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In2Rail

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Integration and Implementation Design – Link to Shift2Rail

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Executive Summary

The predicted growth of transport, especially in railway systems is expected to induce a dramatic increase in freight and passenger services exceeding 80% and 50% respectively, by the end of 2050. To support the sustainable development of these systems, novel Information and Communication Technology (ICT) solutions are required to enable the monitoring and analysis of energy flows for the entire railway system considering jointly rolling stock, energy supply sub-system and passengers stations.

This document presents the "Integration and Implementation design", with the aim to evaluate the options of implementing a complete Smart Metering system in three use cases identified for the Shift2Rail project, as follows:

- commercial line operation use case, to design a fine mapping of energy flows dedicated to the railway systems in commercial operation;
- stationing and maintenance facilities use case, intended to measure energy consumption of non-traction systems such as stations, depots and maintenance facilities as well as of rolling stock in hoteling mode;
- electrical infrastructure monitoring use case, to implement a continuous supervision of the power supply system and its components as well as their specific energy consumption.

Each use case is described according to the respective options of Smart Metering implementation studied in the In2Rail project. Based on the state of the art, the general architecture defined at the beginning of the project, and its deployment on a limited part of the tramway in the city of Reims, the following steps are applied to all three use cases:

- design of the sensors to be installed depending on the environment and the constraints associated with the respective railway system;
- design of the relevant data management system;
- design of the applications allowing the interpretation of smart metering data and the display of results by visualisation methods.

The Smart Metering solution developed within the framework of the In2Rail project are not restricted to the three use cases defined above but can be transferred and applied to other use cases.

Another focus of this deliverable has been to provide a basis for the realisation of a demonstrator in upcoming Shift2Rail (In2Stempo/In2Dreams) activities. Thus, works carried out within In2Rail WP11 may be re-used and Shift2Rail will benefit from WP11 deliverables.

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Abbreviations and acronyms

Abbreviation / Acronyms	Description
AC	Alternating Current
ADC	Analog to Digital Conversion
AFE	Analog Front-End
BMS	Building Management System
C-DAS	'Connected' Driver Advisory System
CMF	Current Measurement Function
CPU	Central Processing Unit
CTHD	Current Total Harmonic Distortion
DAS	Driving Advisory System
DC	Direct Current
DHS	Data Handling System
DMAIC	Define, Measure, Analyse, Improve, Control
DSM	Demand Side Management
DT	Decision Tree
EREX	Energy Settlement System provided by Eress
HV	High Voltage
HVAC	Heating, Ventilating and Air Conditioning
ICT	Information and Communication Technology
IEC	International Electrotechnical Commission
IT	Information Technology
KPI	Key Performance Indicator
LAN	Local Area Network
LTE	Long Term Evolution
MLE	Maximum Likelihood Estimation
MTBF	Mean Time Between Failures
ODM	Operational Data Management
PFC	Power Factor Correction
PNN	Probabilistic Neural Network
PSRR	Power Supply Rejection Ratio
RDERMS	Smart Metering for a Railway Distributed Energy Resource Management System
RF	Random Forest
RMS	Railway Management System
SNMP	Simple Network Management Protocol
SNR	Signal-to-Noise Ratio
SPI	Serial Peripheral Interface
UART	Universal Asynchronous Receiver-Transmitter
VTHD	Voltage Total Harmonic Distortion
WP	Work Package
WS	Wireless Sensor
WWAN	Wireless Wide Area Network

1 Background

The present document constitutes the first issue of Deliverable D11.5 "Integration and Implementation Design" within the framework of the Project titled "Innovative Intelligent Rail" (Project Acronym: In2Rail; Grant Agreement No 635900).

This deliverable describes the implementation of Smart Metering solutions related to the use cases identified in the Shift2Rail project, a program that follows the In2Rail project. Shift2Rail will not only further develop and implement the solutions proposed by In2Rail but also create and study new possibilities of Smart Metering solutions.

This is the fifth and last deliverable of WP11 "Smart Metering for a Railway Distributed Energy Resource Management (RDERMS)"; one of the two Work Packages constituting the "Energy Management" subproject of In2Rail.

The general principle of Smart Metering is illustrated in Figure 1.1 below. The specific objective of WP11 is to design an open system dedicated to the fine mapping of different energy flows within the whole Railway System on a synchronised time basis. Smart metering is the first step to better manage assets and provide access to smart grid concepts [1].

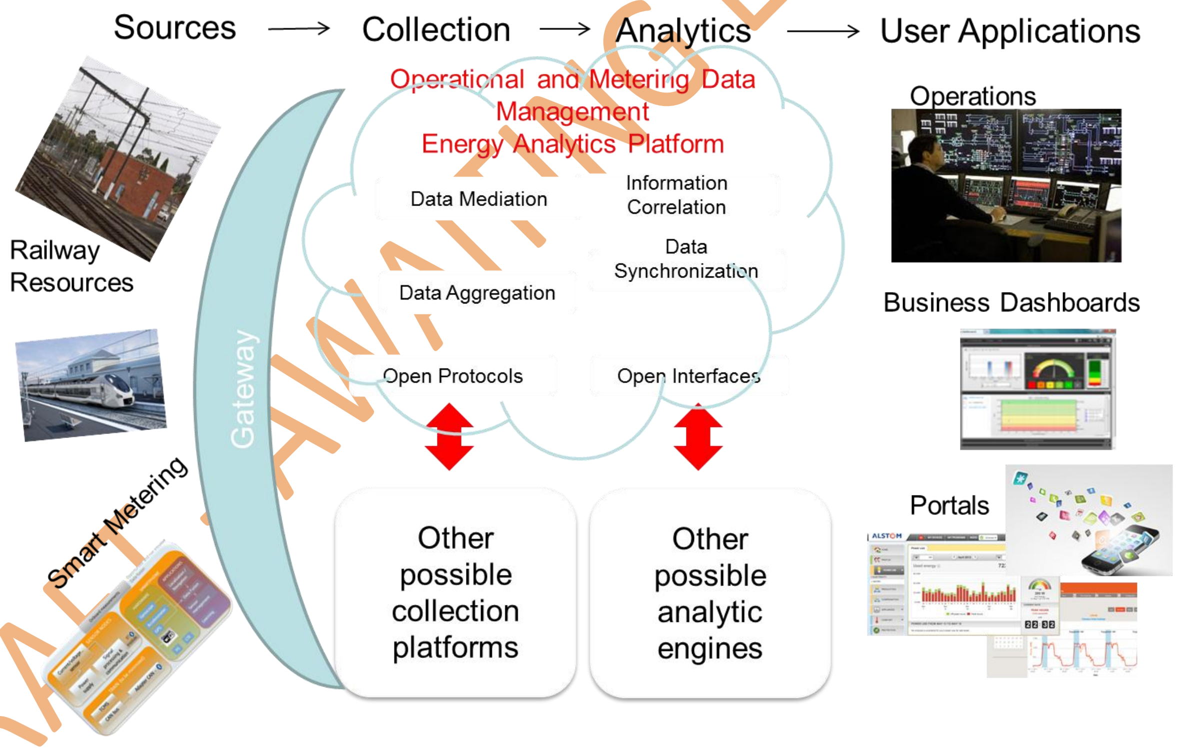

Figure 1.1: Smart Metering for a Railway Distributed Energy Resource Management (RDERMS) principle

This deliverable describes the implementation of Smart Metering solutions related to the use cases identified in the Shift2Rail project, which follows the In2Rail program. Shift2Rail allows not only to further develop the solutions proposed by In2Rail but also to create and study new possibilities of Smart Metering solutions.

This deliverable follows the deliverables D11.2, D11.3 and D11.4 which investigate and propose detailed technical solutions of data management, the design of sensors and measurement means, and the design of applications for the interpretation of data applied to the case study of the tramway in the city of Reims.

1.1 In2Rail WP11 main outcomes

Within Task 11.1, the general Smart Metering architecture was defined, comprising the design of all main blocks and their functional specifications. The state of the art technologies and technical solutions overview has also been performed.

During Tasks 11.2, 11.3 and 11.4, the work was focused on data management design, from measurements to analysis and applications. The developed Smart Metering solutions demonstrate that non-intrusive sensors allow power and energy calculations through modelling and simulation processes. This minimises the number of measurement points.

Another important achievement was the implementation of a Proof-of-Concept in the Reims' tramway system in order to investigate several technologies required by the Smart Metering system. The architecture for data collection, transmission, storage and analysis was deployed in a small scale open source Operational Data Management Platform. A wide range of technical solutions has been investigated:

- sensors and metering technologies to measure currents, voltages and other energy related information, on-board as well as trackside, in a traction power substation;
- data transmission using several communication protocols and means, especially wireless network, from sensors to database.

Figure 1.2: Smart Metering system for Energy Management tested on a limited-scale railway network

1.2 In2Rail WP11 contribution to Shift2Rail

In line with Shift2Rail strategic targets, the expected output of this Smart Metering system implementation is a clear understanding of energy flows within the railway system, a reduction of the energy bill, an optimised asset management and an increase of the offered railway capacity.

The investigations and Proof-of-Concept made during In2Rail provide the building blocks for the Shift2Rail technical demonstrator TD3.10. As illustrated by the following diagram, In2Rail WP11 Smart Metering is directly followed by Shift2Rail TD3.10. The later will be achieved through two different projects. The first is In2Stempo, a Call For Members project, where two Work Packages are dedicated to the Smart Metering topic. The second project is In2Dreams, coming from Open Calls, where three Work Packages are focused on Smart Metering.

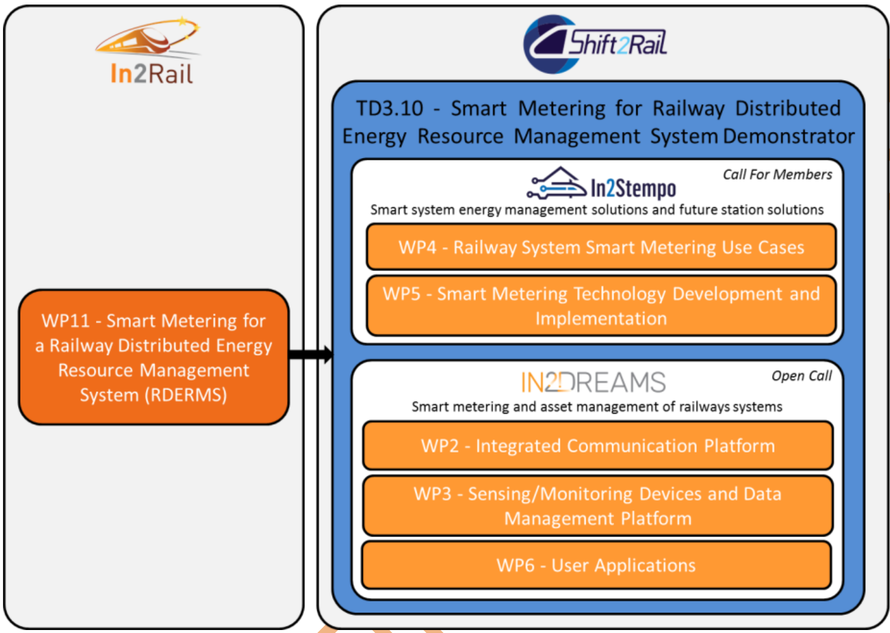

Figure 1.3: Synergies between In2Rail WP11 and Shift2Rail

On the one hand, the use cases defined in this deliverable D11.5 of In2Rail will be studied in details during Shift2Rail.

On the other hand, the general architecture of the Smart Metering System defined during In2Rail will be implemented into the technical demonstrator. The performed gap analysis between available technologies and the required ones will also serve Shift2Rail. From the broad spectrum of technologies tested in the tramway system, several yielded good results and will be further used in TD3.10. In particular, the data management concept developed within the framework of In2Rail is now ready to be realised in a platform to host measurement values for Shift2Rail.

2 Objective / Aim

Based on the principle illustrated by Figure 1.1, the main aim of Smart Metering is to connect a network of physical sensors to advanced analysis tools in order to optimise the management of railway assets and the use of energy in the electrical grid.

The Smart Metering system principle is characterized by the following main features:

- ability to gather a lot of signals, transmit, store and analyse associated data;
- processing capability, in particular to determine non-measured physical values;
- applicable to the entire railway system: rolling stock and infrastructure on the ground;
- time synchronised measurements;
- open system, capable of hosting new sensors and new communicating devices;
- use of standard protocols.

The integration method consists of providing, an existing railway system or one which is under development with:

- sensors installed in railway sub-systems – electrical infrastructure, rolling stock, stations – providing interfaces between the physical variables to be measured in the field and the data to be extracted for the interpretation;
- data management allowing to correlate and synchronise the information to establish the relevant relationships;
- applications allowing to translate the data into comprehensive, viewable and interpretable models enabling management, coordination, optimisation and even forecasting.

The aim is to reach the objectives set for the different use cases as defined in the following chapters..

2.1 Definition of smart metering objectives

2.1.1 Benefits of smart metering in railway systems

In order to reduce the energy consumed for both traction and non-traction subsystems in the railway system, different solutions can be used, such as regenerative braking, eco-driving, minimisation of traction losses in the power grid, smart control for the HVAC and lighting system, etc.

Smart metering applications represent a relatively new solution for the railway domain. Smart energy metering requires the installation of automated metering systems to gather energy consumption information from both vehicles and fixed installations. By using smart metering solutions, the railway operator can monitor the energy flows and implement energy management and energy-saving measures, while also evaluating in real time the effectiveness of these measures.

Smart metering applications provide continuous information about actual energy consumption enabling to monitor and adjust consumption patterns as well as identify abnormal consumption patterns (e.g., in case of malfunctioning equipment, wrong parameter settings) and take preventive or corrective actions.

Further benefits of smart metering applications are related to the increased awareness for energy consumption and the possibility to have a more accurate and more frequent billing based on real consumption. In addition, this provides the access to historical consumption data enabling analysis of consumption behaviour and patterns, more flexibility and cost savings concerning different types of electricity supply contracts.

Smart metering solutions have a broad spectrum of applications, both for railway infrastructures and for rolling stock. For rail infrastructure, main applications are related to the settlement of energy bills, maintenance of the railway infrastructure, energy management of railway buildings and stations. Rolling stock applications can be related to on-board energy management, eco-driving, traffic flow management, preventive maintenance, settlement of energy bill. Combined applications, for both infrastructure and rolling stock, can also be taken into account, for example timetable optimisation.

Different energy management solutions already exist on the market, especially in the sectors of energy production, transmission and distribution, smart grid infrastructures and also building automation. Specifically, in the railway domain, applications are ranging from simple measurement systems to smart metering applications, mainly used for the purpose of accurate billing. One of the first objectives for the implementation of smart metering systems in the railway sector was settlement and billing for railway operators. The EREX system is one well-known application used to bill accurately the energy consumed by trains. It also enables infrastructure managers to fulfil requirements for a neutral and non-discriminatory operation, and railway undertakings to understand their use of energy and thereby save energy and reduce costs. Another type of application is energy efficient driving based on real energy consumption data. Some eco-driving solutions based on Driving Advisory Systems (DAS) use energy consumption data from smart metering applications instead of those from simulation models. C-DAS (Connected Driver Advisory System) applications then allow optimisation of the energy performance at system level, through the use of advanced smart metering applications.

A detailed state of the art analysis has been performed at the beginning of WP11 activities and it has been reported in the first deliverable D11.1.

During the project, for the development of the Railway Distributed Energy Resource Management System (RDERMS) architecture, further analysis on smart metering systems and especially on user’s needs, has been carried out. Interviews and a workshop with stakeholders of the railway domain have been organised.

The requirements of infrastructure managers, railway operators and other companies/stakeholders whose business is related to the railway domain have been collected through a questionnaire prepared by project partners. The main purpose of the questionnaire was to collect the different needs of possible users of the RDERMS.

The analysis of the questionnaire results, and further discussions with the interested companies, have led to the conclusions summarised in Chapter 2.1.2. The questionnaire prepared by project partners and results collected from the different stakeholders are reported in Appendix 8.1 and Appendix 8.2, respectively.

2.1.2 Conclusion of the results of the questionnaire

With reference to business priorities, the most important aspect highlighted is safety, followed by punctuality and cost reduction. Reduction of energy consumption is also considered, mainly as a factor influencing the cost indicator. Interoperability and optimisation of the network capacity are also taken into account, as well as the increase of high-speed lines.

After company and business information, more detailed questions related to smart metering have been analysed, both for the current and future situation, considering three levels of implementation, i.e. operational, tactical and strategic.

The current situation refers to existing smart metering systems (if already implemented) and monitoring currently performed. The future situation refers to systems which are already planned or at least identified as beneficial in future implementations.

At the operational level, the objective of smart metering solutions is restricted to displaying and analysing energy values focusing at optimizing actual performance and not considering adaptations or even systemic changes. Tactical level means that the objective is restricted to small changes and adaptations of sub-systems for railway companies, which do not need huge investments (for example: eco-driving training for the drivers or small changes of time schedules). At the strategic level, the objective of smart metering solutions is the optimization on system level with higher changes and investments needs.

The main motivations for implementing smart energy metering have been analysed. Some companies do not give details about the current situation since no smart metering systems are implemented at present.

2.1.2.1 Objectives of smart metering

Regarding the current situation, at the operational level the most important objectives of smart metering are considered to be: direct monitoring of energy flows (e.g. energy consumed by train in real time), accurate billing, comparison between energy consumed and estimated consumption, compatibility check between infrastructure and rolling stock. Moreover, monitoring of the power supply system and track-side equipment (to identify inefficiencies, irregularities and faults) and the catenary are also taken into account, in order to have a more accurate planning of the maintenance. At the tactical level, the importance of direct monitoring of energy consumption, as well as accurate billing, are highlighted; moreover, the comparison between energy consumed and estimated consumption and compatibility check between infrastructure and rolling stock are marked as important items. At the strategic level, the comparison between energy consumed and estimated consumption is a priority. It is also important to consider the analysis of influence of the behaviour of the train driver on the energy consumption (to eventually introduce green timetables), the monitoring of the status of track, catenary and rolling stock and identification of losses on the line shall be taken into account.

In future situations, at the operational level, strong importance is given to direct monitoring of energy flows, optimisation of energy costs and consumption, the comparison between energy consumed and estimated consumption, track and catenary monitoring and maintenance planning. At the tactical level, accurate billing, the comparison between energy consumed and estimated consumption, compatibility check between infrastructure and rolling stock, identification of losses and monitoring of the track status, planning of maintenance, are mainly considered. At the strategic level, high importance is assigned to monitoring of energy flows, energy billing, optimisation of energy consumption and costs, optimisation of power contracted from the energy supplier, compatibility check between infrastructure and rolling stock, monitoring of the status of the track, catenary and rolling stock for the planning of maintenance.

Smart metering is considered as being important in the current situation at the operational level mainly to understand energy consumption in normal situations, electrical faults in the infrastructure and electrical degraded situations of the infrastructure. At the tactical level, major importance is to understand energy consumption in normal situations. Finally, at the strategic level, the view on the energy consumption in normal situations and electrical faults on the infrastructure and electrical degraded situations on infrastructure are taken into account.

In future situations, smart metering is considered as important to understand consumption in normal and degraded situations, electrical faults in the infrastructure (e.g., for transformer maintenance or in case of heatwaves) and onboard of trains; this is valid for all levels, i.e. operational, tactical and strategic.

The reference frame for measuring the benefits of smart metering is in most cases a line between two stations or an entire line; it can also be an entire local network, a country or the connection between counties, but it can also be defined on rolling stock level.

The time step used for smart metering data at present is real time or at least less than minutes at the operational level, less than an hour at the tactical level and real time at the strategic level. There are no changes expected for times steps in future applications.

Gathering of measurement data both in current and future situations is performed in real time at the operational level, every hour at the tactical level and in real time at the strategic level.

Time-scale of energy consumption data for analysis is less than an hour for current and future situation at all levels of analysis.

2.1.2.2 How to perform monitoring

The items to be monitored presently at the infrastructure level are those having a major influence on energy consumption are traction power substations, signalling system and auxiliaries, and railway maintenance centres, while the passengers areas are mainly relevant for the future situation. Regarding rolling stock, at present, the main item to be monitored is the traction power chain; in future situations it will also be auxiliaries including those for comfort functions.

Regarding the rolling stock level, main important variables to be measured are train's position (latitude and longitude), kilometer point, train’s speed, Input voltage and current at the current collector (pantograph).

At the infrastructure level, the main important variables to be measured are voltage and current at the input side. Moreover, voltage and current at output side shall be measured, as well as auxiliaries’ voltage and current.

In order to monitor the above-mentioned variables, it is suggested to use a sampling frequency of seconds or minutes, depending on the application.

2.1.2.3 Applications/results

Results of the smart metering system can be displayed in different ways; one of the most effective is through charts and curves, to visualise the numeric data.

The main device suggested for displaying the results is a computer, in a monitoring centre; other devices, such as tablet and smartphone, may also be used.

Main information on rolling stock related to speed and position, shall be presented to the Railway Operator, the Infrastructure Manager and the driver. The driver shall also have information regarding specific energy consumption. The Railway Operator shall visualise consumption forecast and the comparison between actual curves and reference. The Infrastructure Manager needs all information related to substations (power and voltage), pantograph voltage, but also infrastructure data, stations and depots consumption.

Applications from other domains, such as buildings, may be used as a reference to implement smart metering systems in the railway domain.

Among all the objectives, the Shift2Rail program focuses on three specific use cases that allow covering the vast majority of objectives indicated in Figure 1.1.

2.2 Objectives of the selected use cases

In railway systems, the supplied energy is consumed in two basic subsystems, where the smart metering can be applied in relevant use cases:

- Traction energy: the energy required to operate the rolling stock across the system. Besides the rolling stock with its main & auxiliary consumers, the traction system also consists of the following subsystems: substations, the traction power network and the traction power system return;
- Non-traction energy: the energy consumed at stations, depots and other facilities in the system. Facilities such as heating, ventilation and air-conditioning, lighting, escalators, moving walkways, lifts and information/advertising screens, etc. are mainly responsible for the energy consumed by non-traction subsystems.

In order to reduce costs, energy consumption and the environmental footprint of the systems (including CO_2-reduction):

- Cost reductions of the traction system are investigated: this corresponds to the Use Case 1: CO-OP (Commercial Line Operation):
- Cost reductions of non-traction are investigated: this corresponds to the Use Case 2: STM-OP (Stationing and maintenance facilities).

In order to improve safety and punctuality of railway systems, the focus is on the electrical infrastructure that supplies the electric traction:

- Increased availability and fault and anomaly identification of the traction power supply system are investigated: this corresponds to the Use case 3: IN-OP (Infrastructure Monitoring).

2.2.1 Use case 1: CO-OP (Commercial Line Operation)

This smart metering use case corresponds to a commercially operated railway line under normal traffic conditions. The objectives include the fine mapping of relevant energy flows, the optimisation of interaction between rolling stock and infrastructure, the identification of energy efficiency potentials, and the implementation of energy management options.

Data collected through smart metering keeps the infrastructure manager or the railway operator informed about the energy behaviour of the system, by combining real time data on energy use and accurate billing. The consumer can act in two directions: by energy saving (i.e. by knowing the sources of over-consumption) and, in the case of freight services, decide on measures for billing reduction (i.e. by switching the consumption to a less expensive period, when possible).

Smart metering enables two basic functions, measuring and analysing, which are useful to introduce the DMAIC (Define, Measure, Analyse, Improve, Control) method for energy management system, which supports and is in line with the ISO 50001 standard on energy management system (see Figure 2.1).

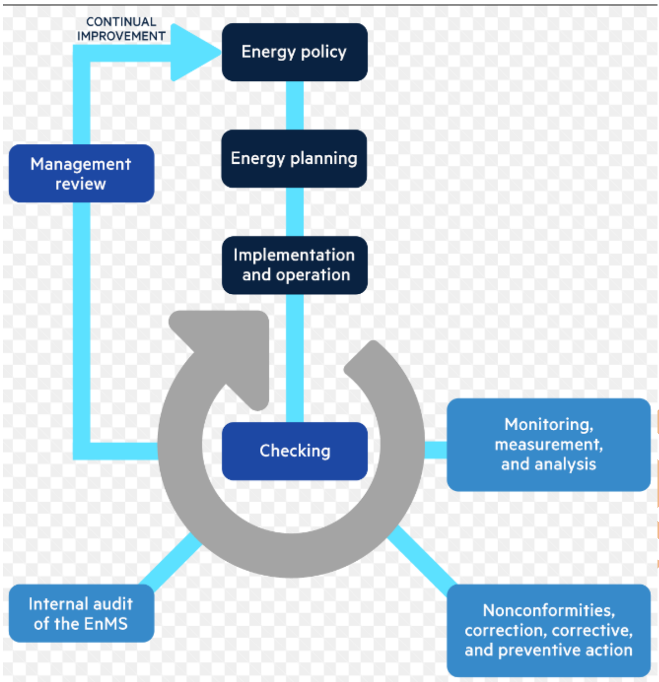

Figure 2.1: ISO 50001 Energy Management System (Process)

2.2.1.1 Energy meter in substations

For each substation, the high voltage network manager sets up at least two meters (primary and redundant). Every meter covers all four quadrants and can measure the following data:

- Voltage and current of different phases;
- Active and reactive powers in the two ways.

Appendix 8.3 describes the sensors and relevant energy meter standards.

Energy meters can record data over a certain period of time which is useful in case of communication failure.

Modern energy meters are designed and set up in accordance with IEC 61850: Communication networks and systems in substations.

Data are collected in an IT server by a Data Management System, which ensures the energy monitoring and billing (see Figure 2.2). Manifold communication channels can be used: phone line, 3G, LTE, IP network, etc.

