SAM Translator (SAMT) that obtain all the debug log files that are generated by the SAM, and with an XML unified model, translate to a common format, independently of the technology of the SAM and interlocking. The translated log files are sent to A4R_MNG in a specific format like the defined in the SysLog protocol and processed along with the data obtained from the field elements. The connection between the SAMs and the A4R_MNG is done through the Ethernet network, using the TCP/IP protocol.

4.2.2.1 Log files

The interlocking systems usually log the actions relating to the field elements. The main data sources used in this thesis are the log files produced by interlocking systems. Each field elements has its own logical entity that pulls and pushes information to the interlocking system. Each operation of a field element gets an operation time stamp in the server and stored in the log files.

For instance, Ojala (2018) combined the log files and maintenance records to predict the failures of the point machines based on Machine Learning techniques. Besides the different phases of one turn i.e. actions required to change the rail direction, log files have information related to additional equipment and problems in the turn actions. The log files indicating problems in turn actions can be regarded as critical alarms. At a high-level log file can be seen as a series of turns and one turn normally gives the log, as shown in Figure 2. From the log it is possible to extract motor on and monitor off times of a turn. The time between turns tells when a switch has been used before. The useful information in the log files can be extracted as the features in context of Machine Learning, while the corresponding actual maintenance records are the ground truth and used as the label. A prediction model can thus trained.

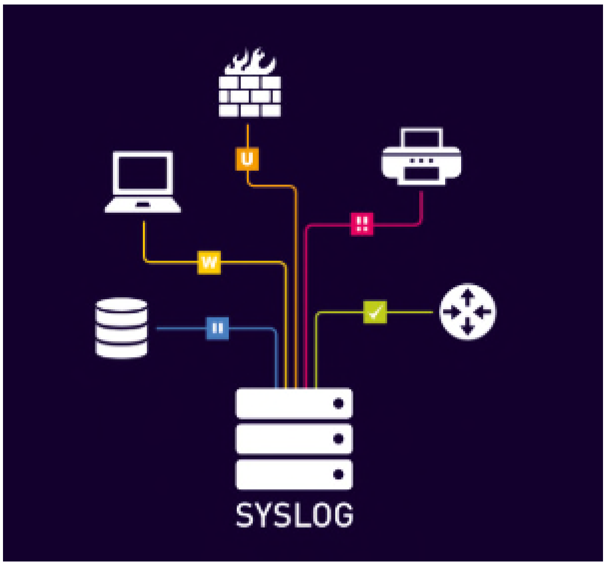
```
| 22:06:23,3  | [ILR3] | V619A_SP1STAGE_DI_________6121  | Vaihtokulkutie 1. porras  | EI | 2.9.2013 |
| 22:06:23,3  | [ILR3] | V619A_SP2STAGE_DI_________6121  | Vaihtokulkutie 2. porras | EI | 2.9.2013Â |
| 22:06:23,6  | [ILR3] | V619A_LOCKEDHMI_DI________6121 | Lukittu                          | EI | 2.9.2013 |
| 22:07:27,9  | [ILR3 ]| V619A_SP1STAGE_DI_________6121  | Vaihtokulkutie 1. porras  | ON| 2.9.2013 |
| 22:07:28,0  | [ILR3 ]| V619A_MOTORON_DI__________6121 | Kntmoottorin kyntitieto (SA) | ON| 2.9.2013|
| 22:07:28,3  | [ILR3 ]| V619A_MINUSHMI_DI_________6121 | Asento miinus                        | EI | 2.9.2013 |
| 22:07:28,3  | [ILR3 ]| V619A_SUPERVISED_DI_______6121 | Valvonta                               | EIÂ | 2.9.2013Â |
| 22:07:28,3  | [ILR3Â ]| V619A_UMLAUF_ID___________6121 | Umlauf-tulo (kntyy/vika/aukiajo) | ON | 2.9.2013Â |
| 22:07:31,2  | [ILR3 ]| V619A_UMLAUF_ID___________6121 | Umlauf-tulo (kntyy/vika/aukiajo) | EI | 2.9.2013 |
| 22:07:31,3 | [ILR3 ] | V619A_MOTORON_DI__________6121 | Kntmoottorin kyntitieto (SA) | EI | 2.9.2013 |
| 22:07:31,3 | [ILR3] | V619A_PLUSHMI_DI__________6121 | Asento plus                      | ON | 2.9.2013 |
| 22:07:31,3 | [ILR3 ]| V619A_SUPERVISED_DI_______6121 | Valvonta                          | ON | 2.9.2013 |
| 22:07:31,4 | [ILR3 ]| V619A_LOCK_ID_____________6121 | Lukitus                            | LUKITUS | 2.9.2013 |
| 22:07:31,7 | [ILR3 ]| V619A_LOCKEDHMI_DI________6121 | Lukittu                          | LUKITTU | 2.9.2013 |
| 22:07:33,6| [ILR3 ]| V619A_SP2STAGE_DI_________6121  | Vaihtokulkutie 2. porras   | ON | 2.9.2013 |
| 22:09:34,2| [ILR3]| V619A_TRACKVACANT_DI______6121 | Vaihdeosuus               | VARATTU| 2.9.2013 |
| 22:09:59,8 | [ILR3] | V619A_TRACKVACANT_DI______6121 | Vaihdeosuus               | VAPAA    | 2.9.2013 |
```

Figure 2 Example of a log file for a point machine in an interlocking system

For the interlocking systems that are compliant with EULYNX, more information could be available, see Section 4.2.

4.2.2.2 Communication protocol

Syslog is a standard for message logging. It allows separation of the software that generates messages, the system that stores them, and the software that reports and analyzes them. Each message is labeled with a facility code, indicating the software type generating the message, and assigned a severity level.



Computer system designers may use syslog for system management and security auditing as well as general informational, analysis, and debugging messages. This permits the consolidation of logging data from different types of systems in a central repository. Implementations of syslog exist for many operating systems.

Syslog utilizes three layers:

- "syslog content" is the management information contained in a syslog message.
- The "syslog application" layer handles generation, interpretation, routing, and storage of syslog messages.
- The "syslog transport" layer puts messages on the wire and takes them off the wire.

Certain types of functions are performed at each conceptual layer:

- An "originator" generates syslog content to be carried in a message.
- A "collector" gathers syslog content for further analysis.
- A "relay" forwards messages, accepting messages from originators or other relays and sending them to collectors or other relays.
- A "transport sender" passes syslog messages to a specific transport protocol.
- A "transport receiver" takes syslog messages from a specific transport protocol.

The following principles apply to syslog communication:

- The syslog protocol does not provide acknowledgment of message delivery. Though some transports may provide status information, conceptually, syslog is a pure simplex communications protocol.

- Originators and relays may be configured to send the same message to multiple collectors and relays.
- Originator, relay, and collector functionality may reside on the same system.

Syslog Message Format:

```
SYSLOG-MSG      = HEADER SP STRUCTURED-DATA [SP MSG]

HEADER          = PRI VERSION SP TIMESTAMP SP HOSTNAME
                  SP APP-NAME SP PROCID SP MSGID
PRI             = "<" PRIVAL ">"
PRIVAL          = 1*3DIGIT ; range 0 .. 191
VERSION         = NONZERO-DIGIT 0*2DIGIT
HOSTNAME        = NILVALUE / 1*255PRINTUSASCII

APP-NAME        = NILVALUE / 1*48PRINTUSASCII
PROCID          = NILVALUE / 1*128PRINTUSASCII
MSGID           = NILVALUE / 1*32PRINTUSASCII

TIMESTAMP       = NILVALUE / FULL-DATE "T" FULL-TIME
FULL-DATE       = DATE-FULLYEAR "-" DATE-MONTH "-" DATE-MDAY
DATE-FULLYEAR   = 4DIGIT
DATE-MONTH      = 2DIGIT  ; 01-12
DATE-MDAY       = 2DIGIT  ; 01-28, 01-29, 01-30, 01-31 based on
                          ; month/year
FULL-TIME       = PARTIAL-TIME TIME-OFFSET
PARTIAL-TIME    = TIME-HOUR ":" TIME-MINUTE ":" TIME-SECOND
                  [TIME-SECFRAC]
TIME-HOUR       = 2DIGIT  ; 00-23
TIME-MINUTE     = 2DIGIT  ; 00-59
TIME-SECOND     = 2DIGIT  ; 00-59
TIME-SECFRAC    = "." 1*6DIGIT
TIME-OFFSET     = "Z" / TIME-NUMOFFSET
TIME-NUMOFFSET  = ("+" / "-") TIME-HOUR ":" TIME-MINUTE


STRUCTURED-DATA = NILVALUE / 1*SD-ELEMENT
SD-ELEMENT      = "[" SD-ID *(SP SD-PARAM) "]"
SD-PARAM        = PARAM-NAME "=" %d34 PARAM-VALUE %d34
SD-ID           = SD-NAME
PARAM-NAME      = SD-NAME
PARAM-VALUE     = UTF-8-STRING ; characters '"', '\' and
                               ; ']' MUST be escaped.
SD-NAME         = 1*32PRINTUSASCII
                  ; except '=', SP, ']', %d34 (")

MSG             = MSG-ANY / MSG-UTF8
MSG-ANY         = *OCTET ; not starting with BOM
MSG-UTF8        = BOM UTF-8-STRING
BOM             = %xEF.BB.BF

UTF-8-STRING    = *OCTET ; UTF-8 string as specified
                  ; in RFC 3629

OCTET           = %d00-255
SP              = %d32
PRINTUSASCII    = %d33-126
NONZERO-DIGIT   = %d49-57
DIGIT           = %d48 / NONZERO-DIGIT
NILVALUE        = "-"
```

The information provided by the originator of a syslog message includes the facility code and the severity level. The syslog software adds information to the information header before passing the entry to the syslog receiver. Such components include an originator process ID, a timestamp, and the hostname or IP address of the device.

A facility code is used to specify the type of program that is logging the message. Messages with different facilities may be handled differently. The list of facilities available is defined by the standard:

Facility code	Keyword	Description
0	kern	Kernel messages
1	user	User-level messages
2	mail	Mail system
3	daemon	System daemons
4	auth	Security/authentication messages
5	syslog	Messages generated internally by syslogd
6	lpr	Line printer subsystem
7	news	Network news subsystem
8	uucp	UUCP subsystem
9	cron	Clock daemon
10	authpriv	Security/authentication messages
11	ftp	FTP daemon
12	ntp	NTP subsystem
13	security	Log audit
14	console	Log alert
15	solaris-cron	Scheduling daemon
16–23	local0 – local7	Locally used facilities

The list of severities is also defined by the standard:

Value	Severity	Keyword	Deprecated keywords	Description	Condition
0	Emergency	emerg	panic [7]	System is unusable	A panic condition.[8]
1	Alert	alert		Action must be taken immediately	A condition that should be corrected immediately, such as a corrupted system database.[8]
2	Critical	crit		Critical conditions	Hard device errors.[8]
3	Error	err	error [7]	Error conditions	
4	Warning	warning	warn [7]	Warning conditions	
5	Notice	notice		Normal but significant conditions	Conditions that are not error conditions, but that may require special handling.[8]
6	Informational	info		Informational messages	
7	Debug	debug		Debug-level messages	Messages that contain information normally of use only when debugging a program.[8]

4.2.3 Data from technical rooms

In order to monitor all the main parameters linked to the technical signalling rooms and ensure that they meet the operational needs of the existing systems in it, monitoring equipment must be installed that are capable of acquiring these values in real time, store them and be able to consult them any time.

