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Deliverable D 3.1
Assessment of Available Technologies

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Table of Contents

1. Executive Summary

The deliverable gives the retained strategy concerning the measured behaviour of the locomotive. It gives also a first block chain of the flux of data the project will need to deal with.

It also presents the selection of available technologies concerning this part of LOCATE project. Thanks to the division of measurement campaign in two parts, an evaluation of the retained technologies will be done before the long-term measurements.

2. Abbreviations and acronyms

Abbreviation / Acronyms	Description
CBM	Condition Based Monitoring
MVB	Multifunctional Vehicle Bus
IMU	Inertial Measurement Unit
CAN	Controller Area Network
EMC	Electromagnetic Compatibility
OBU	OnBoard Unit
MEMS	MicroElectroMechanical System
ERP	Enterprise Resource Planning
MES	Manufacturing Execution System

3. Background

The present document constitutes the Deliverable D3.1 "Assessment of Available Technologies" in the framework of the WP3 – Measured Behaviour.

It does not contribute any TD/WA.

The assumptions made in this document are based on the work of previous tasks of WP2 – Requirements and Specifications, namely the results provided in deliverables D2.1 Use Case Description, D2.3 FMECA Analysis and D2.4 Requirements and Architecture Specification.

4. Objectives / aims

Based on the use cases defined in deliverable D2.1 and validated in subsequent tasks of WP2, the building blocks of the measurement chain available to partners will be assessed in this task: sensors, signal acquisition hardware, data transfer and post-processing infrastructure, maintenance software, etc. The specific focus will be to plan the required work to link the building blocks in a seamless workflow, and to assess the robustness of the hardware to be installed with respect to freight rail operation.

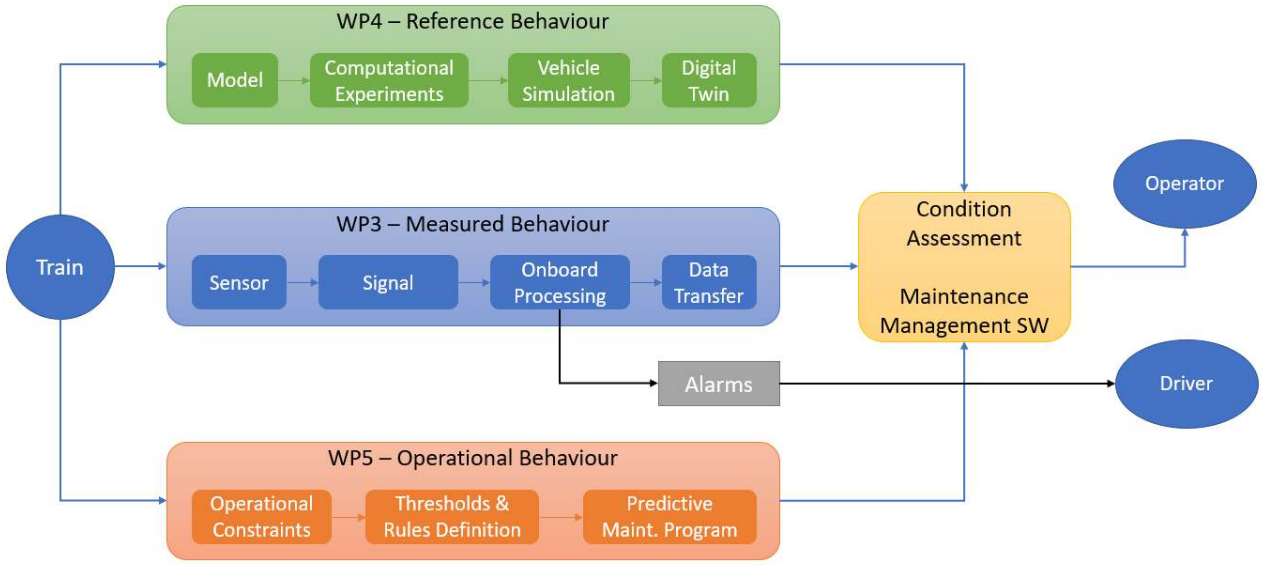


Figure 1 : Signal and information workflow from train to operator

5. Measurement architecture

Deliverable D2.4 defined the LOCATE use cases, architectures, and requirements. The retained architecture is based on the following diagram in Figure 2. It is composed of:

- OBU inside the cabin or inside the control system if available
- Conditioning system outside the cabin or closed to the control system
- Analog sensors on the sub systems

Looking at the diagram resume the retained approach for the demonstrator regarding the environmental constraints and configuration of the locomotive.
It also helps in understanding the approach on locate project for the demonstrator. Indeed, the demonstrator will focus on only one of the two bogies.

