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In2Rail

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Deliverable D2.3
Embedded & Integrated Sensors: Systems Design Hierarchy Report

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		Details of contribution
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Contributor(s)	All participants	Section 6.5 has been discussed in group.
	Ansaldo STS (ASTS) Federico Papa Enzo Sorrentino	Description of safety critical information related to interlocking systems in Section 7.2.4 and 12.3 "Manufacturers of Interlocking Systems". Link with the WP9 "asset status representation" activities.
	Chalmers University of Technology (CHALMERS) Björn Pålsson	Section 4.4 motivations of S&C measurement data for R&D purposes and part of section 6.5 with a list of monitored parameters. Summary of the work in EU-project D-rail, section 11.1.3. Structuring the whole document
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		Details of contribution
	University of Southampton (UoS) Louis Le Pen	Knowledge about measurement with accelerometers, geophones and similar technology. Contribute to section 5.1.1 and 6.1.1. Also involved in structuring the document.
	Vossloh Cogifer Patrick De Lavallee	Knowledge about S&C manufacturing and system for condition monitoring, section 7.2.2

Review Comments

Following the In2Rail midterm review on Tuesday 28th February 2017, this deliverable was requested for revision by the European Commission in the assessment report #Ref. Ares(2017)1734456 - 31/03/2017, In2Rail can confirm that the review comments have been duly considered and this modified report contains revisions to address these specific points.

The below table provides an index to Sections of the revised document that contain the responses to the review comments.

Revision Requested from EC	Revision in document
More evidence is necessary concerning how integrated sensors could be embedded into S&C	See Section 6.4
System principle/concept design needed, clearly indicating the path leading to the aspects to be monitored	See Section 5 for how the information is related to the stakeholders. See Section 6 to correlate technical solutions to the information that is to be captured.
System principle\concept design should include feasibility analysis	See Section 6. For each Section there has been included a sentence about feasibility. For the most promising technologies the feasibility analysis will be developed further in D2.4
Data structure design needs to be included	See Section 8.2.1 This has now included a discussion about an Open System Interconnection model that structures computing system design into layers. It is however acknowledged that the data structure design is still to be developed further and we have not been able to address this in this D2.3 revision to our satisfaction, and therefore propose to ensure that it is adequately covered in the ongoing activity forming the next deliverable D2.4.
Signalling process requirements shall be defined	See Section 6.2
Shortlisting fewer monitoring items\aspects which are expected to offer the most feasible and reliable options, rather than listing all aspirational whole-system monitoring systems with lack of clarity over their applicability to S&C. Three issues would also be suggested to be further investigated in the course of the next stage: number of sensors/amount of data to be collected and interpreted, batteries life and maintenance implications for the batteries, and finally SIL (system integrity level) associated with detection and monitoring.	This has been addressed in that in each part of Section **6** the feasibility of measurement parameters has been described. As additional solutions may emerge that prove more reliable and at lower cost, the descriptions have remained the same in the introduction of Section 6. However, any technologies and information that have the highest priority have been identified.

Executive Summary

It is an established fact that switches and crossings (S&Cs) cost more than regular track to maintain. They are also responsible for a disproportionate volume of train delays due to a high number of in-service failures, and increased repair times.

This deliverable aims to identify possible value-adding S&C monitoring technologies, as well as proposing a possible system architecture for implementation, focusing on realisation through embedded systems; that are integrated into the S&C asset.

There are embedded monitoring systems currently available for S&C that can be used for operational and maintenance purposes, such as measurement of Point Operating Equipment electrical current. In In2Rail this concept has been developed further by defining the system required to monitor additional parameters with the aim of creating a more complete understanding of S&C system condition and its variation over time, enabling informed operational and asset management decision making (such as optimised planning of S&C maintenance and renewal).

Furthermore, the collected information will feed into other In2Rail activities, such as Task 2.4 which will develop self-adjusting S&C systems that automatically compensate for equipment deterioration based on the input from monitored parameters.

A system design approach has been adopted in order to ensure that systems are developed with a clearly defined purpose, supporting calculation of cost benefit ratios and therefore the creation of a business case for implementation.

This has been summarised into four categories, different categories do not always require the same information, although sharing data between categories will offer greater efficiency and potentially lead to additional insight. The categories are:

- Operation;
- Maintenance;
- Asset Management;
- Research and Development
- Train Operators.

Numerous key asset properties are identified as being required by a category. Some categories may require information on the same key property, considering their capture simultaneously will offer greater efficiency and potentially lead to additional insight into asset behavior.

The following key asset properties were identified for monitoring:

- Vertical displacement under train movement;
- Long term settlements;
- Rail fatigue;
- Temperature induced rail stress;
- Switch blade motion;
- Possible switch blade obstruction;
- Switch blade final position;
- Critical flange-way clearance;
- Critical check rail clearance;
- Rail and wheel profile;
- Heating system performance.

Knowledge of the following parameters is required to provide information on key asset properties:

- Dynamic Displacement / Velocity / Acceleration;
- Static Displacement / Offset;
- Strain / Stress / Force;
- Crack Initiation / Length / Propagation;
- Noise emission;
- Form / Profile;
- Electric Current / Voltage;
- Temperature.

A review of existing technologies in use and under development both within the rail industry as well as other industrial sectors was completed to avoid duplication and leverage technology transfer where possible.

Several areas of technology development have been identified in order to effectively measure the required parameters. Some technologies may be embedded within the S&C asset and will become the focus of this Task. Others that are either more efficiently collected by vehicle mounted systems, or are not currently possible or economically viable, these are included for future reference only.

A horizontally integrated, modular architecture is proposed for further development. This enables a flexible approach to future additions, as well as simplified data sharing across functions.

Moving forward, the Task will have the following core deliverables/objectives:

- Identify technology with a viable benefit that the Task has the capability to develop;
- Define a local architecture for the system to adopt;
- Develop a TRL 5 concept demonstrator;
- Propose other technologies that could be developed for the system.

TABLE OF CONTENTS

Abbreviations and acronyms

Abbreviation / Acronyms	Description
DIC	Digital Image Correlation
FMEA	Failure Modes and Effect Analysis
LCC	Life Cycle Cost
MDD	Multi-Depth-Deflectometers
PSD	Position Sensitive Devices
RCF	Rolling Contact Fatigue
RFID	Radio Frequency Identification
S&C	Switches and Crossings
TSI	Technical Specification for Interoperability
USP	Under Sleeper Pads

1 Background

The present document constitutes the second issue of Deliverable D2.3, Embedded & integrated sensor: Systems design hierarchy report, in the framework of the Project titled "Innovative Intelligent Rail" (Project Acronym: In2Rail; Grant Agreement No 635900).

This document has been prepared to provide a description of today's and tomorrow's use of automatically collected data for Switches and Crossings (S&Cs). With the aim of leveraging this information to enhance the operation, maintenance and management of S&C, increasing the performance, reducing the cost to enable a railway fit for future demands.

From previous work in European and national projects much can be learnt. The most important is that the list of parameters mentioned in Chapter 5 has been already discussed in previous projects. In most of these projects there is no attempt to go from single measurement to view of a holistic system that can integrate a number of measurements in a way that maintenance and management will improve for the whole population of S&C. This part of WP2 focuses on the low level technology required to collect information that is useful for S&C, WP6 explores the use of the data for asset management and maintenance whereas WP9 will evaluate the present and future status of the asset with the data for advanced system operation.

This chapter provides some background as to why S&C is a critical asset in the context of Safety, Cost and Capacity. It also highlights the importance of a systematic approach to developing new data collection systems and proposes EN 50126 as a potential framework.

1.1 Safety

Switches and crossings are a safety critical asset as they guide and support vehicles, potentially at high speed, and also separate vehicles on adjacent tracks. Functional failure can lead to derailment as well as potential collision between trains; both of these failures have severe safety implications.

Furthermore, a rigorous inspection and maintenance policy increases the exposure of personnel to the risk of harm, including during site access, contact with traffic as well as exposure to moving parts.

1.2 Cost

The cost for maintenance includes both inspection and maintenance. According to research the cost of inspection, service and test can account for 50 % of the annual cost for an S&C [Innotrack 2010]. The effectiveness of these activities also has a direct impact on the costs associated with operational train delays and asset renewals.

Renewal costs for S&C are often large due to the complexity of the asset as the interface between multiple adjacent tracks as well as between the track and the signalling systems. Due to the inherent need for a gap in the crossing to allow the rail wheel flange to change tracks there is an impact force with a considerably larger magnitude than the nominal contact force in the wheel-rail interface. This often requires use of higher performance materials which bring additional capital and inspection cost. Furthermore, bespoke configurations of the asset for particular track layouts add additional cost.

Finally the cost of delay associated with a failure of S&C can be very high as multiple lines will be affected with the potential for large knock-on effects on the availability of other routes are reduced. This cost of delay is not normally included in life cycle cost calculations, rather presented separately.

1.3 Capacity

Failure rate of S&Cs are in the order of 1 failure/year per S&C in main track. Assuming that a track section (double track 30 km long) has 50 main track S&Cs and the requirement is that all S&Cs should be in function. If each failure leads to a 1 hour down time and the annual need for inspection and preventative repair is about 10 hours then the track section availability will be 94 %. Lower failure rate, less manual inspection, longer life time of components and better maintainability are needed to increase the availability.

As demand for rail services increases there are plans to increase capacity through changes to trains and the control system, while the fixed infrastructure is required to stay the same to reduce costs. This means that much more performance will be required from existing S&C assets in the future.

1.4 Standard to develop new solutions

The development of a final system should be done in a structured way. To follow EN-50126 is a way to assure that the system will be reliable, maintainable and safe and will perform with a high availability. In EN-50126 a process model is proposed, called the V-model.

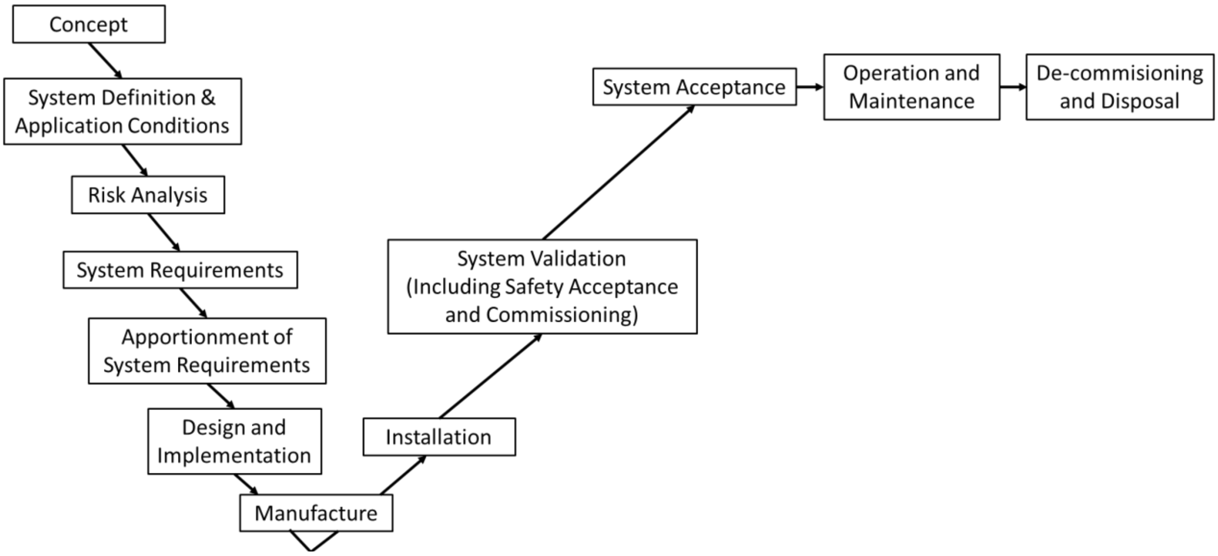

Figure 1.1: V-model according to EN-50126

2 Objective / Aim

The primary objective of this deliverable is to describe the characteristics of the S&C subsystems and identify the requirements for the monitoring system. This also includes a description of which parameters should be monitored and how they can be employed in maintenance decisions, self- diagnosis as well as in simulations tools.

A secondary objective is to identify sensor technologies from other industry sectors for possible to transfer into the rail sector.

This deliverable also starts to discuss the need of ‘meta data’ streams to enable predictive maintenance and ‘meta data’ structures related to infrastructure managers.

3 Report Structure

The report approaches the topic by defining the reasons for collecting data and therefore determining the appropriate parameters to be monitored in Chapter 5. Based on these requirements, a review of available technical solutions is completed in Chapter 6. Findings from these three chapters are then summarised later in the document.

A review of existing related projects and technologies, both from within rail as well as other technology sectors, is completed in Chapter 7 to reduce the chance of duplication and ensure that prior work is exploited. Finally, Chapter 8 proposes a complete system hierarchy which is capable of delivering the identified objectives.

4 Stakeholders for S&C Information

It is important to realise that the instrumentation of S&C provides automatic monitoring of particular parameters. It is essential to first define what this information is in order to ensure that the appropriate technical solutions are proposed.

This section explores the various potential purposes for collecting information and considers the implications for data collection system requirements. The following key general application requirement areas were identified:

- **Risk** – what risk is introduced by failure to supply information? Examples include safety, environmental operational and economical;
- **Availability –** which stakeholder requires the information, where and when;
- **Accuracy** – what margin of error is acceptable in the information; and
- **Collection frequency** – how often must the information be collected.

These application requirements provide essential high level context for the specification of technical solutions. Particular consideration must be given to the reliability and maintainability of a proposed technology in order to demonstrate compliance.

There are many stakeholders within the railway system that require information from S&C including Infrastructure managers, train controllers, train operators, researchers and S&C manufacturers. The coming section explains the different aspect that each stakeholder has.

4.1 Railway Operation and Control

4.1.1 Safe Asset Operation and Control

There are allowable margins built into the design of the asset. For system integrity it is critical that the traffic management system has the information whether the switch is set in the straight or diverging direction. This includes confirmation that the switch is fully set in position and it is therefore safe for a train to proceed at speed, this is referred to as detection. This information is normally captured and distributed within the signalling system.

In railway signalling, interlocking is an arrangement of signal apparatus that prevents conflicting movements through an arrangement of tracks such as junctions or crossings. An interlocking is designed so that it is impossible to display a signal to proceed unless the route to be used is proven safe.

The typical architecture of Interlocking is characterised by a central post, which implements safe management of railway traffic, and a peripheral post, which manages the interface with field devices.

The peripheral post does not perform interlocking functions but relays commands received from the central post to the field devices, and collects the state of these devices and sends the extracted information back to the central post.

Therefore, within the interlocking system it is possible to control the field devices (i.e. railroad switch or light signal) through the peripheral post module that monitors the devices status and their availability.

Part of the information that the peripheral post module provide to the central post is:

- if the switch operation is in progress and the routing position (normal or reverse);
- if the switch is in control or not;
- Error mode of the switch itself (Non-vital error), which can be:
  - Switch blade is not in control according to switch point motor,
  - Switch blade is not in control according to switch point detectors (optional information),
  - Indication there is a vehicle in the S&C area by the train detection system, as there is a command to move the S&C.