It will be necessary to include sensors and monitoring and control elements, if applicable, of temperature, humidity, voltage presence, UPS status and control, air conditioning equipment monitoring, presence and intrusion, or any other that is considered appropriate, and those of command on energy management equipment according to the room configuration (action on remote control switches, switches…).

The remote control of auxiliary systems brings together the command and control of auxiliary systems of security installations such as the control of technical signaling rooms, allowing these systems to be remotely monitored and controlled.

The equipment to control the auxiliary services in the technical rooms will be based on a programmable logic controller.

A programmable logic controller (PLC) or programmable controller is an industrial digital computer which has been ruggedized and adapted for the control of manufacturing processes, such as assembly lines, or robotic devices, or any activity that requires high reliability control and ease of programming and process fault diagnosis.

The PLC will send the information obtained to the SCADA. Supervisory Control and Data Acquisition (SCADA) is a control system architecture that uses computers, networked data communications and graphical user interfaces for high-level process supervisory management, but uses other peripheral devices such as programmable logic controller (PLC) and discrete PID controllers to interface with the process plant or machinery.

Since about 1998, virtually all major PLC manufacturers have offered integrated HMI/SCADA systems, many of them using open and non-proprietary communications protocols. Numerous specialized third-party HMI/SCADA packages, offering built-in compatibility with most major PLCs, have also entered the market, allowing mechanical engineers, electrical engineers and technicians to configure HMIs themselves, without the need for a custom-made program written by a software programmer. The Remote Terminal Unit (RTU) connects to physical equipment. Typically, an RTU converts the electrical signals from the equipment to digital values such as the open/closed status from a switch or a valve, or measurements such as pressure, flow, voltage or current.

The next requirements are used by ADIF to monitoring the technical rooms. It can be used and example.

4.2.3.1 Cabinet

The cabinet houses the auxiliary components of the PLC:

- Source power.
- Magnetothermal protection.
- Signal conditioners.
- Digital output relays.
- Wiring connection. Input and output signals.

The types of signals to be handled by the PLC will be the following:

- 24 Vdc Digital inputs.
- Digital outputs based on relay 2A.
- Analog inputs 0 -10 Vdc

It can handle inputs/outputs according the needs of the technical room.

The automaton's memory will be enough to handle the inputs and outputs of the technical rooms.

The PLC can be powered with 230 Vac voltage.

The independent analog input modules of the PLC to be incorporated will have a resolution o 13 bits (12 signed) being configurable:

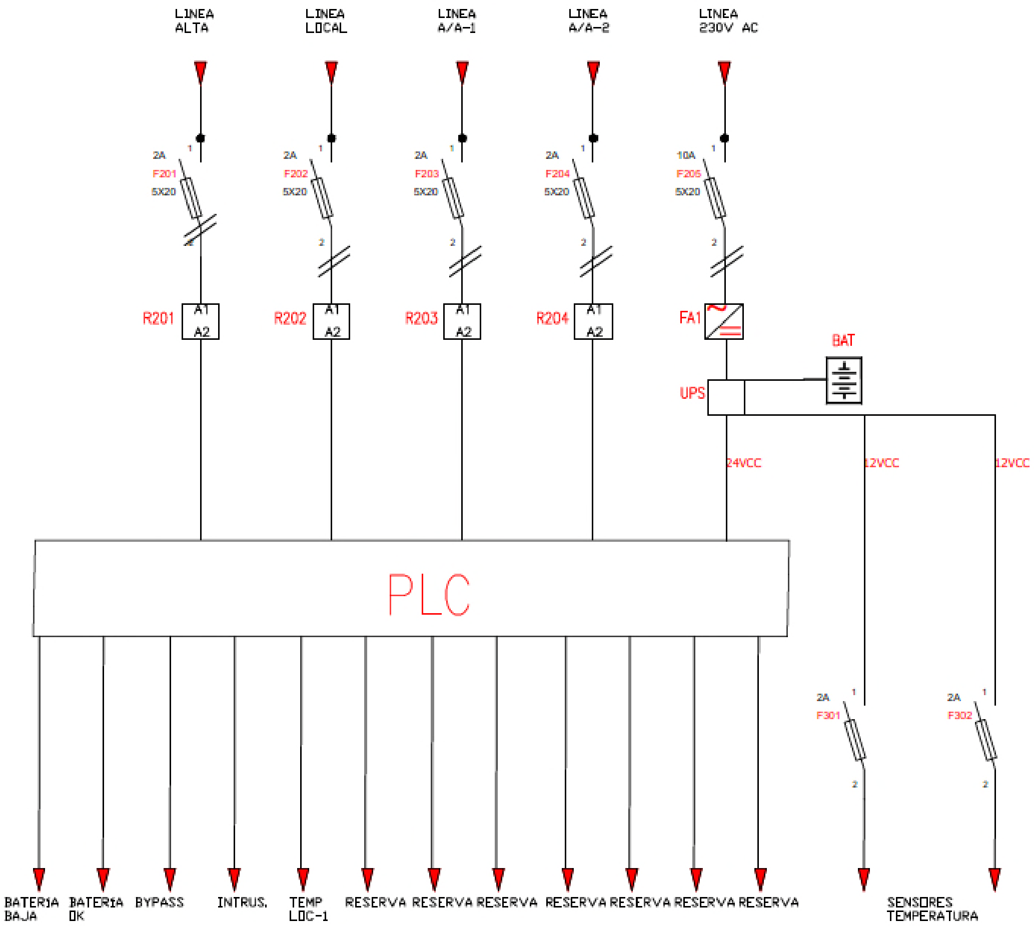
- Voltage: 10V, 5V, 2.5V
- Current: 0-20mA, 4-20mA.

The signal conditioners will have as characteristics:

- Universal isolator of the true RMS of an AC/DC current.
- Admission of continuous and alternating voltage distorted, rectified and with harmonics with frequencies up to 800 Hz.
- Output signal configurable in intensitiy (0-20 mA, 4-20 mA) or voltage (0-5 V, 0-10 V).

They can be powered at 24 Vdc or 230 Vac, with a wide range in both cases.

There will be isolation between the input and the output, and between both and the power circuit.



4.2.3.2 Inputs and outputs

Analog Inputs:

- Voltage: local, UPS (Uninterruptible power supply), 2200/300V.
- Current: Room, Interlocking, points.
- Temperature: Indoor, Interlocking, Batteries, Outdoor.

Digital Inputs:

- Technical room door.
- Voltage.
- UPS, By Pass.

Digital Outputs:

- Start, alarm, bypass, UPS.

4.2.3.3 Sensors

- Temperature sounding line.
- Current sounding line.

Split-core current transformer with built-in converter, capable of measuring up to 100 A, AC, with a converted output of 4 to 20 mA DC, fully compatible with the PLC without the need for any measurement adjustment.

Split-core allows installation without power outages and without complex disconnections of existing wiring.

The transformer is only connected to the equipment by means of 2 wires: one of them provides the power supply and other returns the 4/20 mA signal.

- Open doors detectors.

Normally closed magnetic contact (maximum 100mA at 28 Vdc) and length 45 mm.

4.2.3.4 UPS connection

The connection with the IPV is made through their potential free contacts. These contacts connect directly to the PLC digital inputs.
The remote orders can be:

- switched to by-pass
- remote start.

The connection to the central management server is done through the Ethernet network, using the TCP/IP protocol.

The PLC provides SCADA with a set of addresses in its memory that it can consult and, in some cases, modify:

- Analog inputs, type 32 bits.
- Digital inputs, Boolean type.

The ADIF (Spain) company is using the protocol OPC (OLE for Process Control) to connect the SCADA to the PLC.

4.2.3.5 Communication protocol

SCADA systems have traditionally used combinations of radio and direct wired connections, although SONET/SDH is also frequently used for large systems such as railways and power stations. The remote management or monitoring function of a SCADA system is often referred to as telemetry. Some users want SCADA data to travel over their pre-established corporate networks or to share the network with other applications. The legacy of the early low-bandwidth protocols remains, though.

SCADA protocols are designed to be very compact. Many are designed to send information only when the master station polls the RTU. Typical legacy SCADA protocols include Modbus RTU, RP-570, Profibus and Conitel. These communication protocols, with the exception of Modbus (Modbus has been made open by

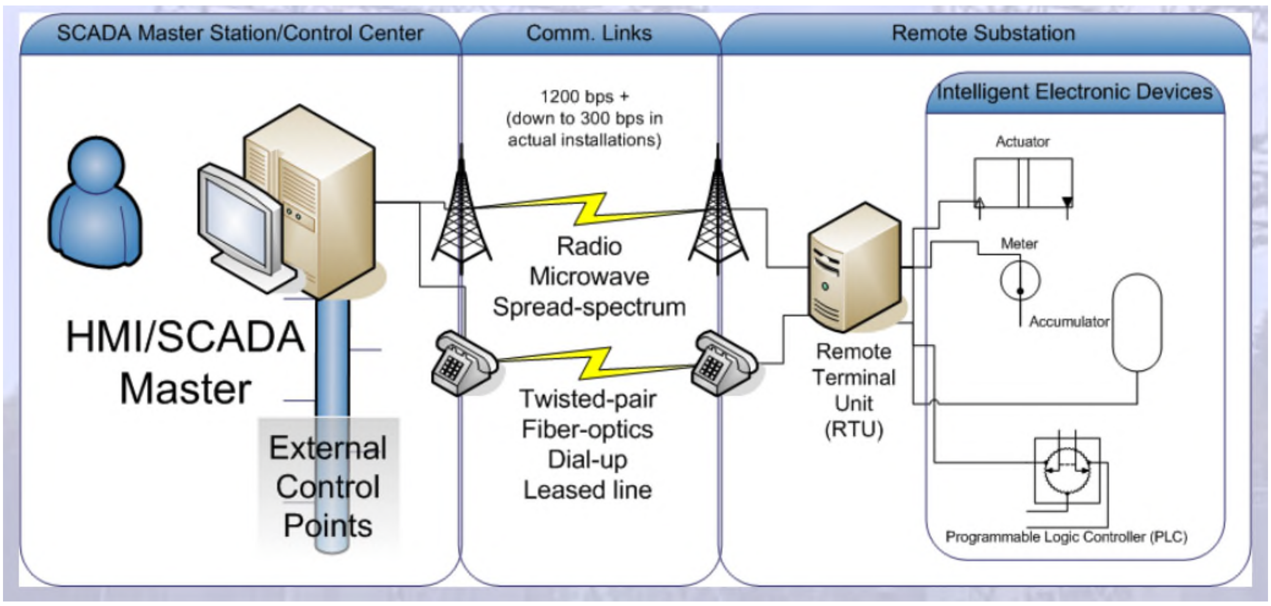
Schneider Electric), are all SCADA-vendor specific but are widely adopted and used. Standard protocols are IEC 60870-5-101 or 104, IEC 61850 and DNP3. These communication protocols are standardized and recognized by all major SCADA vendors. Many of these protocols now contain extensions to operate over TCP/IP. Although the use of conventional networking specifications, such as TCP/IP, blurs the line between traditional and industrial networking, they each fulfill fundamentally differing requirements. Network simulation can be used in conjunction with SCADA simulators to perform various 'what-if' analyses.