Without any available vehicle bus, the general statement of the vehicle will not be known (torque, vehicle speed, engine temperature...). To deal with this lack of data, the measuring system must also bring this missing information using GPS, tachometer, temperature probes and intensity probe.

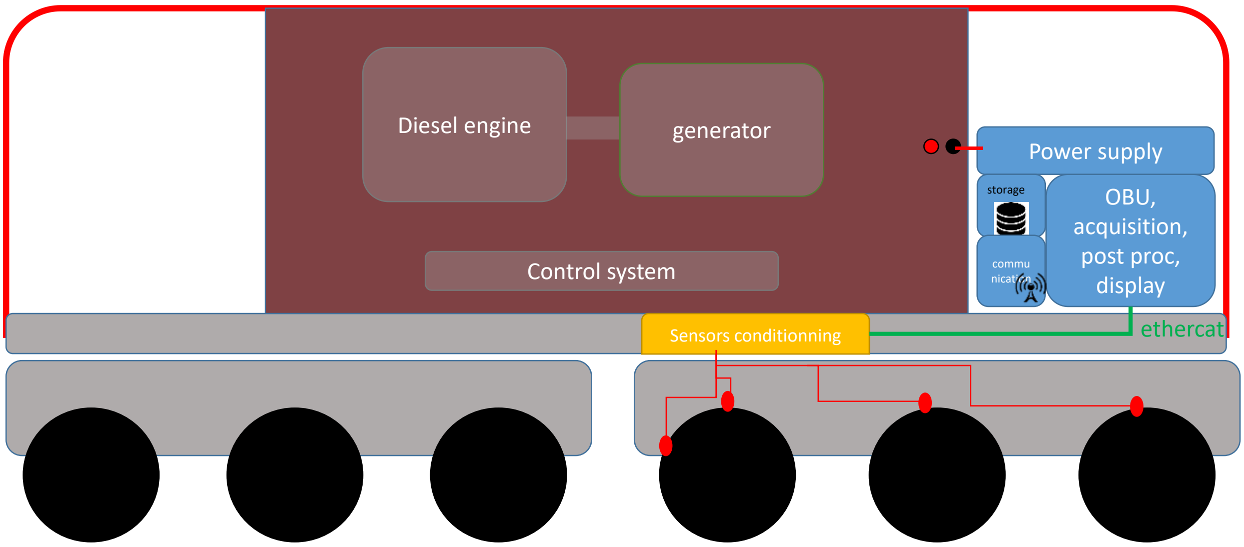


Figure 2 : Overview of the measurement architecture

Due to the fact that the system is on the locomotive, there is no problem concerning power supply and no need in terms of energy harvesting.
The typical architecture for new generation of locomotive should be to install the sensor conditioning and OBU into the control system cabin.

For the demonstrator, because the locomotive is an old generation and there is not an important control system, the OBU will take place inside the driver cabin and sensors conditioning outside on the frame of the locomotive.
This configuration is interesting to evaluate to be able to retrofit the entire locomotive fleet of an operator with a maximum of flexibility.

The measurement campaigns will be divided in two main parts:

Part 1: Measurement for diagnosis and digital twin set-up

Consists of a first short duration measurement campaign (one week) to analysis the dynamic behavior of the locomotive and have a global overview of the track condition. This will support the development of suitable models (digital twins) during WP4 and the evaluation of the best sensors and set-up for the long-term measurement campaign (part 2).

Part 2: Measurement for CBM demonstration

A long terms measurement campaign (several months) that will be correlated to digital twins and OBU to demonstrates the approach implemented in the LOCATE project.

5.1. Signal and information workflow

Based on other Shift2Rail projects and regarding the important offers in terms of industrial solutions, the strategy is to use an agile solution in order to put most of our effort on the methodology rather than the hardware development.
LOCATE main goal is to be able to give recommendations and methodologies on each block of the following diagram. The scope of work for this deliverable is focused on the Measured Behaviour block (WP3).