Related to the key requirements this focus on avoiding safety risk and therefore the accuracy of this information must be very high and is needed to be available at each train passage and switch movement.

4.1.2 Efficient Whole System Operation/Traffic Management

Train operations focus on the current and near future availability of a route. These routes inherently involve switches and crossings and are therefore directly affected by their availability. Asset availability is inferred from the signalling system i.e. whether detection has been made, this gives no indication of the condition of the asset. These topics are part of the studies in WP9.

Related to the key requirements this focus on avoiding risk of train delays and therefore the accuracy of this information must be high and is needed to be available at planning next switch movement.

4.1.3 Enhanced Asset Operation

Information can be used locally to adapt the control of the asset to increase its performance. An example is closed loop control of points heating systems, where rail temperature can be used to activate the heating system improving effectiveness and efficiency. This is illustrated in Figure 4.1.

Another example is closed loop control of dynamic component positioning, where the location of the moving parts of the asset are fed back to the actuator to improve performance.

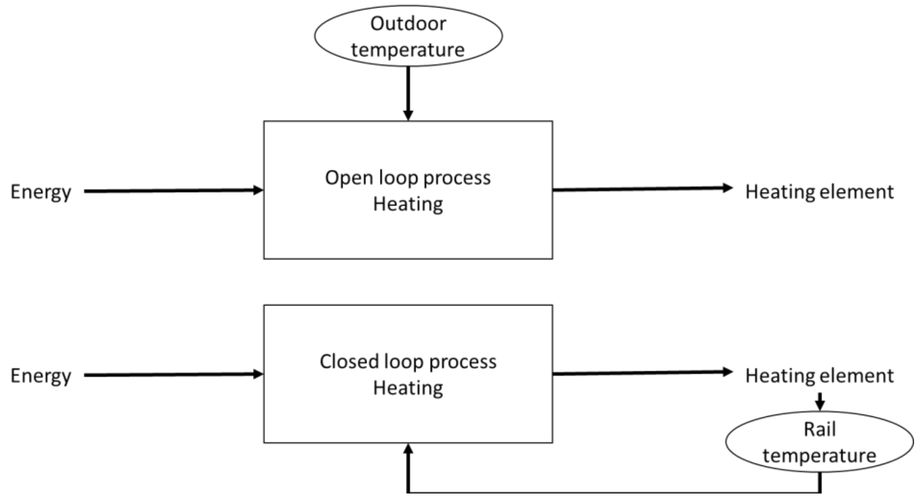

Figure 4.1: Example of process control

Specific types of this use case are explored further in Deliverable 2.7 and 2.8 where closed loop control and self-adjusting mechanisms are discussed.

Related to the key requirements this focuses on avoiding the risk of a failing asset and therefore the accuracy of this information must be high. The frequency depends on the application, heating is controlled each second and movement of a switch blade needs data several times per second during the movement. As this information is for automatic control only alarms are sent to an end user. Such alarms should be sent within a minute to the staff that are responsible for the asset.

4.2 Maintenance

Infrastructure Manager's primary concern is ensuring that the railway infrastructure is delivered safely, to an agreed availability, at the lowest cost. This makes the reliability of the infrastructure a high priority, as high reliability means that effective plans can be made and delivered.

4.2.1 Preventative maintenance

During use the S&C asset will degrade, potentially leading to a loss of performance and low reliability. Instead of replacing whole assets at extreme cost, inspection tasks are carried out to check the condition of the asset, maintenance tasks are then scheduled based on the inspection reports or amount of traffic that has passed. The maintenance action is to repair or replace components that are damaged before the asset fails. Combination of inspection and maintenance tasks is known as a maintenance regime and is typically based on past experience of asset failure, defining cyclical, time based, inspection and maintenance tasks. Information collected during inspection tasks is aimed at the known failure modes of the asset, Failure Mode and Effect Analysis is a scientific method to capture this data and will be completed in Task 2.1 and 2.3. In the meantime the existing documentation for inspection regimes may be used to define the information required by Infrastructure Managers to maintain the availability of the S&C. Related to the key requirements this focus on avoiding risk of safety related failures and therefore the accuracy of this information must be high. The interval varies, depending on type of inspection and how critical the S&C is, from 1 week to 6 months. Many existing inspection techniques rely on subjective judgement, data collection techniques could assist by increasing the objectivity. Such techniques could be used for judging crack type and size in the crossing.

An automatically measured value can be collected and analysed before it is sent. That is sending data can be done once a day as long it is not an alarm that needs immediate attention from the maintenance organization, which is the handled as reactive maintenance.

4.2.2 Reactive maintenance

Despite full preventative maintenance regimes it is possible for assets to reach a condition in which scheduled maintenance cannot prevent failure. Examples include failures which are not safety or service affecting and the decision is made to continue operation and repair when possible, or situations involving abnormal external factors such as defective rail vehicles and extreme weather. Reactive maintenance requires real time information on the status of the asset, particularly whether it has failed or not. Any other information related to the likely cause of failure may help with fault diagnosis and increase the quality of repair.

Related to the key requirements this information is available first after a failure has occurred.

4.2.3 Predictive maintenance

If the future condition of the S&C can be predicted with some certainty then it is possible to maximise the efficiency of the maintenance of the railway system, not only fixing assets before they fail but also scheduling train movements and maintenance tasks for lowest whole life cost. Example of predictive maintenance is tamping based on track geometry degradation. For S&C predictive maintenance is not yet widespread and the existing embedded systems are still more reactive then predictive. To achieve this, information on the current progress of all root cause failure mechanisms is required; to increase effectiveness information should identify failure modes as early as possible. Additionally information on the likely change of condition over time is required, this is best calculated alongside information of the predicted quantity and quality of traffic the asset may experience.

Related to the key requirements this focus on avoiding risk of unplanned maintenance actions and therefore the accuracy of this information must be high. The data collection frequency is not as important as the knowledge of failure mode and the degradation rate.

Most predictive maintenance should be planned several months in advance and therefore the interval can be between one day up to 3 months.

4.3 Management Decision of Asset Renewal or Enhancement

When an asset reaches end of life the Infrastructure Manager must make a decision about whether to renew with the same design, or to enhance the asset. Information on the performance of the asset over its whole life is required in this instance as well as information about the assets in the surrounding area. This information will enable the infrastructure manager to make an informed decision for the lowest whole life cost.

Each infrastructure manager and manufacturing company has business goals that are evaluated in the business process. Monitoring of S&Cs must be incorporated into this by the management system, in such a way there must be a proven benefit using the monitoring system to achieve for instance lower cost, less disturbances or higher safety. Without this benefit the monitoring system will not be implemented by the infrastructure manager.

The condition of the whole switch can be used to predict remaining useful life. WP6 will be dealing with these questions. It is normally done by combining information from several data sources. The amount of traffic that has passed over the switch as well as the current ballast quality and sleeper condition can be information that is used to estimate the remaining life of the S&C.

Related to the key requirements this focus on renewal decisions (life cycle cost) and therefore the accuracy of this information medium. The frequency of data collection should be yearly.

4.4 Information for Manufacturers and Research and Development

To be able to build degradation models and to achieve a more detailed understanding of the cause of deterioration there is a need of condition data. This information will be used to improve the design of the S&C. This type of measurement is done on specific places and during short time period.

The railway research community typically desires the same condition data as infrastructure managers. In addition however, the research community is also interested in data for the creation and validation of simulation models. These models can then for example be used for design optimization of switches and crossings or the prediction of track degradation over time. The data of interest can both be condition data, i.e. what is the status of a turnout, and time measurement data, e.g. what is the structural response of the turnout as a train passes over it. The transition zones that are present in the switch and crossing panels are the most important part regarding static and dynamic measurement data. In section 6.5 these parameters are presented.

Static or dynamic condition data is of interest to know how S&C evolves over time, for example changes in rail profile or track settlements. Dynamic data is of interest for several reasons. The first reason is to better understand the dynamic train-track interaction and the processes that cause degradation. The second reason is to study the variation in for example track forces for different wheel and vehicle passages such that the scatter in loading can be accounted for in for example calculations of settlements. It is also of interest to study how the scatter in loading evolves over time as the S&C degrades. For example how the impact forces at the crossing change with degradation of the crossing geometry.

Related to the key requirements this focus on improving decision making which affects both operational and economic aspects. The information is available for researchers. The accuracy demand on this information depends on purpose and might be very high if it is done just once or low if the information can be captured many times.

4.5 Information for Train Operators

There are several detector systems for vehicle performance today placed in infrastructure. Two of the aspects related to vehicle are most interesting to measure also for S&Cs. That is vertical and lateral dynamic forces and wheel profiles. The degradation of the S&C is strongly depending on the behaviour of the vehicle and excessive values indicates that the vehicle needs maintenance.

Related to the key requirements this focus on avoiding excessive degradation. The accuracy of this information must be high as there is a direct impact on the traffic if a train needs to be taken out of service and a safety issue if a faulty train is allowed to continue. The frequency of measurement is every train passage and if possible the information is only sent as an alarm if there are several indications on the same vehicle axle. The information should be available both for the train operators and for the infrastructure owner as trends and as alarms on a daily/weekly basis.

5 Collection of Information and their Requirements

Health Monitoring of an S&C should be based on a certain number of parameters that is possible to measure. The parameters that are actually measured in a particular case depends on different requirements so the list given here contains a spectrum of measurements suitable for several purposes. The list is extended beyond what is appropriate to be measured with embedded sensor technology and also contains items that are impractical or impossible to realise in a cost effective manner. Nevertheless this information would, if it was available, be interesting to have to better understand the deterioration of an S&C. In Chapter 6 the technology for measurement is presented and the purpose of measurement is combined with parameters and technology to measure.

The purposes for taking measurements and the stakeholders have been described in Chapter 4. The benefit of monitoring data is depending on the character of the S&C described in Chapter 13. Strategically important S&C at large stations or key junctions will require more extensive condition monitoring than less important rural S&Cs. In some cases however the need for measurement data is motivated by the requirement to gain better understanding of the long term behaviour, and is therefore just measured on very few S&Cs.

In this chapter is evaluated how feasible it is to collect the information by embedded sensors or standoff equipment. Embedded system is directly mounted on the S&C. Standoff system can be either cameras, weather stations, current measurement in the interlocking system or other system installed at the site but not directly in the S&C.

Even if the information is collected it needs to be handled in an intelligent way. Chapter 8 describes a system hierarchy that is a solution that could be widely used and also how it can be integrated to the maintenance and management system. The following list, illustrated in Figure 5.1, contains the kind of information that is asked for. Some of this information will most likely be best captured by other methods than embedded monitoring systems, such as vehicle based monitoring systems:

- Vertical displacement under train movement;
- Long term settlements;
- Rail fatigue;
- Temperature induced stresses in rail;
- Motion of the switch blade;
- Possible obstruction of switch blade movement;
- Final position of switch blade;
- Monitoring of narrowest flange way and check rail distance;

- Rail and wheel profile;
- Heating system performance.

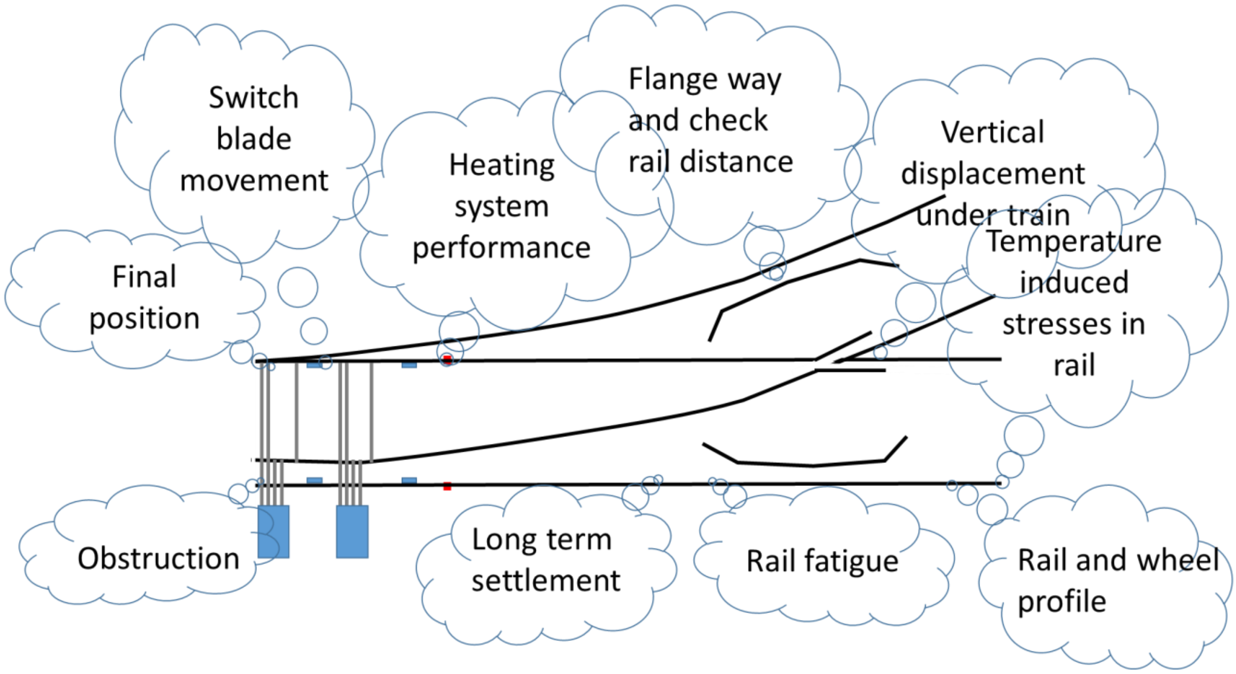

Figure 5.1: Illustration of aspirational information

5.1 Track displacement and settlements

5.1.1 Vertical displacement under train movement

S&C are at increased risk of the development of excessive dynamic forces compared with plain line due to changing rail profiles and varying bearer sizes. Excessive dynamic forces damage the track and substructure leading to increased rates of track geometry deterioration, local component failures (e.g. railclips) and more frequent/costly track bed maintenance requirements.

To better understand performance of S&C measurements of vertical and (more rarely) lateral displacements under train loading can be carried out. The knowledge of the track displacement gives an estimation of the track settlement (Dahlberg2004). The acceleration under the crossing nose also allows for monitoring of the impact load on the frog. A frequency analysis of the measured accelerations provides the characteristic frequencies of the track. An analysis of these frequencies and of their variations over time gives information about the behavior of the track components. In fact, the track components have different resonance frequencies, which change if a modification occurs in the corresponding component.

There is a reasonable understanding in the literature of what may constitute "good" vertical track displacement of sleepers on plain line track (of the order of 0.5 to 2.0 mm). However, for S&C, this understanding is less well developed due to the more complex geometry, varied bearer sizes and changing rail bending stiffness through the S&C. Therefore, further work is required to establish what may be the normal bounds of displacement acceptable for S&C. An improved understanding of acceptable/desirable displacement magnitudes combined with long term monitoring from embedded sensors at S&C could be used to implement more targeted maintenance practices leading to increased S&C asset life and reduced frequency/cost of maintenance.