With increasing security demands (such as North American Electric Reliability Corporation (NERC) and critical infrastructure protection (CIP) in the US), there is increasing use of satellite-based communication. This has the key advantages that the infrastructure can be self-contained (not using circuits from the public telephone system), can have built-in encryption, and can be engineered to the availability and reliability required by the SCADA system operator. Earlier experiences using consumer-grade VSAT were poor. Modern carrier-class systems provide the quality of service required for SCADA.

RTUs and other automatic controller devices were developed before the advent of industry wide standards for interoperability. The result is that developers and their management created a multitude of control protocols. Among the larger vendors, there was also the incentive to create their own protocol to "lock in" their customer base. A list of automation protocols is compiled here.

OLE for process control (OPC) can connect different hardware and software, allowing communication even between devices originally not intended to be part of an industrial network.

Standardisation in the field of mySCADA protocols resulted into the vendor independent protocol called OPC UA (Unified Architecture). OPC UA is starting to be widely adopted among multiple SCADA vendors.

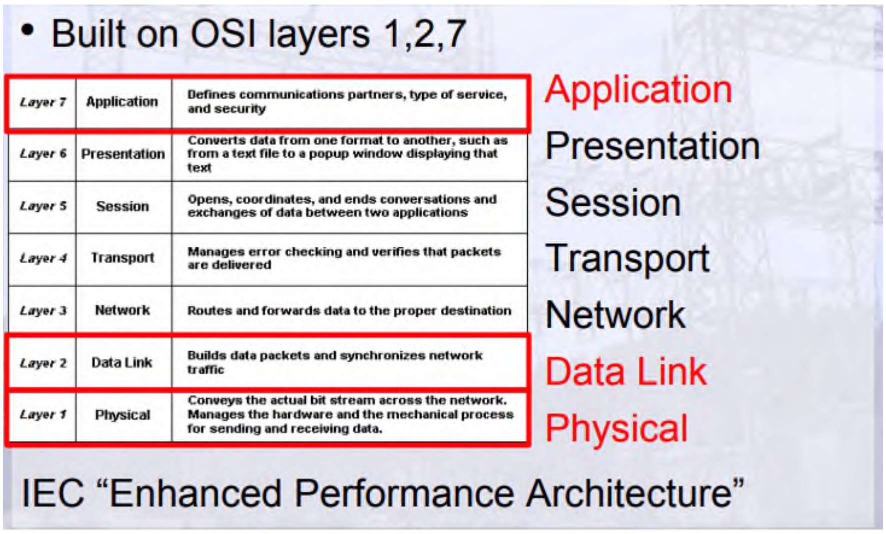


The DNP3 protocol standard defines several aspects of SCADA Master-RTU/IED communications:

- Frame and message formats
- Physical layer requirements
    - 1200 bps+

This project has received funding from the Shift2Rail Joint Undertaking under the European Union's Horizon 2020 research and innovation programme under grant agreement no. 826250 Assets4Rail).

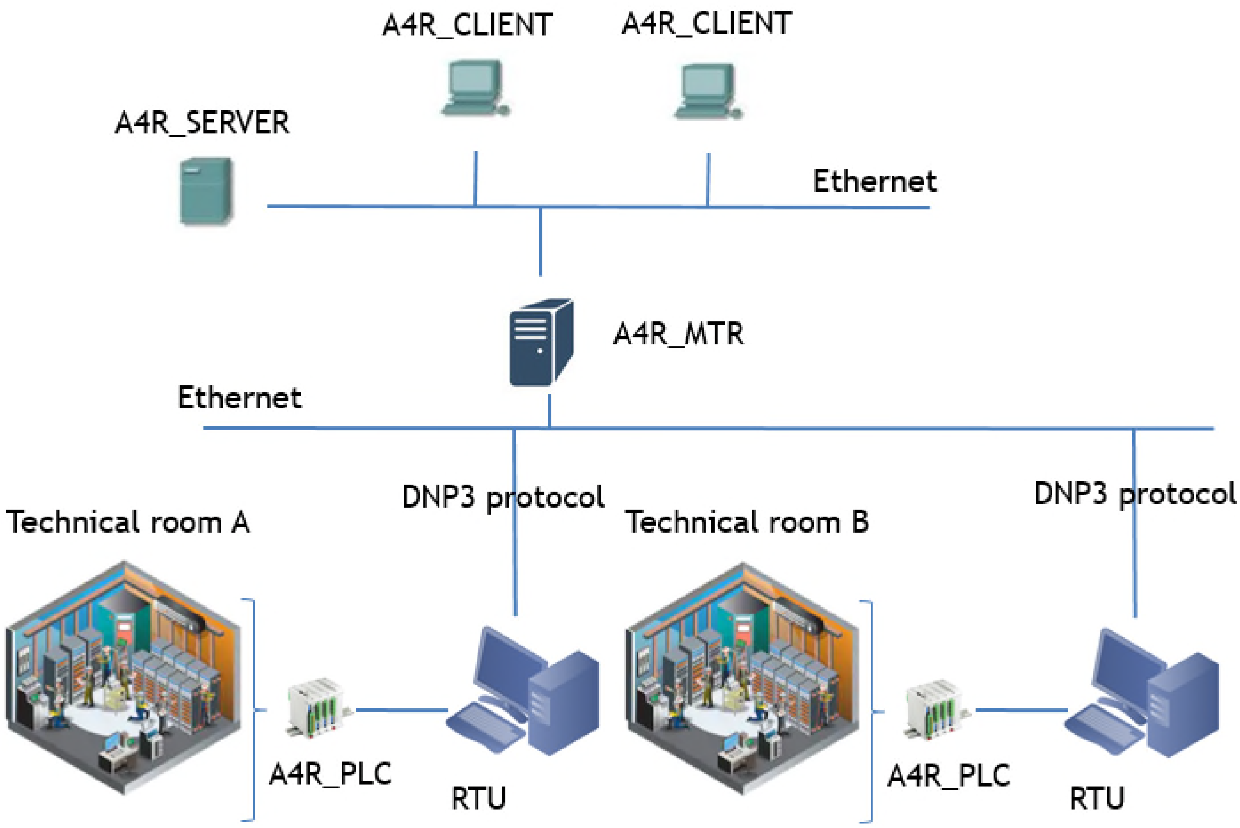
  - Busy link indicator for collision avoidance
- Data-link layer behavior
  - frame segmentation
  - Transmission retry algorithm
- Application layer
  - file transfer
  - time synchronization
  - start/stop service



4.2.3.6 System architecture

A PLC will be in charge of obtaining all the data of the different sensors installed in the technical rooms like UPS, HVAC, temperature, humidity…

The PLC send the information through the RTU to the A4R_MNG (Manager Technical Rooms) with the DNP3 protocol.



4.2.4 Other data sources

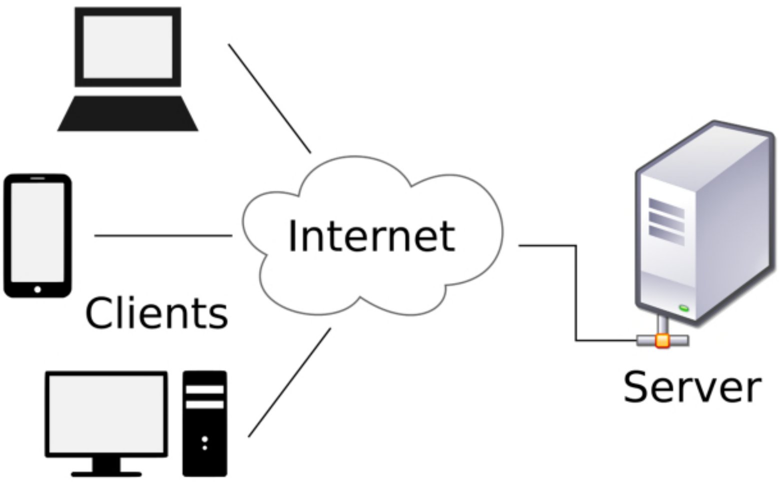
The historical maintenance records are essential for the development of the diagnosis algorithms. On the one hand, the maintenance records can be used for statistical analysis and provide an overview on the critical failure modes of a field element. On the other hand, they provide the ground truth of the obtained parameters from field elements, interlocking systems and technical rooms.
Maintenance records can be stored in an asset management software

4.3 Data management and Storage

A4R_SERVER receives remote information from multiple data acquisition units, storing it in a database. All incoming data is analyzed to determine the status of the assets and generate the corresponding alarms. Users can consult all the information by accessing the A4R_CLIENT client using any web browser of devices such as computers, tablets, mobile phones, etc.

The database server is a server which uses a database application that provides database services to other computer programs or to computers.

Users access a database server either through a "front end" running on the user's computer – which displays requested data – or through the "back end", which runs on the server and handles tasks such as data analysis and storage.



In a master-slave model, database master servers are central and primary locations of data while database slave servers are synchronized backups of the master acting as proxies.

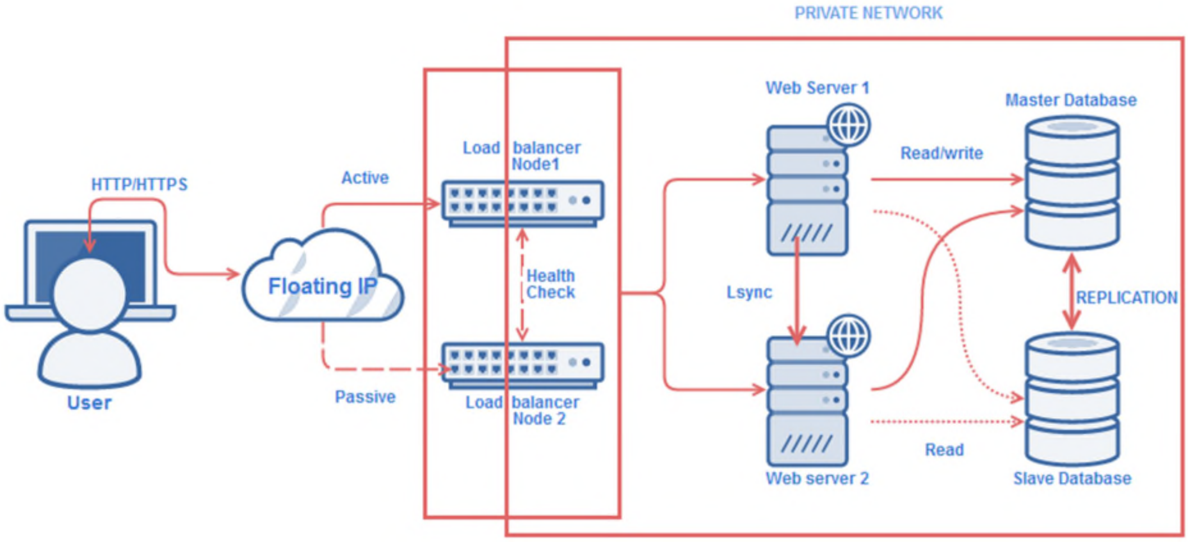
Most database applications respond to a query language. Each database understands its query language and converts each submitted query to server-readable form and executes it to retrieve results.