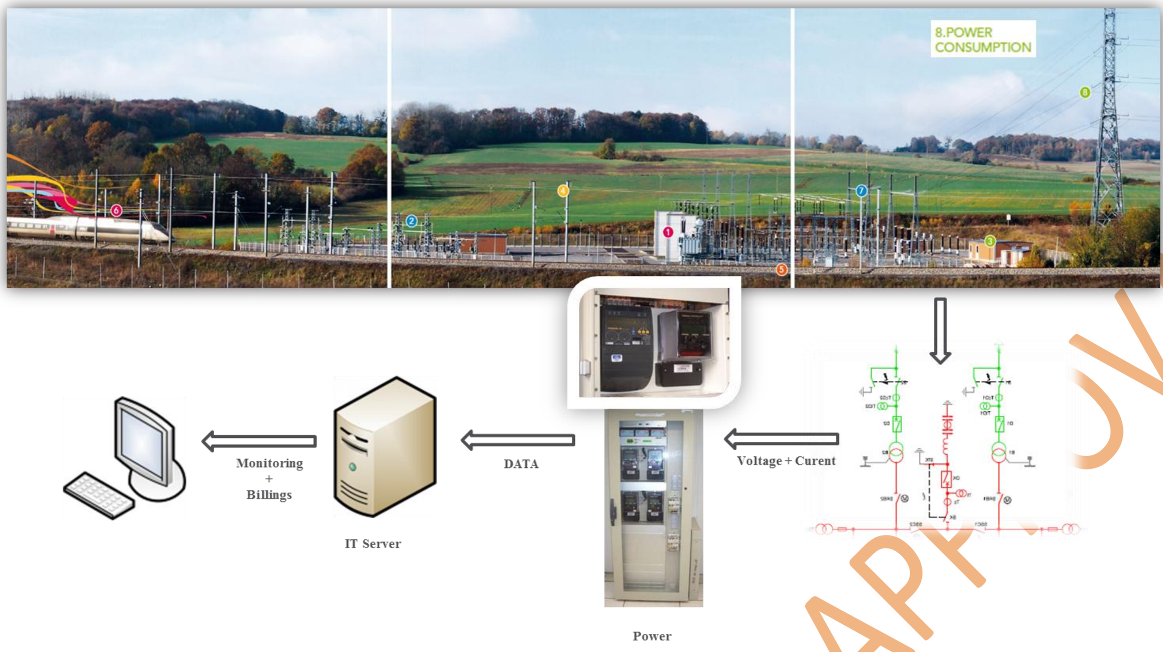

Figure 2.2: Typical sketch of energy measurement in a power substation

2.2.1.2 Data use and treatment

Data collected from the different points of the network (more than one thousand energy meters for SNCF power supply network) are used for the following applications:

- Aggregation of total consumption;
- Short-term energy consumption forecast, used in combination with traffic data and weather forecast;
- Optimisation of energy purchase;
- Weekly publication of a consumption report;
- Correction of missing points;
- Billing;
- Revision and optimisation of contract power.

2.2.1.3 Energy meter on trains

The infrastructure manager is in charge of collecting data of energy consumed by each railway operator (see Figure 2.3). For each train, operator's consumption can either be estimated (type of train, train composition, distance, etc.) or measured. Energy meters on trains follow the same design principles as those installed in substations. Communication between train energy meter and data system management is only available by means of cell networks.

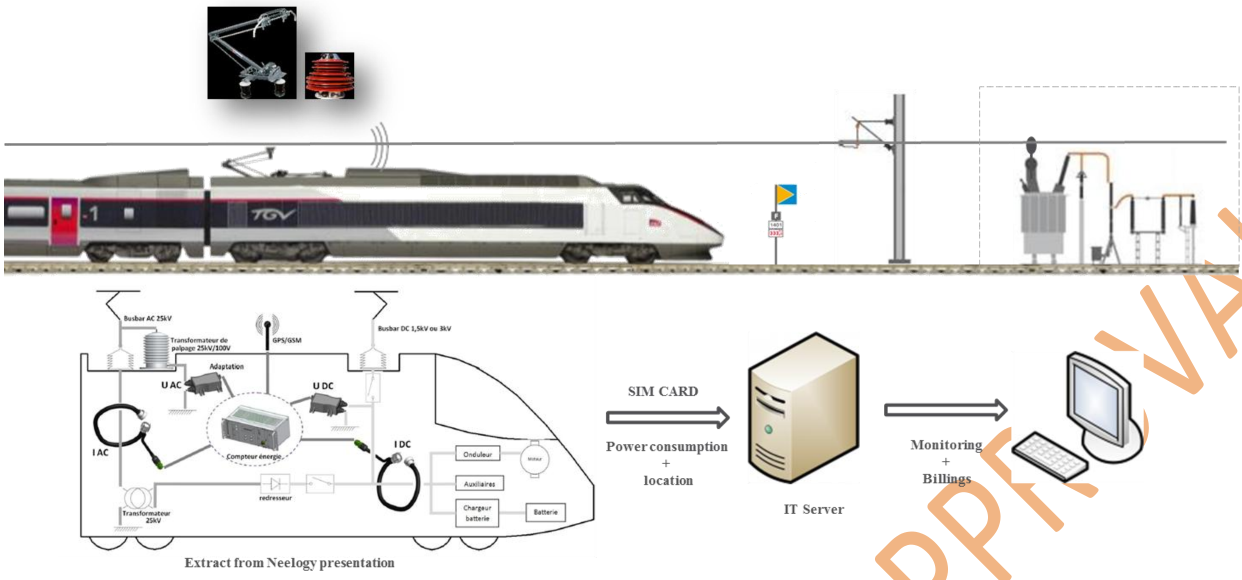

Figure 2.3: typical sketch of energy measurement on-board trains

2.2.1.4 Joint power supply energy measurements

The Figure 2.4 below summarises the use of substation and train energy meters.

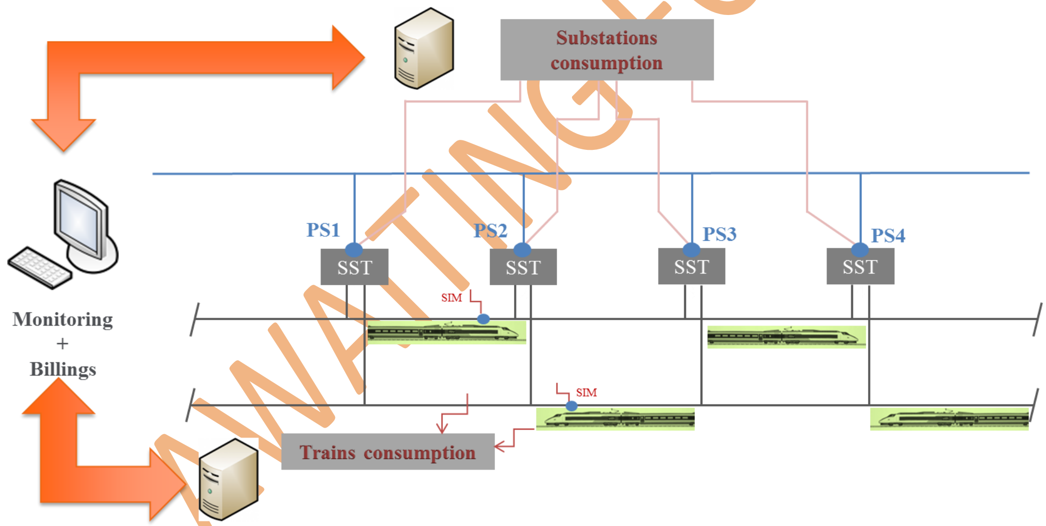

Figure 2.4 : Typical sketch of joint measurements from train and substations

2.2.1.5 Smart metering, sizing optimisation and new energy market

Electricity prices in the new energy market are driven by the relationship between consumption and production, almost in real time. The capacity market encourages consumers to define energy needs over time, date and seasons, in order to optimise energy purchases or capacity sales.

Smart metering is a perfect tool for infrastructure managers or railway operators:

- to manage the energy procurement strategy (financial challenge);
- to get accurate consumption information, which is crucial to optimise the network sizing or dimensioning (technical and financial challenge).

2.2.1.6 Smart metering and energy efficiency

As already stated, thanks to smart metering, infrastructure managers and the railway operators have detailed information about the energy behaviour of the system. They can, therefore, decide on measures for energy saving (i.e. by knowing the sources of over-consumption) and, in the case of freight services, decide on measures for billing reduction (i.e. by shifting the consumption to a less expensive period, when possible).

2.2.2 Use case 2: STM-OP (Stationing and maintenance facilities)

This smart metering use case studies stationing and maintenance facilities. The objectives are to study energy management options and identify energy efficiency potentials in this specific area. This use case also investigates the options for monitoring of relevant infrastructure, the monitoring of rolling stock status, and the improvement of operational performance.

Many electricity users can be connected to substations or catenaries for non-electric traction needs (see Figure 2.5). The most known connections are:

- HV network for signalling;
- Auxiliary transformer for low voltage network (building, command-control, etc.);
- Train stations;
- Railway maintenance centres.

To achieve the benefits described above and to make the billing procedure easier, the implementation of smart metering in those cases can be very useful and interesting.

Figure 2.5 : SNCF Railway maintenance centre, powered by catenaries

2.2.3 Use case 3: IN-OP (Infrastructure Monitoring)

This smart metering use case corresponds to the monitoring of infrastructure assets including the traction network. The objectives are to study the energy monitoring options for individual infrastructure assets as well as for the complete traction power supply network and to integrate technical expertise to identified monitoring options.

The approval of new rolling stock, the compatibility check between infrastructure and rolling stock, the need of heightened monitoring of the network at different point and locations, fully justifies the implementation of a smart metering network (examples: catenaries warming, flicker and network instability due to active power electronic devices).

Data needs depend on the monitoring application and could be: current and voltage including harmonics, temperature, etc. A higher frequency sampling could be required, but by using a defined trigger point data acquisition efforts and data volume can be minimised.

2.3 Assessment of the use cases specific benefits

For each of the three use cases, an assessment of the benefits associated with the implementation of specific user applications based on the smart metering system will be systematically done. The multi-dimensional assessment will determine the impact of the usage of the smart metering system and its applications on the following parameters:

- Operational performance (quality of operation, reliability, availability of systems, planning options);
- Energy performance (energy efficiency, quality of energy supply);
- Maintenance performance (maintenance effort, preventive maintenance) ;
- Strategic performance (planning options, forecasting, flexibility, adaptability, energy flow mapping capabilities);
- Economic performance (cost efficiency, investment needs, life cycle costs);
- Environmental performance (CO_2 emissions, resource consumption).

For each parameter of the multi-dimensional assessment, the potential impact of using smart metering applications is measured by means of Key Performance Indicators (KPIs) against the baseline performance (status quo performance of currently running systems and daily operation).

3 Description of the Commercial Line Operation use case (CO-OP)

3.1 Introduction

The smart metering use case for a commercially operated railway line under normal traffic conditions (CO-OP) will be realised at Network Rail on the line between Redhill and Tonbridge, South of London. The main objectives of this use case are fine mapping of relevant energy flows for infrastructure and rolling stock, optimisation of interaction between rolling stock and infrastructure, identification of energy efficiency potentials during normal line operation and the provision of a solid basis for the implementation of different energy management options.

This use case is very similar to the Reims tramway experimentation in terms of voltage range and objectives of smart metering application.

3.2 Situation overview

Hereafter, some general information about Network Rail experimentation site are presented:

- the Network Rail demonstration site is a 20km-long line of double track between Redhill and Tonbridge (see Figure 3.1);
- power supply is 750 V DC, a very common voltage for British railway networks;
- the supply section is supplied by five substations from Bletchingley Tunnel substation to Chiddingstone substation;
- rolling stock type is Class 377 (see Figure 3.2), a common British electric multiple-unit train (EMU) from Bombardier, with 4 cars, with a maximum speed of 160 km/h, a car length of 20.4 m, and a maximum power of 1800 kW with power supply by contact shoe.

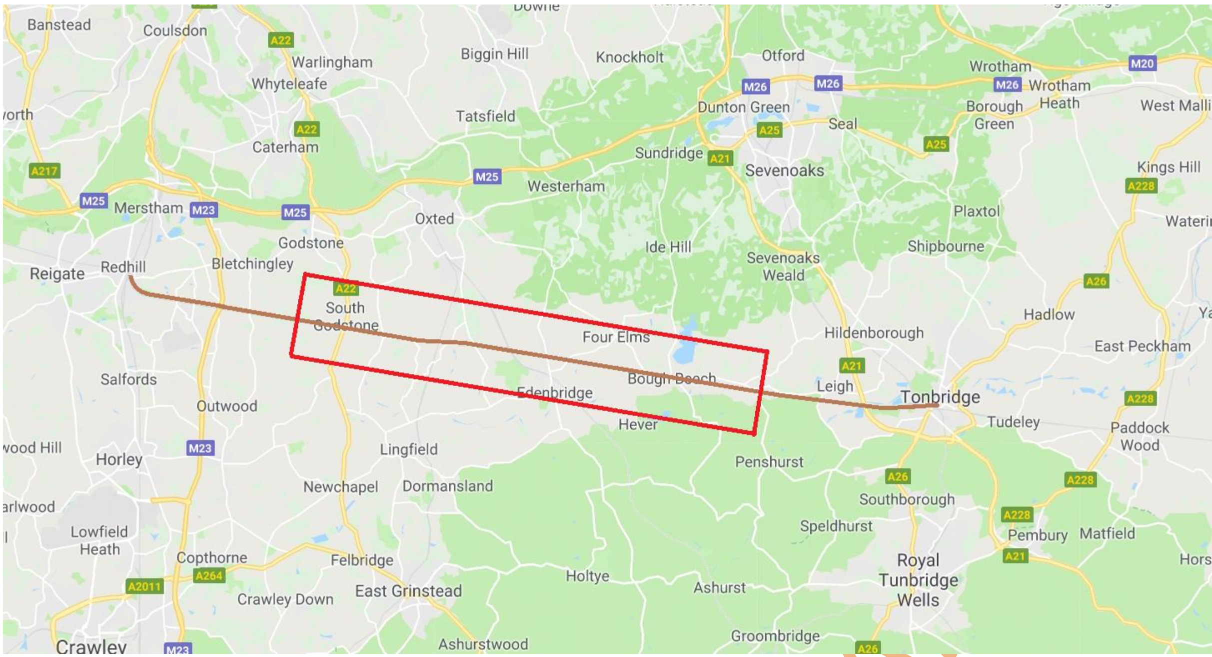

Figure 3.1: Redhill-Tonbridge line map and electrical section studied

Figure 3.2 : Picture of Class 377
(Source: Network Rail)

3.3 Solutions for data management design

As a results of the experimentation of the In2Rail project, two systems for gathering and managing the data coming from the sensors will be described here. The first one is the Open Data Management (ODM) platform which will collect the data collected by the sensors and the second one is the communication platform which will gather and transmit these data to the data base for storage, processing and analysis.

3.3.1ODM Platform

The ODM platform architecture, which corresponds to the situation in Network Rail use case, can be used by the other two use cases as well, as for connected use cases resulting from In2Stempo WP2 and WP3.

The Open Data Management platform will have to collect and aggregate data, and offer applications for visualisation and processing to users by means of dedicated interfaces. The platform will have to manage data from various sources and perform dynamic and real-time management of the operations. High-speed data processing and efficiency are key features of the platform will manage this issue. All sensing devices will be controlled by the platform in accordance with the cloud computing paradigm, offering access to the data without constraints of time or location. Adaptive communication protocols will be created. The access to and configuration of the system have to be easy but must remain highly secured at the same time. The main challenge will be to integrate data of the various systems: trains, trackside infrastructures, maintenance infrastructure, and electrical networks. Because of this ability and broad coverage, the same platform will be used for all three use cases, as well as for use cases resulting from WP2 and WP3 where requested.

3.3.2Communication platform

The Information and Communication Technologies (ICT) platform for future applications of railway systems will have to support a wide range of applications and will have to be highly adaptive. It has to adequately cover the high mobility of train transportation, infrastructures for maintenance, and management of the electrical network. This platform will have to interconnect the ground infrastructures, the maintenance structures, the on-board systems and the operations and control centre, where data bases are hosted. For the on-board and train-to-ground segments, a multi-technology wireless access system will be used, based on the integration of heterogeneous WiFi and Long-Term Evolution system, integrated into the Radio Access Network environment. For the ground-to-OSS segment and the maintenance segment, the existing optical network infrastructures will be used. Several infrastructure slices will therefore be created and used, ranging from wireless to optical technologies and computing domains.

3.3.2.1 Communication Architecture

The system's communication architecture that was used during the Reims experimentation can be used as an example for the trackside communication solution of the first use case which involves substations. In this architecture, we have connected an Analog Front-End (AFE) that receives the current measurements from the Neelogy sensors. These are non-intrusive current sensors, whose output varies from -2.5V to +2.5V proportionally to the current load monitored. However, our Analog to Digital Conversion (ADC) component can support only positive readings. To this end, some pre-processing takes place in the AFE where the input voltage is down-scaled and offset, providing an output voltage in the range of 0.3V to 3V which is supplied to the ADC. The ADC sample the values provided by the AFE with a sampling rate of 1 million samples per second in each of the two channels, average the measured voltages and propagate the aggregated data every second over the ZigBee network from our Wireless Sensor (WS) mote to the Gateway, where the measurements are collected (Figure 3.3).

In the following steps, the data are forwarded from our Gateway to the In2Rail server infrastructure, where they are stored for further processing. The Gateway software is also capable of storing the measurements locally if the link with the In2Rail server is down for any reason and forward the measurements as soon as the connection is recovered.

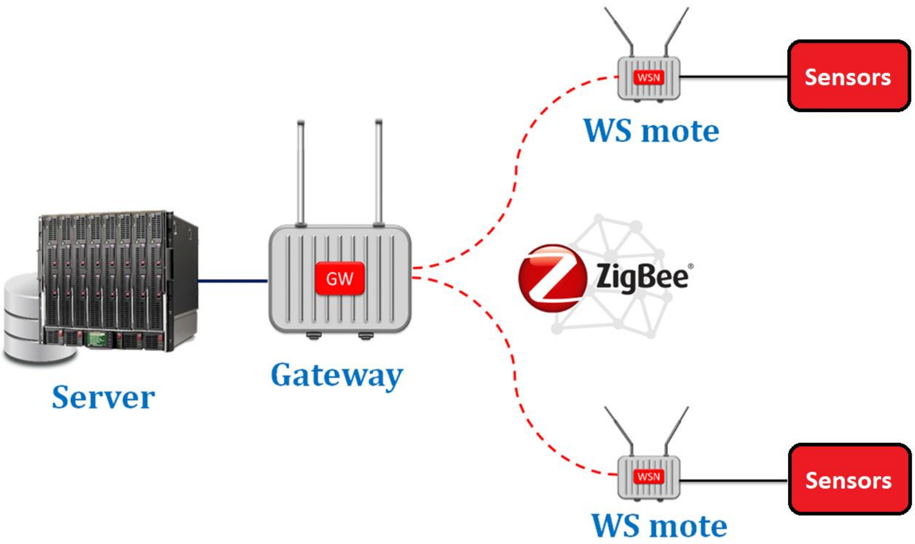

Figure 3.3: Communication System Architecture

3.3.2.2 Communication Interface

3.3.2.2.1 Zigbee

To support long range-low data rate communications, we used the XBee Series 2 (S2) interface provided by Digi - see Figure 3.4. XBee S2 implements the 802.15.4 stack, which is the basis of the widely-known ZigBee protocol, providing up to 250kbps physical data rate. XBee S2 is available in three different transmit power (Tx) units, 3.1mW, 6.3mW and 63mW. The 3.1mW and 6.3mW are for short range-communication suitable for our deployment requirements, while the 63mW Tx power version is for long-range communications capable of reaching up to 3.2km when there is line of sight. When in idle/receive mode, XBee consumes roughly 30mA and just when it transmits it reaches up to 45mA at 3.3V. XBee S2 features a UART channel for communication with the embedded device and operates at 3.3 Volts. In our application, it communicates with the host microprocessor device over UART.

Figure 3.4: XBee S2 module

3.3.2.2.2 Microprocessor Board

The microprocessor device – here represented by the Wireless Sensor (WS) mote on Figure 3.5 - is responsible for collecting the measurements acquired by the ADC unit, calculating an average value and in turn transmitting the data to the gateway node. It features a 32-bit ARM Cortex-M4 microprocessor running up to 72MHz and operating at 3.3V. Moreover, it features 128KB flash memory (program space) and 2KB of EEPROM (long-term storage). A few GPIO pins are exposed and used to integrate a serial communication via SPI protocol with the ADC. The sampled measurements for each channel of the ADC, are collected and averaged. A precise watchdog timer is used to send the stored values with an interval of one second via the XBee modules to the Gateway.

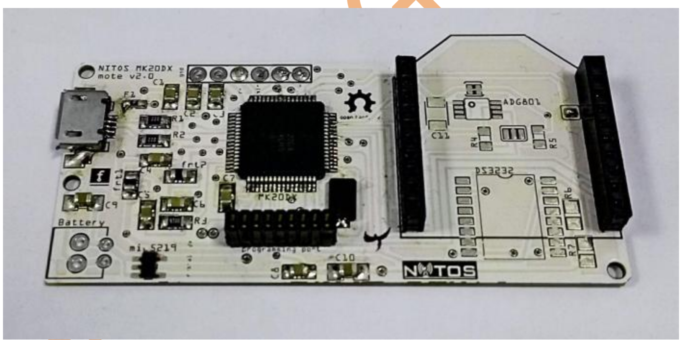

Figure 3.5: WS mote

3.3.2.2.3 Enclosure

In order to protect and easily mount the electronic circuitry required for our measurements, we decided to use a DIN Rail plastic enclosure – see Figure 3.6. It will help secure the position of our boards and protect them from other external factors, since it is IP20.

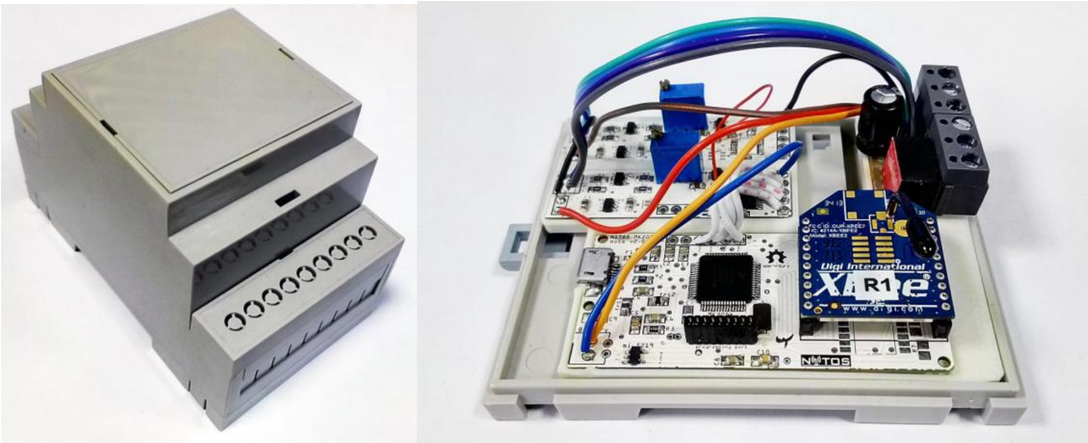

Figure 3.6: DIN Rail Enclosure(left) and the interior of WS mote (right)

3.3.2.3 Gateway Description

Below, we list and describe the main modules of the gateway device.

3.3.2.3.1 Shield with XBee

In Figure 3.7, we present the XBee shield we designed. It can be mounted on top of our Beaglebone Gateway and to host XBee communication modules.

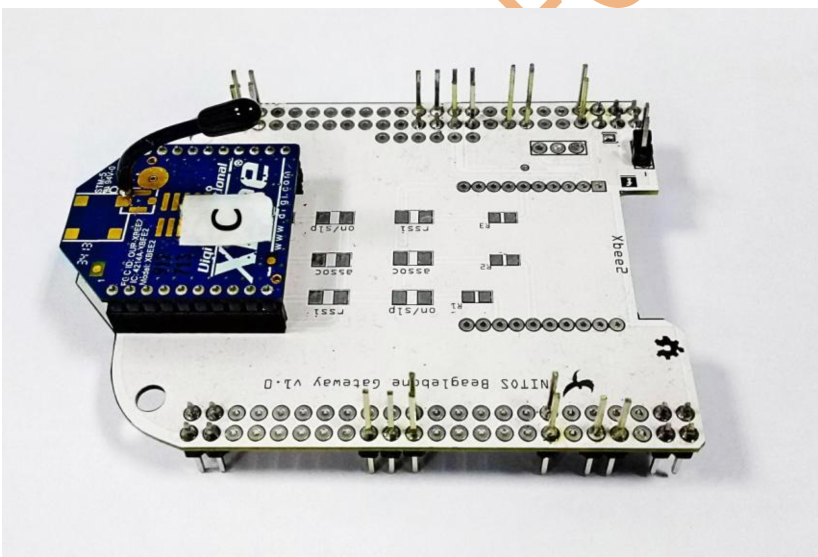

Figure 3.7: XBee Shield for BeagleBone Gateway

3.3.2.3.2 WiFi

The Wi-Fi USB Dongle used is the TP-Link TL-WN722N, as shown in Figure 3.8. It is an 802.11n compliant Wi-Fi dongle that can be fitted with an external antenna. It can reach speeds of up to 150Mbps and features the Atheros AR9002U chipset. The driver used is the Atheros ath9k_htc driver which supports the aforementioned chipset. The ath9k_htc is an open-source driver that can be modified to fit our experimenting needs.

Figure 3.8: TP-Link WN722N Wi-Fi USB Dongle

3.3.2.3.3 Gateway Enclosure

For better protection and ease of implementation, we choose to use a common BeagleBone enclosure – see Figure 3.9. Some modifications were made in the original enclosure in order to accommodate both the BeagleBone Black and the required XBee shield.

Figure 3.9: BeagleBone Enclosure

3.3.2.3.4 BeagleBone

The embedded device we have selected to use is the "BeagleBone Black Rev. C" – as shown in Figure 3.10 -, which is the main board of the system. The BeagleBone Black Rev. C is a low cost, single-board computer. It is a highly versatile community-supported development platform that was designed to have a wide variety of capabilities. It can be used as a basic computer, a DIY platform and realise several other application scenarios.

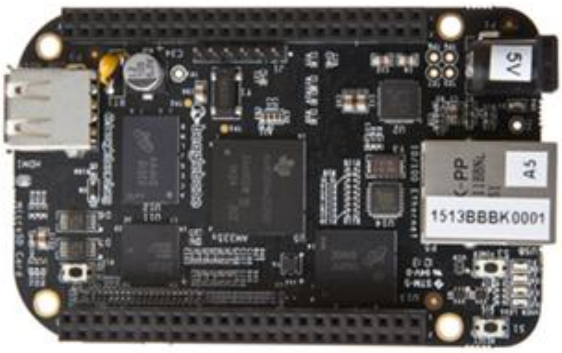

Figure 3.10: BeagleBone Black Rev. C board

The BeagleBone Black Rev. C features:

- 1GHz ARM CPU;
- 512MB DDR3 SDRAM;
- 4GB of eMMC built-in storage;
- 1 USB ports;
- 65 GPIO pins.

BeagleBone also supports several operating systems including Linux, Debian, Angstrom, Ubuntu, Fedora etc. In our prototype, we used the pre-installed Debian OS optimised for the BeagleBone hardware. This operating system is widely adopted by BeagleBone users and offers great support by the community. In the same way, a software is run for the collection, storage and distribution of measurements.

3.4 Solutions for sensors and metering design

This chapter aims to give examples of sensors adapted to the range of this use case and can communicate with the generic platform.

3.4.1 Onboard metering solution

Each sensor will be adapted to the order of magnitude of the value measured, in either case, current or voltage. The information that is collected and transmitted can be used in the same way by the ODM platform, which processes the information in the same way, regardless of the value sent by the sensors.

3.4.1.1 Traction measurements

Voltage sensors for traction on-board measurements are already widely spread. A lot of off-the-shelf products are available on the market. There are no special needs for a new development, because there are standard solutions since many years for these measures, and therefore existing sensors.