This information is useful for both for preventative and predictive maintenance. It can also be used after maintenance (for instance tamping or component replacement) has been performed to check the result.

5.1.2 Long term settlements

Ballast quality, fines in the ballast, and water content in ballast and soil are factors that influence the degradation rate and magnitude of long term settlements. The absolute settlement is normally not as interesting as the relative settlement between sleepers. However, higher degradation rates lead to a higher probability of uneven settlement.

The vertical and horizontal position of each sleeper in the switch panel should be such that the switch blade can be moved without excessive force. In case the settlement is uneven, the probability of malfunction increases.

Measuring long term settlements will give a good understanding of the degradation of track geometry over time. This information is not used for maintenance decisions, instead it is needed to avoid problems when building on new sites with soil conditions that would create problems and also for research purposes.

5.2 Rail Fatigue and Temperature Stresses

5.2.1 Rail fatigue

S&Cs are subjected to fatigue. Fatigue cracks at the running surface are usually rolling contact fatigue cracks. Internal fatigue cracks may also occur. Density of cracks and crack length are parameters of interest. This information is used by the maintenance organisation for predictive maintenance, such as grinding, rail replacement and welding.

Measuring force and wheel position as it passes the transition zones can be used to detect vehicles that generate wheel/rail contact conditions that are damaging to the S&C. This information is used by the train operator to maintain their wheels and by the infrastructure manager to stop vehicles that are out of acceptable limits.

5.2.2 Temperature induced stresses in rail

Variation of outdoor temperature affects performance and might also lead to sudden failures.

High temperatures induce compressive longitudinal stresses in the rails which increase the probability of rail buckling but may also lead the switch blade to lose its alignment. Low temperature instead helps cracks to grow faster. This information is used for predictive maintenance.

5.3 Switch Panel and Crossing Panel

Switch panel and crossing panel are the transition zones and should therefore be monitored both during switch blade movement and in final position. Crossing panel with swing nose crossing will have similar measurement handlings as the switch panel.

5.3.1 Motion of the switch blade

Measurements during the motion of the switch blade can indicate several mechanical problems. The electric current is a normal way to measure the switch blade movement, but force and displacement can also be measured. The rotation of roller elements in the gliding chairs is another piece of information to be collected.

This type of data can be used by WP9 to predict the probability of future failures. Interlocking system can gather information such as time of movement, motor current and voltage. It is also used for preventative maintenance.

5.3.2 Control, Motor, Stretcher Bars and Gliding Chairs

Vibration in control, motor and stretcher bars can indicate loose bolts and other problems. Gliding chairs might break if they are overloaded, so the integrity should be checked. This is information needed for preventative maintenance.

5.3.3 Possible Obstruction of Switch Blade Movement

Extraneous objects such as litter or ice blocks can come in between switch blade and stock rail. These objects will hinder the switch blade to come into control and should be detected before the blade movement starts. This is information for reactive maintenance.

5.3.4 Final position of switch blade

The time to go from one side to the other side is normally registered within the interlocking system. To long time for the movement will activate an alarm. It is not always the movement that is hindered as all control circuits' needs to be activated to tell the interlocking system that the final position is reached. There are sensors that indicate the final position both inside the point machine as well as between the point machines. Information on exactly when these sensors are activated can be used to ensure that the movement is done in a good way. Today time of movement is only evaluated as one single measurement, but could consist of individual event time values for each of the switch point detectors as they come in to control.

A second measurement is to measure the deviation between the actual and the ideal form of the switch blade in the final position. This is possible by measuring the absolute coordinates of the switch blade. This is information for preventative or predicted maintenance.

5.3.5 Monitoring of narrowest flange way and check rail distance

The distance between the switch blade tip and the stock rail on the open side must be at least 55 mm according to TSI Infrastructure (maximum free wheel passage is 1380 mm) to avoid the wheel flange to hit the tip of the blade. Also at the crossing the check rail need to be correctly positioned to avoid the opposite wheel to hit the crossing nose. This is information for preventative maintenance.

5.3.6 Rail and wheel profile

The rail profile in the transfer zones (i.e. switch panel and crossing panel) is important for the wheel/rail interaction. The most important parameters are the slope angle at the crossing nose, the thickness of the switch blade. Visible damages on the switch blade should also be possible to detect.

This information is used for predictive maintenance and also to check that the maintenance has been correctly done. The wheel profile is of interest for the train operators.

This information could be combined with the actual wheel profiles such that simulations of wheel /rail interactions can be used in simulations to predict the degradation of the rail material.

5.4 Heating system performance

Heating system is controlled by measuring outdoor and rail temperature. Rail temperature is not the same in the whole S&C and could be measured on more than single points in the S&C. Weather prognosis would be a more proactive way of controlling the heating system and would save energy as the heating is not necessary if there is now new snow coming into the S&C. All this information can be used to enhance operational performance.

6 Measurement Technologies and Strategies

Relevant sensor technologies for measuring the parameters mentioned in Section 5 are presented in the following subsections. Each parameter category has its own subsection which contains a table of relevant measurement technologies. Many technologies are applicable to multiple categories but are not repeated in each table to avoid duplication.

The most promising areas for embedded sensor technology within S&Cs are measuring:

- motor current and position of the switch blade during motions;
- acceleration at the transition zones of the S&C as displacement, stiffness and cracks can be identified with basically the same technology;
- temperature in the rail to check the efficiency of the heating elements;
- specific weather condition to improve switch heating.

Areas that still is feasible but need more for development before being implemented are measuring:

- bending and longitudinal stresses;
- by acoustic emission or embedded ultrasonic sensors to see crack growth;
- by cameras and use vision systems to identify for instance obstruction objects in the switch area.

6.1 Basic Technology for Measurements

Measurements are based on physical or chemical phenomena. The international system of units (SI) defines 7 basic physical quantities. They are:

- Length (Metre);
- Mass (Kilogram);
- Time (Second);
- Electric current (Ampere);
- Temperature (Kelvin);
- Luminous intensity (Candela);
- Amount of substance (Mole).

There are an unlimited number of derived quantities and SI defines 22 quantities with own units that are directly related to the base units.

Here are some examples that might be of interest:

- Angle (radian);
- Force, weight (Newton);
- Pressure, stress (Pascal);
- Voltage (electrical potential difference), electromotive force (Volt);
- Electric resistance, impedance, reactance (ohm).

The variants of sensors are large and cannot easily be described. Data from sensors might need to be recalculated into another entity before they are presented, an example of this is that forces are presented in Newton even if the sensor measures strain. The conversion might be simple if the physical principle is well defined, more complex relationships may require simulation techniques for the conversion.

6.1.1 Measuring dynamic track displacement and settlements

Track settlements occur more often in and around the S&C than in plain line because of the stiffness variations in the turnout and the dynamic forces that occur in the transfer zones. Accelerometers embedded in the ballast layer enable computation of the track displacement (Cui2014). It seems relevant to place accelerometers under the switch panel, under the closure panel, and under the crossing nose.

Track mounted/embedded sensors are commonly used to obtain acceleration/velocity or displacement measurements of sleepers or rails in response to trains passing. The data obtained may be analysed to determine whether a sleeper or rail is performing acceptably. More recently methods to evaluate track performance using frequency analysis of such measurements have also been proposed.

To achieve this, currently available and relatively mature, sensor types such as geophones and accelerometers can be mounted onto sleepers/bearers or rails. Most commonly the native sensor measurements are then converted to displacements using established signal processing and mathematical techniques. The calculated displacements are used to evaluate how well the track is performing based on both the magnitude of individual location displacements and the variation in displacement magnitudes along the track.

The principal sensors used and methods to determine displacement over time are:

- Accelerometers;
- Geophones;
- video camera followed by digital analysis of the images captured (digital image correlation, DIC);
- laser systems with Position Sensitive Devices (PSD) mounted on sleepers/rails to detect the position of the laser;
- multi-depth-deflectometers (MDD).

These are summarised in Table 6.1.

Instrument and parameter measured	**Attributes, advantages (+) and disadvantages (-)**
Geophone: velocity[A]	+Easy to deploy +Requires only one stage of integration and filtering -Train speed must be above geophone natural frequency -Signal processing requires skill and care
Accelerometer: acceleration[B]	+Micro Electrical Mechanical devices (MEMs) are low cost +Easy to deploy -Requires two stages of integration and filtering -Signal processing requires skill and care
Digital Image Correlation (DIC) of high speed filming: displacement[C]	+Can be used for any realistic speed of train +Accurate at lower speeds where accelerometers, gyroscope and geophones tend to be less reliable -Susceptible to vibration at the camera location (groundborne and wind), although methods to correct for this are available -Line of sight may be problematic
Laser based systems: displacement[D]	As for DIC although differing processing methods may result in relative differences in accuracy.
Multi depth deflectometer: displacement[E]	LVDT (linear variable differential transformer) based system installed in shallow vertical borehole in trackbed +Will give an absolute measure with no zero shift and will in principle measure permanent settlements -Requires fixed datum at depth -Difficult or problematic to install

Table 6.1: Summary of methods for measuring dynamic track displacement

References and further reading:

- A) (Bowness et al., 2007), (Priest et al., 2013), (Le Pen et al., 2014), (Le Pen et al., 2016)
- B) (Lamas-Lopez et al., 2014)
- C) (Bowness et al., 2007), (Le Pen et al., 2014), (Murray et al., 2014)
- D) (Paixão et al., 2014), (Kim et al., 2014)
- E) (Gräbe & Shaw, 2010), (Priest et al., 2010), (Mishra et al., 2014)

The described technologies can be used for measuring the parameters mentioned in Chapter 5.1.1 and 5.1.2.

The benefit of the information about dynamic displacements is an early warning that the movement of critical sleepers is above a certain threshold. The maintenance decisions to be made is when to tamp, when to adjust crossing profile.

The system can be built robust by using covers. Dynamic measurement is a realistic candidate for an embedded system.

Measuring long term settlements will give a good understanding of the degradation of track geometry over time. This information is not used for maintenance decisions, instead it is needed to avoid problems when building on new sites with soil conditions that would create problems.

There is no known available embedded system for S&C to measure settlements. 3D scanning technology can be used, but this would be a standoff equipment or a vehicle performing the scanning.

To measure static settlements is not a realistic candidate for an embedded system.

6.1.2 Measuring impact force, rail fatigue and temperature stresses

Excessive forces appear more frequent in S&C than in plain line. Forces and accelerations can be measured to predict wear and fatigue. The measurements have to be performed on switch rails, stock rails and the crossing nose.

The dynamic train-track interaction in the crossing panel is characterised by the high frequency impact force that typically occurs when a wheel passes over the crossing. Contrary to the crossing panel, the switch panel contains no sharp rail discontinuity, and therefore no corresponding high-frequency impact force. High-frequency response is therefore of less interest, instead there is a need to obtain information on the deformation of the full track structure in the switch panel as the vertical loading and therefore settlement behaviour etc. should be quite similar to regular track besides around the Point Operating Equipment where classic track geometry maintenance techniques are impeded. The effect this maintenance discontinuity may have on the S&C settlement behaviour could be explored. Stock rail to switch rail discontinuity causes large lateral contact forces in the diverging route which makes it also interesting to focus on obtaining information about lateral dynamics in the switch panel.

Vertical loads can be measured using strain gauges glued on the rail web (Kourousis, 2015). Similar gauges can be applied on the crossing nose to measure the vertical load on the crossing nose. The vertical load can then be computed knowing the behavior law of the rail material. To control the fatigue behavior of the rails, it is necessary to count the number of solicitation cycles of the rail. This can be done using a wheel counter sensor, which detects the wheel presence using inductive currents and which is fixed on the rail. This sensor can also measure the vehicle speed. Lateral forces can be measured using strain gauges glued on the rail (Lin2015). Tangential forces can be measured by using instrumented wheel set (Pålsson, 2011) but so far it seems unlikely to measure it along the whole S&C with embedded sensors. From the measurement of tangential forces T and the creepage γ at the wheel rail contact, an estimation of the rail wear can be deduced, assuming that the wear is proportional to the product Tγ.

New measurement methods could increase the precision of the estimation of the rolling contact fatigue and of the rail wear. For instance, an ultrasonic array placed under the rail, enables to measure the size of the contact zone and the pressure at the wheel-rail contact (DwyerJoyce2009). Optical fibers attached to the rail can also be used to detect broken rails, or be used as strain sensors to measure the forces at the wheel-rail contact (Kourousis, 2015). Finally, the measurement of the noise produced by the wheel-rail contact may inform the infrastructure manager about the degradation of the rail surface: for future works, it could be interesting to characterize the noise produced by the impact load on the crossing nose and by the discontinuities in the wheel rail contact, and to study its variation over the time.

Dynamic simulation is also an interesting source of information for the infrastructure managers, once the simulation had been validated using measured parameters. In fact, the simulation of the train dynamics on the turnout yields a precise estimation of rolling contact parameters.

Acoustic Emission techniques have been developed by using sensitive piezoelectric sensors to detect energy propagating through material under stress such as airplane components (Blitz 1991). This can be used to detect crack propagation in crossings (see Section 11.2.1). Other possible technologies are based on ultrasonic probes and visual inspection by camera. Eddy current measurement is today done by vehicle is not probable to be embedded.

Instrument and parameter measured	Attributes, advantages (+) and disadvantages (-)
Strain gauges (electrical)[A]	**+** Not depended on train speed + Low cost **-** Relative measurement as strain gauges is not stable over time **-** Signal processing requires skill and care
Fiber optical strain gauges	+ Absolute measurement as they are stable over time - Strain is temperature dependent - High cost
Piezo-electrical force transducers	
Inductive sensor	
Microphone	**+** Easy to deploy **-** Requires filtering and spectral analysis **-** Signal processing requires skill and care - Dependence on train speed
Ultrasonic	
Acoustic Emission[B]	

Table 6.2: Summary of methods for measuring rail impact and temperature stress

References and further reading:

A) (Kouroussis, et al., 2015), (Lin, Kimoto, & Suda, 2015), (Pålsson & Nielsen, 2011), (Dwyer-Joyce, Yao, Zhang, Lewis, & Drinkwater , 2009)

B) (Blitz & Simpson, 1991)

The described technologies can be used for measuring the parameters mentioned in Section 5.2.1 and 5.2.2.

The benefit of the information is a late warning that there is a crack in a component or an early warning that the stress free temperature is out of range.

The maintenance decisions to be made is when to surface weld, replace the component or restore the stress free temperature.

There are several technical options to observe cracks. No known system exist today that is embedded in S&C design. If it is possible to use either sound or vibration and identify deviation from normal behaviour this would be interesting to develop further.

The today's technology to find cracks is based on trains that measure by ultrasonic or eddy current methods. As a complementary this can also be made by hand held equipment. This is candidate for an embedded system that needs further development.

There are two mayor methods to measure the stress free temperature, either by lifting the rail and measure lifting force vs displacement or by cutting the rail and measure the difference in gap before and after the cut. In WP 6 a train based NDT-method is under development. In Spain (Ineco) work has been done to build system with strain gauges to measure probability of buckling. This is probably not a candidate for an embedded system as the cost to keep the system calibrated is high relatively too other possible way measure.