Examples of proprietary database applications include Oracle, DB2, Informix, and Microsoft SQL Server. Examples of free software database applications include PostgreSQL; and under the GNU General Public Licence include Ingres and MySQL. Every server uses its own query logic and structure. The SQL (Structured Query Language) query language is more or less the same on all relational database applications.

4.3.1 Redundant architectures

Single point of failure (SPOF) is a part of a system, that if it fails, will stop the entire system from working. To overcome SPOFs, High Availability architecture is deployed into web based environments. High Availability(HA) refers to a system that is continuously operational for a desirably long length of time. It is key to any web based environment as it provides continuous operation of the system even in the case of a hardware failure.

4.3.1.1 High availability architecture



Load balancing stage: Load balancers are added to a server environment to improve performance and reliability by distributing the workload across multiple servers. If one of the servers that is load balanced fails, the other servers will handle the incoming traffic until the failed server becomes healthy again.

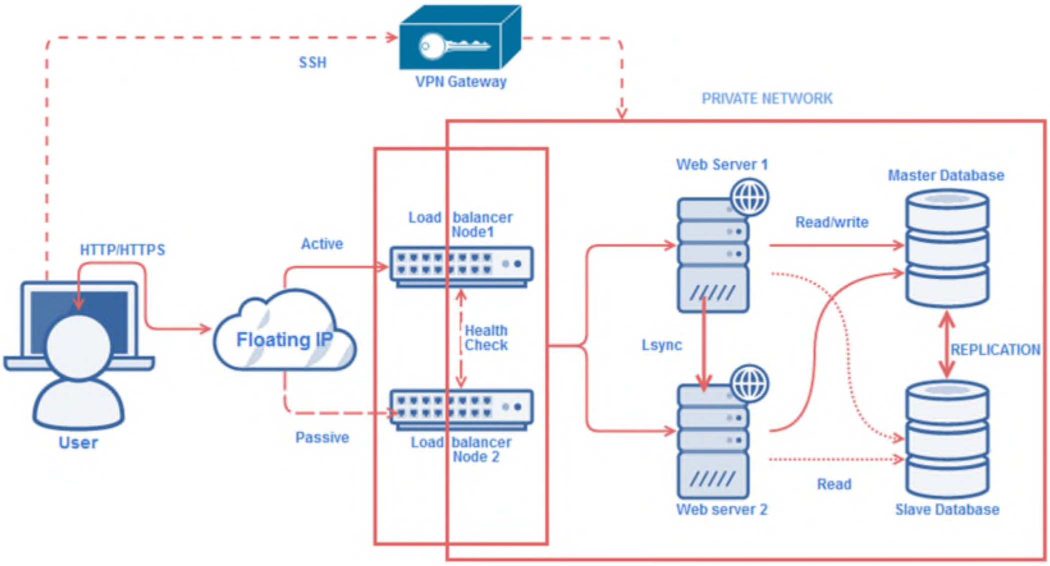
Master/slave database structure: One way to improve performance of a database system that performs many reads compared to writes is to use master-slave database replication. Master-slave replication requires a master and one or more slave nodes. In this setup, all updates are sent to the master node and reads can be distributed across all nodes. Master DB has read/write setup whereas the slave DB is read only.

Pros:

- Enables the user with horizontal scaling, i.e. processing capacity can be increased by adding more servers to it.
- High Availability due to reduced Single Point of Failures (SPOFs), which is achieved by adding a redundant load balancer.

4.3.1.2 High availability architecture with VPN

This architecture is similar to the previous architecture in every way except that a Virtual Private Network (VPN) gateway is provided to access the servers.



A virtual private network (VPN) appliance is provided to ensure greater security over shared networks along with firewall protection, authentication, authorization and encryption. This ensures that the data always flows in an encrypted form providing better security from hacks.

Pros:

- Enhanced security. When user connects to the network through a VPN, the data is kept secured and encrypted.

4.4 Diagnostics Management

Much of data management is essentially about extracting useful information from data. To do this, data must go through a data mining process to be able to get meaning out of it. There are a wide range of approaches and techniques to do this, and it is important to start with the most basic understanding of processing data.

Data processing is simply the conversion of raw data to meaningful information through a process. Data is technically manipulated to produce results that lead to a resolution of a problem or improvement of an existing situation. Similar to a production process, it follows a cycle where inputs (raw data) are fed to a process (computer systems, software, etc.) to produce output (information and insights).

Generally, organizations employ computer systems to carry out a series of operations on the data in order to present, interpret, or obtain information. The process includes activities like data entry, summary, calculation, storage, etc. Useful and informative output is presented in various appropriate forms such as diagrams, reports, graphics, doc viewers etc.

4.4.1 Stages

1) Collection is the first stage of the cycle, and is very crucial, since the quality of data collected will impact heavily on the output. The collection process needs to ensure that the data gathered are both defined and accurate, so that subsequent decisions based on the findings are valid. This stage provides both the baseline from which to measure, and a target on what to improve.

2) Preparation is the manipulation of data into a form suitable for further analysis and processing. Raw data cannot be processed and must be checked for accuracy. Preparation is about constructing a data set from one or more data sources to be used for further exploration and processing. Analyzing data that has not been carefully screened for problems can produce highly misleading results that are heavily dependent on the quality of data prepared.

3) Input is the task where verified data is coded or converted into machine readable form so that it can be processed through an application. Data entry is done through the use of a keyboard, scanner, or data entry from an existing source. This time-consuming process requires speed and accuracy. Most data need to follow a formal and strict syntax since a great deal of processing power is required to breakdown the complex data at this stage. Due to the costs, many businesses are resorting to outsource this stage.

4) Processing is when the data is subjected to various means and methods of powerful technical manipulations using Machine Learning and Artificial Intelligence algorithms to generate an output or interpretation about the data. The process may be made up of multiple threads of execution that simultaneously execute instructions, depending on the type of data. There are applications like Anvesh available for processing large volumes of heterogeneous data within very short periods.

5) Output and interpretation is the stage where processed information is now transmitted and displayed to the user. Output is presented to users in various report formats like graphical reports, audio, video, or document viewers. Output need to be interpreted so that it can provide meaningful information that will guide future decisions of the company.

6) Storage is the last stage in the data processing cycle, where data, and metadata (information about data) are held for future use. The importance of this cycle is that it allows quick access and retrieval of the processed information, allowing it to be passed on to the next stage directly, when needed. Anvesh use special security and safety standards to store data for future use.

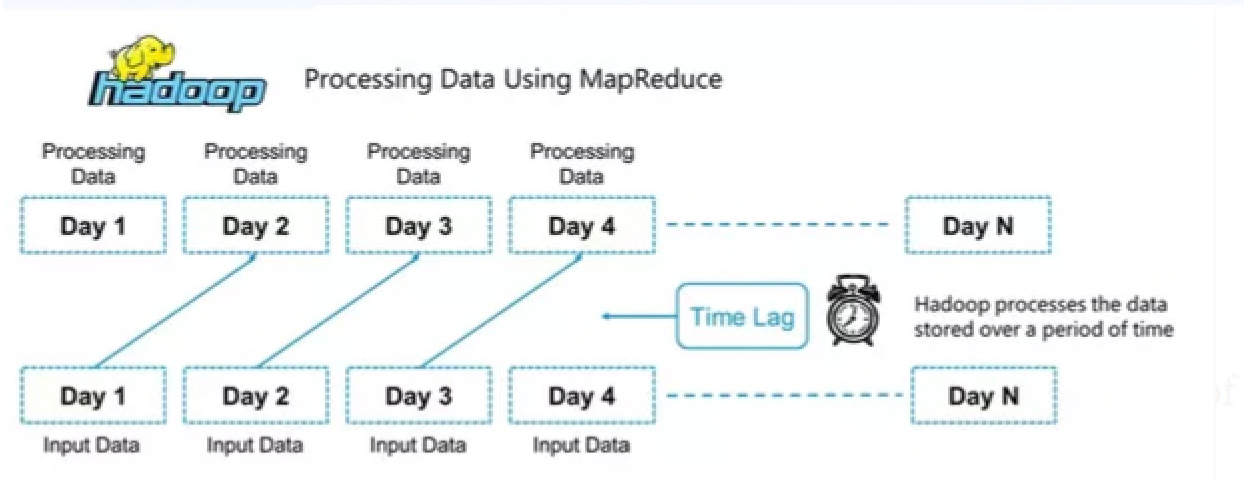
The Data Processing Cycle is a series of steps carried out to extract useful information from raw data. Although each step must be taken in order, the order is cyclic. The output and storage stage can lead to the repeat of the data collection stage, resulting in another cycle of data processing. The cycle

provides a view on how the data travels and transforms from collection to interpretation, and ultimately, used in effective business decisions.

4.4.2 Batch processing

Batch processing is where the processing happens of blocks of data that have already been stored over a period of time. This data contains millions of records for a day that can be stored as a file or record etc. This particular file will undergo processing at the end of the day for various analysis that firm wants to do. Obviously it will take large amount of time for that file to be processed.

Hadoop MapReduce is the best framework for processing data in batches. The following figure gives detailed explanation how Hadoop processing data using MapReduce.

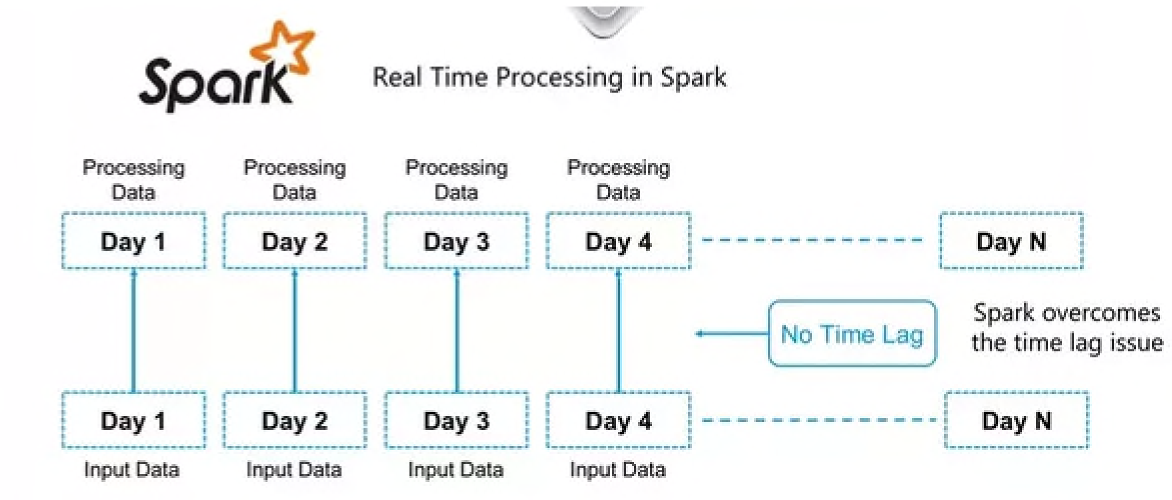


Batch processing works well in situations where you don't need real-time analytics results, and when it is more important to process large volumes of data to get more detailed insights than it is to get fast analytics results.