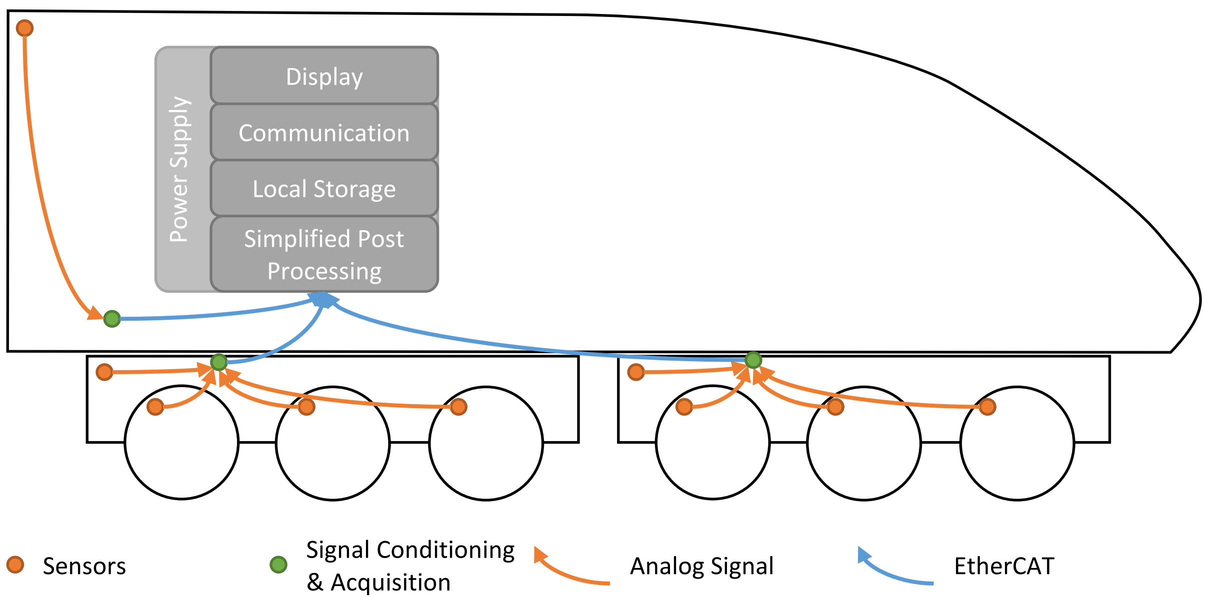


Figure 3 : Signal and information workflow from train to operator and Server

A diagram of the WP3 – measured behaviour block and it's interconnections is presented in Figure 4. It can be seen that the sensor choice and signal quality will be key points to success. The block will also have to post-process the time signal and to interpret the reduced data using numerical twin in a light version in order to send the most informative reduced data to the maintenance software. At this stage of the project the definition of the numerical twin is not clear enough to list some requirements, the maintenance software and strategy is also not already defined. The deliverable will focus mainly on the definition of the sensors, the data acquisition system, and the on-board unit to post-process the data.