6.1.3 Switch blade position in movement and final position

The effort delivered by the points motor may be determined by monitoring the electrical current it draws. This may be used infer the quality of the motion of the switch blade during operation. This technology is already established. By analysing the signal it is possible to identify certain problems when moving the switch blade. A more complete picture can be obtained by directly measuring the forces and the position of the switch blade during movement. Forces can be measured with piezoelectric or resistive sensors. Position can be measured by either mechanically attached sensors or optical sensors.

Vibration in control, motor and stretcher bars can be measured by accelerometers or strain gauges. Integrity in sliding chairs could be measured by attaching wire of the same integrity directly to the component and running a signal voltage through the wire. Both the wire and the component will fail at the same time which will be indicated by a loss of voltage in the wire.

The switch blade form during movement can be measured by a machine vision system, 3D-scanner technology or by strain measurement along the switch blade. An example of measuring strain on a long object is using fibre-optics. It possible to detect if rollers are rotating during the switch blade movement by rotation sensors. If the rollers do not move either the switch blade is not in contact or the roller units have failed.

The final position is detected by sensors included in the safety system. Combining information when these sensors are activated in time and the actual position can be used to make adjustments.

Objects that can obstruct the movement can be detected before the switch blade is moved by a machine vision system.

Instrument and parameter measured	Attributes, advantages (+) and disadvantages (-)
Motor current and voltage	+ Easily deployed + High accuracy + Time of movement can be measured + Possible to integrate in interlocking system
Machine vision system	+ Can be used for multiple purposes + Can cover more than one S&C - High cost - Needs illumination
Rotation sensor	
Integrity sensor	

Table 6.3: Summary of measuring switch blade position

The described technologies can be used for measuring the parameters mentioned in Section 5.3.1, 5.3.3 and 5.3.4.

This type of information can be used by WP9 to predict the probability of future failures or alarm failed components (bars and gliding chairs).

The maintenance decisions to be made is to adjust, replace component or repair point machine.

Current measurements is already a standard product by several manufacturers. Though this is done in the interlocking system and is not embedded in the S&C.

To use accelerometers for this purpose might be easier than for sleeper accelerations (section 6.1.1) as changes in frequency response is probably the method to be used. It might be more difficult to place accelerometer for these components than for the sleeper.

The easiest way to detect obstruction is to analyse the signal when the switch blade is moving together with a distance signal. An obstruction should early in the moving cycle give higher electrical current. This method is feasible. Another method is to use cameras to observe any objects.

There exist automatic system in Japan for rinsing the area from blocking objects. Without automatic system personal needs to go there and until then the S&C is not possible to move.

Control circuit in the point machine, in the middle between two point machines as well as after the last point machines should be measured individually. It should be a further development of the system for measuring electrical current. Interlocking systems have high demands on safety and therefore no condition monitoring system is allowed to be connected directly. A method to read relays without being electrical connected has been developed by Strukton.

Motor current measurement is an existing embedded system that needs development to cope with more failure modes. To develop measurement on when control circuits are active is one development. Acceleration measurement in the switch panel can also be added. All these system are possible candidates for monitoring system.

6.1.4 Profile and gauge measurement

6.1.4.1 Profile measurement

Rail profile and gauge can be measured by laser cameras mounted on passing vehicles. Embedded measurement systems could be used, but to form a valid business case the failure development time must be shorter than the interval possible for vehicle mounted inspections. The described technologies can be used for measuring the parameters mentioned in Section 5.3.5 and 5.3.6.

6.1.4.2 Check rail gauge

Monitoring of the check rail gauge and blade gauge is motivated as an enlargement or a narrowing of these gauges could make the train derail. Distance sensors could be installed on the rails to monitor the gauge. Most common distance sensors are laser sensors using time of flight technology.

Instrument and parameter measured	**Attributes, advantages (+) and disadvantages (-)**
Laser profile measurements	+ Several commercial system available for wheel profiles + Several commercial embedded system available to measure profiles - Sensitive to environment (rain, dirt) - Measuring rail profile is only possible at short distance and placing outside the track will not give good precisions. Automatically moving laser scanner into the track area by robot arm or drones is unlikely to be realized and will be costly, but is mentioned as a possible solution
Proximity sensor	+ Established and reliable technology + High precision at short distances - Normally just measure a specific distance - Limit in distance
Distance sensor laser, time of flight	+ Can measure all distance + High precisions - Measuring one point
Time of flight camera	+Take a whole picture - Low resolution

Table 6.4: Summary of methods for measuring rail impact and temperature stress

Rail profile information is used make maintenance decisions to grind or surface weld. The information about the narrowest flange way check rail distance is used for early alarms and the maintenance decision is to adjust.

Cross rail profile, narrowest flange way and check rail distance is possible to measure with track recording cars if equipped with a laser scanner able to make high frequency measurements. To measure this with embedded or stand-off is too expensive to be a candidate and is much easier to measure by a vehicle.

The longitudinal profile can be measured indirectly by measuring strain and acceleration.

6.1.5 Weather related information

Temperature measurement is well established for switch heating purposes. Weather prognosis based on local temperature, wind and moisture measurement and external weather data could be used to activate switch heating earlier than today's system can do. Temperature combined with strain measurement is also used to avoid rail buckling or rail breakage due to high longitudinal stresses.

Instrument and parameter measured	Attributes, advantages (+) and disadvantages (-)
Temperature sensor attached to rail (Pt-element)	+ Reliable + Low cost - Point measurement
Infrared camera	+ Cover long a whole switch blade in one picture - High cost - Depends on the object
Fiber-optic temperature sensor	+ Cover whole length of a switch blade - High cost
Temperature outdoor (resistance sensor)	
Hygrometer	
Precipitation	
Anemometer	

Table 6.5: Summary of methods for weather related information

The described technologies can be used for measuring the parameters mentioned in Section 5.4.

This information is used to replace or adjust heating elements as well as adjusting the regulated temperature.

Wireless temperature loggers is already low cost system that probably can be used in railway environment. Weather station that can predict coming snowfall should also be possible to adopt to railway environment.

These are realistic candidates for embedded system.

6.2 Signal processing

To be able to use the information from dynamic measurements some kind of signal processing is necessary. Signalling processing is not so vital for static measurement (such as temperature), as the collected values can be directly compared to thresholds or used in trend graphs without signal processing.

6.2.1 Signal processing requirements for geophones and accelerometers mounted on sleepers

The use of geophones and accelerometers mounted on the sleeper/bearer tops to measure track movements on plain line has become established practice [Bowness et al., 2007, Le Pen et al., 2014, Lama-Lopez et al., 2014, Milne et al., 2016]. To interpret the data obtained, signal processing in the form of filtering in the frequency domain is required to produce acceptable acceleration/velocity and displacement data that may be evaluated to monitor the condition/performance of the track. The filtering removes higher frequencies not relevant to the major track movements and errors introduced from lower frequencies below the threshold of linear sensitivity for the sensor used.

Le Pen [Le Pen et al., 2016] provided insights into the frequencies present from passage of trains on plain line by applying a Fourier transform to a beam on elastic foundation representation of the track and evaluating the frequency spectra for known train properties. Their work showed a good agreement between the theoretical spectra and field measurements. This work provides a rationale for selecting appropriate thresholds for filtering. Figure 6.1 shows theoretical displacement and velocity frequency spectra for a typical class of train operating in Europe. In this example the train speed was set to 23.9 m/s as a convenience so that each vehicle passed the observation location in one second, in other words the vehicle passing frequency was 1Hz.

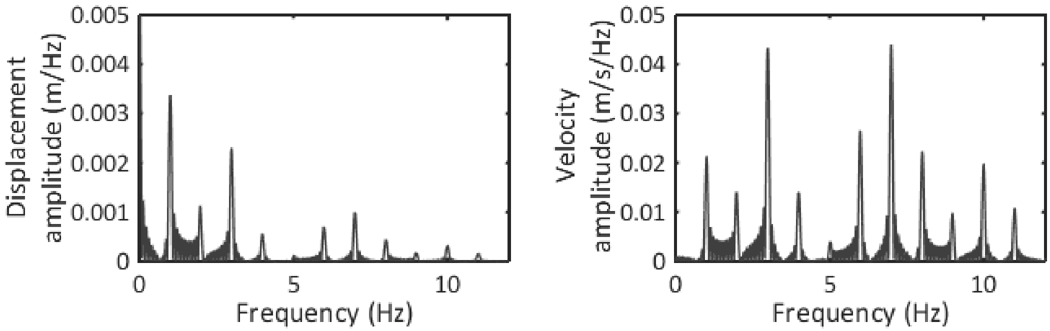

Figure 6.1: Displacement and velocity spectra for an 11 car Pendolino train travelling at 23.9 m/s [Le Pen et., al 2016]

Figure 6.1 shows that the lower frequency velocity content first spikes at the car passing frequency (in this case 1 Hz), the same may be expected for the acceleration spectra (although it is not plotted here). Therefore, the lower frequency filtering threshold may be set to below the equivalent vehicle passing frequency and thus retain the relevant data provided a sensor is used with a sensitivity above this cut off. In practice this means that geophones and accelerometers should be selected to have a reliable sensitivity range as low as possible. However, owing to the limitations of currently available sensors this means that the lower limit for geophone use is approximately 1.0 Hz while for accelerometers it is higher perhaps 2 Hz or 3 Hz.

The higher frequency threshold applied for filtering must capture all the major spikes in relation to the vehicle passing frequency, in practice this is approximately 15 multiples of the vehicles passing frequency. However, in most cases the filtered data is less sensitive to the higher cut off frequency and this may be discarded.

There are also differing methods of applying filtering. Established practice typically adopts the use of forward and reverse Butterworth filters of at least the fourth order with the lower threshold applied at 2/3 of the vehicle passing frequency.

Finally an appropriate data logging system including an oversampling regime is needed in order to reproduce a movement trace that is free of noise. Typically this means logging at

400 Hz or above. Depending on the quality of the sensor used the use of a data recording system capable of applying further noise mitigation measures could also be appropriate.

The above commentary applies to typical passenger vehicles on plain line. More complex axle spacing's on locomotive hauled passenger trains and freight vehicles would require specific evaluation and in general for condition monitoring at a specific site it is preferable to evaluate a reference train with a repeating succession of at least 4 passenger vehicles travelling at not much less than 20 m/s for geophones or 50 m/s for accelerometers.

At S & C the more complex rail geometry influences the frequency spectra present and more work is required to understand how to apply the above signal processing methods which are optimised for plain line. Additionally it is observed that sensor technology is always advancing and in the future the train speeds for which these sensors can reliably be used could reduce.

6.2.2 Signal processing requirements measuring electrical motor current

The normal way to measure electrical motor current depends on the motor in use and the bearings and gearbox. For DC-motors the voltage is stable and therefore only current is necessary. For AC-motors both voltage and current needs to be measured while the phase-angle is not constant.

The analysis is made both in the time domain and in the frequency domain (SKF). The time domain is used to find if more current is used in some of stages when moving the switch blade such as:

- Start-up current;
- Unlocking switch blade;
- Moving switch blade;
- Locking switch blade;
- Shut down of current.

A master curve is created for each individual motor and then each new measurement is compared to the master curve to see if the deviation is too large.

For the time domain 100 – 200 Hz is sufficient to capture the signal.

The frequency domain is used to find:

- Uneven air gap between the rotor and stator;
- Damaged Stator or Rotor Bars;
- Damaged Windings;
- Deteriorating Insulation.

For the frequency domain more than 200 Hz is necessary to analyse for instance the gearbox. To combine electrical data with accelerometer signal in the point machine would make the analysis more precise about which failure mode it might be.

6.3 Whole System Condition

The track is submitted to high forces and accelerations due to the particular running conditions (discontinuities, impacts, gaps). Monitoring the stresses and the accelerations in the track is thus of great importance for the infrastructure managers, in order to be able to predict long term phenomena such that rolling contact fatigue, rail cracks, or track settlements.

Section 6.5 indicates the most important parameters to be monitored, which lead to a degradation of the running conditions (delay, vibrations, and noise) and which require a maintenance action. In any case, a remote monitoring of those parameters reduces inspections in line, and thus takes part in the reduction of Life Cycle Costs. By compiling information from multiple sources, an overview is given about the state of the asset. Besides the actual condition is also needed information about amount of traffic and maintenance performed. This information can be used by the management to calculate the remaining useful life.

6.4 Embedded systems and standoff-systems

There are three possibilities to gather data at site, either by having embedded systems, by using standoff systems or by using vehicle based measurement systems. The In2Rail has limited the work to the two first aspects.

Embedded system can be delivered by the manufacturer of the S&C and at the installation be directly connected to information infrastructure.

Standoff systems are those such as cameras, scanning systems, system measuring in cabinets or systems to measure local weather conditions.

6.4.1 Embedded systems

The three known embedded systems in use are measuring motor current during movement, temperature for heating systems and acceleration of sleepers/crossing. These systems can be integrated into the equipment in track. The data is taken to a node computer by cables and then sent to a server. To avoid cabling, wireless solutions are under development, but so far battery capacity is an issue to be discussed.

6.4.2 Stand-off systems

To measure current in the interlocking system is a good example of a stand-off system. The collection of data is done by a local node computer that can be connected to a large number of sensors (ampere meters, cameras, temperature sensors). This connection can either be by wireless communication or by a cable (for instance CAN-bus). The local computer sends the information to a server where the analysis of the data is done, see Figure 6.2. Local calculation of data is possible in order to minimize the need of data transfer.

Other system that is not placed in track is camera system that can be used to check for instance if there might be an obstruction of the switch blade. Local weather stations could provide data that is relevant for controlling switch heating.

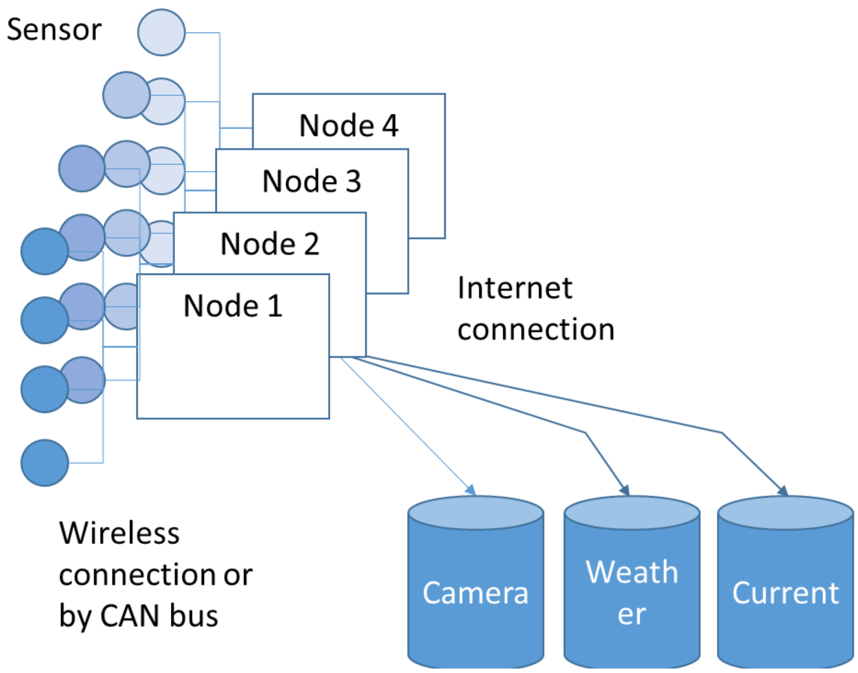

Figure 6.2: Connection from sensor to central storage of data

6.5 Summary of Proposed Monitored Parameters

The report describes how it is possible to measure the information that is asked for in Chapter 5 and how that is linked to the need in Chapter 3. In the table is also a general prioritizing what the group believe is important for Task 2.2 to work further on during the In2Rail project.