4.4.3 Streaming processing

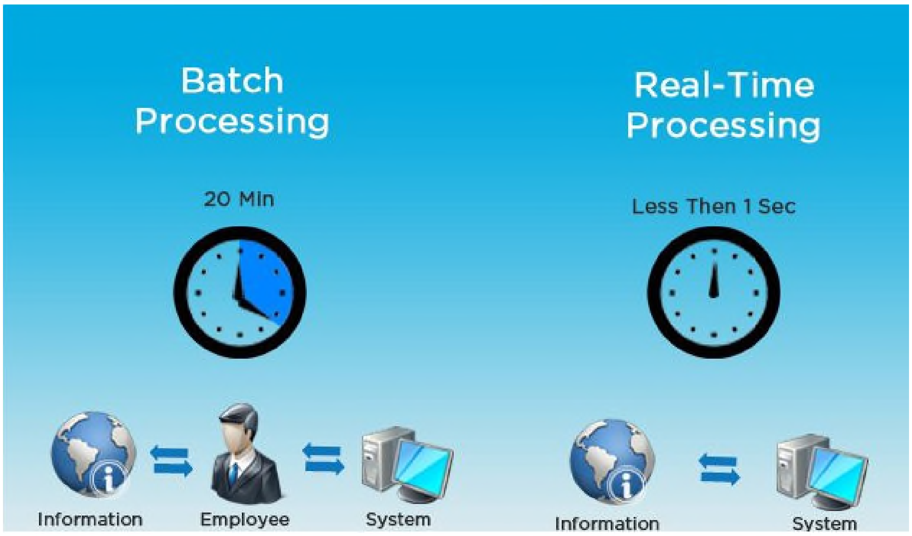
Stream processing is a golden key if you want analytics results in real time. Stream processing allows us to process data in real time as they arrive and quickly detect conditions within small time period from the point of receiving the data. Stream processing allows you to feed data into analytics tools as soon as they get generated and get instant analytics results. There are multiple open source stream processing platforms such as Apache Kafka, Apache Flink, Apache Storm, Apache Samza, etc.

The following figure gives you a detailed explanation how Spark process data in real time.



In Batch Processing it processes over all or most of the data but In Stream Processing it processes over data on rolling window or most recent record. So Batch Processing handles a large batch of data while Stream processing handles Individual records or micro batches of few records.

In the point of performance the latency of batch processing will be in a minutes to hours while the latency of stream processing will be in seconds or milliseconds.



While traditional batch architectures can be sufficient at smaller scales, stream processing provides several benefits that other data platforms cannot:

- Able to deal with never-ending streams of events—some data is naturally structured this way. Traditional batch processing tools require stopping the stream of events, capturing batches of data and combining the batches to draw overall conclusions. In stream processing, while it is challenging to combine and capture data from multiple streams, it lets you derive immediate insights from large volumes of streaming data.
- Real-time or near-real-time processing—most organizations adopt stream processing to enable real time data analytics. While real time analytics is also possible with high performance database systems, often the data lends itself to a stream processing model.
- Detecting patterns in time-series data—detecting patterns over time, for example looking for trends in website traffic data, requires data to be continuously processed and analyzed. Batch processing makes this more difficult because it breaks data into batches, meaning some events are broken across two or more batches.
- Easy data scalability—growing data volumes can break a batch processing system, requiring you to provision more resources or modify the architecture. Modern stream processing infrastructure is hyper-scalable, able to deal with Gigabytes of data per second with a single stream processor. This allows you to easily deal with growing data volumes without infrastructure changes.

For the analysis of the railway assets that protect de safety, it would be necessary to develop a streaming processing solution.

4.4.4 Architecture

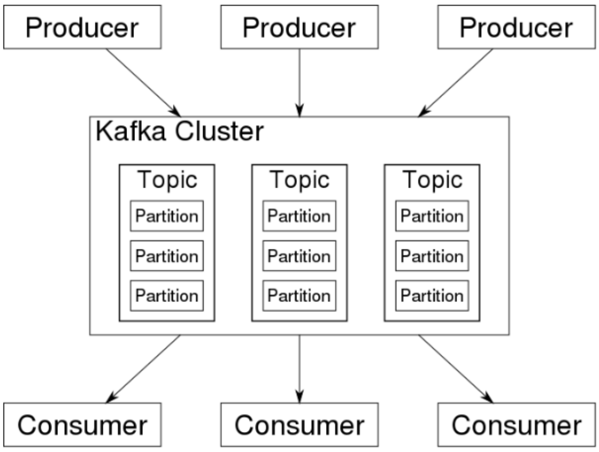
A streaming data architecture is a framework of software components built to ingest and process large volumes of streaming data from multiple sources. While traditional data solutions focused on writing and reading data in batches, a streaming data architecture consumes data immediately as it is generated, persists it to storage, and may perform real-time processing, data manipulation and analytics.

The streaming architecture must include these four key building blocks:

4.4.4.1 Message Broker

This is the element that takes data from a source, called a producer, translates it into a standard message format, and streams it on an ongoing basis. Other components can then listen in and consume the messages passed on by the broker.

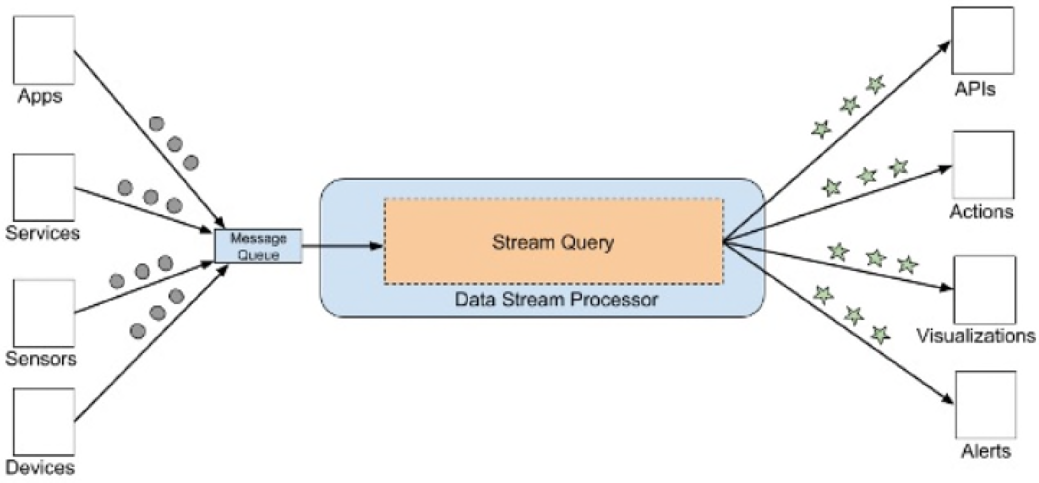
The first generation of message brokers, such as RabbitMQ and Apache ActiveMQ, relied on the Message Oriented Middleware (MOM) paradigm. Later, hyper-performant messaging platforms (often called stream processors) emerged which are more suitable for a streaming paradigm. Two popular stream processing tools are Apache Kafka and Amazon Kinesis Data Streams.



Unlike the old MoM brokers, streaming brokers support very high performance with persistence, have massive capacity of a Gigabyte per second or more of message traffic, and are tightly focused on streaming with little support for data transformations or task scheduling (although Confluent's KSQL offers the ability to perform basic ETL in real-time while storing data in Kafka).

4.4.4.2 Batch and Real-time ETL tools

Data streams from one or more message brokers need to be aggregated, transformed and structured before data can be analyzed with SQL-based analytics tools. ETL platforms receives queries from users, fetches events from message queues and applies the query, to generate a result - often performing additional joins, transformations on aggregations on the data. The result may be an API call, an action, a visualization, an alert, or in some cases a new data stream.



A few examples of open-source ETL tools for streaming data are Apache Storm, Spark Streaming and WSO2 Stream Processor. While these frameworks work in different ways, they are all capable of listening to message streams, processing the data and saving it to storage.

Some stream processors, including Spark and WSO2, provide a SQL syntax for querying and manipulating the data; however, for most operations you would need complex code to write code in Java or Scala. Upsolver's data lake ETL is built to provide a self-service solution for transforming streaming data using only SQL and a visual interface, without the complexity of orchestrating and managing ETL jobs in Spark.

4.4.4.3 Data analytics/Serverless query Engine

After streaming data is prepared for consumption by the stream processor, it must be analyzed to provide value. There are many different approaches to streaming data analytics. Here are some of the tools most commonly used for streaming data analytics.

Analytics Tool	Streaming Use Case	Example Setup
Amazon Athena	Distributed SQL engine	Streaming data is saved to S3. You can setup ad hoc SQL queries via the AWS Management Console, Athena runs them as serverless functions and returns results.
Amazon Redshift	Data warehouse	Amazon Kinesis Streaming Data Firehose can be used to save streaming data to Redshift. This enables near real-time analytics with BI tools and dashboard you have already integrated with Redshift.
Elasticsearch	Text search	Kafka Connect can be used to stream topics directly into Elasticsearch. If you use the Avro data format and a schema registry, Elasticsearch mappings with correct datatypes are created automatically. You can then perform rapid text search or analytics within Elasticsearch.
Cassandra	Low latency serving of streaming events to apps	Kafka streams can be processed and persisted to a Cassandra cluster. You can implement another Kafka instance that receives a stream of changes from Cassandra and serves them to applications for real time decision making.

4.4.4.4 Streaming data storage

With the advent of low cost storage technologies, most organizations today are storing their streaming event data. Here are several options for storing streaming data, and their pros and cons.

Streaming Data Storage Option	Pros	Cons
In a database or data warehouse—for example, PostgreSQL or Amazon Redshift	Easy SQL-based data analysis.	Hard to scale and manage. If cloud-based, storage is expensive.
In the message broker—for example, using Kafka persistent storage	Agile, no need to structure data into tables. Easy to set up, no additional components.	Data retention is an issue since Kafka storage is up to 10X more expensive compared to data lake storage. Kafka performance is best for reading recent (cached) data (cached).
In a data lake—for example, Amazon S3	Agile, no need to structure data into tables. Low cost storage.	High latency, makes real time analysis difficult. Difficult to perform SQL-based analysis.

A data lake is the most flexible and inexpensive option for storing event data, but it is often very technically involved to build and maintain one.