However, Neelogy proposes products using Neel Effect with a couple of advantages: the compactness of the sensors and the resistance to hard environment conditions (see details in Appendix 8.4). Moreover, it is the only clamp-on product available off the shelf for measurement of a DC current with three calibres (1250A, 2500A and 5000A). Thus, these sensors could also be used for this application, for higher performances, compliant with EN50463 standard, accuracy class 1.

3.4.1.2 Auxiliaries measurements

The Spoony sensors provided by DotVision can be used in this situation, to measure the consumption of the auxiliaries, the voltage (around 750 V DC) and the current. The type of voltage and current correspond to the situation in Network Rail. The target is to be able to distinguish power consumption between traction and auxiliaries. A smaller range clamp-on Neel Effect® current sensor could be used (calibre available are 50A, 250A, 500A and 1000A).

These products are not EN50155 compliant, but they could be adapted for an experimentation and be comparable with EN50463 class 1.

3.4.1.3 Bill of quantities

Seen on the architecture of the Reims experimentation, the following can be updated for the first use case regarding the list of quantities per each train – see Table 3.1.

Onboard Metering Solution Design	Type of sensors	Sensor range	Communication
Complete date (year, month, day)	Time synchronisation system	/	1 Wi-Fi Router 1 4G Router
Complete time (hour, minute, second, ms)		/	
Train's position (KP): GPS position: latitude	Position detection system	/	
Train's position (KP): GPS position: longitude		/	
Train's speed	1 speed sensor per train	/	
Input voltage at current collector (contact shoe)	DC: 1 voltage sensor	600 kW - 6 MW	
Input current at current collector (contact shoe)	DC: 1 current sensor per contact shoe		
Traction voltage * (at equipment input level)	DC: 1 voltage sensor AC: 3 voltage sensors	50 kW - 1.5 MW	
Traction current *	DC: 1 current sensor per traction converter AC: 3 current sensors (if needed)		
Rheostat voltage (at equipment input level)	DC: 1 voltage sensor per rheostat	50 kW - 1.5 MW	
Rheostat current	DC: 1 current sensor per rheostat		
Auxiliary converter voltage (at equipment input level)	DC: 1 voltage sensor	50 kW - 1.5 MW	
Auxiliary converter current	DC: 1 current sensor		
Low voltage auxiliary network voltage	DC: 1 voltage sensors	100 W - 50 kW	
Low voltage auxiliary network current	DC: 1 current sensor		

Table 3.1: Bill of quantities for onboard metering solution

* : in some specific cases (no neutral for the AC), only 2 voltage sensors can be used.

3.4.2 Trackside metering solutions design

Each sensor is adapted to the order of magnitude of the value measured, in either case, current or voltage. The information that is collected and transmitted can be used in the same way by the ODM platform, which processes the information in the same way, regardless of the value sent by the sensors.

3.4.2.1 Traction measurements

Neelogy has adapted its technology in order to provide a shunt-like sensor based on Neel Effect®, and this technology can, therefore, be selected for this application. As a solution, the shunt is more accurate than the clamp-on one. A class 0.1 accuracy can be reached. The calibre available can be adapted from 50A up to 5kA.

3.4.2.1.1 Sensing Device Architecture

In order to develop the sensing devices to be interfaced with the Neelogy transducers (Current Sensors), we followed a generic method for the Reims experimentation scenario. This method engages three main components/stages and can be applied likewise in this scenario. These are:

- Analog front-end;
- Analog to Digital Conversion (ADC) component;
- Embedded device / Microcontroller board.

The analogue front-end is an analogue circuit, usually a differential or an operational amplifier, used to prepare (scale, amplify, offset etc.) the input voltage supplied at its input, for the following stages. This is a mandatory step in order to develop a system with high accuracy, since an ADC unit is unable to obtain precise very low voltage measurements. Thus, this first processing step is required.

The Analog-to-Digital Converter (ADC) is a device that converts a continuous physical quantity (in our case the obtained voltage) to a digital number that represents the quantity's amplitude. The conversion involves quantisation of the input, so it necessarily introduces a small amount of error. Furthermore, instead of continuously performing the conversion, an ADC does the conversion periodically, sampling the input. The result is a sequence of digital values that have been converted from a continuous-time and continuous-amplitude analogue signal to a discrete-time and discrete-amplitude digital signal.

Finally, an embedded device or a microcontroller device must be used to collect the acquired data from the ADC component for storing or processing purposes. The collected data can be processed later and new decisions based on the acquired knowledge are held.

An indicative architecture is illustrated in Figure 3.11. Of course, those are just the required stages and several additional components can be used to aid the operatioof the whole system.

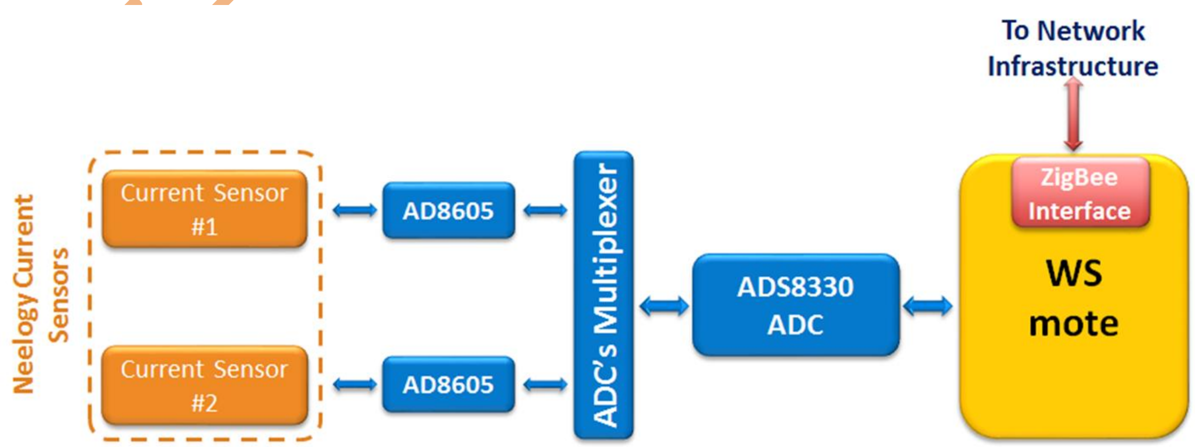

Figure 3.11: Generic Architecture for measuring current Consumption of Devices

3.4.2.1.2 Analog Front-End

As mentioned, the analogue front-end (AFE) depending on the setup can be used for several different reasons. In our case, the analogue front-end is responsible for converting the input voltage supplied from the Neelogy sensors, which ranges from -2.5V to +2.5V, to an output signal in the scale of 0.3V to 3V. It is easily understood that the input signal needs to be down-scaled by a factor of almost 1.85 (from 5V peak-to-peak to 2.7V peak-to-peak). Further, the down-scaled signal needs also to be offset in order to be strictly positive over the whole range of the measurements. In addition, the scaling and offset procedures should be performed with the minimum error, so that the overall accuracy of the sampled data is not undermined.

3.4.2.1.3 Analog to Digital Converter

The Analog-to-Digital Converter is a component of crucial importance for our system. For our application, we decided to use an IC that features 16-bit resolution and high sampling speed, 1 Million Samples per second, as well as a high Signal-to-Noise Ratio (SNR) of 92dB. It operates from 2.7 to 5.5 Volts, which is very convenient for the development. Also, it draws only 7.0 to 7.8mA when operating. Moreover, it communicates over SPI BUS, which is also suitable for our device. The available package type, TSSOP-16, is very comfortable for soldering and might not bring any difficulties in the deployment phase. The supported channels are two, allowing for parallel monitoring of up to 2 different devices.

More specifically, we power both VA and VBD (input supply voltages of the IC) inputs with 3.3V through an ultra-low noise, high PSRR, low dropout regulator. Additionally, we provide an ultra-precision reference signal of 3.3V to the REF+ pin, while REF- is coupled to the ground. The two input channels are connected with the outputs of the analogue front-ends, monitoring the voltage supplied by the Neelogy sensors. Finally, the SPI BUS is interfaced with the embedded device and several coupling capacitors have been used as proposed in the component's datasheet.

Moreover, another necessary component that was used in the development of the energy monitoring card is a precision voltage reference circuit. ADC converters require a highly precise voltage reference in order to perform the conversion to a digital value accurately. A voltage reference is an electronic device that ideally produces a constant voltage irrespective of the loading on the device, power supply variations, temperature changes, and the passage of time. Notably, the parameter that affects mostly the performance of a reference circuit, is the drift one, over different temperature conditions and of course the accuracy. The chosen component presents highly constant output, only 4ppm, and also features accuracy of 0.01%. Thus, we ensure that our conversions are performed with the aid of an accurate reference signal that is not varied over the time.

3.4.2.1.4 Bill of quantities

Given the architecture of the Reims experimentation the following can be assumed regarding the list of quantities per each substation (see Table 3.2):

Onboard Metering Solution Design	Type of sensors	Sensor range	Communication
Complete date (year, month, day)	Time synchronisation system	/	2 WS motes per measurement point 1 Gateway
Complete time (hour, minute)		/	
Power substation – Input side – voltage (3-phase)	AC: 3 voltage sensors	2.5 MW	
Power substation – Input side – current (3-phase)	AC: 3 current sensors		
Power substation – Input side – power factor	AC: 1 Wattmeter		
Power substation – Output side – voltage	DC: 1 voltage sensor	2.5 MW	
Power substation – Output side – current per track feeder cable	DC: 1 current sensor		
Auxiliaries – voltage (3-phase)	AC: 3 voltage sensors	/	
Auxiliaries – current (3-phase)	AC: 3 current sensors	/	
Auxiliaries – power factor (3-phase)	AC: 1 Wattmeter	/	

Table 3.2: Bill of quantities for trackside metering solution

3.4.2.2 Auxiliaries measurements

Voltage and current sensors are used to measure the consumption of auxiliaries, with the type of voltage and current updated to the situation in Network Rail. The target is to be able to distinguish power consumption between traction and auxiliaries.

For the voltage, the Spoony provided by DotVision to measure the Low Voltage auxiliary consumption in the substation and trackside may also be used here.

For the current measure, the sensors of Neelogy should also be used, with respect to the characteristics of the currents of the measured points.

3.4.3 Communication specifications

3.4.3.1 Introduction to train on board and train to trackside communications

There are various types of train on-board networks that are often physically independent (independent wiring and equipment): monitoring/control networks for critical gear systems on one side, and data networks for value-added services to travellers and monitoring of non-critical systems. This second network will be use for the energy monitoring.

Even though this network will not be supporting critical services it will require to be built with equipment according to railway regulations to ensure required levels of performance and non-interference with other on-board systems. Moreover, particular important points are the robustness of the equipment (measured by MTBF) and the use of industrial connectors for high vibration resistance. This is because, statistically, the largest number of related incidents on shipped networks comes from failed connections wiring. Minimizing the number of incidents helps to control maintenance costs (keeping the train on track longer) and service failures that compromise the image of the company and other business processes.

This type of multi-board network for non-critical systems includes the installation of equipment to set up an on-board local network. It is usually composed by switches connected in a ring topology for redundancy, WiFi access points to provide on-board WiFi network and, optionally, other devices like protocol converters to IP (to use the Ethernet network) from serial data and other devices with different protocols (6LoWPAN, LORA ...). Finally, the local network must be connected to "Gateway" devices that manage the train-connectivity.

The following diagram shows the typical architecture of railway communications for non-critical systems (see Figure 3.12).

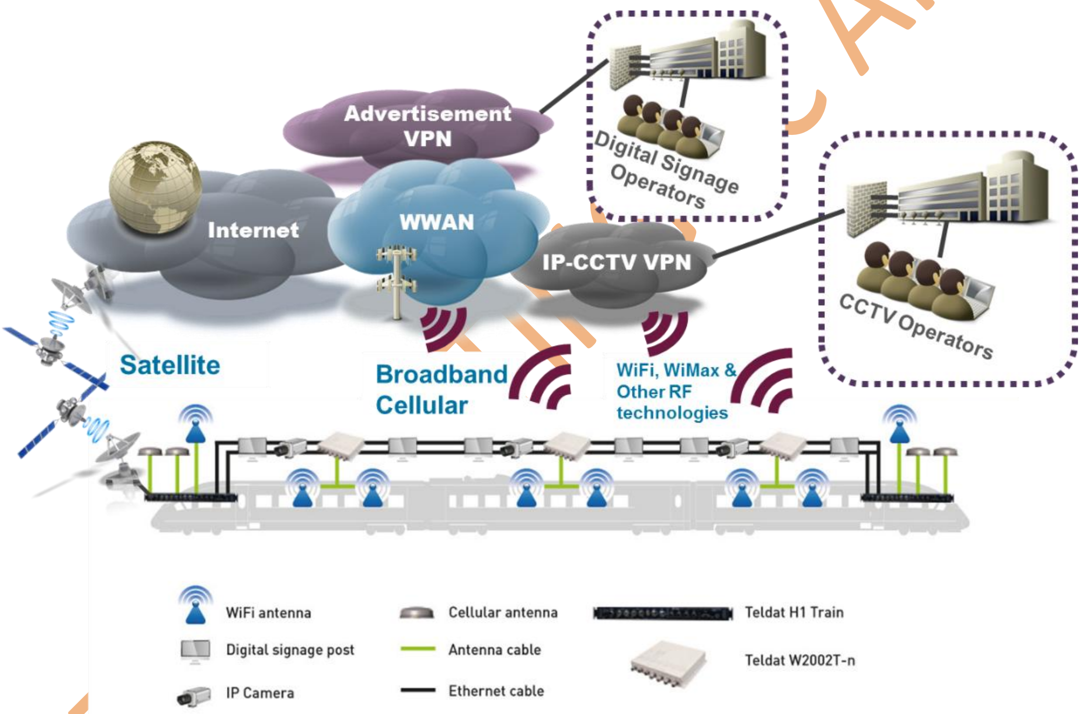

Figure 3.12: Architecture of railway communications for non-critical systems

In this architecture different types of devices are connected to on-board LAN like cameras, access points, and digital signage screens. This network access is where the Energy Monitoring system should be connected to.

Regarding trackside communications, in railway environments, a combination of technologies for train to ground communications is frequently used to maximise coverage along the way. These include the use of mobile technologies such as 3G and 4G, satellite for sparsely populated areas and "trackside deployments of " other wireless technologies that are typically used in metropolitan areas with tunnels. Therefore, the train-to-ground communications gateway should be able to use multiple technologies and switch between them automatically.

It is assumed that the Network Rail South of London Line has a good 4G Mobile service coverage from the mobile operator.

3.4.3.2 LAN communication protocols

3.4.3.2.1 On-Board devices

In local networks, there are different types of connected devices ranging from control devices to network terminals for service delivery and monitoring systems.

The latest networking technologies in corporate environments are based on Ethernet and IP protocol. The railway environment is gradually adopting such mature network technologies that simplify the architecture and are based on protocols widely used. The equipment that allows this architecture are switches, WiFi APs and routers.

- Switches: They operate mainly at the link level although some also have reduced the network layer (layer 3) functionality and primarily aim to ensure interconnection between a minimum of two segments on the same network;
- WiFi access points: They are used to interconnect a WiFi network with a wired network. They provide WiFi coverage and redirect data from the WiFi network to a wired network with access to the Internet or other devices/networks connected to it. They also operate at the data link layer although some APs in the market provide network-level functionality;
- Routers: They operate at the intersection of several networks, managing network-level communications. They manage routing policies and interconnection of networks and implement most internetworking protocols that facilitate the management, reliability, redundancy and quality of service in the interconnection of complex networks.

The terminal devices cover a wide spectrum and are dedicated to performing specific functions. For example, on-board PCs, IP cameras, control monitors, video screens, temperature sensors, alarms, Code Readers (QR or bar), passenger counting sensors, and power/energy consumption sensors are considered terminal devices

3.4.3.2.2 Communication to the sensors

There are multiple types of sensors depending on their required functionality.

- IP sensors: They base their communications on IP packets defined by the IP protocol. They can use the following physical means of data transmission:
  - Ethernet Cable: Ethernet Cabling for railways (with M-12 ports and corresponding certifications). They will be connected directly to the wired network (to a switch port) and have a specific IP like any other type of terminal,

- WiFi: including WiFi Client functionality to connect to an on-board WiFi network with some kind of authentication and send IP packets over WiFi frames. They will be connected to the on-board APs provided by the wireless service provider,
- 6LoWPAN: they use RF technologies that enable lower power consumption and support the transmission of IP packets. They must be connected to an on-board hub element using this technology. 6LoWPAN has better penetration than WiFi, but the radio frequencies must be checked to avoid interference with other bands (such as GSM-R, LTE-R, etc.). They are not widespread in the railway sector as they come from the Smart Grid market,
- LORA: This is the same concept than 6LoWPAN. Independent technology that requires an access point "speaking the same language". The major advantage is that there is no need to be wired and they exhibit minimum power consumption,

- Serial sensors: They use a serial interface for communications. They usually use asynchronous serial frame communications with frame formats independently defined for each sensor. The core software is programmed to that frame definition. To incorporate this information into the IP network, a computer that transforms the asynchronous serial frames to IP packets is required;
- Sensors based on digital I/O: they follow the same concept as serial sensors but with a simplified serial port. As a logic signal is transmitted, it requires equipment to convert this intermediate signal to an IP packet;
- Analogue sensors: They are older and require some type of CODEC for conversion to a digital signal and its transmission via IP packets.

Ethernet cabling will be used when available. Low energy cost 6LoWPAN and LORA are preferred to WiFi. When possible avoid serial sensors and analogue sensors to prevent the need of converters to IP.

3.4.3.2.3 Security, independence and management

3.4.3.2.3.1 Security and independence

The on-board IP network for non-critical services must share the same network resources (cables, switches, wireless APs and radio spectrum) for various types of information and services that must be independent.

In this type of multi-service networks, the isolation of the different services sharing the same network is crucial. For this purpose, there are some service protocols that allow logical isolation and disable any leakage of information between services:

- VLAN: It consists in (IEEE 802.1Q) labelling of IP packets. This way all packets of the same service/sensor carry the same label and cannot be read by devices that do not have configured the same label. This allows creating a "virtual" LAN in which there is only communication between packets with the same label;

- VRF (Virtual Routing and Forwarding): Allows to "split" a physical router into virtual routers. Thus, each virtual router can route packets within the interfaces associated with each particular virtual router. Each virtual router is usually associated with a specific service. VRFs ensure the total isolation of each service as one service will not see interfaces associated to other services;
- QoS: Within the IEEE 802.1Q tags there are fields that allow to prioritise different IP packets. Thus, in the event of bottlenecks in the LAN, when multiple services are sending data at the same time, critical services can be prioritised to prevent less critical services to interfere on the performance of the most important ones;
- Policy Routing: Allows routing by taking into account not only the IP destination fields of IP packets but also by applying other policies based on, for example, source IP, protocol type, and QoS tagged. This allows routing information from different sensors towards different applications without the need of knowing the destination IP previously.

In addition to isolating different services, it is also important to ensure that only devices from a specific service are able to connect to that service. The following technologies can be used:

- MAC Filtering: Allows to filter devices that can connect to the network by setting up a list of MAC addresses with access permissions. This is configurable for both networks, Ethernet and WiFi;
- 802.1X authentication: Allows to use external authentication servers (RADIUS/TACACS+) to authenticate devices/users when connecting to the network. In this way a centralised management of authorised username/password can be performed, as well as connection statistics of such equipment;
- MAB authentication: For simple devices such as sensors, the MAB (MAC Authentication Bypass) protocol allows the use of MAC as user/password in an 802.1X authentication process.

3.4.3.2.3.2 Management

Regarding management, all the equipment on a LAN must support different management profiles so that different types of users with different permissions to manage equipment can manage different technologies. There will be monitoring users who should not have permission to configure at all or other users in a specific service that should not be able to configure equipment that affects other services. Obviously, there will be users who should have special advantages to configure all the options of the equipment. In this case, users (and profiles) must be configurable locally and also using features such as AAA for a centralised management of different profiles and permissions.

In order to manage an on-board device SNMP (Simple Network Management Protocol) protocol is suggested. The use of Standard-based protocols like SNMP is extended through most of the communication networks. It allows easy integration with third party management tools defined to monitor communication networks.

Among the management software, it is important to include the following features to allow easy management of the onboard communication devices:

- Configure a control panel and reports for each user and operator;
- Monitor availability of the whole network in a unique console;
- Index, store and visualise generated logs from the network;
- Monitor of the assets through Network Self-discovery;
- Visualise metrics and performance data in graphs;
- Visualise infrastructure status through geographical maps;
- Generate reports according to Service levels (SLA) to ensure quality in business processes.

SNMP is an OSI layer 7 (application layer) protocol for configuring and monitoring router different characteristics. SNMP enables network hosts to read and modify some of the settings of the router’s operating characteristics. It allows software running on a remote host to contact the router over a network and get updated information about the router on request.

Therefore, centralised management of the routers in the network can be carried out. SNMP’s basic functions include:

- collecting information and modifying router operating characteristics on behalf of remote SNMP users;
- sending and receiving SNMP packets via the IP protocol.

The software that processes SNMP requests runs on the router and is called SNMP agent. The user program that makes SNMP requests runs on the user’s machine elsewhere in the network, not on the router, and is known as SNMP manager. The SNMP agent at the router and the manager at the work station use the UDP/IP protocol to exchange packets.

For more information about SNMP, refer to RFC: a Simple Network Management Protocol. Recommendations RFC 3410 to 3418, RFC 3584 and RFC 3826 provide information on the latest SNMP version, the SNMPv3.

3.4.3.3 Train-to-Ground Communications

The train-to-ground communications are the most critical point of the on-board network solutions requiring data transfer to the Internet or a central point. As a moving device, all technologies that enable communications alongside the line are based on the use of the radioelectric spectrum.

3.4.3.3.1 Train-to-Ground technologies on the market

Railways go through very different environments throughout their journeys ranging from overpopulated areas to sparsely populated areas, through mountains and large plateaus and tunnels and bridges. In the case of metropolitan deployments, the use of tunnels can get to cover most of the way. To have train-to-ground communications in the most cost-effective way, different radio technologies that are best suited to the environment of each segment of the route are used. Therefore, the Communications Gateway should be able to select the best technology available at all times and, in some cases, to use several technologies simultaneously.

Technologies available on the market today include the following:

- GSM-R (and LTE-R): Are technologies using bands defined specifically for remote control of critical railway systems. They are typically not used in non-critical services to avoid any interference;
- Cellular Networks (3G/4G): Reduce the initial investment required to provide train-to-ground communications as the investments are supported by mobile operators to cover their customers. Their main drawback is precisely the lack of coverage in unpopulated areas, tunnels or overhead in densely populated cities. To minimise these disadvantages, there are various strategies ranging from the use of various telecommunication operators simultaneously using private APNs and other services that "prioritise" communications station on other users, installation of BTSs (base stations) dedicated to service specified by the operator, etc.
  It is assumed that a 3G/4G cellular service is available along the Network Rail South of London;
- Satellite Communication: Provides coverage in remote and unpopulated areas and also ensures a contracted bandwidth. There is no competition in the spectrum. Its major drawbacks are determined by the cost of the solution (slightly more expensive in initial investment and maintenance than cellular operator solutions) and the delay associated with satellite communications (minimum 1000ms, compared to 200ms average in 3G);
- trackside WiFi networks: This involves the installation of infrastructure WiFi access points along the route and a WiFi client on-board. It requires a ground control system that enables the "fast-roaming" to move between APs, which says to the on-board WiFi client when to change to a new WiFi AP. It requires a higher initial investment but reduces operating costs (no need to pay for sending data). They are especially recommended in tunnels if there is no cellular coverage;
- other “RF Trackside networks”: It is the same concept as trackside WiFi networks. In this case, there are other technologies such as WiMAX, K-Mesh or WiFi protocols using private bands. Two types of installations, based on antennas or radiating cable, provide coverage along the route. They also require a high initial investment and special equipment and technology, reducing the advantages of scale-economies.

3.4.3.3.2 Standard protocols for aggregate use of several train to ground links

The different train to ground technologies mentioned in the previous chapter use IP protocol as the main communications protocol. Therefore, the Communications Gateway must be based on excellence in the treatment of IP networks and must be able to interact with other devices and IP networks. It is especially important that the router offers capabilities for monitoring and automated responses like NSM (Network Service Monitor) and NSLA (Network Service Level Advisor):

- NSM allows configuring different operations for monitoring WANs. In this case, operations like "Echo IP / ICMP" and "Jitter UDP" are configured (one for each available service and WAN link -including satellite). The "jitter" operation requires a computer in a central site to act as "responder";
- the NSLA facility allows associating these operations with automation mechanisms ("Advisors"). In this facility, acceptable limits for each service are configured, and results are obtained as a logical value indicating whether the quality of the link to the service (according to NSM operations) is acceptable or not.

Another useful functionality for downloading large files is to have GPS based automatisms. Thus, the sending data service would be activated, e.g. just in case of having technologies that do not involve charging for data (WiFi for example). One possible application is detecting that the train is in a garage or station, which would result in automatic switching-on of the wireless client to connect to a maintenance network and then downloading contents (for example sensors records) stored in an on-board computer.

The aggregated use of different WAN interfaces (Train-To-Ground links), to share the available bandwidths in each link, improves the quality of service provided to the internal network.

This sharing of resources based on simultaneous use of different links and the distribution of traffic between them is known as load balancing. However, the way to do this load balancing and the use of other top-level technologies give not only advantages but also some disadvantages, depending on the scenario and the traffic type.

This chapter describes the most commonly used methods, with a particular emphasis on the involved technologies, the efficient transmission of user data and the behaviour in a wireless environment.

3.4.3.3.2.1 Balancing by Packet

Such balancing means distributing packets consecutively via the different available WAN interfaces. In the case that available WAN links are similar and only small behavioural variations (e.g. fibre, Ethernet, etc.) are detected we would achieve high efficiency, avoiding the need of headers and obtaining nearly the sum of the capacities of used links.

This type of balance is used in high-performance computers and communications between large databases with large flows of information.

Its main drawback is that it requires the different links supporting traffic not to have delays in the link nor variation of the link delay, allowing packets to arrive in the right order at the destination (see Figure 3.13).

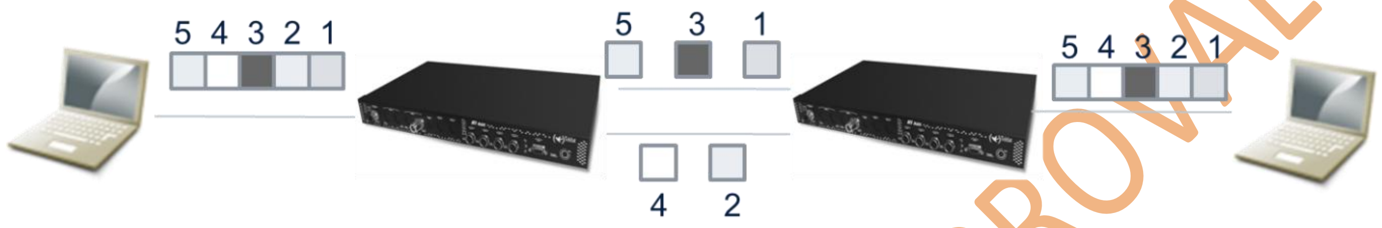

Figure 3.13: Balancing by Packet

3.4.3.3.2.2 Balance by User / Service

This balancing consists of fairly allocating bandwidth to each equipment/user/service on the LAN network. In this way, users are evenly allocated to each link. This ensures that each user/service assigned to a WAN link has exactly the same bandwidth than others in that link.