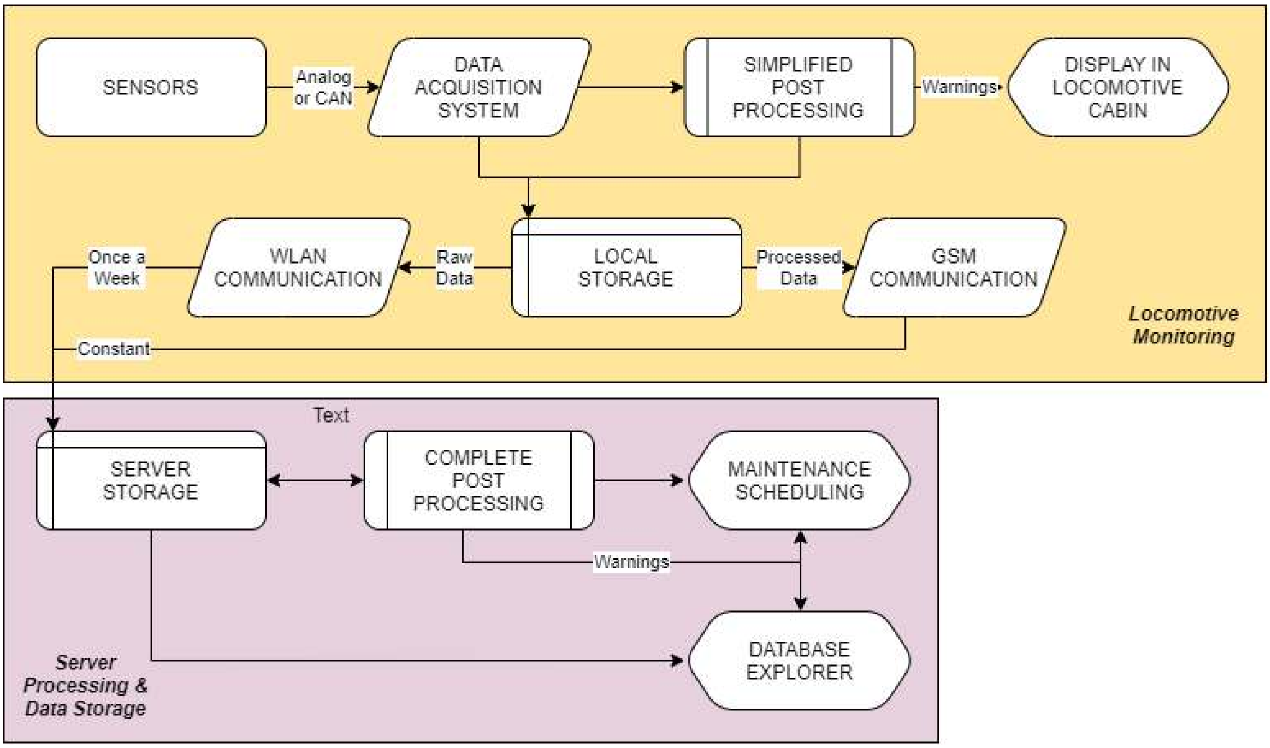


Figure 4 : Diagram of measured behaviour block

6. Assessment of available technologies

Typically, the necessary technologies to monitor the condition of the bogie and associated components/subsystem already exist and are mature. Therefore, the LOCATE project is mainly based on the use of existing technologies in order to focus on the application methods and modelling.
Another part of locate project is to be able to give recommendations regarding the signal quality to reach using feedbacks from the measurement campaigns.
Indeed, most of the digital twin's approaches and methods are developed using only numerical simulations. One major contribution of LOCATE project will be to evaluate some methods using real signal measured on an operational locomotive in a commercial service.

Because it exists several technologies and a wide range of sensor price for measuring the same physical quantity, it is important to be able to evaluate it impact on post processed values.

6.1. Sensors

An overview of the proposed instrumentation is given in Figure 5.