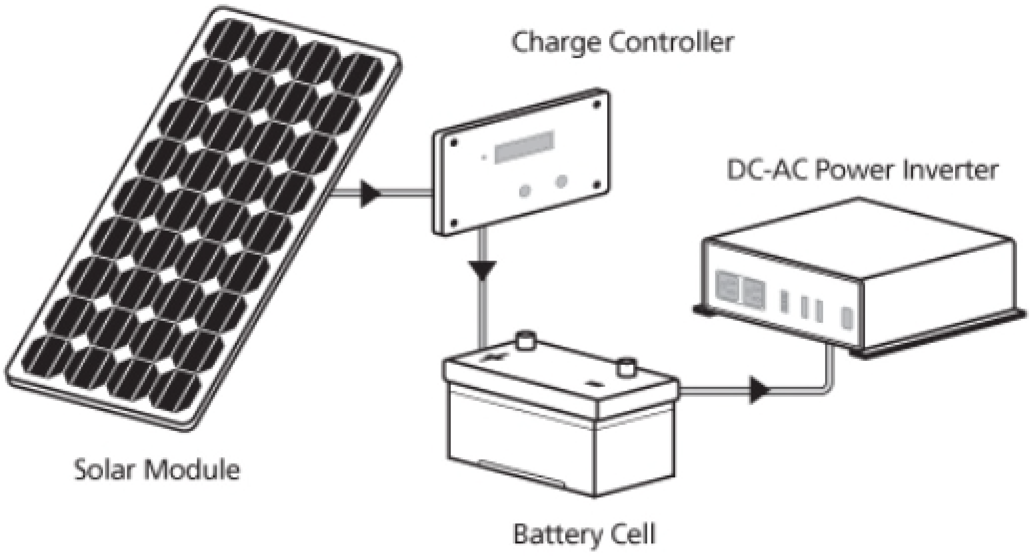
Upsolver's data lake ETL platform reduces time-to-value for data lake projects by automating stream ingestion, schema-on-read, and metadata extraction. This allows data consumers to easily prepare data for analytics tools and real time analytics.

4.5 Power

The A4R_MNG shall supply energy to the devices installed around the station. The energy wires could uses the scoring and perimeter trunking of the current infrastructure in order to segregation and access to the different devices.

If the area in which is required the installation of the measuring point is without an electrical supply, it is possible to add an off-grid PV system.

An off-grid system is not connected to the electricity grid and therefore requires battery storage. An off-grid solar system must be designed appropriately so that it will generate enough power throughout the year and have enough battery capacity to meet the home's requirements, even in the depths of winter when there is less sunlight.



4.6 Interface with external Systems

The system A4R_MNG could have a data interface with an asset management system so that the diagnosis results can be integrated in the overall asset management procedure. However, this is out of the project scope.

This project has received funding from the Shift2Rail Joint Undertaking under the European Union's Horizon 2020 research and innovation programme under grant agreement no. 826250 Assets4Rail).

5. Case study for field elements

5.1 Switch monitoring

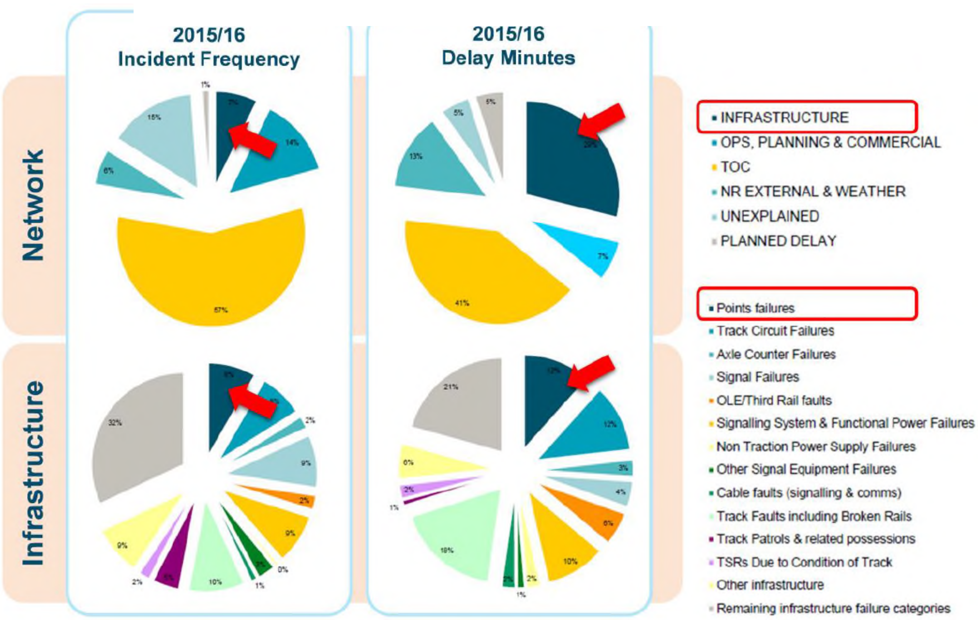
In this section, the switch monitoring is selected as a case study to draw the specifications of data acquisition for the further development.

5.1.1 Failure analysis of railway infrastructure

This subsection aims to assess failure rates, as well as maintenance effort and thereby costs, in Railway Infrastructure in order to identify critical components. Railway Infrastructure is divided into technical subsystems, including substructure, track, electrical system, signaling system, and telecom system. The following summarizes statistical data on Infrastructure failures found in scientific reports and papers.

Network Rail completed an analysis of all service affecting failures, occurring within a 12 month period from April 2015, with special respect to Points Operating Equipment (POE). Figure X gives an overview of the number of incidents occurring across each asset category and the corresponding number of delays attributed to those failures. While failures in Infrastructure asset amounted to only 7% of all incidents, they totaled 29% of all delays and associated costs. By breaking the Infrastructure category a level down, it can be seen that, outside of Track Faults, Points Failures have a significant impact on Network Service, with 12% of all delay minutes. In contrast to making up only 8% of all incidents, this is an indication that a single point failure can significantly influence network availability. Looking at the Mean Time Between Service Affecting Failure (MTBSAF) values for each of the major infrastructure subsystems, it is evident that POE is clearly

Figure - Network Rail (UK) Service Affecting Failures



underperforming, with only 4 years being achieved. The expected value is 6 years, whereas many assets score clearly higher (Coleman et al., 2016).

In a failure analysis made on switches and crossings (S&C) by Trafikverket (Sweden), the normal failure rate for S&C in Sweden is 1.0 – 1.1 failures/S&C/year, where faults attributed to point machines and heating systems dominate (Coleman et al., 2016). A study by the Norwegian University of Science and Technology (NTNU)https://www.ntnu.edu/ found, that in Sweden over 12% of track maintenance and 25% of track renewals are spent on S&Cs. The same study similarly showed, that Network Rail is also using about 17% of the track maintenance budget and 25% of the track renewal budget on S&Cs (Kassa and Skavhaug, 2018)

(Bemment et al., 2017) analysed data published by the United Kingdom's Office of Road and Rail on failure incidents in the financial years 2007-08 and 2011-12 in respect to cost and delay. An overview of their results is presented in Figure X. It can be observed, that faults in Track and Switches dominate the statistics in terms of financial costs and time delay.

	Cost		Delay minutes	
Asset type	(MGBP)	%	(1,000 s)	%
Track	131.9	19.2	3,977	18.8
Switches	121.1	17.6	3,874	18.3
Track circuits	99.5	14.5	3,208	15.2
Signalling system	95.2	13.9	2,727	12.9
Electrification	75.4	11.0	1,529	7.2
Signals	40.2	5.9	1,428	6.8
Cabling	37.4	5.4	1,013	4.8
Track TSRs	34.5	5.0	1,630	7.7
Axle counters	18.5	2.7	495	2.3
Level crossings	13.2	1.9	521	2.5
Other signalling	11.6	1.7	363	1.7
Telecoms	9.1	1.3	363	1.7
Totals	687.8		21,128	

In a field investigation of the Chenzhou West Station, as stated by (Bian et al., 2018), 30% of all signal equipment failures were found to be caused by faults related to point machines, with an average time of repairing the point machine of 23.4 minutes. This demonstrates the impact on the operation of railway and the necessity to detect faults in the point machine in time in order to improve operational efficiency.

5.1.2 Data acquisition from switches

From the maintenance point of view, inspection and maintenance of railway switch and crossing are bundled. The monitoring system should also cover the both, in order to reduce the overall maintenance efforts.

5.1.2.1 Railway switch & crossing

The European Standard EN13232-1 provides an accepted "terminology" for switch and crossing layouts.

The following list groups the most relevant components, as shown in Figure 3, and recalls their definitions:

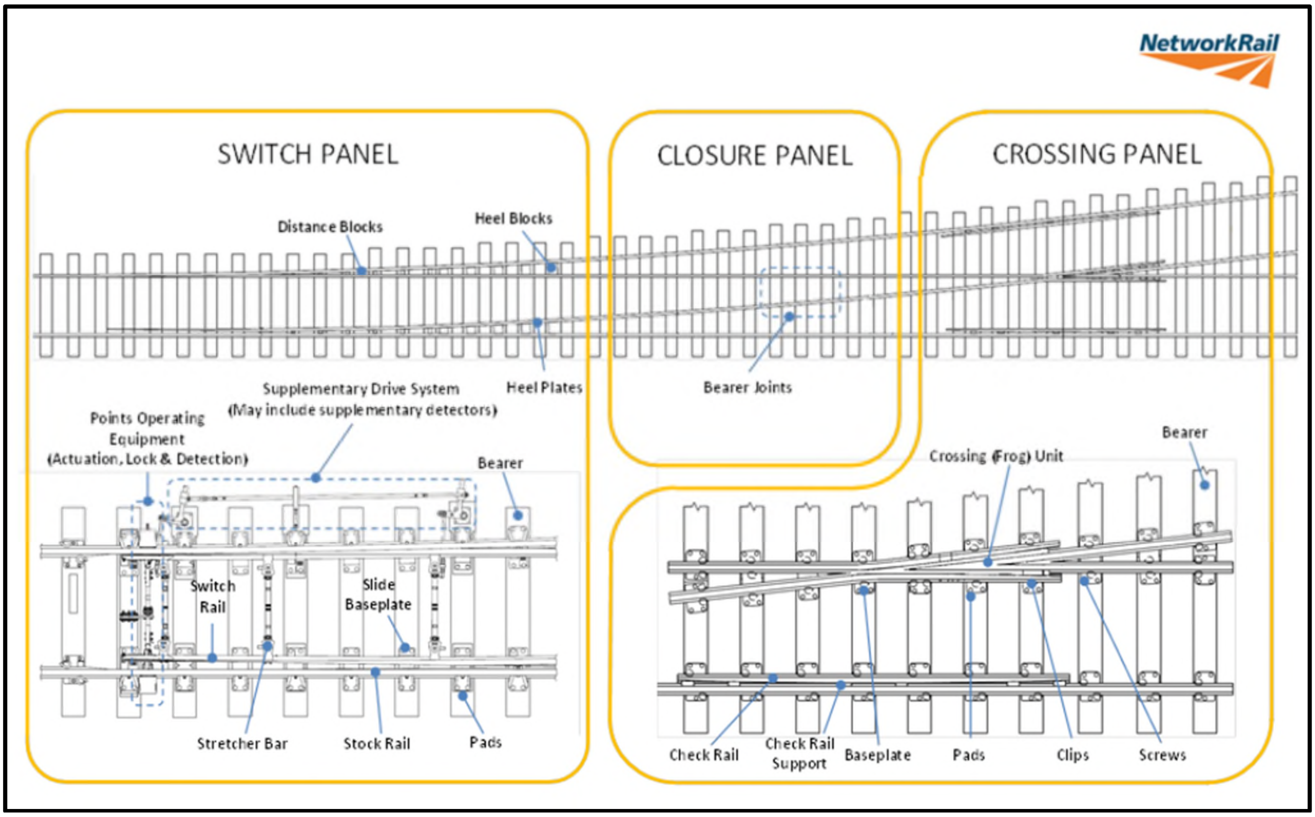


Figure 3 - Technical Picture of a switch

- **Points operating equipment – POE**

  The POE encompasses all components for moving and securing point blades, which includes actuation, detection and locking, for operating railway turnouts.