Thus, with a simple DHCP based configuration and simple routing, fair traffic without overloading configuration is achieved.

Its main drawback is that it can result in wasted bandwidth. If the user/service with less bandwidth demand is connected to a link, while other users/services demanding more bandwidth are connected to another link there could be a link with unused capacity and other with a saturated link (see Figure 3.14).

In addition, equity in the distribution of aggregate bandwidth available depends on the number of users. (If there are three users, two of them will share one link and the third one will be assigned to another link, so that the last user will have twice the bandwidth available). If there are many users, this difference is negligible.

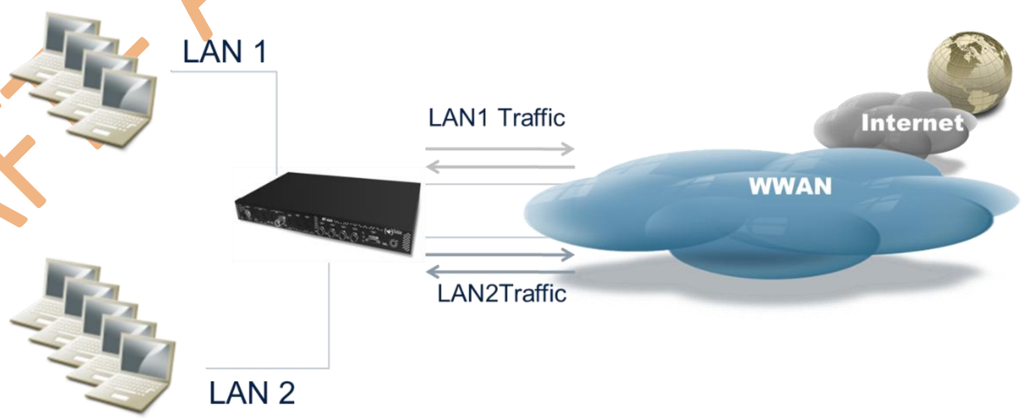

Figure 3.14: Balance by User/Service

3.4.3.3.2.3 Balancing per TCP session

This balancing works by distributing TCP traffic sessions between available links. A user can access different network destinations by opening different TCP / UDP sessions for each one to enable communication.

The disorder on packages from these sessions causes retransmissions and time-outs on applications. Thus, to ensure proper functioning, it is needed to have these packages with controlled entropy.

Furthermore, the use of multiple output interfaces (multiple links) carries different IP origin directions, which may lead to answers to different IPs by applications and therefore a malfunction.

The following diagram (see Figure 3.15) represents the behaviour of packets with packet load balancing in 3G:

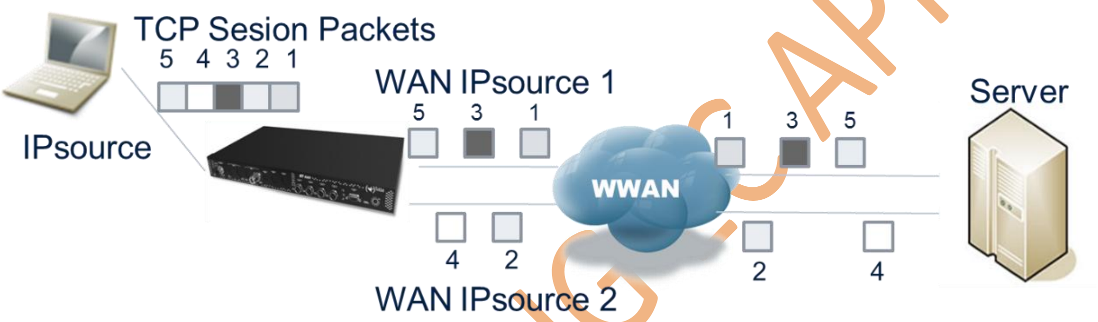

Figure 3.15: Balancing per TCP session

Balancing per session is to use a single WAN link for each session, avoiding disorder and duplication of IPs. Thus the integrity of the TCP/UDP sessions is guaranteed and mistakes are avoided in applications.

This balancing is done exclusively using dynamic routing policies so that no headers or redundant information are added, allowing all information sent by the WAN interfaces to be solely and exclusively traffic data demanded by users.

The diagram Figure 3.16 explains the distribution of traffic with such balancing.

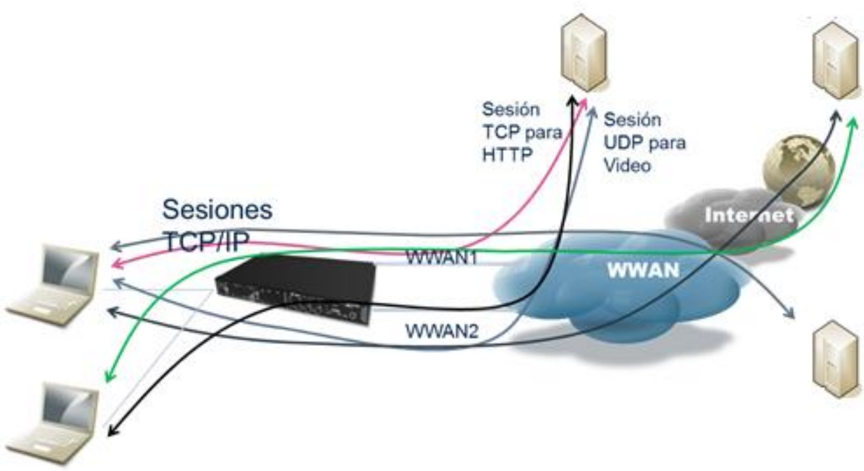

Figure 3.16: Architecture of Railway Communications for Non-Critical Systems

This type of balancing has the disadvantage that a TCP session has at most the capacity of a WAN link. Therefore, for point to point transmissions in a single TCP session, there is no improvement over a single WAN link. However, in an application scenario with multiple users accessing multiple destinations many TCP sessions are distributed evenly among all WAN links.

The advantages of this method are particularly important in the environment of wireless communications on-board and in movement, because the characteristics of WWAN links are highly variable and have a high entropy of delays and IP addressing. The most important advantages are as follow:

- independence from the difference between WAN links
  - important in 3G networks,
- keeps TCP/IP sessions on the same route
  - avoiding TCP retransmissions (connection oriented),
  - significant improvement in user-level applications such as web browsing.
- no overload headers
  - based solely on the data processing by the router,
  - in tariffing systems for data (as is a standard contract 3G) data transmitted are exclusively demanded by the application/user,
- it is the most efficient distribution after balance per package
  - total traffic is divided into minimum units allowing a better distribution among all WAN interfaces.

In a multiuser to multipoint environment, there are many open sessions optimising the distribution of these among the links.

3.4.3.3.2.4 Balancing per Virtual Tunnel

This kind of traffic balancing across multiple WAN links is a system of packet labelling and rearranging at both ends of the links that allows forwarding in order the information to a third party (Internet or other equipment).

With this labelling method, the problems of delays in the different WAN links are avoided and therefore, for applications that run outside the tunnel, packets arrive in order and with the same IP.

Technically, this is achieved by the combined use of protocols such as L2TP (Layer 2), MPPP, Multipath-TCP or proprietary implementations of IPSec.

The flow of information with this system is as follows:

1. the user application sends data;
2. the data arrive at a virtual interface that adds control data;
3. the data with headers are sent through different WAN links to a central IP;

4. in the central point, data are received in disorder;
5. the equipment in the central point stores the data received;
6. the control data is used to reorder packets;
7. the data is transferred to a third party (Internet or equipment) as an ordered packet flow.

The way back is the same but in the reverse direction. To avoid time-out in the applications at both ends, a proxy TCP is installed that continues sending ACKs to keep the application listening and to avoid retransmissions until the reordered packets are reached.

The following diagram Figure 3.17 shows the behaviour of packages with such balancing:

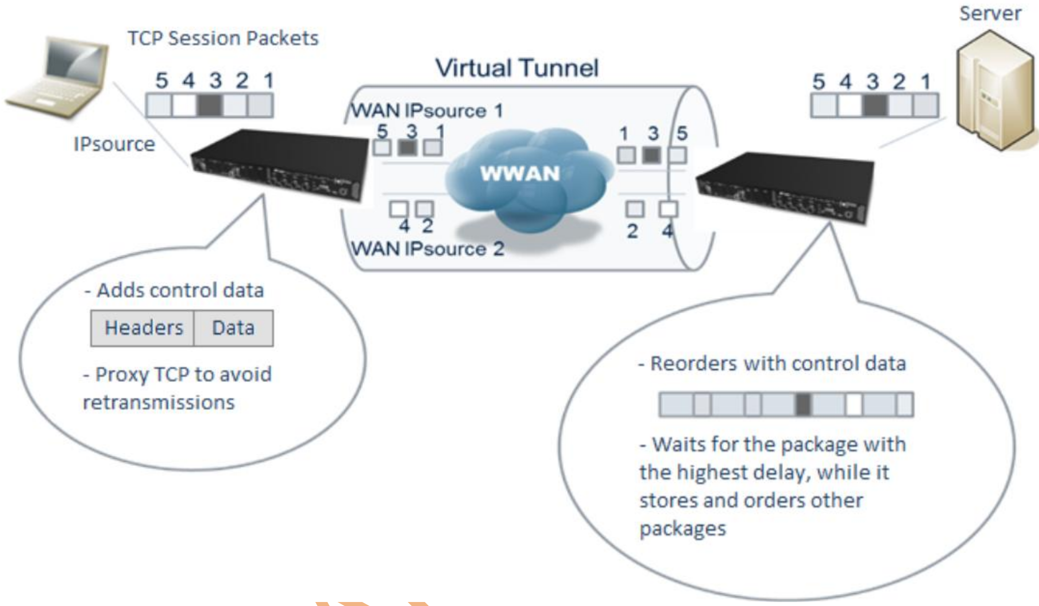

Figure 3.17: Balancing per Virtual Tunnel

This balancing method allows a single TCP session using all the capacity available for the system. Therefore, this type of balancing is commonly called as “bandwidth aggregation”. Its biggest advantage is that it is the only option in systems where one team must send large amounts of data to a single point and a single WAN link is not sufficient bandwidth and its quality does not allow balancing by packets.

By its nature, this solution has the following disadvantages:

- headers overload (up to 70%):
  - sending added information to the user data (Costs associated with data transmission),
- on-board high-power equipment and higher cost:
  - need a powerful processor in the on-board equipment to analyse and reorder packets received from different interfaces,
  - need memory in on-board equipment;
- equipment for high-power plant. Reorder packets sent from each remote unit;
- longer delays (waiting time for the slowest packets) (in 3G, 1-2seg estimated time)

    - high sensitivity in applications with RTP,
    - session timeouts in TCP/IP;
  - more sensitive to declines in service quality offered by operators:
    - operators share infrastructure. If limited by the BSS all overload affects the bandwidth available to the BSS.

Therefore, this solution is very useful in the case of broadband communications between two computers using several WWAN interfaces simultaneously. However, for multi-user environments to multipoint, as is a WiFi service to passengers, this solution is inefficient and costly.

For this reason, the latest trends are to require WiFi solutions using balancing per session.

A comparison chart and use cases of aggregation methods is made in the following Table 3.3:

Balancing type	Advantage	Disadvantages	Recommendation of Use Case
Packets Balancing	High efficiency	Very sensitive to quality of links	High performance computers and cable links, fibre, Ethernet ...
Balancing per User	▪ Easy configuration ▪ Evenly distribution of resources among users	Inefficiency. It may be the case that there are free resources and users saturated in another link	Scenarios in which you want to simplify the solution and provide equal access service (the resources in a link are distributed uniformly).
Balancing per TCP session	▪ it is independent to the difference between WAN links; ▪ keeps TCP/IP sessions on the same route (avoiding TCP retransmissions); ▪ no overload header (based solely on data processing from the router); ▪ it is the most efficient deal after balancing per packet	One session is limited to one link maximum capacity	WiFi services on-board ▪ mobility scenarios with great variability in the WAN links for communications type multipoint-to-multipoint.
Balancing by Virtual tunnelling	Allows aggregated traffic for a single session.	▪ headers overload (up to 70%); ▪ need a powerful processor in the on-board equipment to analyse and reorder packets received by different interfaces; ▪ high sensitivity in applications with RTP; ▪ session timeouts in	▪ PtP scenarios involving needs of bandwidth higher than available WAN link capacity. For instance: - streaming video, - synchronisation of databases via WWAN.

Balancing type	Advantage	Disadvantages	Recommendation of Use Case
		TCP / IP.	

Table 3.3 : Aggregation methods

3.4.3.3.3 Security, Independence, isolation and prioritisation of services

This chapter contains the requirements for the train-to-ground communications service to be provided by the mobile network operator. The most used technologies in the areas of security, independence, isolation and prioritisation of services are discussed.

3.4.3.3.3.1 Security

In the case of train-to-ground communications, different services share the same communications leading to a single point of failure that can impact multiple services simultaneously.

For this reason, it is important that gateways implementing train-to-ground communications enable redundancy protocols like VRRP with a master router and one back-up automatically activated in case of failure of the first one (see Figure 3.18).

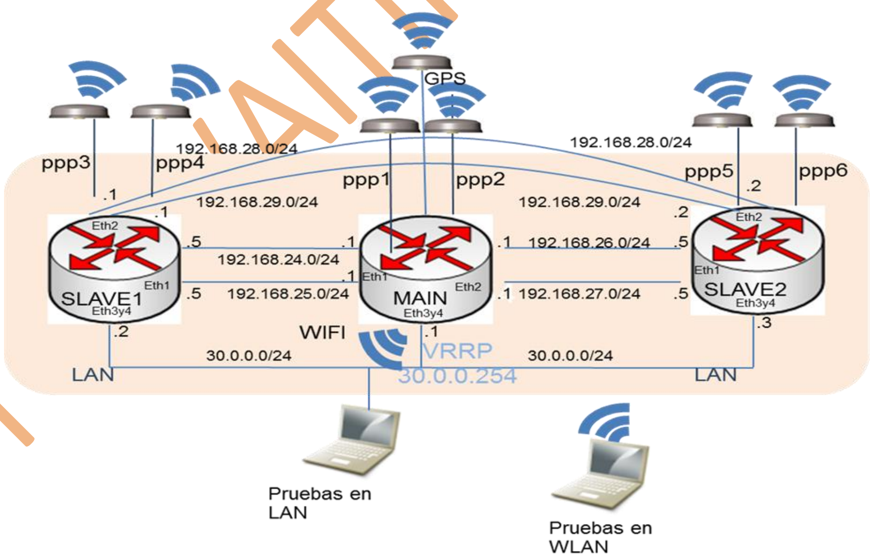

Figure 3.18: Gateway for train-to-ground communications

Moreover, some of these services may require encryption because they must be secure and confidential and will use third party networks (e.g. cellular, satellite, and WiFi). Therefore, the Gateway must be able to establish IPSec tunnels with certified encryption and support Dynamic routing for easy configuration of the central point. Using DMVPNs also facilitates the establishment of tunnels, new trains and communication between these thanks to the NHRP protocol.

If high security configurations using certificates are chosen, the SCEP protocol simplifies managing them by easing the update and synchronisation of certificates.

3.4.3.3.3.2 Multiservice communications

The multiservice communications are those that are designed to use the same communication link shared between several services. The advantages of establishing multiservice communications are:

- equipment specialised in communications can monitor and debug failures (e.g., coverage, packet loss, network synchronisation);
- just as a router in office, an on-board router is designed to interconnect different PCs with QoS mechanisms, FW and port monitoring that enables debug service behaviour and interaction with other network components;
- a unique and reliable communication device allows sharing the same interface across multiple services (e.g., access to marketing services, entertainment, internet access, monitoring sensors and cameras);
- it simplifies maintenance of communications to single equipment and one or more train-to-ground links;
- shared facilities, the same antennas are used for different services;
- it adds scalability to add new services in the future easily;
- it can incorporate different market services with the independent providers that best suit each type of solution;
- using a device certified by the operator ensures accountability of communications in the communications provider.

Multiservice communications must ensure the independence and isolation of the different services and monitor the less critical services likely to interfere on those most critical.

The use of tools such as policy routing, tunnelling (VPN) and QoS allows marking and prioritising traffic from different services. Applying prioritisation policies on the train-to-ground link that sets minimum bandwidth for each service, discard excess of packets if needed by one service or in case of collision between different services.

Policy routing allows the parameterisation of the policies to be applied in accordance with the values obtained in the monitoring of different links. For example, if it is detected that a link has more jitter than another, the policy routing allows automating the voice sending over the link with less jitter.

3.4.3.3.3.3 Tunnel Concentrators

In order to send all the information to a central site in a secure way, a tunnel concentrator which supports all the tunnelling standards is needed.

This tunnel concentrator should support the state-of-the-art of the following technologies:

- IPSec: In order to send the information in a secure way, the most common standard is using IPSec tunnelling. IPSec, is one of the most commonly used protocols for secured communications. The implementation of this standard and the number of options to configure it determine the security level that can be reached;
- GRE tunnelling: Allows automatic configuration of the central site with NHRP (Next Hop Resolution Protocol) and without configuring the VPN concentrator in each installation. The combination of GRE and IPSec is known as DMVPN;
- Dynamic Routing: The use of Dynamic routing protocols in the central site will allow no additional configuration for every new installation. Simplifying maintenance activities, thus, minimising failures and costs.

The Tunnel concentrator should be powerful enough to deal with all the installed base and it is preferable if it supports redundant configurations (using VRRP protocols and supporting IPSec prioritisation for backup tunnels).

3.4.3.3.4 Synchronisation

The NTP protocol (Network Time Protocol) is used to synchronise a set of network clocks using a distributed client and server set. The NTP protocol is constructed over UDP (User Datagram Protocol) supporting transport mechanisms not orientated to the connection. NTP provides a high precision synchronisation mechanisms and allows local clock error estimation at the same time as discovering the reference clock characteristics.

The goal of the service is to make sure - by means of the NTP protocol - that all the devices connected to an accurate clock source synchronise with it. Each NTP client, therefore, sends requests to various NTP servers and processes the replies when these arrive. This allows to select the most accurate clock at any given moment and to synchronise with it according to the samples received.

On-board devices should incorporate the following options:

- an NTP client. This synchronises the router's base time with the NTP servers;
- simple-NTP Server. This is a server for less precise applications, e.g. the synchronisation of devices connected to the router over a local network. The SNTP server can operate in two modes:
  - Unicast: the server responds to synchronisation requests from clients. This is the server's default mode,
  - Broadcast: the server sends NTP broadcast packets over the interfaces defined through configuration. In this mode, the server also responds to synchronisation requests from clients.

In devices that do not have a real-time clock (RTC), it is advisable to configure an NTP client with the idea that the SNTP server provides an adjusted base time. In any case, the server always responds to unicast requests even if the base time is not synchronised or adjusted. In broadcast mode, the base time must be synchronised or adjusted to real time. This behaviour is defined in RFC 4330 standard.

3.5 Solutions for applications design

This chapter aims to give examples of the algorithms to implement for data interpretation and the visualisation and decision-making tools that will answer the objectives of this use case.

A list of preferred applications will be chosen by Network Rail and project partners in a joint discussion.

3.5.1 Learning and estimation algorithms

3.5.1.1 Introduction

In this chapter, several learning and estimation algorithms will be proposed in order to solve a set of problems and challenges in relation to the energy consumption management of the railway system commercial line operation:

- a physical model of the train based on the fundamental principle of dynamics will be proposed. This model allows having a direct relationship between the different variables to be measured on the rolling stock, namely the electrical power from the pantograph, the speed, the acceleration, GPS coordinates, etc;
- based on the physical model of the train and the recorded data on the rolling stock (voltage, current, speed, acceleration, etc.), Bayesian Monte Carlo methods can be used in order to estimate some unknown or unmeasured parameters of the train that are very useful to achieve the energy management objectives;
- regression methods (e.g. Support Vector Regression, neural networks and decision trees) can be used in order to predict the energy consumption of the rolling stock.

Improving energy efficiency requires building accurate and adaptable models to study energy consumption. The data-driven models are built using machine learning algorithms. Building data-driven models does not require any domain knowledge; their accuracy depends mainly on the quality and quantity of the data.

3.5.1.2 The physical model of the train

Applying the fundamental principle of dynamics to the rolling stock, we can obtain the following relation between the electrical power from the pantograph, the mechanical parameters measured on the train: speed, position, acceleration, and slope gradient and the train characteristics, as in Equation 3-1:

$$km\frac{dv}{dt} = \frac{\left(U_p I_p - P_d - P_{aux}\right).\eta^d}{v} - \left(a + bv + cv^2\right) - mg\sin\alpha$$

Equation 3-1

where:

- k: the inertial coefficient;
- m is the mass of the train;
- v is the speed of the train;
- P_{aux}: the power of the auxiliaries;
- P_d: the power of the electrical losses;
- U_p : the voltage at the pantograph or at the contact shoe;
- I_p : the current at the pantograph or at the contact shoe;
- η : the engine efficiency;
- d : this coefficient takes the value of 1 when the train is in traction mode and -1 when the train is in braking mode;
- g: the gravitational acceleration;
- α : the slope of the track;
- a, b and c are the train running resistance coefficients.

3.5.1.3 Particle Expectation Maximization algorithm

Once the model is specified with its parameters, and data have been collected, the task is to estimate the unknown parameters. The Maximum Likelihood Estimation (MLE) is a quite popular method of estimating the parameters of a statistical model given observations. The basic idea behind this technique is to find the parameter values that make the observed data the most probable, i.e. maximise the likelihood of making the observations given the parameters.

Starting from an independent and identically distributed sample $\boldsymbol{x} = (x_1, \ldots, x_n)$ from a population with density $f(\boldsymbol{x}|\theta_1, \ldots, \theta_k)$, the likelihood function is, in Equation 3-2:

$$L(\theta|x) = L(\theta_1, \ldots, \theta_k|x_1, \ldots, x_n)$$

$$f(\boldsymbol{x}|\theta_1, \ldots, \theta_k) = \prod_{i=1}^{n} f(x_i|\theta_1, \ldots, \theta_k)$$

Equation 3-2

More generally, when the x_i are not i.i.d, the likelihood is defined as the joint density $f(x_1, \ldots, x_n|\theta)$ taken as a function of θ. The value of θ, denoted $\hat{\theta}$, which is the parameter value at which the likelihood function attains its maximums is known as the maximum likelihood parameter.

In particular, this method can be used for the parameter estimation of dynamic system in state-space form [2]. In fact, we consider the problem of identifying the parameters θ of the following state-space model structure, as in Equation 3-3:

$$\begin{cases} x_{t+1} = f(x_t, u_t, w_t, \theta) \\ y_t = h(x_t, u_t, v_t, \theta) \end{cases}$$

Equation 3-3

where x_t is the state variable, y_t is the observation and u_t is the input response. Furthermore, θ is a vector of unknown parameters. Finally, w_t and v_t represent mutually independent vector. Independent and identically distributed processes are described by the probability density functions $p_w(.)$ and $p_v(.)$. These are assumed to be of known form but parametrised by values that can be absorbed into θ for estimation if there are unknown.

The problem here is the estimation of the parameter vector θ based on the N inputs $\boldsymbol{u}_{1:N} = [u_1, \dots, u_N]$ as well as the N measurements $\boldsymbol{y}_{1:N} = [y_1, \dots, y_N]$. A MLE framework is employed and an EM algorithm in combination with a particle filter is derived to compute the ML estimates.

In fact, MLE involves maximising the likelihood $p(\boldsymbol{y}_{1:N}|\theta, \boldsymbol{u}_{1:N})$, as in Equation 3-4:

$$\hat{\theta} = arg\max_{\theta \in \Theta} p(\boldsymbol{y}_{1:N}|\theta, \boldsymbol{u}_{1:N})$$

Equation 3-4

or according to Bayes' rule the likelihood density can be decomposed as follows, as in Equation 3-5:

$$p(\boldsymbol{y}_{1:N}|\theta, \boldsymbol{u}_{1:N}) = p(y_1|\theta, \boldsymbol{u}_{1:N}) \prod_{t=2}^{N} p(y_t|\theta, \boldsymbol{u}_{1:N}, \boldsymbol{y}_{1:t-1})$$

Equation 3-5

Accordingly, since the logarithm is a monotonic function, the maximisation problem is equivalent to the minimisation problem, as in Equation 3-6:

$$\hat{\theta} = arg\min_{\theta \in \Theta} -L_\theta(\boldsymbol{y}_{1:N})$$

Equation 3-6

where $L_\theta(\boldsymbol{y}_{1:N})$ is the log likelihood defined as in Equation 3-7:

$$L_\theta(\mathbf{y}_{1:N}) = log\, p(\mathbf{y}_{1:N}|\theta, \mathbf{u}_{1:N}) = log\, p(y_1|\theta, u_1) + \sum_{t=2}^{N} log\;\; p(y_t|\theta, u_t, \mathbf{y}_{1:t-1})$$

Equation 3-7

So, a particle filter is implemented to calculate the prediction density $p(y_t|\theta, u_t, \mathbf{y}_{1:t-1})$ and an EM algorithm [3] is derived to compute the MLE.

3.5.1.4 Supervised learning (regression)

Based on the pre-processed data, our objective is to obtain the most accurate energy consumption model of the train. We then can use supervised learning algorithms which establish a relationship between a speed profile and its energy consumption. To evaluate energy consumption, in the context of energy management, we use regression algorithms. Regression is used when the target attribute takes continuous values. Started from known values of input attributes, the regression model estimates the class value. In order to estimate the power consumed for traction, we can use several machine learning algorithms such as Probabilistic Neural Networks (PNN), Decision Tree (DT) and Random Forest (RF).

Neural networks are computational models based on the underlying structure of biological neural systems. A neural network is composed of neurons which work in parallel to provide an output value based on the values of the input attributes. The learning algorithm modifies iteratively the parameters which regulate the connections between the neurons in order to minimise the error on the training set. The neural networks were used in [4] in order to compute the energy consumption of electric trains. In this work, we use the Probabilistic Neural Network (PNN) which is trained based on the Dynamic Decay Adjustment method using Constructive Training [5] as the underlying algorithm.

Decision trees algorithm is a very effective method in supervised learning. It has been introduced by [6]. The algorithm takes as input a collection of tagged data, and outputs a tree. Each internal node represents an input attribute where each value corresponds to an edge to children. Each leaf represents a value of the target variable. In order to determine the best splitting attribute, it is possible to use several methods such as gain ratio impurity [6].

The Random Forest model is introduced by [7]. It is an efficient machine learning model which was used widely for many real world applications. It is an ensemble learning algorithm based on the average prediction of different decision trees. Each tree is fitted on a part of the data.