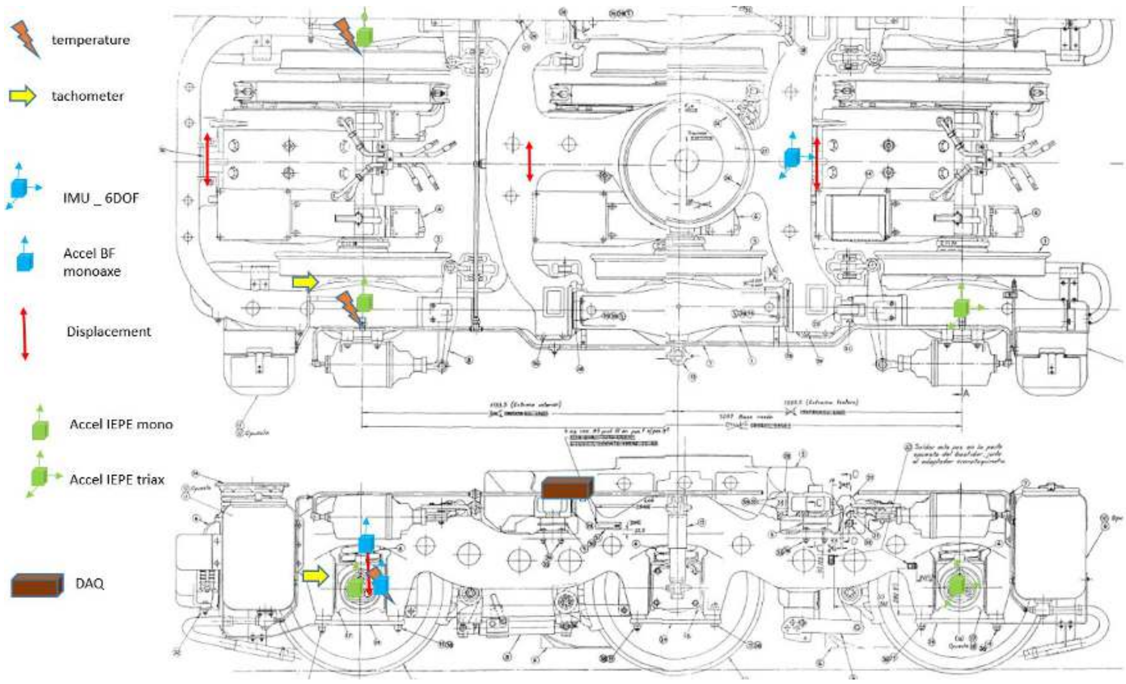


Figure 5 : Overview of the instrumentation for the two measurement campaigns

Regarding the state of art in terms of CBM of railway bogie, most of the methods for the selected use cases are based on accelerometers signal and displacement sensors to monitor the dynamic motion of the bogie. LOCATE project will use most of these different technologies and methods to take stock of all existing methods.

The selected sensors technologies will be:

1. High frequency accelerometers based on piezo-electric technology (10kHz)
2. Low frequency accelerometers based on MEMS technologies (0-20Hz)
3. Displacement sensor
4. Inertial measurement Unit
5. Temperature probes
6. GPS
7. Tachometers
8. DC current clamps

A summary of the proposed sensor technology and parameters for each of the selected use cases is provided in Table 1.

Table 1: Summary of Selected Sensor Technology and Use Cases

Sensor Technology	**Parameter**	**Use Cases**					
		Wheelset	**Axle**	**Braking System**	**Suspension Components**	**Bogie Frame**	**Traction Motor**
Accelerometer	Acceleration	X	X		X	X	
Displacement Sensor	Displacement				X		
Inertial Measurement Unit		X			X	X	
Temperature Probe	Temperature			X			
DC Current Clamps	Current						X
Tachometer	Speed	Location identification and model inputs					
GPS	Longitude / Latitude						

A presentation of the most critical sensors technologies is provided in the following sections.

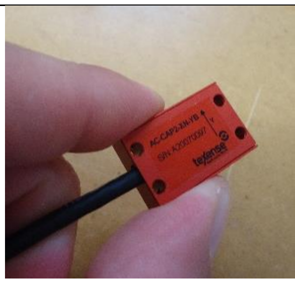
6.1.1. Low frequency accelerometers

Low frequency accelerometers are based on capacitive or MEMS technology.
The useful bandwidth is 0-20Hz to observe dynamic motion of the locomotive.
A wide variety of products exist on the market and the LOCATE project provides a good opportunity to evaluate the relationship between cost and signal quality under the harsh environment which they will be subjected to on the bogie of a locomotive transporting Potash in Catalonia.
The retained strategy is to use three types of sensors:

1. High cost sensor from well-known company
2. Mid cost sensor habitually used in automotive and aeronautic industry
3. Low cost sensor habitually used for smartphones and drones.

The retained sensors are the following: PCB 3741F, Texense AC-CAP1-X and Analog Device ADXL335.The cost is from 750 to 14€. Frequency band of interest, sensitivity to high frequency vibration and drift due to temperature are subjects to influence the signal quality and provide deviation on indicators. We should be able to provide recommendations to choose the correct ratio between signal quality and cost at the end of the LOCATE project.

Type	Selected sensor	Picture / dimensions
LOW COST	ADXL335 MEMS technology 550mV/g +/-3g DC to 50Hz (-3dB @50Hz)	 Dim: 19*19*3 mm 2grams

MID COST	Texense AC-CAP1-X Capacitive technology IP66 Aluminium housing DC to 50 Hz (-6dB @100Hz) 400mV/g +/-5g	 Dim: 25*16*8 mm 15grams
HIGH COST	PCB 3741F Capacitive technology Aluminium housing DC to 1000Hz From +/-10g to +/- 100g	 Dim :25*21*7mm 10grams

6.1.2. Displacement sensors

There are several technologies to measure displacement that can be grouped into two main families:

1. Contact: potentiometric or incremental encoders
2. Non-contact: based on magnetic field or optical technology.

Contact technology is more robust and less subject to be affected by the electromagnetic field generated by the electrical engines of the locomotive. But it is less robust considering the environment.
Non-contact technology is interesting due to its robustness to harsh environment, but it is suited for small distances (1 to 10 mm) and electromagnetic field can disturb the signal. On the opposite optical technology is good for mid distances and not disturbed by electromagnetic field but is not recommended for railway due to the presence of dust.
For the first measurement campaign different sensor technology will be tested to choose the best technology for the longer-term measurement campaign.
The following sensors technology will be evaluated using the Vibratec equipment:

1. Potentiometric,
2. Magnetic field

Figure 6 : Potentiometric displacement sensor (wire or cylinder body)

6.1.3. Tachometer

Due to environmental conditions usually observed on the railway, the tachometer will be based on magnetic technologies. The chosen tachometer is a variable reluctance or a Hall Effect sensor with a magnet glued on the wheel. These technologies allow an important sensing distance and is not sensitive to dust. The retained sensors are BAUMER (IHRM_12P1501_KS34P type) and MESUREX (CI 107 03 MA MX).

Figure 7 : Typical magnetic tachometer

6.1.4. IMU

The IMU is a 6-axis sensor. It allows to measure the 6 degrees of freedom using 3 accelerometers and 3 gyroscopes in only one measuring point. This type of sensor is well suited for dynamic motion evaluation. It is not usually used in railway applications and it is interesting to add into LOCATE project to enlarge the available technologies for dynamic motion measurement. The retained sensor is the IB-6 CAN from Texense. Another interesting part of this sensor is that time signal date is digitized directly on the sensor and a CAN protocol is used to transfer the data. CAN protocol is an automotive standard and LOCATE project will allow to evaluate this standard on railway application.

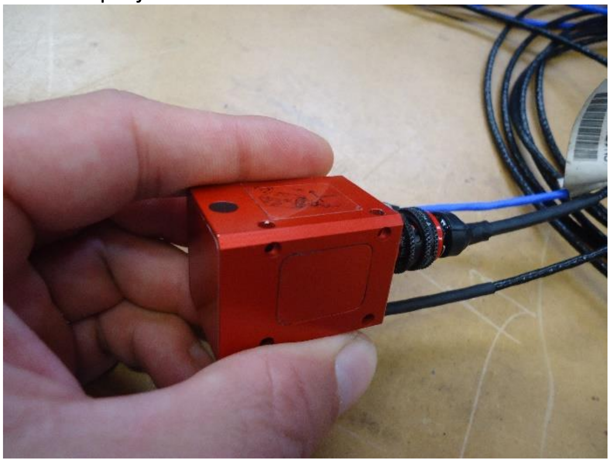


Figure 8 : IMU (numerical output using CAN BUS)

6.1.5. High frequency accelerometers

High frequency accelerometers are already used for different methodologies (like the well-known Axle Box Acceleration method) and is a robust technology. These sensors are based on piezo-electric technology. The retained sensor will be PCB 356A02 which is a tri-axial IEPE accelerometer and PCB 352C03 which is a

mono-axial IEPE accelerometer.
These accelerometers have a nominal sensitivity of 10mV/g and useful frequency range from 0.5Hz to 6kHz.
They are hermetically sealed and can resist to important temperature shift from -54°C to 121 °C.
These sensors will be glued using bi-component glue like epoxy.
A view of a PCB 356A02 glued on an axle box is given in Figure 8 .

Figure 9 : High frequency tri axial accelerometer (PCB 356A02) on an axle box

6.1.6. Temperature probes

The temperature will be measured using thermocouple probes. These temperature probes are based on thermocouple K type which are the most common type of thermocouple (Nickel-Chrome/nickel alloy) that are precise, flexible and easy to install. It exists a wide variety of dimensions.
The sensors will be conditioned using a THNX4 conditioner from Texense that directly convert analog signal to digital signal using CAN bus interface. It is a cheap way to measure temperature.

6.1.7. Current clamp

For the first measurement campaign one VIBRATEC current clamp will be installed. It is a Chauvin-Arnoux PAC22 type to measure DC current from 0 to 1400 A maximum.