Information sought/purpose	Quantity to be measured	Measurement technology	Data used for	Priority in In2Rail	Area of interest for	Scoring Feasibility (1- No feasibility 10–High feasibility)
Structural displacement and impact force in crossing panel. The impact force doesn't follow directly from the acceleration, but can be estimated.	- Vertical displacement and acceleration - Noise	- Accelerometer - Displacement sensors - Microphone	- Management - Maintenance - Research & Development	High	- DB - NR - SYSTRA - TRV - University of Southampton	9
- Crossing deformation - Switch rail deformation - Contact zone This information can be used to estimate contact loads and the fatigue life of the crossing and switch rail. It might also be possible to estimate where a particular wheel makes the transition.	- Strain - Contact area - Lateral wheel position at transition - Forces in checkrail	- Strain gauge - Ultrasonic probe - Radar, lidar - Piezo-electrical sensors	- Research & Development	High	- Chalmers - NR - SYSTRA - TRV	(Not yet discussed) Preliminary 7
- Switch panel geometry - Crossing running surface geometry Repeatedly profile measurement will give a better understanding of the wear and deformations.	- Rail profile - Kink of crossing	- 3D-laser-scanner	- Maintenance - Research & Development	Low (More effectively done by vehicle measurement)		Cross rail profile 3 Longitudinal profile 8
Check rail gauge	Distance	Laser	Maintenance	Low (More effectively		3

Information sought/purpose	Quantity to be measured	Measurement technology	Data used for	Priority in In2Rail	Area of interest for	Scoring Feasibility (1- No feasibility 10–High feasibility)
				done by vehicle measurement)		
How the load is distributed and transferred from rails to sleepers.	Forces in rail-sleeper connections	Piezo-electrical load cells	Research & Development	Middle	Chalmers	5
Structural deformation. With information on sleeper deformations and accelerations it should be possible to obtain information about how the impact load of the crossing propagates down through the track structure.	- Sleeper displacements and accelerations along their length - Ballast displacement	- Accelerometer - Displacement sensors	Research & Development	High	- DB - Chalmers - NR - TRV - University of Southampton	9
Information on the sleeper-ballast contact pressure is the most important parameter when it comes to determining ballast crushing and track settlement.	Sleeper-ballast contact pressure	Pressure sensors	Research & Development	Low (Difficult to measure)		3
- Local crossing damage (e.g. RCF, squats, cracks etc.); - Type and location of damage for the validation of damage models.	Cracks	Ultrasonic probe (using long wave), eddy current and acoustic emission	- Maintenance - Research & Development	Middle	- NR - TRV -	4
Long term development of track irregularities/settlements	- Track geometry (vehicle based) - 3D laser scanner on site	Track geometry car/In service vehicle with accelerometers	Maintenance Research & Development	Low (More effectively done by vehicle	- SYSTRA - TRV	4

Information sought/purpose	Quantity to be measured	Measurement technology	Data used for	Priority in In2Rail	Area of interest for	Scoring Feasibility (1- No feasibility 10–High feasibility)
				measurement)		
Longitudinal stresses	- Strain - Rail temperature	- Strain gauge - Temperature sensor	Operation	Middle (Cooperation with WP5.3 which try to do this by vehicle measurement)	- NR - TRV	6
Sleeper condition, remaining useful life	Sleeper strength	Acoustic emission	- Management - Maintenance	Low (Difficult to do by measurement, other information sources should be used)		(Not yet discussed) Preliminary 4
Friction or poorly adjusted position detectors	Energy need over time for the movement	- Electric current, force, position, time of movement	- Operation - Maintenance - Management	High (Measurement is developed but the data flow to decision is still do be improved)	- DB - NR - TRV	9
Switch blade form during movement and final position	Form of switch blade	- Fiber-optic probes - Strain	Research & Development	Low (If possible to be included in		(Not yet discussed) Preliminary 3

Information sought/purpose	Quantity to be measured	Measurement technology	Data used for	Priority in In2Rail	Area of interest for	Scoring Feasibility (1- No feasibility 10–High feasibility)
		- Machine vision - 3D scanner		future work)		
Switch blade obstruction	Picture to identify objects	Machine vision	Operation	Middle		4
Motor, control and stress bar condition	Vibration in different type of bars	Accelerometers	- Operation - Maintenance - Management	Middle	DB	6
Local weather prognosis	- Outdoor temperature - Rail temperature - Wind - Moisture - Precipitation	- Temperature sensor - Anemometer - Hygroscope	Operation	High	- DB - NR - TRV	8

Table 6.6: Information asked for and possibility to measure by condition monitoring with embedded sensors

7 Cross-Match Existing Knowledge

Chapters 4, 5 and 6 describe why information is required, what that information is and how it could be collected. Before proceeding to discuss an appropriate system design, this Chapter reviews known projects which have covered these areas before, including European and national projects, as well as existing product solutions and technology deployed in other industry sectors. More detailed information is given in Appendix A.

7.1 Previous and ongoing research

The two European project Innotrack and Capacity for Rail have information on using embedded sensors. In Innotrack motor current measurement was studied and measurement with strain gauges and accelerometers was used to study train passages in new S&Cs.

Capacity for Rail study wireless sensor technology which can measure strain, temperature or acceleration. This project also studies heating systems and their control.

On national level there are and has been project about switch blade movement, acceleration measurements and crack formation in crossings.

Switch heating, wheel profile measurement and machine vision system for pantographs and other purposes are already in use by railway industry/owner.

To be able to collect condition and asset information in a structured way Network Rail has started the Rail Infranet project.

7.2 Existing Condition Monitoring Systems

7.2.1 Monitoring system 'Roadmaster'

The point machine always controls in which position the S&C is. During the movement of the switch rail, time for movement, force, motor current, hydraulic pressure and/or the distance can be measured. Voestalpine offers the system 'Roadmaster' that is a system that includes both point machine measurements and track measurements in the S&C.

7.2.2 Monitoring system 'SURVAIG'

'SURVAIG' is a system of sensors and data analysis developed for SNCF and installed on 250 turnouts. It is planned to be spread over the high speed TGV and regional Ile de France networks.

The purpose is to allow a preventative maintenance by giving information and providing alerts prior to incidents.

The surveillance is possible on both the drive system as well as the turnout elements.

It has been initially developed for the construction with a single point machine and a back-drive system.

The system is modular, furbishing any turnout with a dedicated set of sensors (force, displacement, vibration, temperature, moisture), depending on the needs.

It can detect and quantify the main sources of performance degradation (actuation force, point machine defect, switch blade position…) linked to actuation during the movement of the tongue or during the train passage.

7.2.3 Monitoring system 'POSS'

A system to monitor of point machine has been developed by Strukton in Holland and has been in use for many years. The system prevents switch failures and increases the availability of the switch by measuring the electric current and uses this signal to analyse mechanical or electrical problems. 'POSS' communicates with GPRS or Ethernet to a cloud application. 'POSS' can also be used to monitor level crossings, rail temperature, heating systems and several other applications. Task 6.4 will develop applications based on 'POSS'.

7.2.4 Monitoring system 'Intelligent infrastructure'

This automatic monitoring system is deployed on Network Rail infrastructure and samples the point motor current draw, producing several hundred data points during each operation. This data is sent to a central server where it is stored and analysed. The peak, duration and average of this signature are compared to predefined Alert and Alarm levels, chosen to indicate an asset condition that can be practically rectified before failure. Alerts and Alarms are received by dedicated personnel within the Control Centre who take relevant action based on review of the available information.

The system also interfaces to the points heating system as well as monitoring rail temperature, track circuit voltage and signalling power supply insulation resistance.

7.2.5 Interlocking Systems

A modern interlocking system is computerised and modularised systems. A node in such a system can be used to control of a switch and communicates with a central computer. The interlocking system carries out automatic diagnosis, operator assistance and data recording to maximise the efficiency of both the signalling operators and maintenance staff. In addition to normal self-diagnostics it is equipped with a detailed monitoring facility for attached equipment, which detects equipment malfunctions and can support predictive maintenance interventions. The software can be configured and adapted to various types of signal control and operational rules as may be required by different infrastructure managers.

This report presents parameters proposed by WP9 that should be measured to collect data for asset status representation.

S&C Data			
Name	**Data Type**	**Refers to component**	**Source info**
Current position	Enumeration (straight, left, right)	Switch - Points – Rail	Internal
Device temperature	Decimal (°C)	Switch - Thermal probes and heaters	Internal
Device status	Enumeration (OK, KO, No-Response, Sufferance, etc.)	Switch	Internal
Switch Motor Voltage	Decimal (V)	Actuation devices - POE	Internal
Switch Motor Current	Decimal (A)	Actuation devices - POE	Internal
Switch Electromagnet Voltage	Decimal (V)	Actuation devices – Locking Elements	Internal
Switch Electromagnet Current	Decimal (A)	Actuation devices - Locking Elements	Internal
Manoeuvre time	Time	Actuation devices	Internal
Electromagnet Peak Time	Time	Actuation devices - Locking Elements	Internal
Manoeuvre total number	Integer	Actuation devices	Internal

Table 7.1: Parameters to be monitored identified inside the deliverable D9.1

7.3 Analysis of other Technology Sectors

Many industrial sectors have developed sensor technology much further than what is implemented within the railway. In this chapter only a brief summary about other technology sectors is given and the more detailed description is placed in the appendices, chapter 11.

7.3.1 Automotive industry

Automotive industry uses several hundred sensors in a modern car. These sensors can be categorised by which system they belong, powertrain, chassis control or body systems.

Powertrain systems main objectives are to maximise the performance with a good control of emissions and need of fuel. **Chassis control systems** main objectives are to increase safety, manoeuvrability, handling and stability. **Body systems** main objectives are occupant safety, security, comfort/convenience, navigation and cruise control.

Data from the powertrain system can be used to give alerts on when service is needed instead of using just the time or mileage as indicators of when maintenance should be performed.

7.3.2 Process Industry

Process Industry interfaces to a wide variety of other industries, and is often associated with high investments in terms of plant assets and large production volumes. Production is controlled at all stages to be able to secure a high yield. This information is used both automatically in closed loops to keep process parameters within limits as well as indicators of when to do maintenance.

The types of sensors used in the process industry are normally robust and cover most measurements required by the railway. Some companies specialise on condition monitoring of equipment and have developed knowledge on equipment deterioration. Moving equipment and equipment that are under high stress or wear condition are measured continuously as other equipment less susceptible for failures measured at regular interval (for instance transformers, electric cabinets).

Process industry is normally planning their preventative maintenance to be carried out during a few stops per year and has adopted the equipment to be easily maintained by using modular replacement and reliable enough to perform required function during the time between maintenance stops.

8 System Design Hierarchy

Within this chapter the emerging design requirements for the embedded and integrated monitoring system are discussed.

The intended purpose of the information, the environment in which data is captured and the scalability around an entire network as well as the introduction of future applications are considered.

8.1 High level system requirements

Review of previous sections reveals the following high level system requirements, the system shall:

1. Interface to numerous sensors distributed across the S&C asset;
2. Interface to numerous types of sensor depending on the monitored parameter;
3. Carry out different levels of signal processing depending on sensor type;
4. Transmit different types of data depending on sensor type;
5. Provide data to different stakeholders depending on purpose;
6. Provide data at different frequencies depending on purpose;
7. Generate trusted information for trusted decisions depending on purpose;
8. Be scalable across different types of S&C across different networks.

In loose terms the system must be constructed from multiple Capture and Use Points.

Capture Points are collocated with the monitored parameter, which depending on the sensor type, could be physically on the S&C asset. These locations are geographically dispersed and often hostile. Sensors require accompanying hardware to sample, process, package, and transmit the data. This, to some extent, must be physically attached to the sensor.

Use Points are located where the captured data is integrated into another system or process. This could be human orientated at a data presentation terminal, or automatic by integrating into a computational model or control loop. These locations could be anywhere across a rail network, company or wider industry.

8.2 Horizontal system architecture

These requirements call for a highly flexible, scalable system, enabling multiple capture points to be connected with relevant use points. This can be achieved with a horizontal, open interface, system architecture.

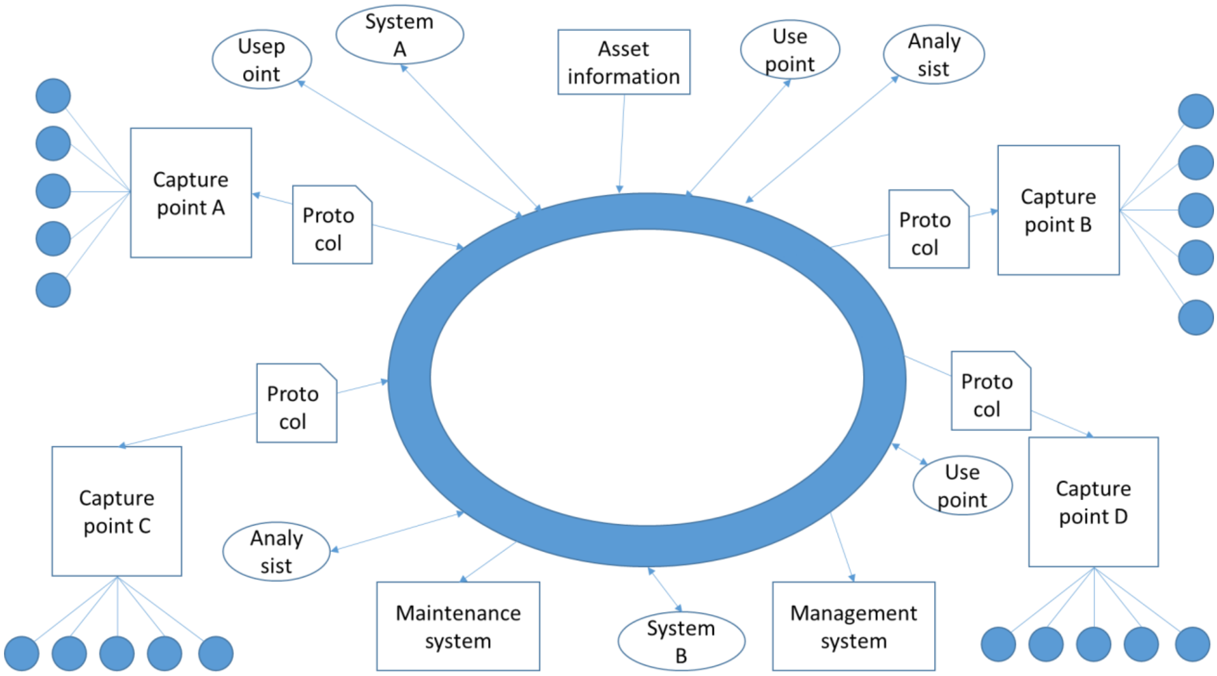

Figure 8.1: Illustrating a way of configuring local capture points with other information system and the use points

8.2.1 Open System Interconnection model

International Organization for Standardization has created a conceptual model for communicating with data. The Open System Interconnection model (OSI) describes 7 layers from the lowest level dealing with the transmission of signals (physical layer) to the highest level where user is displayed the information (application layer). In this deliverable is only discussed layer 3 (Network layer) and 4 (Transport Layer).