3.5.1.5 Process for application

3.5.1.5.1 On-board measured data

In the context of the In2Rail experimentation, a data set has been made. Such data could also be acquired in the use case 1. In the In2Rail experimentation, the train measured dataset is composed of various parameters collected from sensing devices installed on-board. Measurements include voltage, current, speed and GPS position. The sampling frequency is equal to one second. In the deployment of practical systems such as the electrical railway system, information has to be collected from heterogeneous sensors. The electrical railway environment is characterised by the presence of high voltage and current with abrupt variation and train movements following urban topography (tunnels, bridges, hills, etc.).

These factors disturb the data measurement and transmission. Therefore, the collected data contain errors and inconsistencies.

3.5.1.5.2 Pre-processing

The aim of the pre-processing steps is to reduce errors, filter, clean and transform data. Several general pre-processing steps to be performed:

- management of missing values: the time steps where there are missing values are either ignored or replaced;
- train route extraction: the route is an ordered list of waypoints where each waypoint represents a turn or significant step of the track;
- extract train trips: identification of each distinct trip and its direction;
- computation of additional parameters.

3.5.1.5.3 Input attributes

In the In2Rail experimentation data set, the measurement frequency is one second. Each speed profile between two stations is then represented by the speed as a function of time. To compute the whole energy consumption of a speed profile, a model could be built to estimate the traction power in each second. To train and evaluate the different models (PNN, DT and RF) the following input attributes may be used: speed, train energy efficiency, acceleration, jerk (the rate of change of acceleration) and gradient (slope of the track). In order to estimate the electrical power accurately for each second, in addition to the information about the current second, the information about the previous and the next seconds could be used.

3.5.2 Visualisation and decision-making tools

Plenty of sensors allow the measurement of various physical elements in the railway system, yielding a huge volume of data. Therefore, advanced methods have to be used to summarise and visualise such data. We adopt web-based tools for rendering the observed and analysed data such as D3.js, Node.js and Vaadin. These tools are based on Java-script.

Graph and curve visualisation tools can be used to create energy management relevant applications such as visualising speed profiles between two stations. For example, in order to display interstation speed profiles, it is possible to select a line, a direction, a geographic section, a day type (working day or week-end) and a period (peak or off-peak). For each interstation, all corresponding speed profiles and traction power curves are displayed depending on the kilometric position or the time (See Figure 3.19 and Figure 3.20).

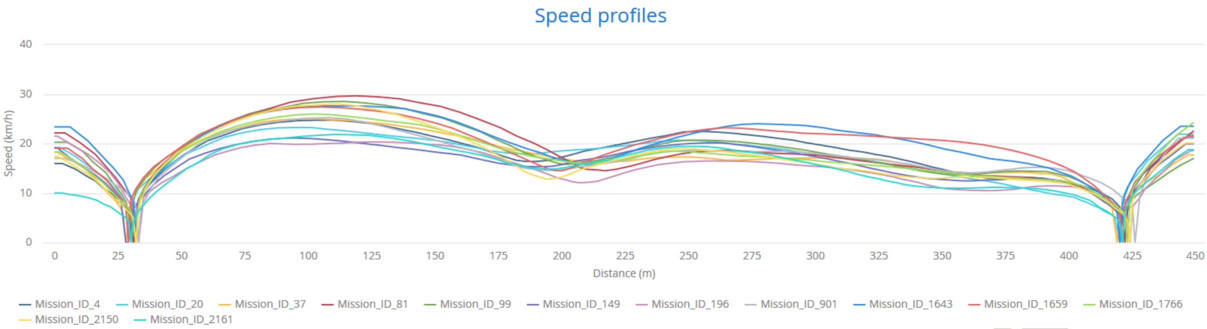

Figure 3.19: Example of interstation speed profiles

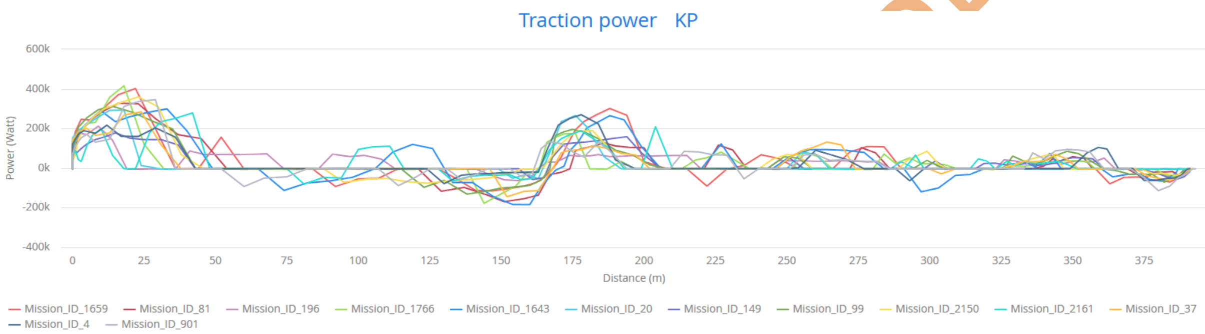

Figure 3.20: Example of interstation traction power

Each profile can be selected in order to show its detailed information such as energy consumption in function of specific criteria such as time, position, running time and average speed (See Figure 3.21).

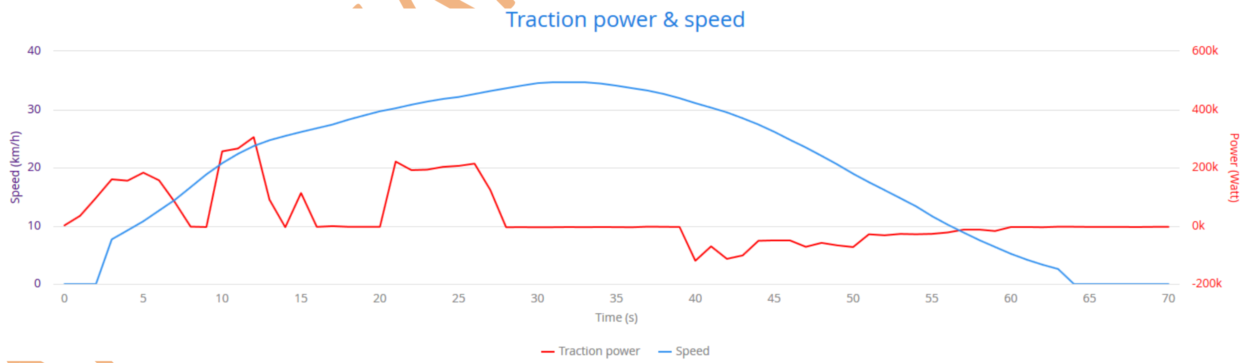

Figure 3.21: Example of traction power corresponding to the selected speed profile

In addition to the driving strategy, the energy consumption also depends on the slope of the track. The visualisation of the elevation makes it possible to evaluate the impact of the train's position on energy consumption (see Figure 3.22).

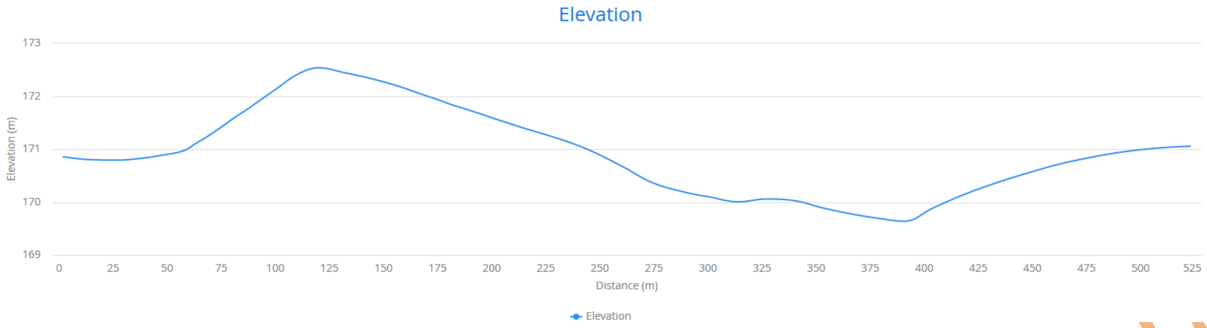

Figure 3.22: Example of elevation of the track

The speed profiles can be compared in order to find the best one which reduces energy consumption and satisfies operational constraints (respect of timetable, speed limitations, passenger comfort, etc.). The profiles can be sorted by function of all displayed parameters (speed, consumption, time, etc.). This allows evaluating speed profiles according to different criteria see Figure 3.23).

Mission ID	Positive Traction Energy_ Wh	Traction Energy_ Wh	Time_s	Speed_ Km H	Valid	Energy Class	Time Class	Ranking
Best_Profile	1 180	858	102	24	YES	A+	F	1
Mission_ID_194	1 231	929	103	23	YES	A	F	2
Mission_ID_146	1 345	919	106	23	YES	A	F	3
Mission_ID_62	1 346	959	99	24	YES	A	F	4
Mission_ID_80	1 388	954	102	24	YES	B	F	5
Mission_ID_36	1 423	981	101	24	YES	B	F	6
Mission_ID_1642	1 575	1 047	97	25	YES	C	D	7
Mission_ID_899	1 650	944	101	24	YES	D	F	8
Mission_ID_2160	1 658	1 130	94	26	YES	D	B	9
Mission_ID_1255	1 832	1 172	93	26	YES	E	A	10
Mission_ID_1738	1 995	1 227	92	26	YES	F	A	11

Figure 3.23: Evaluation of speed profiles

Similarly, information of the electrical consumption can be realised, to bring a better understanding of the energy flows in the network. The evolution among time of the consumption can be analysed in further details (See Figure 3.24).

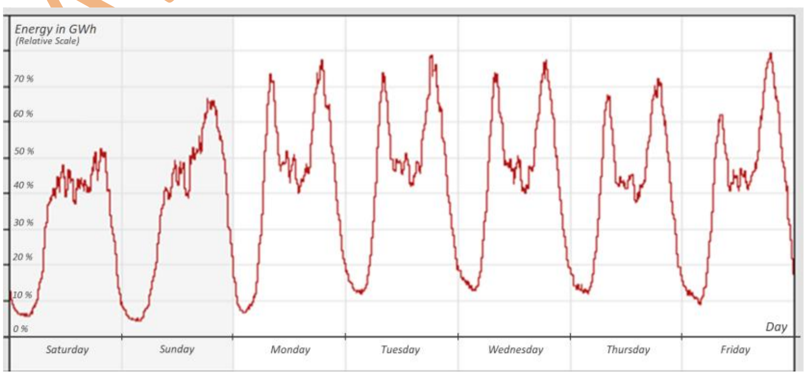

Figure 3.24: Evolution of a weekly consumption on SNCF Power Supply Network

3.6 Planning of Shift2Rail demonstrator implementation

Two main WPs, which work jointly, have been identified in the Shift2Rail/In2Stempo project: the technological solutions will be developed in WP5, and they will be integrated in a technical demonstrator for each use case defined in WP4. Therefore, the solutions are proposed generically within the framework of the project, but their application and their integration depend on the site concerned and the associated constraints. During the In2Stempo project, we will study the case of integration in the site of Network Rail according to the following planning.

In2Stempo WP4 – Railway System Smart Metering Use Cases		
Task 4.1 – Commercially operated line Smart Metering use case (CO-OP)	*Subtask 4.1.1: Functional specifications of the CO-OP operational use case*	Start date: 01/09/2017 End Date: 01/07/2018
	Subtask 4.1.2: Implementation of the CO-OP operational use case	Start date: 01/09/2018 End Date: 01/07/2019
	Subtask 4.1.3: Integration Tests of the CO-OP operational use case	Start date: 01/07/2019 End Date: 01/01/2021
	Subtask 4.1.4: Demonstration and Assessment of CO-OP operational use case	Start date: 01/01/2021 End Date: 01/09/2021
In2Stempo WP5 – Smart Metering Technology Development and Implementation		
Task 5.1 – Sensors & Telecommunications	*Subtask 5.1.1: Technical Specification and Design – link with In2Rail*	*Start date: 01/09/2017* *End Date: 01/09/2018*
	Subtask 5.1.2: Technological components implementation in use cases	Start date: 01/09/2018 End Date: 01/07/2019
	Subtask 5.1.3: Technological test, demonstration and assessment of functional operation in use cases	Start date: 01/07/2019 End Date: 01/01/2021
Task 5.2 – Operational Data Management	*Subtask 5.2.1: General Specification and Architecture Design - link with In2Rail*	Start date: 01/09/2017 End Date: 01/09/2018
	Subtask 5.2.2: Technological components implementation into the use cases	Start date: 01/09/2018 End Date: 01/07/2019
	Subtask 5.2.3: Technological test, assessment and validation of ODM platform in an operational context	Start date: 01/07/2019 End Date: 01/01/2021
Task 5.3 – User Applications and Decision Support Tools	*Subtask 5.3.1: General Specification and Architecture Design - link with In2Rail*	Start date: 01/09/2017 End Date: 01/09/2018
	Subtask 5.3.2: User Application implementation into the use cases	Start date: 01/09/2018 End Date: 01/07/2019
	Subtask 5.3.3: User Applications and Decision Support Tools test, demonstration and assessment of functional operation in use cases	Start date: 01/07/2019 End Date: 01/09/2021

Table 3.4: In2Stempo Planning

3.7 Conclusion

In this chapter, the adaptation of the experimentation of the In2Rail project to the use case for a commercially operated railway line under normal traffic conditions has been shown. The Reims tramway has numerous similarities with this use case: the analogue levels of DC voltages and current involved allow to employ the same sensors to collect the data, and to manage the flow of information. Furthermore, the adaptive architecture of the ODM platform of In2Rail can also be applied in this use case, thanks to its generic structure.

Moreover, the methods used for the applications of the Reims experimentation can approximately be applied here, since the projects share close objectives. The same algorithms for prediction and interpretation can be used, such as the visualisation tools.

This chapter has therefore demonstrated the feasibility of the first use case of Shift2Rail, directly based on the experimentation of the In2Rail project.

4 Description of the use case Stationing and Maintenance Facilities (STM-OP)

4.1 Introduction

The smart metering use case for stationing and maintenance facilities (STM-OP) will be implemented at the Eurotunnel infrastructure in France. The main objectives of this use case are studying the energy management options and identifying energy efficiency potentials for stationing and maintenance facilities and the rolling stock parked there, monitoring of the relevant infrastructure and rolling stock status as well as to improving the infrastructure performance.

4.2 Situation overview

Hereafter, some general information about Eurotunnel experimentation site are presented:

- the Eurotunnel site on the French side is composed of several railway buildings which constitute the French terminal:
  - Depot: will concern the management of energy consumption of the infrastructure and rolling stock,
  - Maintenance facilities: will concern the management of energy consumption of the infrastructure and rolling stock, and the lighting,
  - Terminals for loading and unloading vehicles on the trains: will concern the management of energy consumption of the infrastructure and rolling stock, and the lighting,
  - Railway Passenger building: will concern the lighting and the HVAC,
- The power supply of the electrical infrastructure is 25 kV AC, and the buildings are supplied with high voltage, converted to common supply voltage for the lighting and the HVAC;
- Rolling stock used on this field, which are passenger shuttles for cars and buses and truck-shuttles for the lorries are coupled with the same electrical locomotives, with a power of 5.6 MW for the oldest engine, and 7 MW for the updated ones.

The table below identifies the different energy consumer buildings in function of the different sites of the Eurotunnel zone from the French side.

Services concerned	Train supply	Lighting	HVAC
Depot	x		
Maintenance facilities	x	x	
Loading and unloading platforms	x	x	
Railway passenger building (Charles Dickens)		x	x

Table 4.1 : Type of energy consumption functions of railway building

The In2Rail project did not study the case of the energy consumption of the lighting systems. The train supply systems is more related to the use case 3 in terms of sensors implementation. Therefore, in the use case 2, only the application of the In2Rail solutions for the HVAC systems, and will be detailed in this chapter.

The map below identifies the different buildings on the Eurotunnel site:

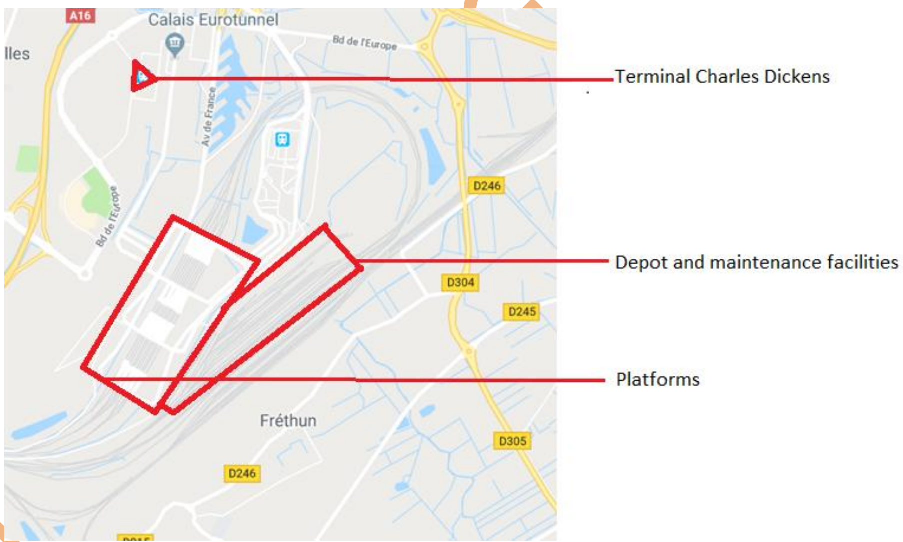

Figure 4.1: Eurotunnel stationing and maintenance facilities map

Figure 4.2 : Loading and unloading platforms (Source: Revue Générale des Chemins de Fer n° 206 – June 2011)

Figure 4.3: Maintenance workshop (Source: Revue Générale des Chemins de Fer n° 206 – June 2011)

Figure 4.4: Passenger terminal Charles Dickens

Eurotunnel owns two kinds of rolling stock:

- Passenger shuttles:

These trains convey cars, low vehicles and buses.

Figure 4.5: Passenger shuttle (Source: Revue Générale des Chemins de Fer n° 206 – June 2011)

- Truck shuttles:

Moved by the same locomotives, it runs with truck wagons instead of passenger shuttles.

Figure 4.6: Wagons of truck shuttles (Source: Revue Générale des Chemins de Fer n° 206 – June 2011)

4.3 Solutions for data management design

As indicated in the first use case, the platform used for the use case should be the same as for the three use cases: the ODM platform is normally a generic solution.

4.3.1 ODM Platform

Since the platform described in Chapter 3.3.1 will manage data for the three use cases, the description of the platform is here the same as in the chapter.

4.3.2 Communication platform

The communication described in Chapter 3.3.2 gather the types of communication for the three use cases. The description on the platform is here the same as in this chapter.

4.4 Solutions for sensors and metering design

The aim of this chapter is to show that the sensors can be adapted to the range of each use case and can communicate with the generic platform.

4.4.1 Onboard metering solution

4.4.1.1 Traction measurements

As in the first use case, the same variables like voltage and current sensors to be installed to measure the electrical traction power and consumption: the sensors will be updated to the Eurotunnel use case (25 kV ac).

4.4.1.2 Auxiliaries measurements

Voltage and current sensors will be installed to measure the consumption of the auxiliaries. The type of voltage and current will correspond to the situation in Eurotunnel.

4.4.2 Trackside metering solutions design

As in the first use case, the same variables like voltage and current will be measured (Item 3.4.2).

4.4.2.1 Bill of quantities

The substation is composed of three transformers. One of them supplies the French terminal for the traction system. Similarly to the use case 1, the following can be assumed regarding the list of quantities for this transformer.

Trackside Metering Solution Design	Type of sensors	Sensor range	Communication
Complete date (year, month, day)	Time synchronisation system	/	2 WS motes per measurement point 1 Gateway
Complete time (hour, minute)		/	
Power transformer – Output side – voltage	AC single phase: 1 voltage sensor	75 MVA	
Power transformer – Output side – current	AC single phase: 1 current sensor		
Power transformer – Output side – power factor	AC: 1 Wattmeter		
Auxiliaries – voltage (3-phase)	AC: 3 voltage sensors	600 kVA - 6 MVA	
Auxiliaries – current (3-phase)	AC: 3 current sensors		
Auxiliaries – power factor (3-phase)	AC: 1 Wattmeter		

Table 4.2: Bill of quantities for trackside metering solution

4.4.3 Auxiliaries metering solutions design

4.4.3.1 Optimisation of HVAC energy consumption

Within this second use case, HVAC equipment is present only in the railway passenger building: terminal Charles Dickens. Therefore, this building is taken as a possible target for applying the energy efficiency solutions proposed here. However, it has not been possible to gather detailed information about HVAC equipment in terminal Charles Dickens. As a result, general assumptions are stated and a general bill of quantities is proposed for each of the solutions.

In the following paragraphs, the above-mentioned solutions are introduced and their benefits are discussed. Then, a description of a plausible scenario for the existing HVAC facility in the building is presented, including the assumptions critical for the technical feasibility of the solutions. After that, details are provided about the implementation works and, finally, a separate bill of quantities is provided for each of the solutions.

4.4.3.2 HVAC energy efficiency solutions

The solutions proposed here address energy efficiency with two different and complementary approaches: optimising the rational use of energy and optimising technology efficiency. On the one hand, a demand side management solution (which is referred to as *Station Solution* in deliverable D11.4) is a solution to optimise the rational use of energy in the whole of the HVAC system of the building (i.e. centralised production, water distribution, air handling units and fan-coils) by enforcing certain demand side management (DSM) actions. Indeed, it models the behaviour of the building (energy use and indoor temperatures) as a function of the possible DSM actions and the environmental conditions (outdoor temperature). Then, on a daily basis (at night) and taking into account the weather forecast, it simulates different scenarios of possible DSM action schedules (e.g., different start/stop times for HVAC system or different temperature setpoints modulation curves) and chooses those schedules optimising the energy use while ensuring the comfort range established by the facility manager. Finally, these daily schedules are sent from the Cloud to the Energy Controller installed in the building, which takes care of governing the BMS accordingly.

On the other hand, Chiller Optimiser is a second, independent solution which optimises the efficiency with which a chiller produces refrigerated water or a heat pump produces hot water and, thus, it applies only to the centralised production (as opposed to the demand side management solution). In other words, it optimises the efficiency with which thermal energy is produced out of the electrical energy consumed, but it does not affect the rationality with which this thermal energy is used. To accomplish this, an application in the Cloud accesses the internal working parameters of the chiller or heat pump through a local hardware unit (Chiller Optimiser) and a communication card that must be supported by the machine. The communication card provides the application with real-time information on internal status and allows for internal working parameters to be adjusted. The application in the Cloud runs the assessment and optimisation process whereas the local hardware unit enables continuous operation even in the case of loss of communication with the Cloud.

The benefits expected from these solutions are as follows. Regarding energy performance, the demand side management solution can provide up to 10 % of savings in the total yearly energy use whereas Chiller Optimiser can provide between 15 and 20 % of savings in the total yearly use. When installed simultaneously in a building, both solutions provide added savings because of their complementary operating principles. Combined savings can reach 28 %.

Regarding operational performance, the demand side management solution can improve quality of operation in the sense that consistency in comfort settings (temperature setpoints) is centrally established for the whole building and ensured by the Cloud, thus avoiding arbitrary exceptions enforced directly in the local BMS for certain parts of the building. However, failure in communication with the cloud platform providing DSM actions could lead to HVAC systems not working with proper schedules. In this or any other case, local maintenance staff can disable cloud-control mode and configure back the BMS as needed.

For its part, Chiller Optimiser is transparent as far as operational performance is concerned and, thus, has no substantial impact on this respect.

Regarding maintenance performance, Chiller Optimiser provides specific functionalities which can have a substantial impact. Indeed, all internal status parameters in the chiller or the heat pump are continuously monitored and abnormal deviations from expected values are automatically detected and used to report a maintenance alert which can anticipate a possible failure in the machine. This alert can assist maintenance staff in diagnosing the problem and fixing it efficiently. For its part, the demand side management solution has a neutral effect regarding maintenance performance and, thus, has no impact on this respect.

4.4.3.3 Description of the baseline scenario and assumptions

It is assumed that general (utility) meters are present for electricity and natural gas supplies and that these meters are able to provide readings of consumption, at least on a dry-contact basis. However, no additional energy monitoring capabilities are taken for granted.

It is also assumed that HVAC equipment roughly meets the following description:

- centralised production of refrigerated water by two electric chillers;
- centralised production of hot water by two natural gas boilers;
- primary treatment of air by two air handling units;
- secondary treatment of air by multiple fan-coils.

The HVAC system is supposed to be integrated into a building management system (BMS) comprising the following components:

- personal Computer hosting the supervisory software for maintenance staff to operate the HVAC system;
- ethernet-based local area network with access to the Internet;
- controllers and instrumentation (measurement and actuation) implementing local control and regulation loops for the HVAC equipment;
- local room displays for building occupants.

The key assumptions specific to the feasibility of demand-side management solution include:

- existence of a BMS controlling the HVAC system;
- BMS supporting OPC or BACnet IP protocols;
- presence of maintenance staff in charge of operating the building;
- off period during night, e.g. from 12 pm to 5 am.

On the other hand, the key assumptions specific to the feasibility of Chiller Optimiser solution include:

- centralised production of refrigerated water by chillers and/or centralised production of hot water by heat pumps (instead of boilers);

- communication capabilities on chillers and heat pumps by smart cards.

4.4.3.4 Description of works involved

In the following lines, actions necessary for the implementation of both energy efficiency solutions are detailed. In any case, prior to any intervention, technical visits to the terminal Charles Dickens would be conducted to confirm feasibility and coordination with the facility management service responsible for the building would be ensured.

Regarding the demand side management solution, the necessary works would be as follows:

- **Energy Manager:** supply of a software-as-a-service (SaaS) subscription for the use of that energy management platform for two years;
- **Subscription:** supply of a SaaS subscription for the use of the app for two years, running within the above-mentioned account of the Energy Manager;
- **Energy Controller**: supply and installation of control cabinet Energy Controller (700 x 500 mm), including Energy Controller CPU and a gateway. Also, it includes connexion to UPS 230 Vac network existing in the building as well as Ethernet connexion to local area network existing in the building, in such a way that simultaneous connectivity with the personal computer hosting the BMS supervisory software and with the Internet is enabled;
- **Integration of the general (utility) electricity meter** into the Energy Manager account, including:
    - supply and installation (if needed) of communication device in the meter,
    - supply and installation of cable between the meter and the gateway and connection at both ends,
    - declaration of new device in the Energy Manager account;
- **Integration of the general (utility) gas meter** into the Energy Manager account, including:
    - supply and installation of pulse emitter in the meter (if needed) and pulse counter,
    - supply and installation of cable between the meter, the pulse counter and the gateway and connection at both ends,
    - declaration of new device in Energy Manager account;
- **Electricity meters for chillers**. Supply, installation and integration into Energy Manager account of two electricity meters, including:
    - supply and installation of cable between meters and the gateway and connection at both ends,
    - declaration of new devices in Energy Manager account;
- **Intervention on the personal computer hosting the BMS supervisory software**. Supply and installation of auxiliary software to allow communication of BMS supervisory software with Energy Controller;

- **Tailored development and commissioning**, including:
    - assessment of the building and definition of the abstraction model: control zones and thermal zones,
    - installation and configuration of the demand side management app, including:
        - installation of the app in the Energy Manager account,
        - selection of the reference meteorological station,
    - programming of the Energy Controller CPU, including:
        - configuration to enable communication with the Cloud and the personal computer hosting the BMS supervisory software,
        - programming customised for the building, mapping the DSM actions received from the Cloud with controls (i.e. on/off buttons, etc.) existing in the supervisory software,
    - gathering and declaration of training data, to allow the algorithms in the Cloud to obtain the model of the building's behaviour,
    - definition of events and alarms for supervision,
    - activation of the cloud-driven mode and intensive surveillance during the subsequent two weeks,
    - training course (2h) for the operation and maintenance staff.