  - **Actuation devices**
  - **Locking elements**
  - **Detection**

- **Switch and stock rails**
  - **Switch Rail**
    Moveable machined rail, often of special section, but fixed and/or joined at the heel end to a rail to provide continuity of wheel support.
  - **Stock Rail**
    Fixed machined rail, ensuring the continuity on the main or diverging track with the switch in the open position.

- **Stretcher Bar**

Part joining the two switch rails of the same set of switches.

- **Check Rails**
  Special section bar ensuring (by guidance of the wheel) the safe passage of the axle opposite the neck gap of the common crossing.
- **Crossing (Frog) Unit**
  Arrangement ensuring the intersection of two opposite running edges of turnouts or diamond crossings and having one crossing vee and two wing rails.
- **Plates**
  - **Slide baseplate**
    Part which supports and retains the stock rail and a flat surface upon which the foot of the switch rail slides.
  - **Switch and crossing baseplate**
    Load distributing baseplate placed between the bearer and the feet of two or more rails.
- **Fastening Material**
- **Bearers**
  A turnout bearer is a special type of railway sleeper that is used to support the rail when mainline track 'turns-out' to form one or more diverging lines.
- **Ballast**
  Track ballast forms the trackbed upon which railroad ties (sleepers) are laid.
- **Relay**
  Signaling relay is the control element that transfers the control signals from the interlocking system to the electrical circuits of the point machine.

5.1.2.2 Common failure modes

Table 1 lists the critical failure modes for each S&C subsystem in terms of severity and frequency, based on the previous study in the IN2RAIL and IN2TRACK project.

Table 1 Common failure modes of the switches and crossings attributed to the subsystems (Coleman et al., 2016) (DENLEY et al., 2018)

Component	Failure Mode
POE - Actuation devices	Backdrive mechanism failure including out-of-adjustment, loose and worn components
POE - Actuation devices	Point motor failure including false adjustment of clutch, springs and incorrectly setup components
POE - Actuation devices	Points failing to move
POE - Detection	Incorrect detection assembly
POE - Detection	Points failing to detect
POE - Detection	Supplementary detection failure

POE - Locking elements	Clamplock mechanism failure
POE - Locking elements	Locking mechanism failure
POE – Heating system	Heating system fails to heat
Switch and stock rails	Sideworn stock rail associated with little used switch
Switch and stock rails	Stock rail and switch rail both sideworn
Switch and stock rails	Stock rail headwear associated with a less head worn switch rai
Switch and stock rails	Switch rail damage
Switch and stock rails	Switch rail with a sharp gauge corner profile
Switch and stock rails	Rail defect through the machined length of the switch blade
Switch and stock rails	Rolling Contact Fatigue (RCF) through machined length of switch rai
Switch and stock rails	Lipping on switch and stock rail
Switch and stock rails	Spalling of stock rail
Switch and stock rails	Soft spots in the running surface
Switch and stock rails	Non-compliance of narrowest flangeway (residual switch opening)
Switch and stock rails	Incorrect lateral attachement of switch rail
Switch and stock rails	Debris in switch flangeway
Crossing (frog) unit	Deformation of crossing nose and wear of wing rail due to wheel impact/contact (Cast)
Crossing (frog) unit	Deformation of crossing nose and wear of wing rail due to wheel impact/contact (Fabricated and part fabricated)
Crossing (frog) unit	Cracks in cast crossings from defects or damage
Crossing (frog) unit	Tri-metal weld defect
Crossing (frog) unit	Wear/damage to newly installed cast crossing
Crossing (frog) unit	Debris in crossing flangeway
Crossing (frog) unit	Cast crossing defects due to squats, wheelburns, batter, flaking/shelling, metal breaking out of wheel transfer area
Check Rails	Excessive wear on check rails
Stretcher bar	Cracked/broken stretcher bar, bracket or gooseneck (fixed stretcher bar
Stretcher bar	Cracked/fractured/broken stretcher bar or bracket (adjustable stretcher bar)
Baseplates	Break of plates
Slide plates	Switch roller seizes
Slide plates	Contamination / Excessive wear of slide plates
Slide plates	Slide plate insert (pin) failure

Fastening Material	Break / Loosening of fastening elements
Fastening Material	Broken bolts / screws
Fastening Material	Broken fishplate
Bearers	Rotten / broken timber bearers
Bearers	Cracked / broken concrete bearers
Bearers	Warped / twisted (crippled) bearer
Bearers	Misaligned bearers
Bearers	Worn gauge stop
Ballast	Ballast degradation under switches

IN2Rail D2.1 (Coleman et al., 2016) analysed the failure distribution for point machine. It was found that the largest contribution to total failures at Network Rail comes from the backdrive mechanism (POE actuation), drive components (POE actuation), motor and actuator (POE actuation), detection components (POE - Detection), baseplates and signaling relays, while the failures from POE actuation, detection system and heating system dominate the overall failures of S&C at Trafikverket.

IN2TRACK D2.1 (DENLEY et al., 2018) carried out FMECA analysis on S&C and found that the most critical failure modes are deformation, crack and wear of crossing(frog) unit, rolling contact fatigue (RCF) and sideworn of switch rail

5.1.2.3 Existing data acquisition methods

C4R D1.3.1 lists the failure catalogue of S&C and the corresponding measurement methods for each failure mode. In the current inspection routine, most failures are examined by visual inspection. The wear of the profile is measured by track geometry coaches or measurement trolleys. In the modern point machines, there are self-diagnostics module measuring current and voltage. The interlocking system contains the information of operation duration of the point machines. However, the most existing conventional point machines and interlocking systems cannot provide any digital data for diagnosis. Additional sensors are required for data acquisition. IN2TRACK D2.3 splited the S&C measurements into three monitoring categories (Turner et al., 2019):

- During switch movement
- During train passage, either from trackside or on-board sensors
- Environmental conditions when an event happens (train passage or switch movement)

Switch movement	
Measurement	Data acquisition methods
Switch duration (time)	The duration of a throw can be determined from most sensor measurements that detect the start and end of a point machine being activated. It can also be determined based on the signalling relay switch on/off times. Since a lot of infrastructure operators monitor their relay switch times, it is possible to use just this for the simplest and cheapest form of monitoring. Some faults can be detected from increased movement time and jitter in the movement duration.
Current	Current can be monitored in-line by measuring a voltage across a resistance or using a non-

	contact current transducer such as the LEM PCM 30-P. Current is proportional to force but can only give us relative force change based on the effort of the motor and not static force.
Voltage	Voltage can be non-invasively measured by e.g. a LEM AV100-500 sensor. Voltage can be used to identify power supply problems and detect increased resistance in mechanical switching contacts when the machine is not moving.
Force	The driving force can be measured by a load pin, being fitted to replace a pin in the drive assembly or strain gauges around the switch to determine the stresses experiences by different parts of the S&C during points movement and train passage. Unlike current and pressure which are used to drive the movement, such sensors can tell us the static force when the machine is locked rather than just the change in force.
Displacement	The displacement can be estimated from the current or directly measured by displacement transducer. The displacement indicates if the switch rail is in the right position.
Train Passage	
Acceleration	Acceleration can be measured by accelerometer. It indicates the dynamic response of the structure, such as sleeper, ballast and crossing nose, and can be used for abnormality detection and detection of the specific failures.
Noise	Noise can be structure-borne noise which is measured by accelerometers or acoustic emission sensors. Noise can also be air-borne noise which is measured by microphone. Noise is similar as acceleration, indicating the dynamic response of the structure.
Environmental conditions	
Temperature and humidity	Temperature and humidity can be measured by Temperature and humidity sensors. Since the aforementioned measurements could be affected by season and weather. The Temperature and humidity could be used to compensate for season and weather.

It is essential to understand the characteristics of the measurements under the specific failure modes in order to choose the proper parameters for diagnosis and prognosis of the specific failure modes. Asada (2013) proposed the monitoring solutions for overdriving/underdriving of the driver rod (belonging to POE actuation). This failure results in out-of-adjustment in Table 1. The drive force, the electrical current and voltage were collected for diagnosis. Silmon (2009) measured the current, force and displacement to detect the misadjustment of the backdrive and overdriving of the driver rod (belonging to POE actuation). Lee et al. (2016) used microphone measurements for diagnosis of obstruction issues, such as ice obstruction, ballast obstruction and slackened nut.

The data acquisition is triggered by the event. In this case, the measured parameters in the category of "Switch movement" is triggered by switch movement. The measurement should last the entire operation. It is desired to send all of raw data to the central back-office to collect as much as possible data, ensuring the robustness and the continuous improvement of the developed data processing algorithms. However, it takes more resources to transmit, store and process data. Alternatively, edge computing could be applied to extract the most important information from the raw data and send back only the extracted information. This takes less resources, but does not allow update and improvement of the developed data processing algorithms.

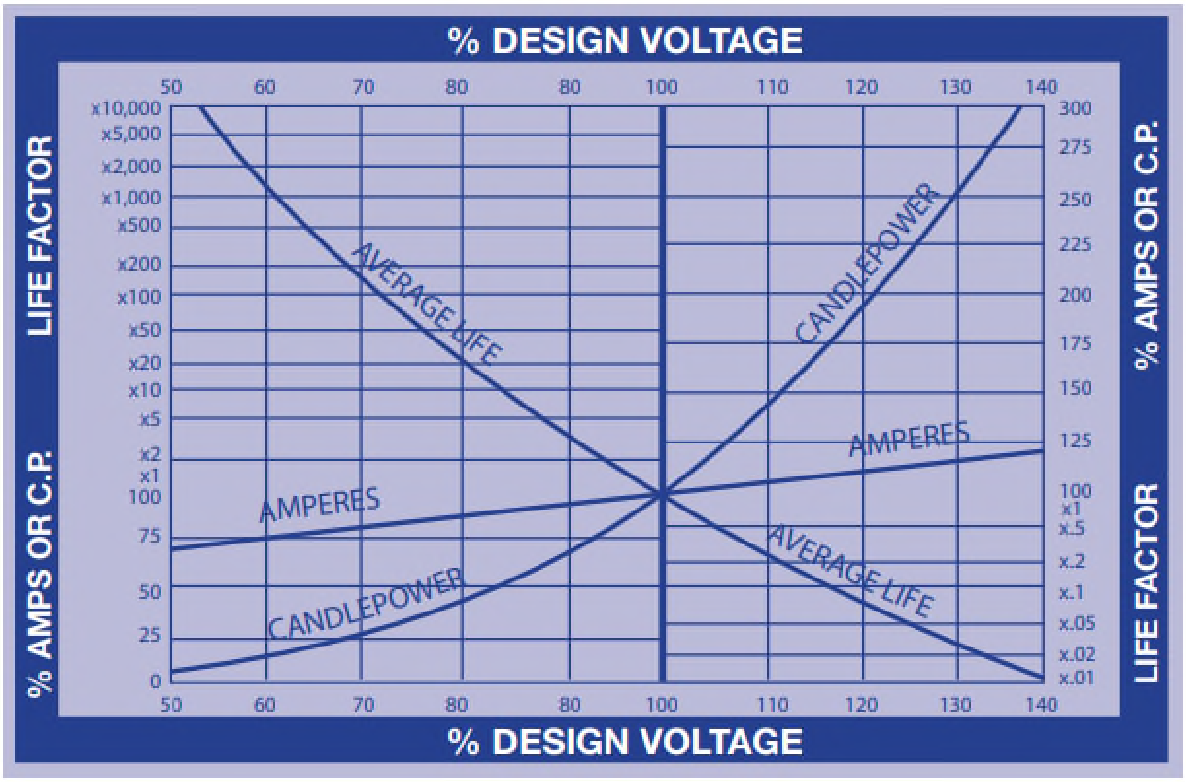
5.2 Light signal monitoring

In this section, the light signal monitoring is selected as a case study to draw the specifications of data acquisition for the further development. The developed system is modular and can be adapted to any other field elements.