8.2.1.1 Network Layer

The network layer provides the functional and procedural means of transferring variable-length data from a source to a destination through a number of intermediate nodes. A network is a medium to which many nodes can be connected, on which every node has an *address* and which permits nodes connected to it to transfer messages to other nodes connected to it by merely providing the content of a message and the address of the destination node and letting the network find the way to deliver the message to the destination node

Example of protocols are IPSec and IPv6.

8.2.1.2 Transport layer

The transport layer provides the functional and procedural means of transferring variable-length data sequences from a source to a destination host via one or more networks, while maintaining the quality of service functions.

Examples of a transport-layer protocol in the standard Internet stack is Transmission Control Protocol (TCP) and User Datagram Protocol (UDP).

The transport layer controls the reliability of a given link through flow control, segmentation/desegmentation and error control.

8.2.2 Local networks

Capture points in close proximity, on the same or adjacent assets for instance, can be integrated into a local system, reducing the number of connections required to the horizontal bus. This also facilitates the addition of further compliant sensors for larger or more complex assets.

8.2.3 Wireless communications

Wired connections between sensors, their associated hardware and the rest of the system present numerous challenges in terms of robustness, scalability, cost, range and maintenance. Wireless communication technologies can overcome these challenges whilst adding two more; power supply and connection reliability.

Power supply problems may limit the number and type of sensor which can be deployed, fibre optic systems and those with a high sample frequency for example have a higher energy demand. Some improved battery technologies combined with power management strategies can offer many years life for low power applications. Many energy harvesting technologies are available including solar, wind, radio wave and kinetic. Solar and wind approaches are not guaranteed to perform equivalently for all S&C installations, and are not likely to eliminate many wires due to size and installation location requirements. Kinetic harnessing may offer a solution when considering kinetic energy transferred by passing trains into the S&C, modules could be small enough to be integrated directly into a sensor node. Lastly radio wave harnessing technologies such as those deployed in RFID may offer a solution, whereby a mains powered interrogator device can emit radio waves to energise and sample sensors distributed within range around the asset.

Many wireless communication technologies built on principles such as mesh networking and handshaking can offer high connection reliability, however this is not guaranteed in the scenario of passing vehicles, considering their metallic structure and numerous electromagnetic emissions. This could be a particular challenge for dynamic data requiring collection during the passing of a train, some on sensor buffering for example could solve this issue.

8.2.4 Processing at the edge

Readily available, low cost, high performance processing systems allow more intelligence to be deployed into the local system, at the edge of the network. Computation of relevant information can be executed locally using potentially advanced techniques such as pattern recognition, Fourier transformation and model based analysis. This reduces the bandwidth demand of the local systems connection to the network, reducing transmission costs as well as remote data storage costs. Algorithms can be used to minimize the size of data so that old data is compressed. For instance fresh data is stored with an interval of one second and after one month this is recalculated into a value per hour.

8.2.5 Many to many communications

With data being processed and stored on the network it may be necessary for particular use points to access capture points directly to obtain the required information. A robust and highly available capture point access management policy must be in place to support implementation of this sort of structure. Internet Protocol and message queuing protocol (such as AMQP) are examples of this approach.

If highly available direct access to the capture point cannot be supported for whatever reason, then strategies should be considered for the capture point to deliver relevant data to a high availability point of presence elsewhere on the network.

Allowing access between capture points and capture systems may lead to discovery of greater insight through data fusion techniques; sensors may even become available for multi-use applications.

8.2.6 Open interface protocol

Communication between capture points, local networks and use points must be carried out with open interface protocol. This determines the manner and format in which data is exchanged. An open interface allows systems developed elsewhere to integrate into the wider system. In S&C monitoring this might mean additional sensor types or even adapters for existing systems such as maintenance and traffic management systems. This requirement is highlighted by numerous previous projects and is also covered by In2Rail WP6.

8.3 Reliable monitoring systems

In order for an automatic monitoring system to be introduced into an operational business, it must be seen as reliable and trusted. Since the key aim of automatic information capture is to achieve efficiencies, it is essential that the capture system does not decrease efficiency through unreliability. Examples include false alarms, where incorrect analysis requests additional unnecessary maintenance visits, or system failure, where the monitoring system fails more often that the asset it is monitoring.

8.3.1 Trusted decisions

To realise the highest efficiencies and benefits, monitoring systems must be trusted to operate largely unsupervised. Potentially huge volumes of data are generated, making review and assessment by a human impossible. Together with having a clear understanding of the intended purpose of the system, verification and validation activities must be completed in order to gain trust in the output.

This area poses the biggest implementation challenge to automatic monitoring systems as the intent of the system must be well defined, understood and accepted by stakeholders, and proven to deliverable by the system design. Until the output for the systems can be trusted they will not be implemented, until they are implemented they will not bring benefits.

8.3.2 Reliable by design

The design of the system is essential to achieving reliable performance; consideration for well-tried design principles should be made:

- Appropriate redundancy:
    - Multiple sensors, signal routes and independent signal evaluation;
- Adequate noise immunisation:
    - Screened cables and vibration isolation;
- Mechanical environment consideration:
    - Multi frequency vibration, high accelerations, falling objects, heavy duty maintenance processes, passing workers, extreme weather and animals.

Many of these issues can be eliminated by mounting equipment adjacent to the track whilst also increasing maintenance access. Stand-off monitoring techniques such as optical and acoustic methods may therefore be of benefit, although this type of equipment is possibly most efficiently deployed on monitoring vehicles and therefore outside of the scope of this Task.

8.3.3 Safety Integrity Levels

When safety critical decisions are made with the data then the Safety Integrity Level (SIL) of the system must be evaluated. Detection of the switch blade in either the normal or reverse position is a clear safety critical decision; attaining the necessary SIL typically adds cost and complexity to the system. The use of collected information to automatically assess the condition of the asset and replace existing inspection regimes could also be considered a safety critical decision. This area requires more work going forwards.

8.4 Scalability

The criticality of an S&C asset should be determined by both the level of traffic that crosses it, including speed, weight and quantity, as well as the number of operation cycles it undergoes. Those situated on high traffic mainlines may experience the most loading and potential for damage and wear, whereas those positioned close to multi-platform stations and junctions may experience higher operation cycles and are therefore prone to other failure modes; both of these installations are considered high criticality. There are then also low criticality assets, such as those which are infrequently crossed or operated. The impact asset failures have on the network differs vastly based on criticality. Failures on high criticality assets may quickly affect the entire network, whereas lower criticality may not affect the service at all.

It is therefore logical for the system to be able to scale to suit different S&C installations. High criticality assets may justify much more expensive monitoring equipment as the potential benefit of avoiding failure is far greater.

9 Conclusions

The aim of this report has been to explore the sensor technology that already exists in the railway industry as well to look on other sectors and see what can be learned from there. Included is also a general proposal of how the system hierarchy should be designed.

In practice, many examples of sensor technology exist in the railway, although they are not yet developed for use as embedded sensors in S&C. A few of the technologies are in regular use and others are under development, while many still need to be developed in order to determine if the technology is useful.

The purposes for measurements have been divided into:

- Operation;
- Maintenance;
- Management;
- Research and Development.

Most of the proposed measurement technologies presented in Section 6.5 fall in to the Research and Development category which is quiet natural as there is a clear need to understand the deterioration and possibility to predict failures before developing systems just for operational or maintenance purposes.

The analysis of other technology sectors shows that there are many possible technologies available and the next step is to evaluate which of these are cost effective, reliable and able to predict deterioration accurately.

Numerous key asset properties are identified as being required by a category. Some categories may require information on the same key property, considering their capture simultaneously will offer greater efficiency and potentially lead to additional insight into asset behavior. The following key asset properties were identified for monitoring:

- Vertical displacement under train movement;
- Long term settlements;
- Rail fatigue;
- Temperature induced rail stress;
- Switch blade motion;
- Possible switch blade obstruction;
- Switch blade final position;

- Critical flange-way clearance;
- Critical check rail clearance;
- Rail and wheel profile;
- Heating system performance.

A horizontally integrated, modular architecture is proposed for further development. This enables a flexible approach to future additions, as well as simplified data sharing across functions.

Moving forward, the Task will have the following core deliverables/objectives:

- Identify technology with a viable benefit that the task has the capability to develop;
- Define a local architecture for the system to adopt;
- Develop a TRL 5 concept demonstrator;
- Propose other technologies that could be developed for the system.

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11 Appendix A - Previous or ongoing projects

There are several projects funded by the European Commission that has had question about condition monitoring of switches and crossings. UIC has a working group for S&Cs and nationally there has been and still are ongoing work to improve this area. A few of them are listed here.

11.1 European Railway Projects

11.1.1 Innotrack

In Innotrack major track cost drivers were analysed with the aim to reduce maintenance costs for sub-structure, track, S&C including LCC and logistics aspects. Especially for S&Cs one sub-project worked with identifying key parameter and possible sensors for monitoring. In the FMEA made different type of actuators, switch & stock rail assembly, crossover panel, crossing panel and heating system was analysed. In another subproject an open interface for interlocking including monitoring was discussed.

In D3.3.3 recommendation of monitoring parameters is given:

- Monitoring of heater activities;
- Monitoring of narrowest flange way;
- Monitoring of drive forces;
- Monitoring of fluid pressure;
- Monitoring of motor current;
- Monitoring of displacement;
- Monitoring of end position;
- Monitoring of acceleration levels;
- Monitoring of switch blade temperature;
- Monitoring of air temperature;
- Monitoring of shocks at crossing nose.

11.1.2 Automain

In the Automain project automated inspection methods was discussed. For S&Cs existing road-rail vehicle that can measure rail profile and make video-based visual inspection was described [D3.2 "Modular Self inspecting Infrastructure", Automain; http://www.automain.eu/public-documents].

Furthermore a camera for inspection placed on the overhead wire, a trolley for laser measurement, using in service train for track geometry inspection purpose and solutions for indicating failures at stretcher bars was developed during the project.

11.1.3 D-rail

D-rail was an EC-sponsored project with the objective to develop the future rail freight system to reduce the occurrences and impact of derailment. A part of D-rail WP3 focused on the prediction of the flange climb derailment limit in switches as a function of vehicle configuration and track conditions using numerical simulations. In total the influence of 25 different parameters was considered. The methodology and results are presented more closely in D-rail deliverables D3.2 (Braghin et al. 2013) and D3.3 (Ekberg et al. 2013).

The studied traffic situation was traffic in the diverging route of a small radius (R=190m) right hand turnout. This scenario was chosen because simulations and measurements show that the Y/Q-ratios for traffic in the diverging route are larger than those recorded for the through route. Further, simulations show that traffic in a small radius turnout generates larger Y/Q-ratios than a turnout with larger radius for typical speed limits. As the Y/Q-ratio correlates to the risk of derailment according to Nadal's criterion, the small radius turnout is considered to be the most critical case.

Based on the performed parameter studies, the parameter categories with the largest influence on derailment risk were found to be:

- Friction. The wheel rail friction coefficient is the most important in this category (as can be expected from Nadal's criterion), but also the friction coefficients in the primary and secondary suspensions are important. They affect among other things the yaw stiffness of the vehicle. The magnitude of influence for the different friction coefficients depend on the load state of the vehicle;
- Skew loading of the vehicle. Especially combined lateral and longitudinal skew loading;
- Chassis twist. It was found that chassis twist and longitudinal skew loading can interact in a non-linear fashion when they both strive to unload the same wheels. According to DB measurements (Chapter 3 of D3.2), diagonal load imbalance for tare state wagons in traffic can be significant which indicates the existence of significant chassis twist for wagons in traffic;
- Track irregularities, especially track twist.

The D-rail methodology can be used to assess possible changes in derailment risk as a function of switch rail geometry and position and therefore also as a function of locking tolerances and limits.

11.1.4 SAFTInspect

European Commission funded project to develop the Synthetic Aperture Focusing Technique for Cast Manganese Crossing inspection. This technique is covered further in 11.2.1.

11.1.5 Capacity4Rail

Capacity4Rail is an ongoing project which gives recommendations for Open-Source and Open-Interface for advanced railway monitoring applications. In the project monitoring applications for slab-track are tested.

In WP1.3 S&Cs the following areas are studied:

- Track geometry;
- Rail profile;
- Prognostic weather data input for switch heating systems.

In WP4 sensor data collecting technology, wireless communication and energy harvesting technologies is developed.

11.1.6 UIC Working Group for Switches and Crossings

UIC has had a working group devoted for switches and crossings. The group mostly investigated what information that was gathered about S&Cs and which decision was taken based on this information. The information is mainly gathered by either visual inspection or by vehicles:

- Simple visual inspection;
- Detailed inspection containing a visual part and a measured part;
- Ultrasonic rail inspection;
- Track irregularities measured by a track measuring car.

Example of video inspection trains was also mentioned in the report (Inspection of switches and Crossings, 2011).

11.2 National Railway Projects

11.2.1 Remote Condition Monitoring of Cast Manganese Crossings

This section will include an overview of technologies already being investigated, outside of In2Rail, for the detection of crack initiation and subsequent monitoring of crack growth within Cast Manganese Crossings.

Cast manganese steels, 11-14 in wt %, are commonly used for manufacturing rail crossings due to their high resistance to fatigue crack initiation and thus longer life span. However the use of this steel presents an issue as there is no appropriate methodology available to evaluate the structural integrity of in-service crossings. Manual visual and liquid penetrant inspection is used instead, these techniques are:

- Subjective with low reliability and repeatability;
- Unable to detect and monitor defects initiating/propagating below the surface or those introduced at manufacture;
- Require prolonged direct access by personnel which increases risk of harm and reduces asset availability.

Subjective damage assessment means defect propagation prediction is based on experience rather than robust theory, a particular problem when determining the remaining life of an asset as well as relevant operational constraint such as speed restriction.

A novel hybrid ultrasonic testing process is under development by Plant Integrity utilising the outputs of SAFTInspect. Guided Wave Testing is a low frequency ultrasonic inspection technique which can examine the full cross section of the crossing. Once the presence and approximate location of a defect is detected it can be investigated in more detail with the Synthetic Aperture Focusing Technique (SAFT). This enhanced ultrasonic inspection utilises large, synthesised probe apertures combined with advanced signal processing algorithms. Two dimensional matrix array probes enable beam steering to maximise coverage despite limited surface access. The equipment is presented to the external surfaces of the crossing via a highly automated, precise positioning system.