As far as Chiller Optimiser is concerned, the implementation works include:

- **Chiller Optimiser subscription**. Supply of a SaaS subscription for the use of Chiller Optimiser for two years;
- **Chiller Optimiser cabinet**. Supply of control cabinet Chiller Optimiser (300 x 400 mm), including cables for connection to UPS 230 Vac network existing in the building;
- **Peripherals for Chiller Optimiser cabinet**. Supply of pressure and temperature sensors, including cables for connection to Chiller Optimiser cabinet;
- **Communications cards**. Supply of communication cards for existing chillers, enabling access to their internal working parameters and status variables;
- **Autonomous Outdoor sensor.** Supply of Zigbee sensor for outdoor temperature, humidity and solar radiation, including cable for connection;
- **Installation and commissioning of the system**, including configuration of SaaS user interface.

4.4.3.5 Bills of quantities

The following Table 4.3 and Table 4.4 include the bills of quantities that summarise the items of work involved in each of the HVAC energy efficiency solutions.

Demand Side Management Solution		
No.	**Item of work**	**Qty (pcs)**
1	Supply of yearly subscription of Energy Manager (SaaS)	2
2	Supply of yearly subscription of SaaS app	2

3	Supply of Energy Controller cabinet, including Energy Controller CPU and gateway.	1
4	Installation of the Energy Controller cabinet, including connection to existing UPS 230 Vac and Ethernet networks	1
5	Integration of general (utility) electricity meter into the Energy Manager account	1
6	Integration of general (utility) gas meter into the Energy Manager account	1
7	Supply, installation and integration into the Energy Manager account of electricity meter for chiller	2
8	Intervention on the personal computer hosting the BMS supervisory software to enable communication with Energy Controller cabinet	1
9	Tailored development, commissioning and training of the system, including: - assessment of the building - installation and configuration of the app - programming of the Energy Controller CPU - collection and declaration of training data - definition of events and alarms - start-up the systems and 2-week follow-up - 2-hour training for the maintenance staff	1

Table 4.3. Bill of quantities of solution

Chiller optimiser		
No.	**Item of work**	**Qty (pcs)**
1	Supply of yearly subscription of Chiller Optimiser (SaaS)	2
2	Supply of Chiller Optimiser cabinet	1
3	Supply of peripherals for Chiller Optimiser cabinet	1
4	Communication card for existing chiller	2
5	Autonomous ZigBee sensor for outdoor temperature, humidity and solar radiation	1
6	Installation of components and commissioning of system	1

Table 4.4. Bill of quantities of Chiller Optimiser solution

4.4.4 Loads Optimisation Process

4.4.4.1 Description of works involved

The first step to do in a process of electrical energy efficiency is to carry out an electrical energy diagnosis and audit. In this process, measurements of power and energy will be taken, as well as other variables necessary for making the suitable decisions.

Secondly, a proper data analysis should be made, in order to identify the misbehaviours of the electric installation, billing overpaying due to excessive load currents or overheating on some circuit or circuits. Afterwards, technical conclusions are deduced from the aforementioned analysis and real solutions proposed. The communications part is also important here, to establish the most suitable protocol and architecture for the new optimisation system. The whole process' chart is shown below (See Figure 4.7).

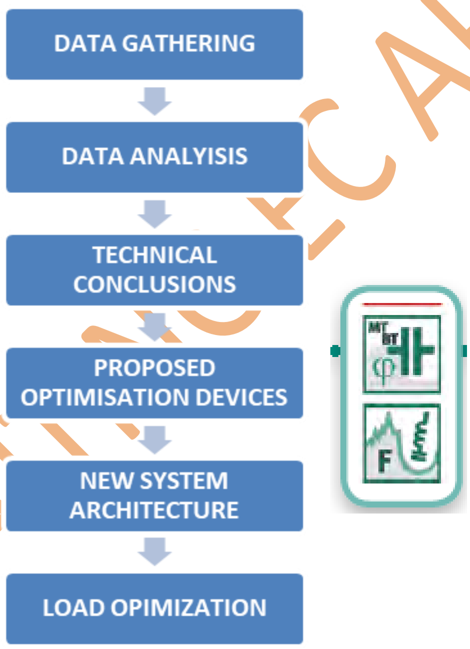

Figure 4.7: Process' chart

Each of these steps will be described in the following chapters.

4.4.4.2 Data gathering

4.4.4.2.1 Equipment to be used

The measurement equipment will be Circutor AR5-L power quality analysers, whose main characteristics will be:

- power supply: 230Va.c. 50Hz, 15VA;
- measurement circuit: three-phase;
- transformation ratio: programmable;
- internal memory: 1MB;
- accuracy class (see Table 4.5).

Voltage	0.5% ±2 digits
Current	0.5% ±2 digits
Real power	1% ±2 digits
Reactive power	1% ±2 digits

Table 4.5: Accuracy class

- security: Category III – 600V;
- connection to portable PC through serial cable for downloading data;
- current measurement sensors: six units of clamp current meters whose characteristics are shown on Table 4.6):

Measuring range	0.05A...5A
Dielectric rigidity	5200V, 50Hz, 1min
Full scale error	1 %

Table 4.6: Characteristics of current sensors

Voltage measurement sensors: eight units of voltage cable with banana connectors and eight units of crocodile clamps. All these are category III- 1000V devices.

Some images -Figure 4.8, Figure 4.9, Figure 4.10, Figure 4.11 and Figure 4.12- are given below to show the devices to be used here:

Figure 4.8: AR5-L power quality analyser (front view)

Figure 4.9: AR5-L power quality analyser (rear view)

Figure 4.10: Clamp current meters

Figure 4.11: Clamp current meters (detail)

Figure 4.12: Voltage measurement sensors and conductors

4.4.4.2.2 Measurement equipment installation

Two different situations deserve differentiated attention:

- measures that require putting out of service some Stationing and Maintenance Facilities loads, such as automatic escalators drives, lighting system, portable tools power supply, etc;
- loads that are of no use for the railway system throughout the whole night must be switched off.

The voltage and current measurements will be taken from the main AC distribution panel input. This panel is in charge of supplying all the Facility loads. To measure the current there will be connected three current clamp meters around the cables coming from the auxiliary services transformer. The maximal error value given from the current clamp when 1A is provided is between 0.4% and 4.2%.

To measure the voltage there will be connected three voltage sensors in the panel copper busbars.

To sum up, the different measurement sensors will be installed as shown in the following image (See Figure 4.13):

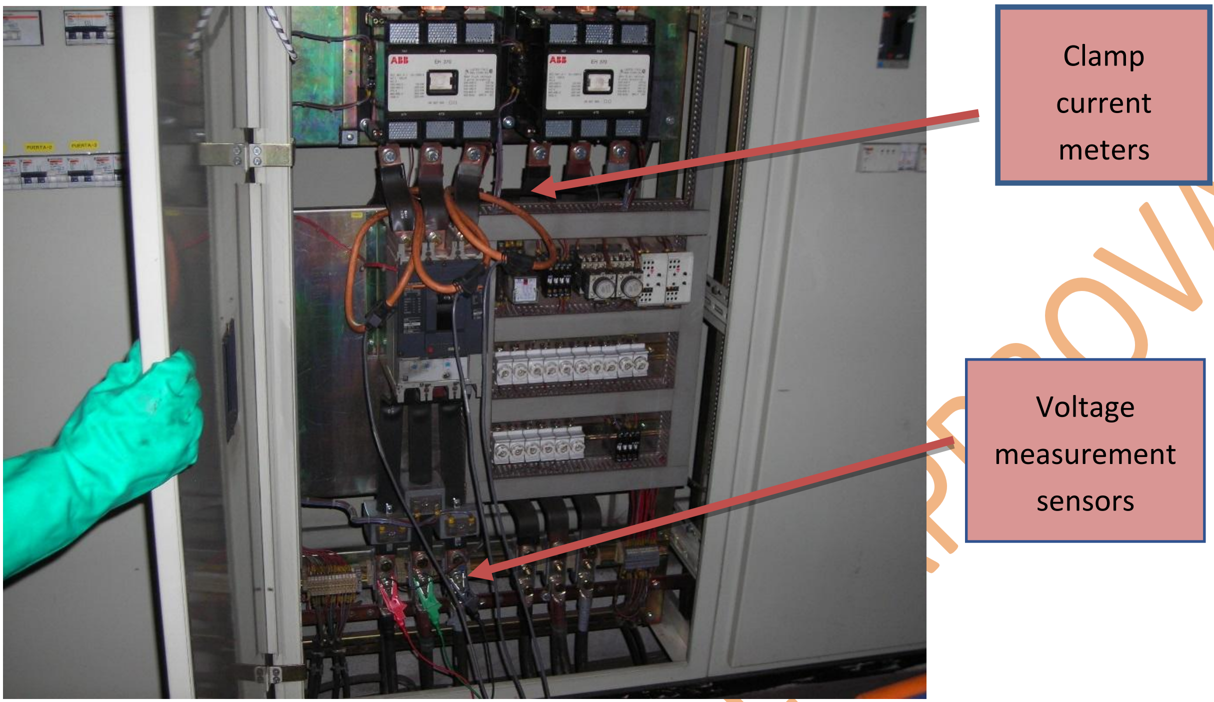

Figure 4.13: Measurement sensors to be installed

The voltage and current cables must be bridled and tied to a secure point of the main AC distribution panel. The power supply of the analyser must be connected to the closer socket. Later the analyser will be switched on, and it will be properly configured.

To perform all installation and removal operations of the portable measurement devices safely, it is recommended to use the following personal protective equipment:

- electrical safety gloves;
- safety goggles;
- safety boots, with toe cap and midsoles;
- isolated bench;
- helmet.

4.4.4.2.3 Data to be gathered from the installation

- three-phase and one-phase Voltage;
- three-phase and one-phase Current;
- three-phase and one-phase True Power;
- reactive Power (and its inductive or capacitive components);
- power factor;
- Voltage Total Harmonic Distortion (VTHD);
- Current Total Harmonic Distortion (CTHD).

It is worth pointing out that the VTHD and CTHD components should also be gathered, so a table like what is shown below must be filled (see Table 4.7):

HARMONIC	1	3	5	7	11	13	∑ THD
U_n (%)	--						
I_n (%)	--						
I_n (A)							

Table 4.7: Detailed harmonic values worth gathering

The measurement duration it is recommended to last about a week, in order to gather enough data as to reach a comprehensive idea of the electrical behaviour of the electric system of each Stationing and Maintenance Facilities Buildings. In order to get it, a measuring planning will be worked out properly.

4.4.4.3 Data analysis

Once the data has been gathered from the installation, it will be downloaded to a PC and analysed using the Power Vision Software, manufactured by Circutor.

This software will allow us to figure out the electrical behaviour of each installation, as voltages, currents, power factor and harmonic distortion are concerned (see Figure 4.14 and Figure 4.15):

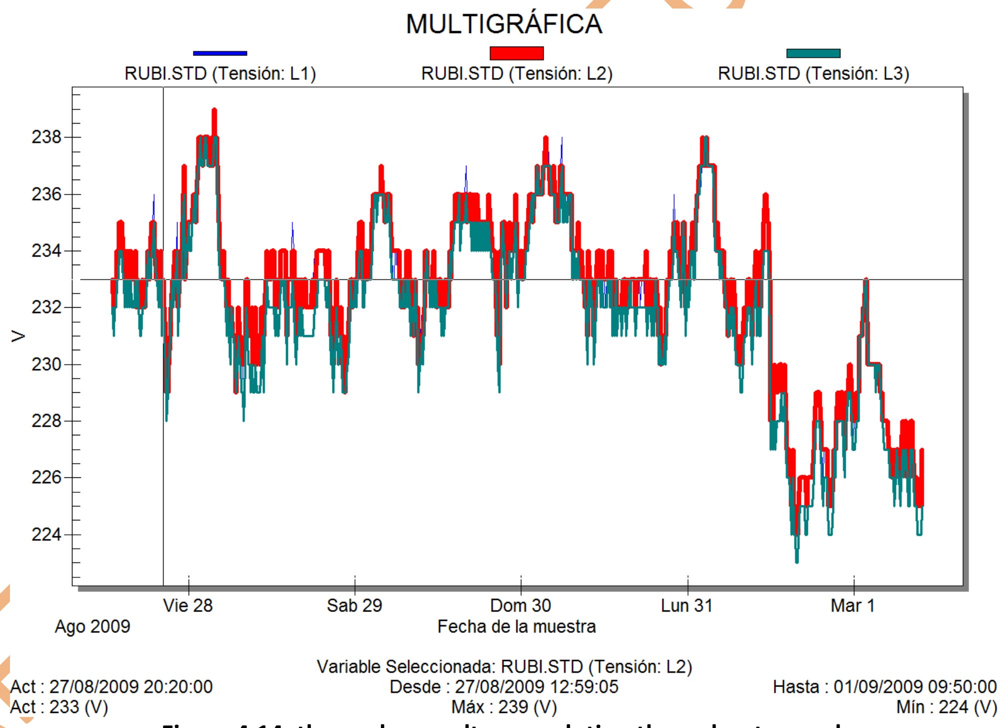

Figure 4.14: three-phase voltage evolution throughout a week

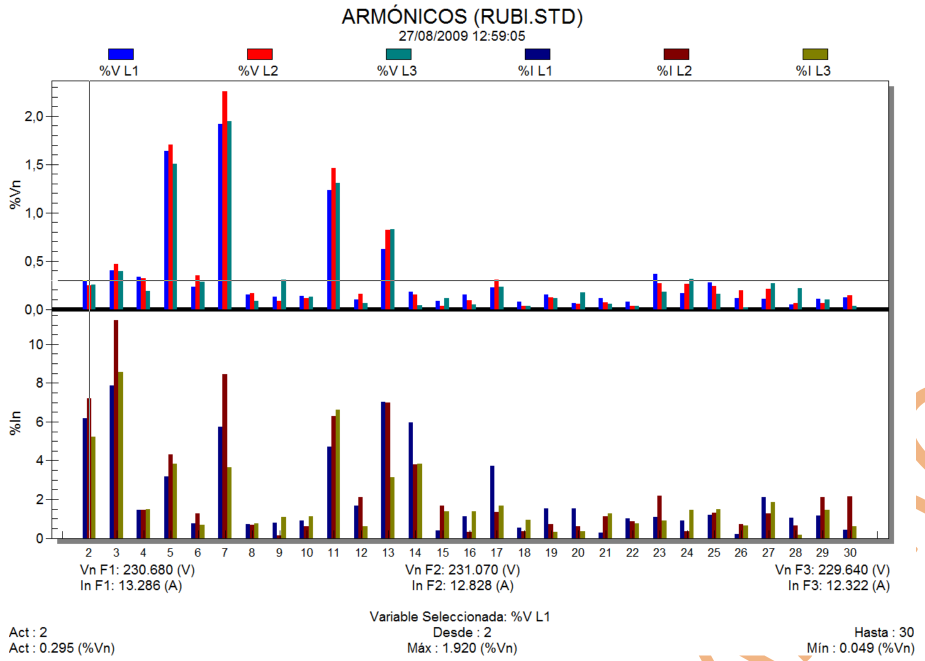

Figure 4.15: Voltage and Current Harmonic Distortion evolution throughout a week

In addition, a complete analysis of the power consumption – which is, in the end, the most sensitive data to be studied- will be made, and its evolution figured out as well. It will be shown as appears in the following example (see Figure 4.16):

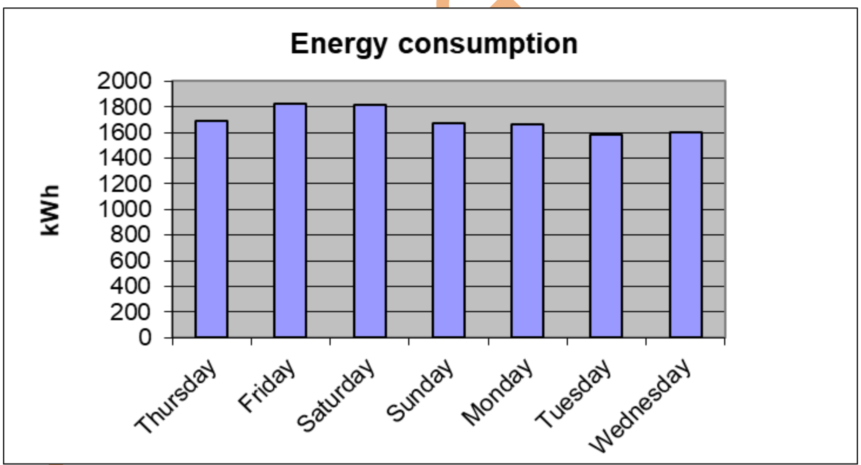

Figure 4.16: Energy consumption in a similar Facility Supply system throughout a week

Once the data has been downloaded, the first step will be making sure that it does not exceed the values stated in the UNE EN 50160 regulation, which are (see Table 4.8 and Table 4.9):

Parameter	Stated value according to UNE EN 50160
Sudden voltage changes	- 5% : Normal Operation - 10%: Not frequent - Long Time Period (PLT) ≤ 1 during 95% week time
Voltage dips	- V < 60% during 1 second: normal operation
Voltage unbalance	- Up to 2% during 95% week time
Voltage harmonics	See Table below

Table 4.8: Some of the sensitive data whose maximum values are stated by European regulations

Harmonic (n)	Harmonic rate (%)	Harmonic (n)	Harmonic rate (%)

3	5	2	2
5	6	4	1
7	5	6..24	0.5
9	1.5		
11	3.5		
13	3		
15	0.5		
17	2		
19	1.5		
21	0.5		
23	1.5		
25	1.5		

Table 4.9: Maximum voltage harmonic distortion component values allowed by UNE EN 50160

The major problems produced by the receivers that most usually cause disturbances in the railway facilities installation are listed in the following table (see Table 4.10):

	Disturbances	**Harmonics**	**High frequency**	**Leakage on earth**	**Unbalances**
	Effects	- *Overloading* - *Heating* - *Breaker tripping* - *Resonances*	- *System shutdowns*	- *Differential protection tripping* - *Risks to persons and installations*	- *Overloading* - *Under-utilising networks and transformers*
Load types	Computers and systems	X		X	X
	Variable speed drives, UPS	X	X	X	
	Lighting lines	X		X	X
	Electronic equipment	X		X	
	Transformer + installation method	X		X	X

Table 4.10: Main disturbances and its causes

Notice that Stationing and Maintenance Facilities have all this equipment installed:

- Computers → IOS (Remote Control System);
- UPS →125 VDC and 48BVDC rectifiers with batteries;
- Transformer → ancillary services equipment to feed all the aforementioned devices.

4.4.4.4 Technical conclusions

Once the weaknesses of the electric installation have been noticed, demand management can be carried out. Technically, demand management involves all the different actions to be taken to decrease the power and the energy demanded to the network. This can be achieved by removing or reducing at its minimum value all the weaknesses or sources of interferences.

To sum up, the process to be taken into account can be described as shows the following chart (see Figure 4.17):

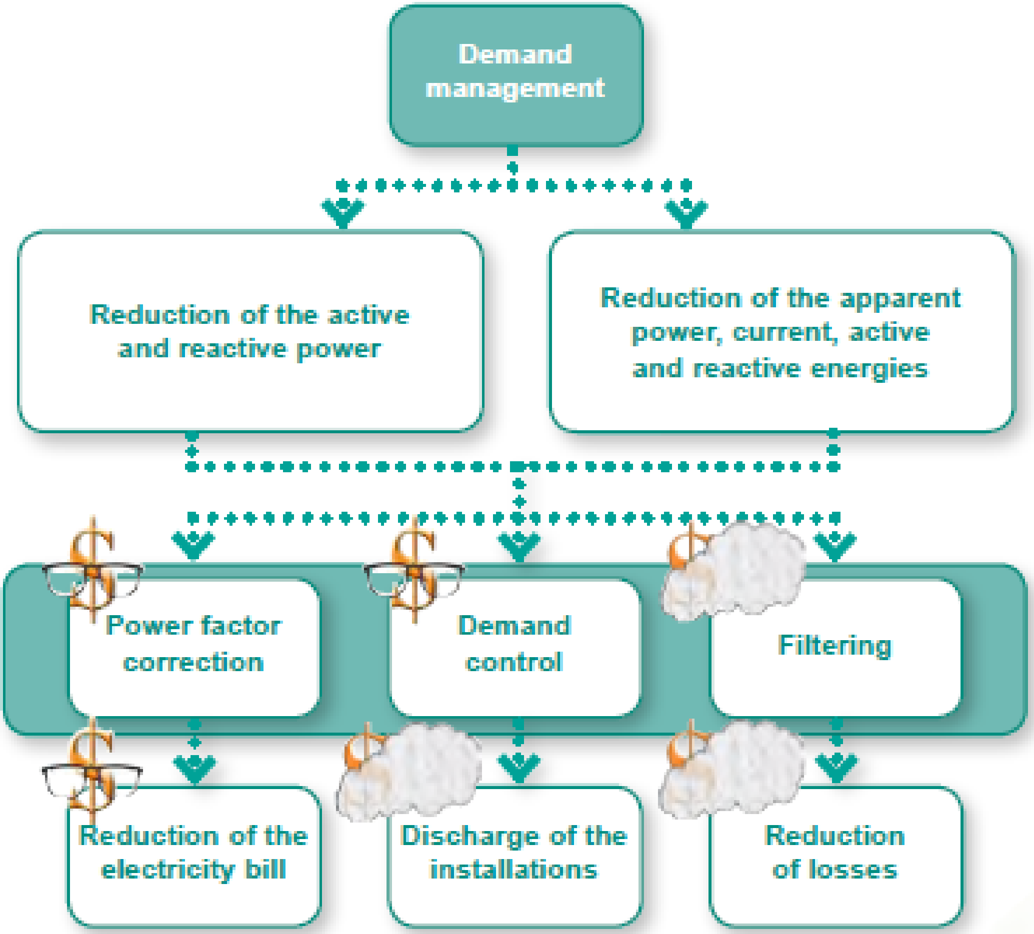

Figure 4.17: Standard demand management chart

Therefore, as shown here, two goals have to be achieved to reach a proper optimisation:

- maximum demand control;
- the reactive power has to be reduced;
- the harmonic distortion has to be avoided;
- the phases have to be balanced between them.

The chart that shows the different problems to be faced is shown below (see Figure 4.18).