6.2. Data acquisition system

Following the requirements specified in deliverable D2.4, several data acquisition systems were evaluated mainly on multi-conditioning ability, ergonomic, easiness to configure and mainly robustness considering the environment. Gantner, HBM, IMC, NI and DEWESOFT were evaluated. The most versatile and ergonomic compared to price is Dewesoft Krypton. It allows multi sample rates and
It allows also to implement Python or C++ post processing module and native data can be read directly under Matlab and LabVIEW platforms.

Figure 10 : Retained DAQ system for LOCATE project (Krypton device from Dewesoft)

6.3. Post processing

Time signal processing will be based on statistical functions, spectral analysis, wavelet, cross-correlations, cyclostationarity methods and filtering methods. Most of the methods that will be used in LOCATE are well described in literature. An overview of the approach is given in [1], methods for wheelset, wheel/rail contact forces and fault detection in gearbox are discussed in [2] and axle cracks detection and wheel flat detection are described in [3] and [4]. The interaction with digital twins is partially described in [5]. Fr8rail project gives also interesting feedback concerning the necessity to implement an edge computing strategy in order to reduce the data on board. Most of the indicators could be post-processed in-line but not on-line. It does not necessitate real-time computation resources. Most of the methodologies are running under Python, Matlab and/or LabVIEW platform. The OBU must be able to fulfil the requirements to use Dewesoft X3 and standard post process platforms. The OBU must run under Windows 10 having a minimum of 16 Gb of ram and 250Gb of SSD.

6.4. Data management

There will be necessary to store raw data and post processed data.

The volume of raw data can be important due to numerous sensors and high frequency bands of interest. It represents approximately 5Gb of data per day considering 8h of operation of locomotive per day. A disc space of 250 Gb will allow to record approximately 50 days of operation (400h). The strategy to transfer the raw data can be adjusted using local copy on an external hard drive manually for example. Indeed, LOCATE project will not need to automatically transfer raw data but it can be interesting for some partners of the project to have access to the data to evaluate other methods of reduction of data for example.

6.5. Communication system

The post processed data should be reduced in terms of size and telecommunication system will be able to send these data 24/24 to maintenance centre. The volume of data will be low when the minimal data sets will be defined but there are no energy constraints. It is preferable to use 4g/5g system to be able to use big data solutions already existing and to avoid limitation in terms of flow rate using low energy protocol like Sigfox.
Also, for increased volumes of data, like Sensors RAW data (useful in development stage), Wi-Fi connections will be used on know Access Points, which can be located in Stations or Depots.

6.6. Digital twins

Digital Twins are software surrogates of detailed, and eventually complex, analysis software tools, which represent the behaviour of a particular system or subsystem. In fact, they constitute a metamodel for which using the input for the system, such as those obtained from the sensoring system, the outputs are the system response. Their construction can be based on Machine Learning Procedures, for which the knowledge of the physics of the system is not necessary but requires a thorough database of system responses, or on the use of Design of Experiments of detailed models of the actual system. In this work, the Digital Twins are metamodels of the real system built by using Design of Experiments with physically based models of the systems and subsystems. The Digital Twins identified are those of the use cases of the project selected in WP4, and further detailed in its deliverables.

6.7. Maintenance software

The LOCATE Maintenance software is meant to be based on a computerized maintenance management system (CMMS), with the predictive maintenance as the core of the planning management. Currently there commercial CMMS software's available such as eMaint or UpKeep. Along with these, is also usually implemented ERP or MES system to keep track of parts and ensure availability of them for the maintenance activity.

For the LOCATE project, and in the scope of the Demonstrator, it will be used open source software that can be moulded to support the requirements of the project, for example Apache OfBiz. The Goal is simple to create a simple user interface where the LOCATE system can interact with existing planning activities, by proposing shifts on the previous planning.

7. Conclusions

All the sensors for the initial measurement campaign have been selected and different technologies will be evaluated. This had also has input the knowledge and previous experience from industry leaders in a LOCATE Advisory Board Meeting, including members from Shift2Rail Project FR8Rail III.

The outputs from this first measurement campaign will provide the data to allow this evaluation to take place, prior to selecting the sensors for use on the longer-term measurement campaign.

The post-processing resources and adequate on-board computational resources will also be adjusted in function of the field experience acquired during the first measurement campaign and work supply by the different work packages.

8. References

Other refs that might be useful:

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