Acoustic Emission techniques are also under development which uses sensitive piezoelectric transducers to detect energy propagating through the crossing when under load from in-service trains. The portion of the signal generated attributed to the rolling stock is filtered out, leaving just the signature of the crossing. By cross referencing this signal with those of known defects it is possible to determine the probable quantity and size of internal defects and ultimately the condition of the crossing. The piezoelectric transducers are quickly and easily bonded directly to the crossing, are non-invasive, non-intrusive and wired to a wayside signal processor for filtering and analysis.

11.2.2 Radio Frequency Identification (RFID)

It is established that this is not really suitable for the type of whole system S&C sensor network but will be included to show that we have considered it.

To identify the progress and whereabouts of a bearer within the supply chain after order and before delivery an RFID tag is embedded within the bearer during production. Each tag is programmed with the unique serial number for that bearer. Correct use of a database system aligns the serial number to its construction content. RFID tags are passive and require no embedded power source. Tags are interrogated by an RFID reader in close proximity that can extract the unique identity.

Industry working groups such as ID in Rail should consider the development of a standardised bearer identification system. Compatibility with other RFID systems, such as Automatic Vehicle Identification and Selective Door Operation should be reviewed.

RFID Sensors, can embed sensors within the RFID tag to retrieve sensor data (temperature, strain, pressure) as well as identity on interrogation. Essentially deploying passive wireless sensors.

11.2.3 Embedded Bearer Accelerometers

Displacement of bearers under load is a key indication of the condition of the S&C support system. Increased motion can lead to accelerated component wear as well as increased risk of derailment. Sensor nodes containing a battery, accelerometer, micro-processor and Bluetooth radio are deployed on the bearer. Some specialist bearers provide a recess for the node; they can also be embedded during manufacture or bolted onto existing components.

A nearby data logger receives data from the nodes wirelessly. Signal processing is not conducted within the node. Other data streams could be collected with the same technology, offering a battery-backed wireless sensor network.

Figure 11.1: Wireless sensor embedded in a purpose-built concrete sleeper

Figure 11.2: Wireless sensor fixed to existing timber sleeper for demonstration purposes

11.2.4 Fibre based Distributed Acoustic Sensors

An Interrogator Unit sends conditioned pulses of light into a fibre optic, either existing at the trackside or purpose laid. By modulating these pulses the signature of each 5 metres of fibre is discernible. Acoustic pressure waves cause minute variation in strain within the fibre, these variations are detected by the Interrogator Unit and are processed to produce an audio feed; essentially turning a fibre into a distributed array of virtual microphones. Distances of 50km can be reached, in either direction from the Interrogator Unit along a linear asset, meaning 100 km and 20,000 distributed microphone arrays per interrogator unit. Power is only required at the Interrogator Unit.

This technology is well established for other industries and applications within rail, demonstration of S&C monitoring has not yet been achieved. Similar technology can be used to measure strain and temperature. Experimentation to determine which S&C parameters can be detected in which scenarios.

11.2.5 Heating Control System

At Trafikverket a central system to collect and control switch point heating is under implementation. Today about 560 sites are controlled centrally including about 2 400 switches.

In this system data of temperature, power consumption and mal function of heating elements is collected. If an error is detected an alarm is sent to the central computer. The information is presented graphically and in tables and communicated to the users. At the train dispatch centre the technicians are alerted and take actions when for instance there is a failure of a heating element.

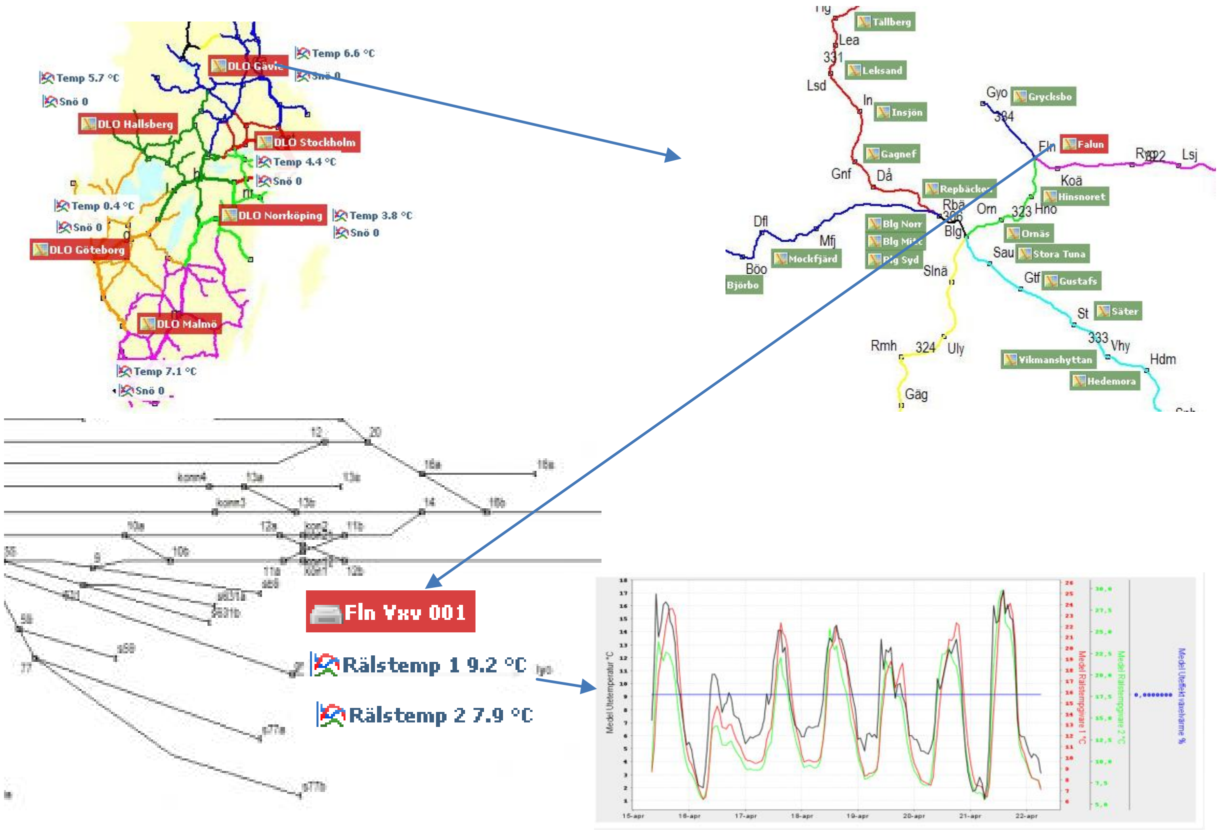

Figure 11.3: Example of presentation from switch heating control system

For a user it is possible to change the settings for individual S&Cs if the heating is not sufficient to melt the snow. A special feature is that the rail temperaure in the system can be raised 10 degrees the coming 4-24 hours if for instance a snow storm is coming by just activating this. Up to 3 years data stored locally can be exported to a single user for analysing purposes. No temperature data is stored in the centralised computer.

11.2.6 Automated detection of pantograph condition

Trafikverket use a machine vision system to detect condition of pantographs. The camera takes picture which are analysed and pattern recognition is used to identify damages in the pantograph coal strip.

Figure 11.4: Automatic detection of coal strip failures

12 Appendix B - Other Technology Sectors

12.1 Automotive Industry

A modern car has sensors and monitoring systems which span from providing driver comfort to collision avoidance. A modern car has more than 100 different sensors, see Fleming (2008) and Prosser (2007). Three major areas of systems application for automotive sensors are identified by Fleming (2001). These three areas are powertrain, chassis and body. Brief overviews of the mentioned areas and some of the pertinent sensors are given below. The reader is referred to Fleming (2001), Fleming (2008) and Prosser (2007) for more comprehensive overviews.

Powertrain systems consist of engine, transmission and on board diagnostics. The main objective is to optimise a combination of economy, emissions and performance. Sensors in the powertrain area of application monitor temperatures (e.g. oil, coolant), pressure, fluid levels, mass flow, vibration (e.g. knock sensor), chemical composition and gas composition (e.g. oxygen sensor).

Chassis systems consist of braking/traction control, steering, suspension, tyre condition and vehicle stability. The objectives of chassis control systems are to increase safety, manoeuvrability, handling and stability. Anti-lock brakes (ABS), traction control and electronic stability control are examples of systems that are included in chassis control systems. The key sensor in these systems measures the rotational speed of wheels to determine the rotational acceleration and deceleration. For electronic stability control additional sensors, such as a yaw rate sensor and a lateral acceleration sensor, have to be employed together with measurement of driver inputs (e.g. measurement of the position of the accelerator pedal). A control unit processes the information from the sensors and send actions to the engine and wheel brakes to control the stability of the vehicle

Body systems main objectives are occupant safety, security, comfort/convenience, navigation and cruise control. Examples of applications that are included in body systems are parking assist, forward collision warning, lane departure warning and adaptive cruise control. Distance sensors such as radar, lidar, ultrasonic and camera vision employed in the previously mentioned applications. Another application of sensors in the body systems category is vehicle crash detection. Here accelerometers positioned around the vehicle are employed to determine whether front airbags, side airbags or curtains should be triggered. Examples employed in sensors comfort and convenience applications measure light (for dimming mirrors), solar radiation/twilight sensors (to give input to air-condition system and to automatically turn on headlights), infrared sensors (to measure passenger exposed-skin temperatures to provide inputs to the air-condition system).

Besides this three mentioned areas there is an ongoing research of self steering vehicles which is based on body systems, but needs to take more advanced decisions than similar systems just are used for warning. For instance pattern recognition is used to read all signs along the road, to identify what type of obstacle that is close to or on the road (stone, animal, human being).

Measured quantity	Type of technology	Description
Rotational motion	Variable Reluctance Wigand Effect Hall Effect Magnetoresistor AMR Magnetoresistive GMR Magnetoresistive	
Pressure	Piezoresistive Micromachined Capacitive Touch Mode Micromachined Capacitive Ceramic-Module Piezoresistive Polysilicon-on-Steel	
Angular and linear Position Sensors	Potentiometric Hall Effect AMR Anisotropic Magnetoresistive Optical Encoder Magnetostrictive Pulse Transit Time	
Temperature	Silicon Integrated Circuit Thermistor RTD Resistive Temperature Detector	
Linear Acceleration	Piezoresistive MEMS Capacitive MEMS Resonant-beam MEMS	Micro electro mechanical systems (MEMS)
Angular Rate	Vibrating ring Vibrating tine Vibrating plate and disk	
Distance	Radar Lidar Ultrasonic	Light Detection And Ranging
Pattern recognition	Camera	Parking assistance, self-steering vehicles

Table 12.1: Measured quantities and description of sensor technology for automotive industry

12.2 Process Industry

Process industry is often associated with high investments in terms of plant assets. Due to the large amount of invested capital the return of investment must be secured either through the production of high revenue products or large production volumes. On a global market where the margins could be under pressure from competitors the efforts has to be put on cost reduction or increased production. One of the aspects that have to be optimised to achieve this is the optimisation of the availability of the production line. This has to be as high as possible whilst the cost of maintenance must be as low as possible. This is a general optimisation problems which require good RAM (Reliability, Availability and Maintainability) and LCC (Life Cycle Cost) simulations in order to choose the right type of strategy.

The preventative maintenance strategy chosen for many process industries is another aspect that is worth mentioning when comparing the railway sector with the process industry. Often preventative maintenance is carried out during a few large stop each year. All maintenance actions are clustered in time to these stops. This strategy together with the investment intensive properties of the process industry will call for a condition monitoring to prevent unnecessary stops and in-service component failures.

Previous condition based maintenance strategies (CBM) in the Industry relied on separate measurement systems which measured the asset statuses. Today many component manufacturer starts to offer asset health monitoring (AHM) as an added value to their products. Instead of selling an ordinary component the manufacturer sells a function which includes all aspects of the life cycle including the AHM.

12.2.1 Thermal measurements

Depending on the application different types of sensors are used to monitor the asset status in the process industry. One of the most common measurements in the process industry is temperature measurements. These monitoring systems are now being complemented by thermal imaging cameras eg. tank level monitoring using thermal imaging, see Figure 12.1 (upper images). Previously thermal imaging was an expensive technique but now the price of thermal cameras has dropped dramatically. Cameras compatible with normal smart phones for the price of a couple of hundred euros can be found on the market. In Figure 12.1 (lower images) an example when using a smart phone compatible camera can be seen. Even though affordable thermal cameras have been around for many years the revolution using thermal imaging in the process industry has just started.

Figure 12.1: Upper images: Tank level monitoring using rugged industrial thermal camera. Lower images: Low cost thermal camera for smart phones. (Source: www.flir.com)

12.2.2 Vibration and strain measurements

Strain measurement is often used to monitor processes where the structural integrity is changing with a low rate of change (quasistatic properties). Strain gauges are fairly cheap and can without any larger investments be connected to units with easy wireless connection. Strain measurements can be used in the process industry to investigate a specific problem like a crack. Strain gauges can also be used to measure thermal expansion inside components.

Vibration measurement is the most common measurement technique used to monitor rotating machinery or other processes where a mechanical structure is excited eg. pipes excited by a liquid flow. For rotating machinery different components can be monitored like shafts, generators, compressors, bearings, gears and fan blades, in engines, pumps, valves, electric motors, and gear boxes, etc. Vibrations can be measured, using accelerometers, velocity sensors or displacement sensors. Vibrations could also be measured using load cells or force transduces, even though it seldom is referred to as vibration measurement when using these types of censors. Piezoelectric (PE) accelerometers can respond to vibrations with frequencies down to.

Approximately 4 Hz while true velocity sensors offer a better low-frequency response, typically 0.5 Hz or less (Bogue 2013). Displacement sensors or proximity sensors offer the best performance when it comes to low frequency (0Hz). This performance comes with the price of poorer performance on higher frequency. Proximity sensors can be based on capacity, induction, optical (often laser based), or mechanical.

For simple applications, vibration measurements are often analysed in the time domain using different time domain indicators like, RMS (Root Mean Square), Crest Factor, Peak value, Kurtosis, Shape factor, etc. For more advanced applications the signal is analysed in the frequency domain. Bearing faults are often analysed in the frequency domain where different fault locations can be identified (Randall 2011). In the process industry a mix of stationary sensors and measurements points manually measured by portable equipment's can be found. The measurement strategy is dependent on the failure development time, cost of the measurement and the consequence if a failure would occur.

Acoustic emission is a technique which measures stress waves in a material and is another measurement technique which can be found in the process industry. This technique is however not as common as vibration measurement since it requires higher sample frequencies and hence more expensive data acquisition units. Acoustic emission is a technique which is similar to vibration measurements. The main difference is that acoustic emission focus on excitation events on higher up in the frequency band eg. 40kHz-several MHz. Acoustic emission can be used to detect the propagation of eg. events like impacts, sudden crack development, fibre breakage and delamination in composites.