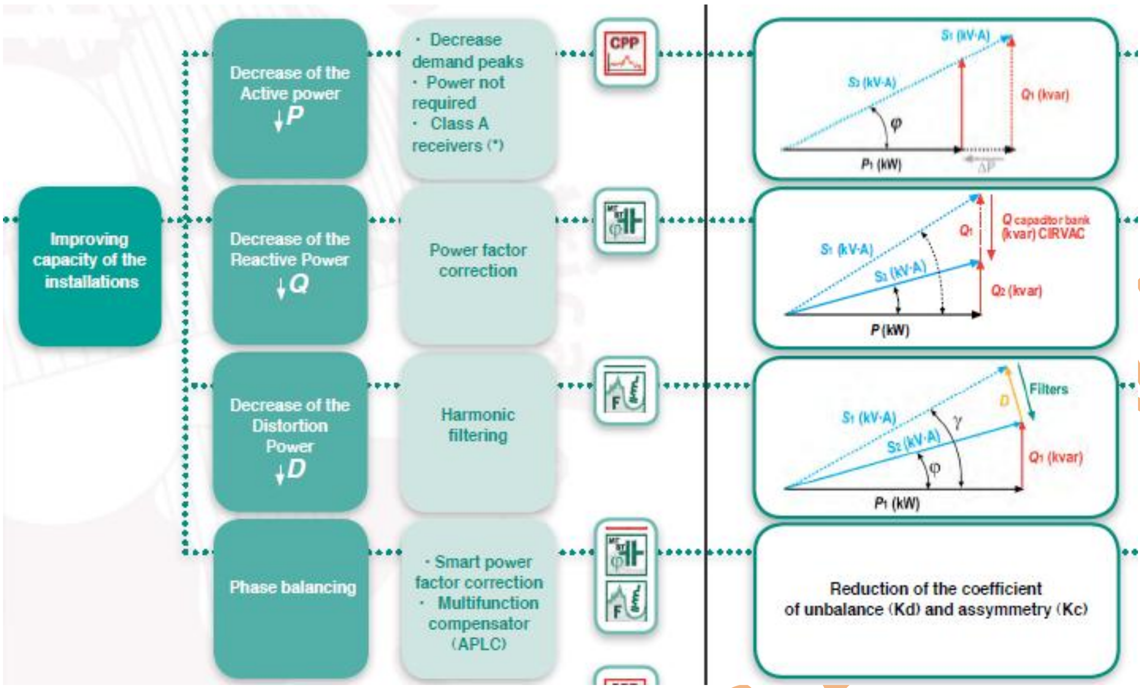

Figure 4.18: Detailed demand management chart

Depending on the disturbance origin and its effects on the electric system, the solutions are different. Most energy optimisation manufacturers propose the following chart (see Table 4.11):

Disturbances	**Harmonics**	**High frequency**	**Leakage on earth**	**Unbalances**
Effects	- *Overloading* - *Heating* - *Breaker tripping* - *Resonances*	- *System shutdowns*	- *Differential protection tripping* - *Risks to persons and installations*	- *Overloading* - *Under-utilising networks and transformers*

Harmonic filtering	High frequency filtering	Smart leakage protection	Multifunction compensator

Table 4.11: Main disturbances and proposed solutions

4.4.4.5 Proposed optimisation devices

4.4.4.5.1 Power factor correction (PFC)

PFC is the reduction of the reactive energy demanded to the network by means of the installation of capacitor banks. It also implies a reduction in the electricity bill. After the $\cos\varphi$ of the installation has been measured, the capacitor will be dimensioned accordingly. The proposed automatic system will be programmed using a table like the one shown in Table 4.12.

	cosφ final												
cosφ inicial	0.80	0.85	0.90	0.91	0.92	0.93	0.94	0.95	0.96	0.97	0.98	0.99	1
0.60	0.583	0.714	0.849	0.878	0.907	0.938	0.970	1.005	1.042	1.083	1.130	1.191	1.333
0.61	0.549	0.679	0.815	0.843	0.873	0.904	0.936	0.970	1.007	1.048	1.096	1.157	1.299
0.62	0.515	0.646	0.781	0.810	0.839	0.870	0.903	0.937	0.974	1.01 5	1.062	1.123	1.265
0.63	0.483	0.613	0.748	0.777	0.807	0.837	0.870	0.904	0.941	0.982	1.030	1.090	1.233
0.64	0.451	0.581	0.716	0.745	0.775	0.805	0.838	0.872	0.909	0.950	0.998	1.058	1.201
0.65	0.419	0.549	0.685	0.714	0.743	0.774	0.806	0.840	0.877	0.919	0.966	1.027	1.169
0.66	0.388	0.519	0.654	0.683	0.712	0.743	0.775	0.810	0.847	0.888	0.935	0.996	1.138
0.67	0.358	0.488	0.624	0.652	0.682	0.713	0.745	0.779	0.816	0.857	0.905	0.966	1.108
0.68	0.328	0.459	0.594	0.623	0.652	0.683	0.715	0.750	0.787	0.828	0.875	0.936	1.078
0.69	0.299	0.429	0.565	0.593	0.623	0.654	0.686	0.720	0.757	0.798	0.846	0.907	1.049
0.70	0.270	0.400	0.536	0.565	0.594	0.625	0.657	0.692	0.729	0.770	0.817	0.878	1.020
0.71	0.242	0.372	0.508	0.536	0.566	0.597	0.629	0.663	0.700	0.741	0.789	0.849	0.992
0.72	0.214	0.344	0.480	0.508	0.538	0.569	0.601	0.635	0.672	0.713	0.761	0.821	0.964
0.73	0.186	0.316	0.452	0.481	0.510	0.541	0.573	0.608	0.645	0.686	0.733	0.794	0.936
0.74	0.159	0.289	0.425	0.453	0.483	0.514	0.546	0.580	0.617	0.658	0.706	0.766	0.909
0.75	0.132	0.262	0.398	0.426	0.456	0.487	0.519	0.553	0.590	0.631	0.679	0.739	0.882
0.76	0.105	0.235	0.371	0.400	0.429	0.460	0.492	0.526	0.563	0.605	0.652	0.713	0.855
0.77	0.079	0.209	0.344	0.373	0.403	0.433	0.466	0.500	0.537	0.578	0.626	0.686	0.829
0.78	0.052	0.183	0.318	0.347	0.376	0.407	0.439	0.474	0.511	0.552	0.599	0.660	0.802
0.79	0.026	0.156	0.292	0.320	0.350	0.381	0.413	0.447	0.484	0.525	0.573	0.634	0.776
0.80		0.130	0.266	0.294	0.324	0.355	0.387	0.421	0.458	0.499	0.547	0.608	0.750
0.81		0.104	0.240	0.268	0.298	0.329	0.361	0.395	0.432	0.473	0.521	0.581	0.724
0.82		0.078	0.214	0.242	0.272	0.303	0.335	0.369	0.406	0.447	0.495	0.556	0.698
0.83		0.052	0.188	0.216	0.246	0.277	0.309	0.343	0.380	0.421	0.469	0.530	0.672
0.84		0.026	0.162	0.190	0.220	0.251	0.283	0.317	0.354	0.395	0.443	0.503	0.646
0.85			0.135	0.164	0.194	0.225	0.257	0.291	0.328	0.369	0.417	0.477	0.620
0.86			0.109	0.138	0.167	0.198	0.230	0.265	0.302	0.343	0.390	0.451	0.593
0.87			0.082	0.111	0.141	0.172	0.204	0.238	0.275	0.316	0.364	0.424	0.567
0.88			0.055	0.084	0.114	0.145	0.177	0.211	0.248	0.289	0.337	0.397	0.540
0.89			0.028	0.057	0.086	0.117	0.149	0.184	0.221	0.262	0.309	0.370	0.512
0.90				0.029	0.058	0.089	0.121	0.156	0.193	0.234	0.281	0.342	0.484

Table 4.12: Relationship between the initial and final $\cos \varphi$

4.4.4.5.2 Filtering

Filters should be installed to eliminate harmonic currents, reduce high frequency signals and balancing of a three-phase unbalanced system. The disturbances could be produced by the loads described above. These devices have the following benefits:

- increase capacity of the distribution lines;
- discharge transformers;
- reduce losses and heating in lines and electrical machinery.

The location of these devices will be accurately chosen.

4.4.4.5.3 Smart earth-leakage protections

The smart earth-leakage protections convert a real current into digital value, as to be integrated into an energy and process supervision system. They will allow the system to:

- make a secure self-reclose and remote measurements management;
- guarantee continuity of service;
- the installation safety level is maintained.

4.4.4.5.4 Smart automatic reclosers

The smart automatic reclosers help to maintain the continuity of service and remote management of the electric distribution system.

4.4.4.5.5 Smart metering system

Metering devices will also be provided in the existing electrical system. These devices' function will be critical, as they will be in charge of:

- register and follow up every event that occurs in the electric installation;
- determine the source of events to subsequently prevent and correct them;
- remotely sending information to a centralised control station;
- communicate with the new management system.

4.4.4.6 New system architecture

The idea is to implement the following criteria (see Figure 4.19).

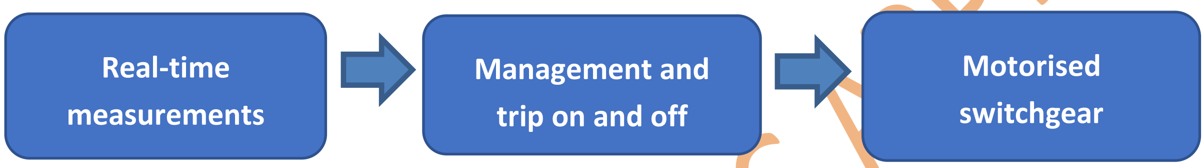

Figure 4.19: New system architecture

The system, shown in the SL-01 drawing, will be able to optimise as much possible the electrical system behaviour. The AC distribution which has been used to show that is an example of a similar railway installation.

4.4.5 Communications specifications

The Eurotunnel infrastructure has 4G Mobile service coverage, therefore the same specification used for 3.4.3 applies.

4.5 Solutions for applications design

This chapter aims to give examples of the algorithms to implement for data interpretation and the visualisation and decision-making tools that will answer the objectives of this use case.

4.5.1 Learning and estimation algorithms

In this chapter, the main goal is the management of the energy consumption for the trains out of commercial line operation, namely at stationing and maintenance facilities. In such a context, it is necessary to focus on the energy consumption of auxiliaries. The physical model of the previous use case cannot be used here because the train will not be in motion. Development of new models for the auxiliaries will be necessary. The pre-processing and regression methods proposed in the previous use case can be used in this use case in order to predict the energy consumption of each auxiliaries' subsystem per operation (maintenance, train dispatching, stand-by).

4.5.2 Visualisation and decision-making tools

The visualisation and decision-making tools of the previous case can be also used for the depot and maintenance facilities energy consumption are based on the same model as for the previous use case.

4.6 Planning of Shift2Rail demonstrator implementation

As in the previous use case, two main WPs, which work jointly, have been identified in the Shift2Rail project to study the technological solutions developed in WP5, and to integrate them for each use case defined in WP4. Therefore, the solutions are proposed generically within the framework of the project, but their application and their integration depend on the site concerned and the associated constraints.

We will study the case of integration in the Eurotunnel site – stationing and maintenance facilities during the In2Stempo project. WP5 is already defined in Chapter 3.6.

In2Stempo WP4 – Railway System Smart Metering Use Cases		
Task 4.2 - Stationing and maintenance facilities operation Smart Metering use case (STM-OP)	*Subtask 4.2.1: Functional specifications of the STM-OP operational use case*	Start date: 01/09/2017 End Date: 01/07/2018
	Subtask 4.2.2: Implementation of the STM-OP operational use case	Start date: 01/09/2018 End Date: 01/07/2019
	Subtask 4.2.3: Integration Tests of the STM-OP operational use case	Start date: 01/07/2019 End Date: 01/01/2021
	Subtask 4.2.4: Demonstration and Assessment of STM-OP operational use case	Start date: 01/01/2021 End Date: 01/09/2021

Table 4.13: In2Stempo Planning

4.7 Conclusion

In this chapter, the adaptation of the experimentation of the In2Rail project to the use case for stationing and maintenance facilities has been realised. This use case presents several similarities with the Reims experimentation, despite its highly novel dimension. The generic ODM platform can certainly be applied, as described in the previous use case. The knowledge developed in the sensor technology could also be used here. Indeed, even if the levels and types of voltage and current cannot be exactly determined at present, a general guideline can be drawn. The auxiliaries have here a prominent role, contrary to the first use case, and management of the energy flows have been paned to solve this issue.

Moreover, the methods used for the applications of the Reims experimentation can be applied here. The same algorithms for prediction and interpretation can be used, as well as the visualisation tools. The distinction to be made will rely on the data collected from the sensors. This chapter has therefore brought technical elements for the development of the second use case of Shift2Rail, directly based on the experimentation of the In2Rail project.

5 Description of the Infrastructure Monitoring use case (IN-OP)

5.1 Introduction

The smart metering use case for electrical infrastructure monitoring through the detection of electrical anomalies (IN-OP) will also be realised at the Eurotunnel infrastructure, mainly inside the 50.45-kilometre rail tunnel linking the United Kingdom with northern France. The main objectives of this use case are continuous monitoring of electrical infrastructure, optimisation of the infrastructure performance and the implementation of preventive maintenance.

5.2 Situation overview

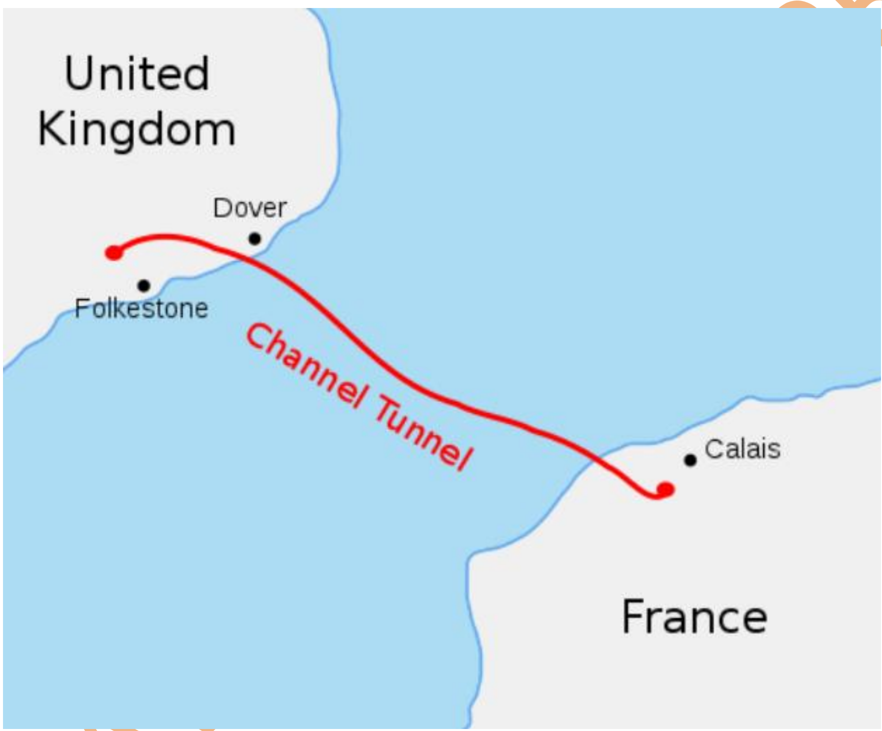

Figure 5.1: Channel Tunnel site map
(Source : https://upload.wikimedia.org/wikipedia/commons/c/ce/Course_Channeltunnel_en.png)

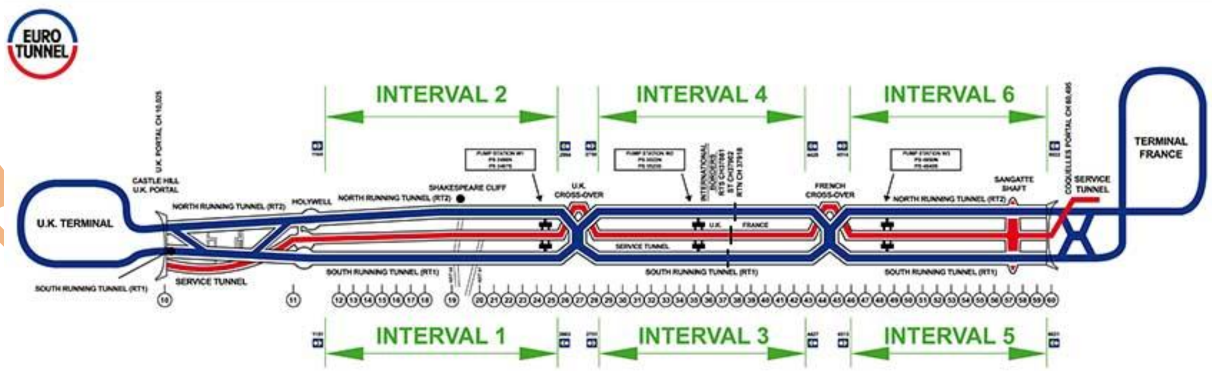

Figure 5.2: General scheme of the tracks into the tunnel (Source: Revue Générale des Chemins de Fer n° 206 – June 2011)

Hereafter, some general information about Eurotunnel use case site are presented:

- it concerns a 50.45-kilometre rail tunnel linking the United Kingdom with northern France, composed of two tracks, as shown in Figure 5.1 and Figure 5.2. Maximum train speed is 160 km/h;
- power supply of the infrastructure is 25 kV AC. In normal situation, one power supply substation coming from France is sufficient, a load balancer is implemented in England to stabilise the traction voltage up to 50 km from the source;
- The Eurotunnel is operated with 4 different types of trains:
    - truck shuttles (Eurotunnel rolling stock),
    - passenger Shuttles (Eurotunnel rolling stock),
    - Eurostar trains: two kinds of trains are running:
        - TGV TMST with a maximum power of 12 240 kW,
        - Eurostar e320 with a maximum power of 16 000 kW,
    - freight trains: many kinds of trains, circulating in the night – specific periods,

5.3 Solutions for data management design

The aim is to identify the quantity of material required to apply smart metering in this particular case. The list of bill of quantities is more qualitative than quantitative.

As indicated in the first use case, the platform used for the use case should be the same than for the three use cases: the ODM platform is normally a generic solution.

5.3.1 ODM Platform

The ODM platform architecture proposed is nearly corresponding to it of the situation in Network Rail use case. As indicated for the first use case, it should be the same for the three use cases.

Since the platform described in Chapter 3.3.1 will gather the data management for the three use cases, the description of the platform is here the same as in that chapter. Realisation of ODM is planned for the Shift2Rail project.

5.3.2 Communication platform

Proposal of Service requirements, technology solutions and infrastructure management.

The communication described in Chapter 3.3.2 gather the types of communication for the three use cases. The description on the platform is here the same as in that chapter, with major concerns on the types of constraints of the application.

5.4 Solutions for sensors and metering design

As in the previous use case, the aim of this chapter is to show that the sensors can be adapted to the range of each use case and can communicate with the generic platform.

5.4.1 Trackside metering solutions design

5.4.1.1 Traction measurements

Below are presented the possible measures which can be made in the maintenance structures. The type of sensors will depend on the infrastructures, with respect to the network (25 kV AC).

A Neel Effect® clamp-on solution could be used for the measurement of the AC current. These sensors has been co-developed by Neelogy and RTE for a smart substation application. They can be adapted with a very big inner diameter (>30cm) around a HVAC bushing or with a small inner diameter onto insulated cable.

5.4.1.1.1 Bill of quantities (trackside system)

The French substation is composed of three transformers which supply either one of the two running tunnels, or the French terminal (for further details, see [8]). Similarly to the use case 1, the following can be assumed regarding the list of quantities per each transformer:

Trackside Metering Solution Design	Type of sensors	Sensor range	Communication
Complete date (year, month, day)	Time synchronisation system	/	2 WS motes per measurement point 1 Gateway
Complete time (hour, minute)		/	
Power transformer – Output side – voltage	AC single phase: 1 voltage sensor	75 MVA	
Power transformer – Output side – current	AC single phase: 1 current sensor		
Power transformer – Output side – power factor	AC: Wattmeter		
Auxiliaries – voltage (3-phase)	AC: 3 voltage sensors	600 kVA - 6 MVA	
Auxiliaries – current (3-phase)	AC: 3 current sensors		
Auxiliaries – power factor (3-phase)	AC: Wattmeter		

Table 5.1 : Bill of quantities for trackside metering solution

Due to very high voltage of the substation input side, only the output side (25 kV) is considered.

5.4.1.2 Auxiliaries measurements

Like the first use cases, the kind of sensors will depend on the infrastructures.

5.4.2 Onboard metering solution

5.4.2.1 Traction measurements

The sensors will be the same type as in the Chapter 3.4.1.1, adapted to the range of voltage and current.

5.4.2.2 Auxiliaries measurements

The sensors will be the same type as in the Chapter 3.4.1.2, adapted to the range of voltage and current.

5.4.2.3 Bill of quantities (onboard system)

Onboard Metering Solution Design	Type of sensors	Power range	Communication
Complete date (year, month, day)	Time synchronisation system	/	
Complete time (hour, minute, second, ms)		/	
Train's position (KP)	Position detection system	/	
Train's speed	1 speed sensor per train	/	
Input voltage at current collector (pantograph)	AC: 1 voltage sensor per pantograph	1 MW - 20 MW	
Input current at current collector (pantograph)	AC: 1 current sensor per pantograph		
Traction voltage * (at equipment input level)	DC: 1 voltage sensor AC: 3 voltage sensors	1 MW - 20 MW	
Traction current *	DC: 1 current sensor per traction converter AC: 3 current sensors (if needed)		1 Wi-Fi Router 1 4G Router
Rheostat voltage (at equipment input level)	DC: 1 voltage sensor per rheostat	1 MW - 20 MW	
Rheostat current	DC: 1 current sensor per rheostat		
Auxiliary converter voltage (at equipment input level)	DC: 1 voltage sensor	600 kW - 6 MW	
Auxiliary converter current	DC: 1 current sensor		
Low voltage auxiliary network voltage	DC: 1 voltage sensor	100 W - 50 kW	
Low voltage auxiliary network current	DC: 1 current sensor		

Table 5.2 : Bill of quantities for onboard metering solution

5.4.3 Communications specifications

The Eurotunnel infrastructure has 4G Mobile service coverage, therefore the same specification used for 3.4.3 applies.

5.5 Solutions for applications design

This chapter aims to give examples of the algorithms to implement for data interpretation and the visualisation and decision-making tools that will answer the objectives of this use case.

5.5.1 Learning and estimation algorithms

In this chapter, we will provide a short review of anomaly detection methods that can be used for the detection of the abnormal energy patterns, of abnormal energy consumption, of abnormal measured voltage or current values as well as of any abnormal conditions compared to the normal/reference patterns and normal energy consumption.

This review will allow selecting the most suitable techniques to this context.

5.5.1.1 Problematic of anomalies detection

The goal of this use case is to build the electrical infrastructure monitoring by continuous supervision of power supply equipment states and their specific energy consumption. Therefore, in this chapter, we will provide a short review of anomaly detection methods that can be used for the detection of the abnormal energy patterns, of abnormal energy consumption, of abnormal measured voltage or current values as well as of any abnormal conditions compared to the normal/reference patterns and normal energy consumption. This review will allow us to select the most suitable techniques to our context.

Anomaly detection is the identification of items, events or observations which do not conform to an expected pattern or other items in a data set. Anomaly detection techniques depend on different factors such as the nature of input data, the availability of labelled data as well as the type of anomalies. Therefore, it is important to have a prior knowledge on the specificities of our application domain and take into account each of these factors in order to select an appropriate method.

Based on the availability of labelled data, anomaly detection techniques are categorised into three main classes namely supervised anomaly detection, semi-supervised anomaly detection and unsupervised anomaly detection. Supervised anomaly detection techniques require a labelled training data set including both normal and anomalous samples. This training data set is used to learn a predictive model for normal and anomalous classes. The learned model is then applied to the test data set in order to determine for each sample of the test data set which class it belongs to. Any new instances of data are compared with the model to trigger an alarm when an abnormal situation is detected. This approach is used by [9] to monitor and protect Electric Power System and by [10] to detect anomalies in electricity consumption data of buildings.

Semi-supervised anomaly detection techniques also require the availability of a labelled training data set, but only for normal data. The basic idea is to build a model for the normal class and then anomalies can be identified by deviating from the learned model. Finally, unsupervised anomaly detection techniques do not require any labelled training data set, and thus are the most commonly used.

In our context, unsupervised anomalies detection techniques are well suited because it is difficult to obtain labelled data. In fact, this is often expensive and requires substantial effort.

Moreover, anomalies are not known in advance and the nature of anomalies is constantly changing, e.g. new types of anomalies may occur, thus obtaining a training dataset that accurately describe all possible type of anomalous behaviour is almost impossible.

There are several types of anomalies. More precisely, we can distinguish between three categories:

- point anomalies: when a single data sample is anomalous with respect to the rest of data;
- contextual anomalies: when the data sample is anomalous in a specific context and not otherwise;
- collective anomalies: when a set of data samples is anomalous with respect to the rest of data. Each data sample of the set may not be anomalous by themselves, but their occurrence together as a collection is anomalous.

As already mentioned, the choice of an appropriate anomaly detection method should be based on the type of anomalies that may occur in our specific context. In fact, a given anomaly detection method can be suitable for a specific type of anomaly and not suitable to another one. In our context, we will be concerned by the first two types of anomalies: Point anomalies and contextual anomalies.

A special attention should be paid to the nature of the dataset before applying an anomalies detection method. In fact, there are several type of data sequence data, graph data, spatial data, etc. The nature of input data determines the applicability of the anomaly detection methods. For this study, we will be interested only in sequential data.

5.5.1.2 Methods for anomalies detection

In the following, we shortly introduce some anomaly detection techniques that can be used in our context namely: clustering, statistical techniques and information theory techniques.

5.5.1.2.1 Clustering

Clustering techniques [11] are one of the most famous techniques of unsupervised learning. Unsupervised learning techniques do not require labelled data and thus are widely used. The aim of clustering is to organise unlabelled data into similarity groups such that the observations in a group will be similar to one another and different from the observations in other groups.

The authors in [12] group clustering based anomaly detection techniques into three categories:

- the category of clustering techniques which rely on the following assumption: "Normal data instances belong to a cluster in the data, while anomalies either do or do not belong to any cluster";

- the category of clustering techniques which rely on the following assumption: “Normal data instances lie close to their closest cluster centroid, while anomalies are far away from their closest cluster centroid”;
- the category of clustering techniques which rely on the following assumption: “Normal data instances belong to large and dense clusters, while anomalies either belong to small or sparse clusters”.

5.5.1.2.2 Statistical techniques

Statistical anomaly detection techniques are based on the following assumption: “Normal data instances occur in high probability regions of a stochastic model, while anomalies occur in the low probability regions of the stochastic model” [12]. In this technique, the anomalies are the instances that have a low probability to be generated from the learnt model.

5.5.1.2.3 Information theory techniques

Information theory techniques are used to study the quantification, storage, and communication of information. The information content of a dataset is analysed using different information theoretic measures such as Kolomogorov Complexity, entropy, etc. Such techniques are used for anomalies detection based on the following assumption: “Anomalies in data induce irregularities in the information content of the data set” [12].

5.5.2 Visualisation and decision-making tools

Mapbox GL JS [13] is an open source Javascript based on WebGL. The library is used to display Maps. It allows adding interactivity and customisation.

Using Mapbox GL JS, maps are rendered on the fly in the client-side. Therefore, it possible to change the map’s style and to update the displayed data on the fly in response to user interaction.

Compared to traditional JavaScript map libraries, Mapbox GL JS has no distinction between base layers (image tiles that provide the foundation of the map) and overlay layers (data displayed on top of base layers). This means that all elements of the map can be modified. Each layer provides rules about how certain data should be drawn in the browser, and the renderer uses these layers to actually draw the map on the screen.

For example, using Mapbox GL JS, the information about the transportation network can be displayed in real-time such as train positions, electrical consumption of trains and electrical production of sub-stations. The Figure 5.3 shows a Mapbox GL JS application [14] which displays real-time positions of different types of public vehicles.

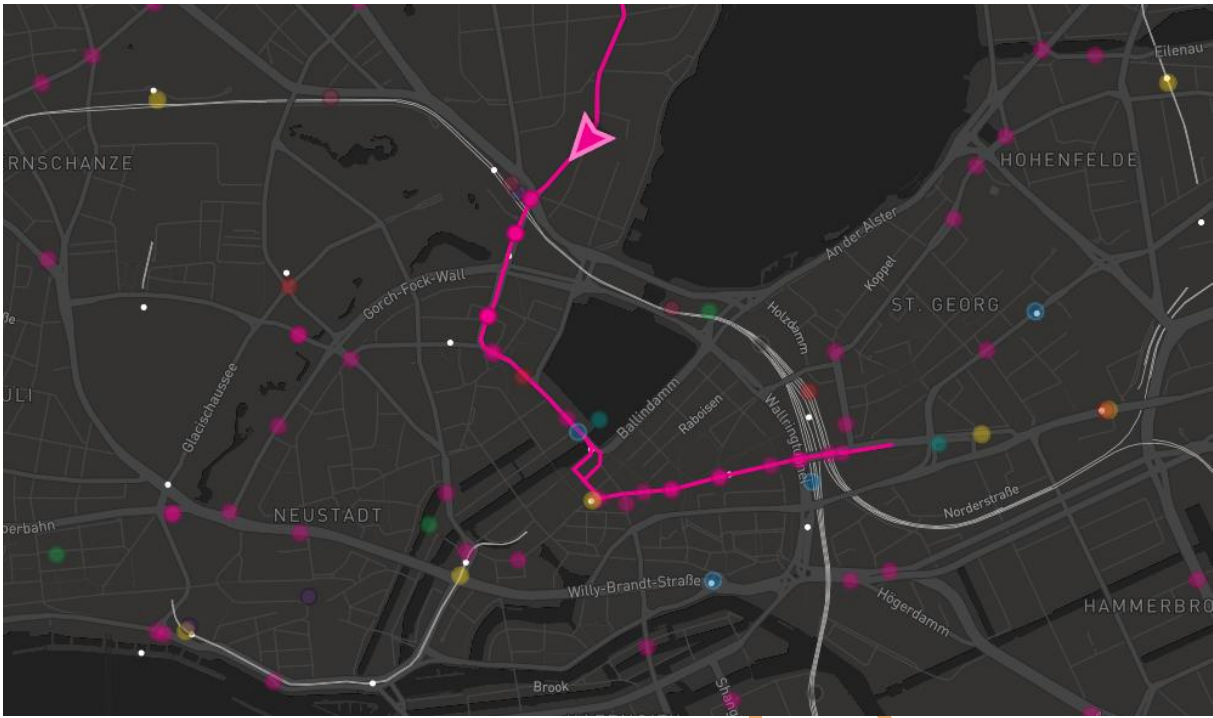

Figure 5.3: A map displaying real-time positions of vehicles

In addition, the tools described in Chapter 3.5.2 can also be used to provide information about the energy flow in the network (See Figure 5.4): voltage, current and power. This visualisation is used to display several anomalies, and provide further details to characterise them.