5.2.1 Failure analysis of railway infrastructure

The major causes of failure in the light signals are the following:

- Corrosion: Water, dirt, salt and any other contaminants can enter a lamp or connector, providing an electrical path, which can vastly accelerate corrosion.
- Shock, Vibration and burnout.
- Inadequate wiring: Wire size or gauge is very important. The use of a wire gauge too small can cause dim or intermittent operation or excessive voltage drop and presents a potential fire hazard.
- Excess voltage.
- Poor grounding.



5.2.2 Data acquisition from light signals

The main values monitored are:

- Peak and average current consumption.

- Peak and average voltage.
- Frequency.
- Inductance.
- Reactive and active power
- Temperature.
- Humidity.

The light signals have different functionality depend on the time of the day. During the night, the light emitted is less than during the day (around 35%).

5.3 Train detection assets monitoring

In this section, the train detection devices monitoring is selected as a case study to draw the specifications of data acquisition for the further development. The developed system is modular and can be adapted to any other field elements.

5.3.1 Failure analysis of railway infrastructure

A track circuit failure can delay trains because the signalling system is designed to fail to a safe state. Normally, a failed track circuit will act as if a train is present. This results in delays because the system can only allow train movements when it knows it is safe to do so – when the track ahead is clear of other trains.

Potential causes of failures include a broken rail, a blown fuse, faulty electrical parts, cable theft, or a loose connection, all of which form a break in the track circuit.

Meanwhile, flooding, contaminated ballast, or other problems with insulation between the rails can bypass the circuit; crushed leaves or ice on the rails can form an insulating layer that makes the circuit unreliable.

A failure is an (unwanted) event on a technology-based system that compromises its ability to operate correctly.

A track circuit is a safety-critical asset; therefore, it is designed to be fail-safe.

A fail-safe in engineering is a design feature or practice that in the event of a specific type of failure, inherently responds in a way that will minimize or eliminate the possibility of harm to other equipment, the environment, or to people.

This means that a failure in a track circuit will result in it being shown as occupied, regardless of whether or not this is actually the case, as the status of the block in question is uncertain. This has a significant impact on track availability and day-to-day operations.

Given the gravity of a track circuit failure, the next question is: how often does it fail?

Track Circuit	Number	Failures per year	Failure rate	Delay impact (min)
AC TC	3643	1264	0.347	158000
TI21	1326	524	0.395	65500
FS2600	528	241	0.456	30125
HVI TC	952	390	0.410	48750
Reed TC	1895	1304	0.668	163000
Overall	8344	3723	0.446	465375

According to a recent study "Condition Monitoring of Audio Frequency Track Circuits -" by the University of Railway Engineering of Birmingham, there are nearly 80,000 track circuits in operation on the mainline railway network within the UK. Table shows the number of track circuits installed in Network Rail's Southern Zone together with typical failure statistics.

The average failure rate is around 45% per year per installation, and any track circuit failure can cause significant disruption to rail services.

Over 12,000 track circuit failures were reported in the UK during one operational year, resulting in 1.5 million minutes of delay. Typically, the infrastructure operators are penalized by £20– £60 per delay minute arising from infrastructure failure, but in the case of a heavily used network section, this can go up to £250 per delay minute.

Therefore, the ability to detect and diagnose track circuit failures to provide a fast response to failures/incidents has a significant economic benefit.

The following failure examples can be critical either in terms of availability and/or safety:

- Shunt failure: A Shunt Failure (safety critical) occurs when the short circuit current cannot be measured correctly; therefore, the device is not able to perform its main function. This type of failure might occur for a number of different reasons. For example, a broken or oxidized rail, or a failure in transverse impedances (for TC equipped with electrical joints) are among some of the most frequent causes of shunt failure.
- Frequency Drift: Frequency drifting is an unintended and generally arbitrary offset of an oscillator from its nominal frequency, due to component aging, changes in temperature, or problems with the voltage transmitter. It is a common problem in AC Audio Frequency track circuits, since it impairs the correct operation of all frequency tuned elements, creating track availability issues.
- Leaking Electrical Joints (Tuning units): In the case of jointless AC track circuits, one of the most common failures takes place in electrical joint components, such as the LC tuned passive components which are affected by drifting capacitance. The tuned LC components fail to properly filter and separate adjacent frequencies from the side segment, producing a leak (also known as longitudinal crosstalk) from one track circuit segment to another. This can severely impair the correct detection of the train, causing the segment to look occupied when it is not.

5.3.2 Data acquisition from train detection assets

Remote Condition Monitoring (RCM) is the process of monitoring a number of parameters in a device, in order to identify any significant changes which may indicate that a fault is developing.

In the case of track circuits, a common form of RCM is to constantly measure the current levels at the track circuit receiver for free and occupied segments. Unfortunately, this cannot guarantee a preventative approach, because the relationship between the Track Circuit parameters along the track and the current value at the receiver and transmitter ends is not linear. This means that they are not good indicators of a potential failure.

To be defined as comprehensive and effective, each measurement session should be able to detect and assess the quality of the following parameters:

- Icc (shunt current) levels for each relevant frequency
- Transversal elements (electrical joints)
- Compensating capacitors, if present, along the track
- Data transmission modulation and verification for both pointwise and continuously transmitted data.

5.4 Level crossings monitoring

In this section, the level crossings monitoring is selected as a case study to draw the specifications of data acquisition for the further development. The developed system is modular and can be adapted to any other field elements.

5.4.1 Failure analysis of railway infrastructure

The major causes of failure in the level crossings are the following:

- Power supply is out of limits for correct operation.
- Lights
- audible alert
- gate and boom arm emergency switches
- Battery voltage health indication

5.4.2 Data acquisition from level crossings

Level crossing monitoring systems detect and record the condition of a level crossing, typically those fitted with protections and warnings for vehicular and/or pedestrian traffic. This includes traffic booms and/or pedestrian gates, with visible and audible alerts.

Level crossing monitoring systems (hereafter referred to as the monitoring system) are deployed to comply with safety integrity requirements, or to support improved maintenance practices.

A monitoring system is used to comply with safety integrity requirements at actively controlled level crossings, by monitoring and recording the status of various components of the level crossing. The monitoring system may also be used for maintenance purposes.

Remote monitoring of level crossing status and live reporting of failure conditions should be provided, where it is reasonably practicable to implement a communications link.

As a minimum, a level crossing monitoring system shall monitor and record:

- operation of the level crossing;
- availability of primary power supply;
- primary power supply or battery voltage:

- timing and operation of visual and audible alerts and, where applicable, boom barriers and/or pedestrian gates;
- train detection systems and associated circuitry;
- controls that operate, override or test the level crossing system.

The monitoring system should have a facility to prevent false alarms being raised during maintenance tasks (also known as maintenance mode).

The monitoring system may include (but is not limited to) any of the following:

- Level crossing monitoring and communications hardware.
- Level crossing power supply and battery system.
- Level crossing obstruction detection system.
- Monitoring location system, e.g. GPS.
- Wayside monitoring systems.
- Environmental monitoring, e.g. temperature, rainfall, rock slip, etc.

Level crossings may also be remotely monitored via Closed-Circuit Television (CCTV) cameras. CCTV can be a component of the monitoring system or an independent system.

Digital Inputs:

The following non-exhaustive list is the types of digital inputs:

- Train detection systems and associated circuitry.
- The level crossing control and repeat relays.
- Test switch.
- Door switch.
- Gate and boom arm state.
- Lights, audible alert, gate and boom arm emergency switches.
- Power supply state indication.
- Battery voltage health indication.
- Any other function that qualifies the operation of the Level Crossing (for example approach signals).
- Audible alert state.
- Reset fault or warning.
- Output state of each flasher.
- Other relays/contacts of interest.

- Other wayside monitoring peripherals.

Analog inputs:

The functionality of the analogue inputs may include:

- battery and/or power supply monitoring;
- lamp driver/flasher unit correct operation;
- individual lamp health; and
- audible alert monitoring;

6. Conclusions

This deliverable described the overall concept of the data collection from the fail-safe systems which refers to the railway signaling and control systems. Based on the fact that the base element of a railway signaling system is the interlocking system. For one region, there is one interlocking system, controlling the distributed field elements. Therefore, a high-level architecture of the data collection system The A4R_SYSTEM has been designed for the interlocking system. The A4R_SYSTEM creates a network of capture and concentration of data to be analyzed. The data could be potentially collected from the interlocking system, technical rooms and diverse field elements.

The core elements of A4R_SYSTEM are the data acquisition nodes. In principle, there are two ways of data acquisition. The first is to directly read the existing data from the target systems, in case that the target systems are digitalized and have data interface. For the EULYNX compliant interlocking systems and field elements, all data processed and stored together with the outputs are shown in the maintenance support system of each interlocking. This system shows all the main data values, alarms, processor logs, debug logs. The maintenance assistance systems have different protocols depending on each technologist, so it is necessary to define a standard protocol ensuring the interoperability.

Although EULYNX was proposed for standardizing signaling systems, the majority of the existing interlocking systems are not compliant with EULYNX. For the traditional mechanical and relay based interlocking systems, additional sensors are required. Therefore, the second way is to measure the parameters by adding sensors. Depending on the target systems, the sensors could be installed in the technical rooms and/or directly on the field elements. Several case studies are performed to figure out the common failure modes of the field elements and the measurement methods for key parameters:

- Switches (incl. point machine): current, voltage, force, displacement, accelerations, noise and switch duration, temperature and humidity.
- Light signals: current, voltage, inductance, frequency, power, temperature and humidity
- Train detection (track circuit): shunt current levels for each relevant frequency, transversal elements (electrical joints) and compensating capacitors
- Level crossing: control and repeat relays, test switch, door switch, gate and boom arm state, lights, audible alert; gate and boom arm emergency switches; power supply state; battery voltage; reset fault or warning, output state of each flasher; other relays/contacts of interest; battery and/or power supply monitoring; lamp driver/flasher unit correct operation; individual lamp health;

The data acquisition can be triggered by the event, i.e. either an operation action or a train passage. After measurements, the data could be either processed on site or directly transmitted. It depends on the design of the diagnostic system and the restriction of power supply and communication facilities.

Since the difference of the existing interlocking systems, it is recommended to identify a specific interlocking system and a specific field element for the further development of the data acquisition nodes and the diagnostic algorithm. The data acquisition node should also be a modular system and easily adapted to different field elements to be monitored by replacing sensors.

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