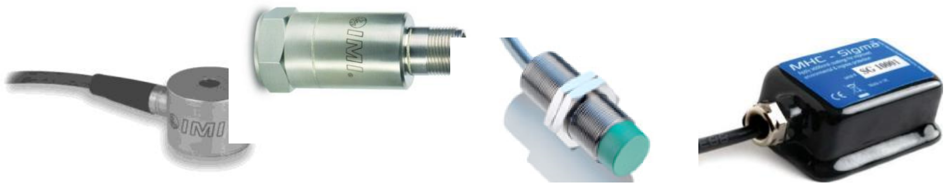

Figure 12.2: From the left: Accelerometer, Velocity sensor (Source www.pcb.com), Proximity sensor (displacement sensor) Source www.baumer.com, Acoustic emission sensor Source: Holroyd, part of Parker Kittiwake

12.2.3 Electrical motor current

For electrical motor applications the motor condition is normally measured by temperature sensor, vibration sensors and motor current analysis. By examining the current consumed by the electrical motor the condition of the motor coil or the resisting torque can be analysed. An increased resistance could be due to some other problems along the drive train.

12.2.4 Oil analysis

In many process industry applications lubricants are present. By analysing the condition and the content of the lubricant the condition of different machine elements can be determined. By examining the viscosity of the lubricant the lubricating property of can be determined. This is an important aspect since many failures in rotating machinery has its root cause in inadequate lubrication. The viscosity can be measured either of line in a lab or on line by the use of on line sensors. By analysing additional content in the lubricant the status of other machine elements scan be analysed. The shape, size, quantity and composition of particles, and the rate of change, can provide valuable information of the condition of the components. Spectral analysis can be performed either of line or on line to determine the type of contamination. For example, if silicon is present, a seal failure could be present or improper maintenance routines where dust has been introduced.

Figure 12.3: Upper left: Viscosity sensor: Source: www.machinerylubrication.com. Lower left and right: Wear debris sensors Source: Parker Kittiwake http://www.kittiwake.com/

12.2.5 Machine vision

Machine vision is a term where imaging technologies are combined with image processing techniques to automatically inspect, monitor different objects, control processes or guide robots. Imaging is performed by capturing an image with a defined light source.

12.2.5.1 Image capturing

For imaging there are different parameters that control the outcome of the image. The selection of lenses will control the projection of the light on to the CCD sensor and is governed by the quality of the lenses, the focal length and the aperture. The focal length controls the zoom factor and the aperture the size of the aperture in which the light has to pass through. The size of the aperture will control the amount of light and hence the light sensitivity of the lens and the depth of field (sharp part). A small size of the aperture will generate a large depth of field but a less light sensitive setting and vice versa. Another parameter that will control the light sensitivity of the imaging process is the shutter speed. It defines the window in time where the aperture is open or when the CCD sensor set to sample the pixels. Hence the shutter can be controlled mechanically by closing the aperture or electronically by sampling the CCD. The shutter window can also be reduced in time by using an illumination pulse with a smaller length in time than the shutter window and with a larger intensity compared to the ambient light.

By reducing the shutter speed (increasing the shutter window in time) a larger amount of light will reach the CCD sensor. The downside with this is the smearing effects that will occur if the object and the camera system are moving relative to each other.

The quality of the CCD sensor that samples the projected light will also affect the light sensitivity of the camera system. The better the CCD sensor is the lower the signal to noise (SNR) level is. This makes it possible for high quality CCD sensors to increase the amplification and the light sensitivity, compared to low quality sensors, by increasing the sensor amplification. Other aspects of the CCD sensor that will govern the final imaging result are the spatial resolution, measured in number of pixels, and the dynamic range of the pixels for the relevant wavelengths. A CCD is normally sensitive to a larger range of wavelengths than a human eye. This means that for CCD cameras, which job is to produce normal pictures, have to be equipped with a filter to remove the infrared light. This is used in e.g. commercial night vision cameras where the filter is removed to set the camera in a night vision mode.

12.2.5.2 Illumination

The second and equally important part of the imaging process is the illumination of the object which will be reflected towards the CCD sensor. Reflected light can be divided into diffuse reflections and specular reflections. Based on the application the right type of light has to be selected. By choosing different wave lengths the receiving censors can distinguish between eg, different surface properties like water, ice or snow (Casselgren et.al, 2016). For many industrial applications laser light is used to illuminate the object. Different light patterns projected onto the object in combination with image processing techniques can be used to determine geometrical properties of the object eg. anomaly detection using grid illumination . The speckle property of the laser light can also be used in speckle holography to detect geometrical changes (Molin, 2004). Other imaging techniques using X-ray and thermal radiation could also be used in Machine Vision applications.

12.2.5.3 Image processing

The second part in the concept of machine vision is image processing part. There are a variety of different techniques which can be used to highlight specific features in an image which can be used for machine vision applications. Some of them are:

- Filtering and correlation techniques;
- Pattern and edge detection;
- Geometrical shape, blob and object detection;
- Metrology: Spatial distance measurement;

- Intensity/colour deviations, analysis and thresholding;
- Area measurement.

There is a vast number of different machine vision applications in the industry. The following bullet points gives some examples:

- 1D and 2D barcode and text (OCR) reader for maintenance inspection and component detection;
- Inspection of surface texture of welds. (Rajashekar, Rajaprakash 2016);
- Particle size distribution measurements(Igathinathane, Ulusoy, 2016);
- Image analysis of iron-ore pellet structure (Nellros, Thurley,2011);
- Analysis of paper impurity (Bianconi et. al., 2014);
- Machine vision based monitoring of an industrial flotation cell in an iron flotation plant (Mehrabi et. al. 2014), see Figure 12.4.

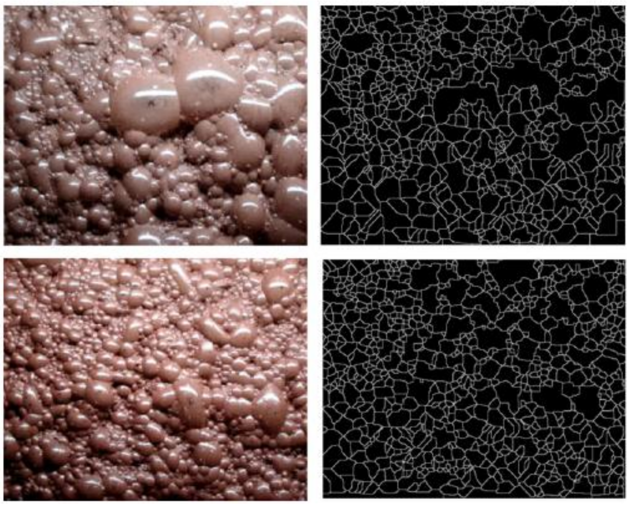

Figure 12.4: Froth quantification in iron flotation plant using image analysis source [Mehrabi et. al.]

There are also different 3D imaging techniques which can be used for different applications The oldest one is the stereo imaging technique which requires two cameras with a fixed distance. Another technique uses the effect of low grazing angel light from different directions where the length of the shadows can be related to the height of the object (Luk wt. al. 1989). Other techniques use time of flight or the previously mentioned grid anomaly method. Recently developed methods like motion capture, mostly used in robotics, gaming and movie industry uses e.g. predefined reference points which the computer algorithm tracks usually through a set of cameras.

12.3 Manufacturers of Interlocking Systems

Computer-based Interlocking are currently in use all around the world, including the most demanding High Speed networks (France, Italy, Spain, UK, Belgium, China and South Korea); on Main Lines and also in metros. One of the most complete family of Computer-Based Interlocking for rail and transit is available from Ansaldo STS. ACC, SEI and MicroLok® computer based interlocking (briefly described here below) could be applied to High Speed, Main Lines, Freight or Metros. Their integration with Centralized Traffic Control (CTC) and with Automatic Train Protection (ATP) systems has also been proved in High Speed applications. As anticipated here below is reported a very synthetic description of this three computer based interlocking:

- ACC Computer-based interlocking, is a modular system for railway and metro applications that can control the operation of very large and complex track layouts with high traffic volumes. Operation execution times are assured including at times of peak traffic demand. ACC can control all vital applications used in railway signalling and train traffic control. This system can carry out automatic diagnosis, operator assistance and data recording to maximise the efficiency of both the signalling operators and maintenance staff. In addition to normal self-diagnostics, It is equipped with a detailed monitoring facility for attached equipment, which detects equipment malfunctions and can support predictive maintenance interventions. The availability of these automated tools for design, testing, fault finding and maintenance significantly reduces the implementation times and general plant costs. ACC software can be configured and adapted to various types of signal control and operational rules as may be required by different infrastructure managers;
- SEI interlocking provides continuous line of route control and interlocking functions. The safety processor core is designed using ‘2 out of 3’ digital technology able to interface up to 200 object controllers with each object controller in turn supporting interface to up to 20 objects. SEI supports open standard data communications interfaces and thus is able to take advantage of modern hierarchical digital telecommunication system infrastructure without requiring dedicated cables between the central safety processor and its associated object controllers. Placement of the object controllers units near to the controlled objects makes this system easily adaptable to various rail network types. The functions carried out can be remotely checked by the control centre or via a local control station;
- MicroLok II Interlocking Control System is a multi-purpose monitoring and control system for rail and transit wayside interlocking equipment. Its wide range of functional capabilities include vital interlocking control, non-vital code system

applications, train detection, rail integrity, coded track circuit communication and more. Easy-to-use programming tools allow configuration to meet the specific requirements of the intended application. This system has fully integrated TCP/IP port for vital and non-vital Ethernet communication. Compact, rugged design fits into a wayside junction box and allows quick replacement in the field Web-based tools enable users to monitor and troubleshoot via Internet Explorer I/O wiring is terminated into a Wago plug connection eliminating the need for intermediate termination points.

As described inside Section 0 and also repeated here above existing interlocking systems are mainly focused on safety/vital related information and, in some cases, could also manage non safety/non vital information which are in any case related to the diagnosis of the interlocking components. Regarding the possibility to develop new interlocking systems able to manage not only safety related information but also to collect and transfer to other systems (such as the Train Management System) diagnostic/maintenance related information theoretically speaking the interlocking systems could also be used for that purpose. In any case it must be noted that such solution, that technically speaking could be implemented configuring a “non-vital data transfer”, requires heavy configuration and validation activities to certify that this new feature has no impact on the vital part of the system. Taking into account this consideration and also its economic impact the suggestion is to develop alternative solutions to transfer the diagnostic/maintenance data from the field.

Speaking about possible data to be collected using new embedded & integrated sensors there are no particular requirements related to interlocking needs but Ansaldo STS, inside the In2Rail WP9, has already identified, starting from a more general analysis, a set of data that must be monitored to support future maintenance activities. This has been created starting from the information collected inside the WP9 deliverable “D9.1 - Asset status representation” but taking into account only the S&C data that could be collected using embedded sensor (for all the other information please refer to the D9.1 document).

13 Appendix C - Categorization of switches

Different switch types / locations will require different levels of monitoring. For example, low traffic rural S&C may require a reduced scope of monitoring system to S&C located within high speed lines and / or station throats.

S&Cs in rail road system has been manufactured since late 18th century and has evolved especially in material, rail profiles, size and point machines. Modern S&Cs in Europe are with 49-60 kg/m rail and in main track and higher speed (>=160 km/h) have at least radius of 300 meter.

Rather late developments are:

- swing nose crossing;
- use of hardened steel;
- switch panel designed to have less wear and rolling contact fatigue;
- crossing panel designed to have less wear and rolling contact fatigue;
- soft rail pads;
- under sleeper pads.

The size of an S&C is important. Longer S&Cs with bigger radius allows higher speed in diverting route and reduces the wear and the rolling contact fatigue in the switch panel and crossing panel. A very long S&C with radius of 2500 meter or more requires more point machines and swing nose crossing and therefore more complicated and will have less reliability than a medium sized S&C. The best performance from a reliability point of view can be expected from S&Cs in the range of 500 m <= R <= 2000 m.

The normal function of an S&C is to carry a train in a safe way from point A to either point B or point C. The ratio between using route C or using route B together with the total amount of traffic can be used to describe the importance of the S&C. When the ratio is 1 that means that 50 % of the trains go route B and 50 % go route C the S&C is much more important to monitor than for an S&C with ratio 0.001 which is used once a week for diverging route. (One exception from this rule are the protection S&Cs which are described later).

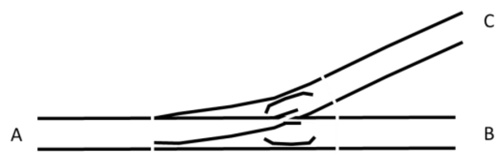

Figure 13.1: Sketch of a switch and crossing including breathing sections

For single track a normal station can be configured as shown in Figure 13.2. For heavily used single track line all S&Cs have great importance. For a single line with not so dense traffic the mayor station with passenger exchange or station where trains normally meet has the most important S&Cs.

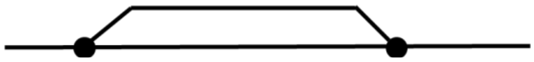

Figure 13.2: Sketch of a station in a single track line

Between single and double track lines and at junctions where traffic flow is directed in two direction the ratio between route B and C might be around 1, Figure 13.3. These S&Cs are usually of larger sizes as they allow high speed in diverting route.

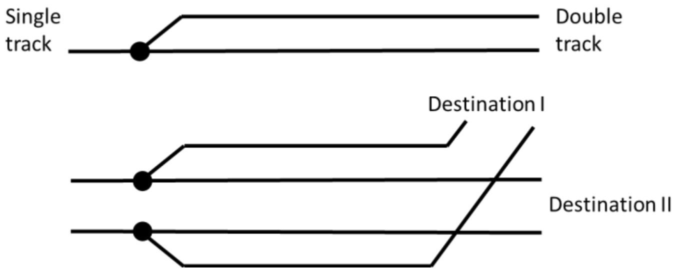

Figure 13.3: Sketch of a junction S&Cs

For double track line there are several configuration of cross over S&Cs as shown in Figure 13.4. Keeping them long apart (left) means it is easier to tamp them. A compact cross-over (middle) is more difficult to tamp if the two closest S&Cs are close (< 5 m). Even more difficult is it when there is a crossing in the middle (right). These S&Cs are very seldom used in diverging route.

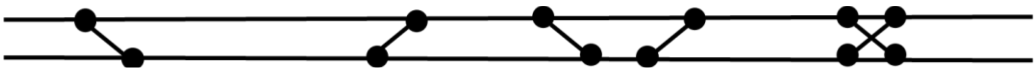

Figure 13.4: Sketch side of different possible cross-over S&Cs

Side tracks are used of trains stopping at a station or by slower trains, which are overtaken. These S&Cs can be heavily worn in diverging route. In this sketch there are also four protection switches in the side track. These might be designed as in this sketch where only diverging route is used or designed so that only straight route is used. In the first case the switch blade are heavily worn and need more frequent replacement than in the latter case.

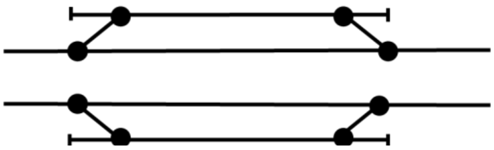

Figure 13.5: Sketch side tracks on double track lines