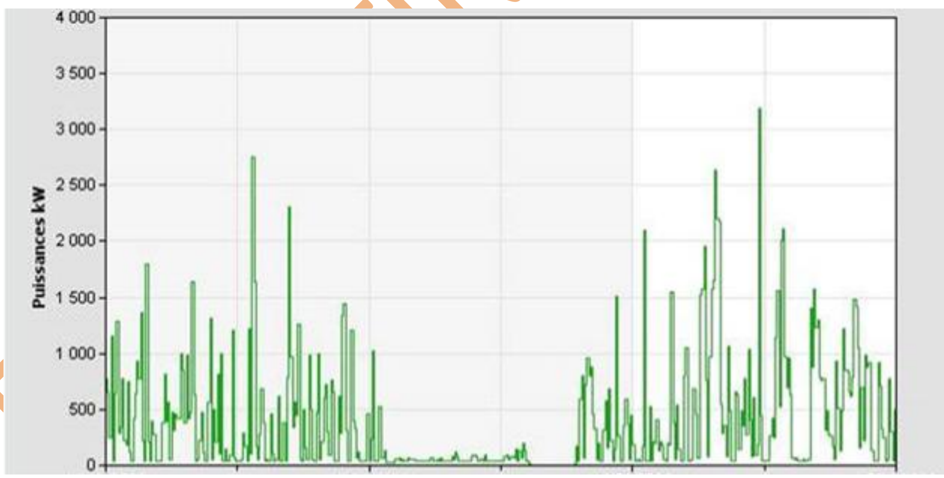

Figure 5.4: Monitoring application – identification of a stolen return cable by current monitoring

5.6 Planning of Shift2Rail demonstrator implementation

As in the previous two use cases, two main WPs, which work jointly, have been identified in the Shift2Rail project to study the technological solutions developed in WP5, and to integrate them for each use case defined in WP4. Therefore, the solutions are proposed generically within the framework f the project, but their application and their integration depend on the site concerned and the associated constraints.

During project, we will study the case of integration in the Eurotunnel site – monitoring of the electrical infrastructure. WP5 is already defined in Chapter 3.6.

In2Stempo WP4 – Railway System Smart Metering Use Cases		
Task 4.3 – Electrical Infrastructure monitoring by Smart Metering use case (IN-OP)	*Subtask 4.3.1: Functional specifications of the IN-OP operational use case*	Start date: 01/09/2017 End Date: 01/07/2018
	Subtask 4.3.2: Implementation of the IN-OP operational use case	Start date: 01/09/2018 End Date: 01/07/2019
	Subtask 4.3.3: Integration Tests of the IN-OP operational use case	Start date: 01/07/2019 End Date: 01/01/2021
	Subtask 4.3.4: Demonstration and Assessment of IN-OP operational use case	Start date: 01/01/2021 End Date: 01/09/2021

Table 5.3: In2Stempo Planning

5.7 Conclusion

In this chapter, the adaptation of the experimentation of the In2Rail project to the use case for electrical infrastructure monitoring through the detection of electrical anomalies has been demonstrated. This use case presents some similarities with the Reims experimentation regarding the infrastructure. Although the levels of voltage and current are here different, since Eurotunnel mainly uses AC current, the structure of the network is well known, and the elements of In2Rail can be easily applied. The ODM platform can again be used here, given its board scope of application. The sensor technologies involved here are similar to the two other use cases, with only the power changings.

The breaking point will be in the application field, as this use case aims to detect anomalies. Several new algorithms should be developed, with some being derived from the algorithms of the Reims experimentation. The visualisation tool should also be adapted to the specificities of the Eurotunnel infrastructure.

This chapter has thus shown how to apply the experiences of the In2Rail project to the use case 3 of Shift2Rail, and how to adapt them to its uniqueness.

6 Conclusions

The preparation of use cases shows that all the work done in In2Rail project can be applied for other applications of Smart Metering, such as the three use cases defined for Shift2Rail project, but not limited to them.

This report describes the three use cases that will be further studied during Shift2rail. The first one “Commercial Line Operation CO-OP” is close to the solutions tested during In2Rail Proof-of-Concept. A lot of solutions and applications have been presented, and this use case will therefore greatly benefit from this project. The second use case “Stationing and maintenance facilities STM-OP” and the third use case “Infrastructure Monitoring IN-OP” are slightly more different from detailed studies of In2rail. Less solutions have consequently been suggested, and these use cases will need more development than the first one. However, as presented in this report, the 3 use cases use a common Smart Metering architecture with possibly same or similar technologies.

The In2Rail project and therein the WP11 have elaborated a comprehensive approach to enable Shift2Rail for building a holistic Smart Metering system. Within this individual Work Package, energy flows and energy consumptions have been investigated, resulting in a proposal of signals to be measured, exchanged and treated. Furthermore, a beneficial architecture from the sensor to complex machine learning algorithms has been described. Latest digital technologies are part of the proposal which has been documented in this deliverable D11.5.

D11.5 - together with previous deliverables D11.1 to D11.4 of the Work Package 11 - shall be seen as the basis for a follow-up and the realisation in the TD3.10 of Shift2Rail. This Technical Demonstrator 3.10 aims to develop the described Smart Metering solutions for the three defined use cases.

7 References

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[14] https://hvv.live/

8 Appendices

8.1 Appendix 1: Questionnaire concerning the applications design

The main purpose of this questionnaire is to collect the different needs of the possible users of the Railway Distributed Energy Resource Management System (RDERMS). The questionnaire is dedicated to different stakeholders of the railway domain and aims at investigating the applications of the RDERMS. It is composed of different sections, related to objectives of smart metering, how to perform smart metering and to present/exploit results.

Definitions and explanations (on the questions)

Operational level: the impact is only to display and analyse the values without considering the details (that means in real time or only in some curves to display several days later).

Tactical level: the impact is small changes for the railway companies, but does not need huge investments (for example: eco-driving training for the drivers, small change of time schedule, …).

Strategic level: the impact is higher changes and maybe need investments or a different point of view of the infrastructure and the rolling stock.

Current situation shall be referred to existing smart metering systems (if any) and monitoring currently performed.

Future situation shall be referred to systems that could be or are desired for future implementation

COMPANY AND BUSINESS INFORMATION		
Which is your company main business? (please select among the options or add another option)		
Please select among the following options:		
Infrastructure Manager		
Railway Operator		
other: please specify (e.g. Rolling Stock Manufacturer)		
Which are your company business priorities?	*Please assign a value from 1 to 5 (1 being the lowest, 5 the highest)*	
safety		
punctuality		
cost reduction (please specify type of costs, e.g. maintenance, operating costs, ...)		
consumption reduction (please specify type of consumed media e.g.diesel, electric energy,...)		
other: please specify (e.g. EHS-targets, CO2 reduction targets)		

OBJECTIVES OF SMART METERING						
Specify main interests for energy smart metering:	*Please assign a value from 1 to 5 (1 being the lowest, 5 the highest) (or put a cross if not concerned)*					
	Current situation			*Future situation*		
	operational level	*tactical level*	*strategic level*	*operational level*	*tactical level*	*strategic level*
direct monitoring of energy flows (e.g. energy consumed by the train in real-time, ...)						
accurate billing						
optimisation of energy costs						
optimization of energy consumption (e.g. targetting CO2-reduction)						
optimisation of power contracted with energy supplier						
comparison between energy consumed and estimated consumption (e.g. from simulations)						
compatibility check between infrastructure and rolling stock (technical approval during traffic testing)						
smart grid application (implementation of smart grid network, hardware and/or software)						
evaluation of other parameters during travel (e.g. CO2 released) for providing comparison with other transportation systems						
analysis of the influence of the scheduling of the trains (timetable) on the energy consumption to eventually introduce green timetable						
analysis of influence of the behaviour of the train driver on the energy consumption						
utilization of the prediction (simulation) of the energy consumption to determine if energy storage is a feasible solution for some electrical substations						
identification of losses on the line						
monitoring the track: inefficiencies, irregularities, faults, etc.						
monitoring the catenary: geometric, mechanical (e.g. contact force) electrical (e.g. voltage)						
inform users/externals (passengers, citiziens) of rail energy consumption behaviour						
monitoring of status of rolling stock (e.g. failures)						
more accurate planning of maintenance						
other: please specify						

OBJECTIVES OF SMART METERING						
Smart metering is important to understand:	*Please assign a value from 1 to 5 (1 being the lowest, 5 the highest) (or put a crossif not concerned)*					
	Current situation			*Future situation*		
	operational level	*tactical level*	*strategic level*	*operational level*	*tactical level*	*strategic level*
energy consumption in normal situations						
energy consumption when the trains are delayed						
energy consumption in degraded situations (one train without a motor bogie functionning)						
electrical defaults on the infrastructure						
electrical defaults onboard of trains						
electrical degraded situations on infrastructure (e.g tranformers maintenance)						
electrical degraded situations in case of heatwaves (e.g. high temperature can be critical for catenaries and transformers…)						
other: please specify						

Reference frame to be taken into account to measure the benefits of smart metering	*Please tick where relevant*	
	Current situation	*Future situation*
line between two stations		
one entire line		
the entire local network		
region		
country		
connection between countries		
stations		
depots		
rolling stock		
other: please specify		

OBJECTIVES OF SMART METERING						
Time step for smart metering	*Please tick where relevant*					
	Current situation			*Future situation*		
	operational level	*tactical level*	*strategic level*	*operational level*	*tactical level*	*strategic level*
real time						
less than seconds						
less than minutes						
less than hour						
day						
other: please specify						
Gathering of measurements	*Please tick where relevant*					
	Current situation			*Future situation*		
	operational level	*tactical level*	*strategic level*	*operational level*	*tactical level*	*strategic level*
real time						
every minute						
every hour						
every 24 hours						
other: please specify						
Time scale of energy consumption data for analysis	*Please tick where relevant*					
	Current situation			*Future situation*		
	operational level	*tactical level*	*strategic level*	*operational level*	*tactical level*	*strategic level*
less than seconds						
less than hour						
day						
week						
month						
year						
other: please specify						

HOW TO PERFORM MONITORING						
Specify items to be monitored (having major influence on energy consumption):	*Please tick where relevant*					
	Current situation			*Future situation*		
	operational level	*tactical level*	*strategic level*	*operational level*	*tactical level*	*strategic level*
Rolling stock:						
traction power + traction auxiliaries						
comfort auxiliaries (specify what: HVAC, lighting, etc.)						
other: please specify						
Infrastructure:						
traction power substations: specify what: HV network for traction low voltage auxiliary network (building, control-command, etc.)						
passengers area (specify what: HVAC, lighting, etc.)						
railway maintenance centres (workshops/depots)						
signalling system and auxiliaries						
other: please specify						

HOW TO PERFORM MONITORING						
Which parameters have to be measured? (Rolling stock)	*Please tick where relevant*					
	Current situation			*Future situation*		
	mandatory	*optional*	*not useful*	*mandatory*	*optional*	*not useful*
Train's position (KP): GPS position: latitude						
Train's position (KP): GPS position: longitude						
Train's position (KP): GPS position: altitude						
Km point						
Train's speed						
Input voltage at current collector (panthograph...)						
Input current at current collector (panthograph...)						
Traction voltage (voltage at equipment input level)						
Traction current						
Rheostat voltage (voltage at equipment input level)						
Rheostat current						
Auxiliary converter voltage (voltage at equipment input level)						
Auxiliary converter current						
Auxiliary converter power (3-phase output)						
Acceleration						
Ambient temperature (outside train)						
Fresh air humidity						
Saloon temperature (inside train, HVAC)						
Duct air Humidity (inside train, HVAC)						
Duct air CO2 (inside train, HVAC)						
Passengers number / Total passengers load						
other: please specify						

HOW TO PERFORM MONITORING						
Which parameters have to be measured? (Infrastructure)	*Please tick where relevant*					
	Current situation			*Future situation*		
	mandatory	*optional*	*not useful*	*mandatory*	*optional*	*not useful*
Power substation: input side: voltage and current (giving active and reactive power consumed/generated, cos phi, etc.)						
Power substation: output side: voltage and current (giving active and reactive power consumed/generated, cos phi, etc.)						
Auxiliaries: voltage and current (giving active and reactive power consumed/generated, cos phi, etc.)						
Other parameters (please specify)						
On line measures (Voltage / current / temperature)						
other: please specify						

Specify suggested sampling frequency for the parameters:	*Please suggest a value*
seconds	
minutes	
other (please specify)	

APPLICATIONS/RESULTS				
Which are suggested ways of displaying the results:	*Please tick where relevant*			
	mandatory	*optional*	*not useful*	
numerical information				
charts, curves, etc.				
other: please specify				
Which kind of device is most effective to display results:	*Please tick where relevant*			
	mandatory	*optional*	*not useful*	
smartphone				
tablet				
computer				
screens in stations				
monitoring center				
screens onboard trains				
other: please specify				

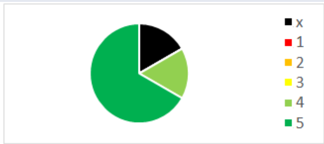
APPLICATIONS/RESULTS			
Which data/information shall be displayed and to whom?	*Please tick where relevant*		
	to Railway Operator	to Infrastructure Manager	to Driver
speed			
position			
pantograph voltage			
substations power			
substations voltage			
infrastructure data (maximum speed, altitude of the track, etc.)			
comparison between actual curves (e.g. speed, consumption, ...) and reference			
specific energy consumption of drivers			
consumption forecast for XX minutes (please comment on "XX")			
consumption forecast per section or per train (please comment on your preference for section or train)			
stations consumption			
depots consumption			
other: please specify			

Which user applications from other domains can be used for the railway application? If so, please suggest which ones and propose how to use them in the railway domain?	*Please tick where relevant (and add description, if possible)*
applications for building consumption monitoring	
applications for car consumption monitoring	
other: please specify	

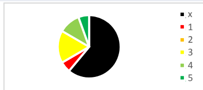
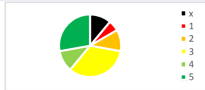
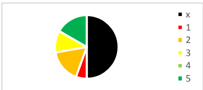
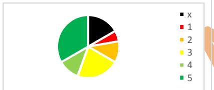
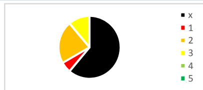
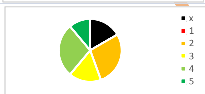
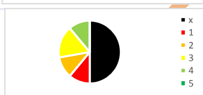
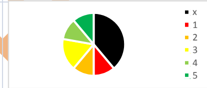
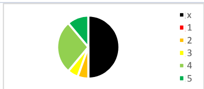
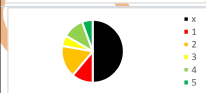
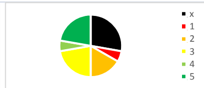
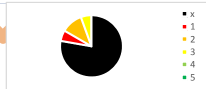
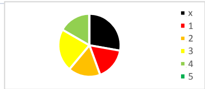
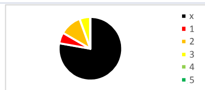
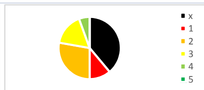
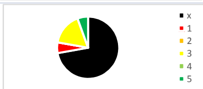
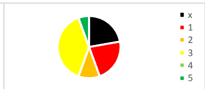
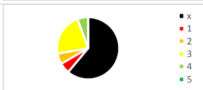
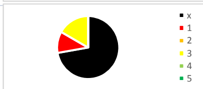
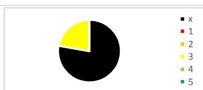
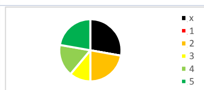
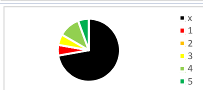
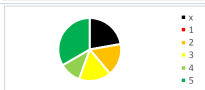
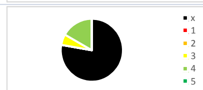
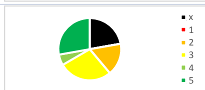
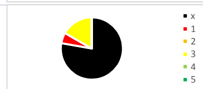
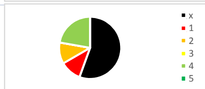
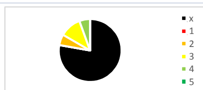
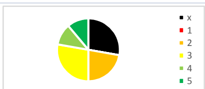
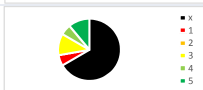
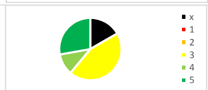
8.2 Appendix 2: Analysis of the results of the questionnaire

BUSINESS PRIORITIES

(Value in range from 1 to 5, 1 being the lowest, 5 the highest)

	**Safety**
	**Punctuality**
	**Cost reduction**
	**Consumption reduction**

OBJECTIVES OF SMART METERING - (Value in range from 1 to 5, 1 being the lowest, 5 the highest)

	Current Situation	Future Situation
direct monitoring of energy flows (e.g. energy consumed by the train in real-time, …)		
accurate billing		
optimisation of energy costs		
optimisation of energy consumption (e.g. targeting CO2-reduction)		
optimisation of power contracted with energy supplier		
comparison between energy consumed and estimated consumption (e.g. from simulations)		
compatibility check between infrastructure and rolling stock (technical approval during traffic testing)		
smart grid application (implementation of smart grid network, hardware and/or software)		
evaluation of other parameters during travel (e.g. CO2 released) for providing comparison with other transportation systems		
analysis of the influence of the scheduling of the trains (timetable) on the energy consumption to eventually introduce green timetable		
analysis of influence of the behaviour of the train driver on the energy consumption		
utilisation of the prediction (simulation) of the energy consumption to determine if energy storage is a feasible solution for some electrical substations		
identification of losses on the line		
monitoring the track: inefficiencies, irregularities, faults, etc.		
monitoring the catenary: geometric, mechanical (e.g. contact force) electrical (e.g. voltage)		
inform users/externals (passengers, citizens) of rail energy consumption behaviour		
monitoring of status of rolling stock (e.g. failures)		
more accurate planning of maintenance		

8.3 Appendix 3: Sensors and energy meter standards

In general way, transformers adapt the current and the voltage used in HV substations to a level suitable with low voltage device (meters, protection, etc.).

Current Transformer Standards	- IEC 61869-1 : Instrument Transformers - Part 1: General requirements - IEC 61869-2 : Instrument Transformers – Part 2: Additional requirements for current transformers (replace IEC 60044-6 et IEC60044-1) - Norme CEI 60044-8 : Instrument transformers – Part 8:Electronic current transformers (will be replaced by IEC 61869-8)
Voltage Transformer Standards	- IEC 61869-1 : Instrument Transformers - Part 1: General requirements - IEC 61869-3 : Instrument transformers – Part 3: Additional requirements for inductive voltage transformers (replace IEC 60044-2) - IEC 61869-5 : Instrument transformers – Part 5: Additional requirements for capacitor voltage transformers (replace IEC 60044-5) - Norme CEI 60044-7 : Instrument transformers –Part 7:Electronic voltage transformers (will be replaced by IEC 61869-8)

Energy Meter

For billing applications, Energy meters are design to measure consumed and generated active or reactive power (four quadrants) with at least a 10 minutes frequency sampling.

Energy Meter Standards	Standards - IEC 62053-31: Electricity metering equipment (a.c.) – Particular requirements – Part 31: Pulse output devices for electromechanical and electronic meters (two wires only) - IEC 62052-11: Electricity metering equipment (AC) – General requirements, tests and test conditions – Part 11: Metering equipment

8.4 Appendix 4: Neel Effect® sensors

8.4.1Series 9: DC clamp-on current sensors compliant with railway standard

It exists calibre from 1250A to 5kA nominal current.

Precision Flexible DC Current Probe **SPD 9-1** I_{max} **= 2400 A**
based on **Neel Effect®** Technology

⇨ **Highlights**

- Accuracy < 1% on a large measurement scale, 240A to 2400A. (Class 1 EN50463)
- Galvanic Insulation between the Primary Circuit (conductor) and the Secondary Circuit (transducer)
- Digital Output SPI (CAN & Ethernet optional) or Analogue Current Output
- Easy Installation: Transducer is a "Flexible Cable". Simply Open it and Clamp it on!
- Ideal Solution for Tight Spaces. Adaptive to any Busbar or Cable Configuration
- Excellent Resistance to Vibrations: secondary current is measured over the whole length of the transducer
- No Calibration Checks required: **Neel Effect** technology is Hysteresis Free
- Reduced Thermal Drift
- Small Size and Space Savings. Light Weight

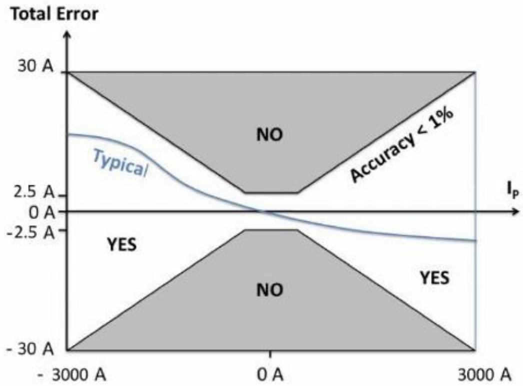
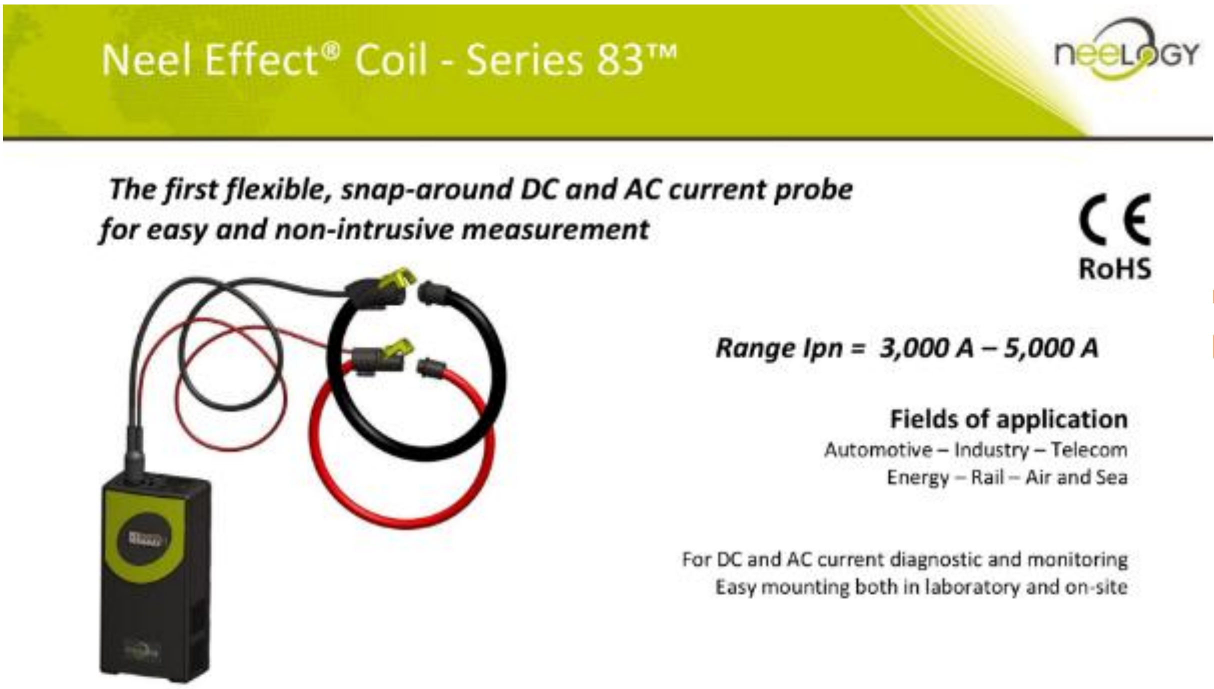
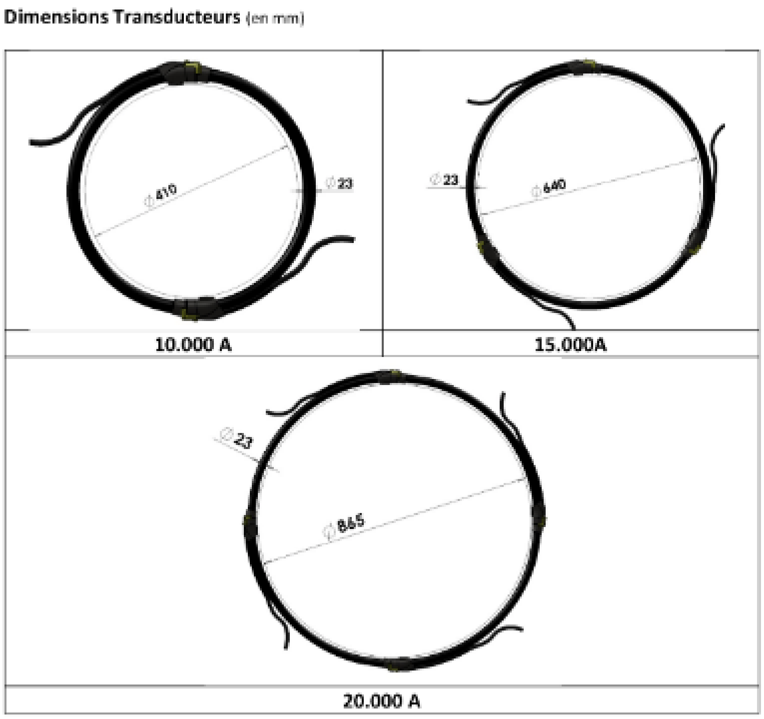


Fig. 1 : Total Error vs Primary Current

8.4.2Series 83: DC and AC (up to 20kHz) current sensors from 3kA to 20kA



Series 83 has been developed in order to be assembly to extend the current range. With up to 4 units of 5kA sensors, you can build easily a unique 10kA, 15kA or 20kA current sensor. Transducers has to be connected in series (as show here bellow) and the voltage output has to be connected in parallel to create a new analogous output (2V/Ipn ratio).



8.4.3Series 13: Small current DC+AC current sensors from 50A to 1kA

The first flexible, clamp-on, current probe for the robust and non-intrusive measurement of DC leakage currents

CE
RoHS

Range Ipn = 50 A

Current range could be adapted on-demand

Fields of application

Automotive – Industry – Telecom
Energy – Rail – Air and Sea

For testing and monitoring low DC currents, easy to implement in laboratory and on the field

Benefits

- DC flexible measurement made possible by Neel Effect®only, available in large diameter
- Easy installation : the flexible Neel Effect® coil snaps around any busbar, pipe or cables
- Ideal for tight spaces and adaptable for small and large conductors of various shapes
- Galvanic isolation between the primary and secondary circuit
- The Neel Effect® is a technology with no hysteresis, no magnetic offset
- No primary circuit insertion loss
- Current overload capability without damage
- Analog output