



Development of the Future Rail Freight System to Reduce the Occurrences and Impact of Derailment

D-RAIL

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Executive Summary

The D-Rail project has set out a target of a proposed LCC reduction by 10 - 20% of all derailments and the reduction of severe events by 8 - 12 % in 2050. As shown in WP 7, this target is possible with existing technologies if properly deployed and coordinated.

Risk assessments and risk-related decision making are activities on the level of every national actor in the railway industry. Therefore the installation strategy of interventions cannot be homogeneous for all of Europe (not to forget about the already existing variability in Europe). Different national risk assessment criteria and local conditions will lead to different optimum solutions, considering e.g. geography, climate, infrastructure network conditions, traffic mix, traffic speed, track utilization, vehicle types, commodities of goods. Taking into account further systems installed not only due to safety reasons but also due to customer needs, the variety will increase additionally.

A key aspect where harmonization is possible and shows a large leverage is the exchange of collected data among interested parties, nationally and internationally. National and international solutions are already in use, but limited to specific interests. Basic questions such as transaction protocols, safe communication interfaces, firewalls and server solutions are solved. The remaining problems lie in the assignment of the operational data to the technical data, e.g. matching a vehicle ID to the measurement from a wayside train monitoring system. This topic is not treated sufficiently in any of the existing regulations or even in any of the Technical Specification for Interoperability, although technical solutions, e.g. based on RFID are available.

Actions due to potentially improper vehicle and infrastructure states are only possible and economically beneficial for the railway sector and society if the data exchange includes all interested parties. Measured and interpreted quantities must lead to actions, either to prevent derailments or to save money due to condition based maintenance. One precondition for this is to enhance the legal framework. When implementing the proposed business cases, every actor needs a clear legal basis that defines duties and responsibilities. This gap is not filled by the Regulation (EU) N° 1078/2012 on the CSM for monitoring.

Another aspect of data exchange deals with interpretation of the transported content of the data. If data from different systems, suppliers and locations will be transmitted among different parties and across borders in the future, a uniform interpretation of the data is not guaranteed. For this reason a generic approach is proposed, which enables integrating different types of measurement data.

Currently, many systems are already deployed in Europe. Some countries rely heavily on automated techniques, whereas others are only beginning to see the potential for automation. Those that heavily use automation are more interested in getting the highest leverage out of their investment and will improve data usage, especially to optimize maintenance activities, and data exchange to improve the overall safety levels. Countries with a low level of automation will benefit from the lessons learned of the early adopters and can deploy interventions in a cost effective way.

The economic pressure is challenging for the railway sector. As shown in the present delivery, the benefits of automated interventions exceed safety improvements. Important savings and thus a better competitiveness against other modes of transport are accessible through condition-based maintenance based on data exchange between all actors.

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Glossary

ALARP	As low as reasonably practicable (a standard in risk-related decision making)
ALC	Axle Load Checkpoint
AVI	Automatic Vehicle Identification
CMMS	Computerized Maintenance Management System (CMMS)
CSM-RA	Common Safety Methods - Risk Assessment
DB	Deutsche Bahn AG (German Railway)
DDD	Derailment Detection Device
DG	Dangerous good
DPD	Derailment Prevention Device
DNV	Det Norske Veritas
DPD	Derailment Prevention Device
EAM	Enterprise Asset Management
ECM	Entity in Charge of Maintenance
ERA	European Railway Agency
ERP	Enterprise Resource Planning
EU	End User
GAMAB	Globalement au moins aussi bon (a standard in risk-related decision making)
GIS	Geographic Information System
GSM-R	Global System for Mobile communications – Rail(way)
HABD	Hot Axle Box Detection
HWD	Hot Wheel Detection
IM	Infrastructure Manager
IMD	Infrastructure Management Device
ISR	International Service Reliability
LCC	Life Cycle Costs
LIDAR	Light Detection and Ranging (distance measurement by light)
LS	Low Speed
MCDA	Multi Criteria Decision Analysis
NMA	National Market Authority
NPV	Net Present Value
NSA	National Safety Authority
OMD	On-board Monitoring device

OPEX	Operational Expenses
RCM	Reliability Centered Maintenance
RFID	Radio Frequency Identification
SLA	Service Level Agreement
RU	Railway Undertaking
SMS	Safety Management System
TGMS	Track Geometry Measurement System
TPM	Total Productive Maintenance.
TRV	Trafikverket, Infrastructure Manager in Sweden
TSI	Technical Specification for Interoperability
TSI TAF	Technical Specification for Interoperability relating to the Telematic Applications for Freight subsystem
TSI TAP	Technical Specification for Interoperability relating to the Telematic Applications for Passenger subsystem
TSI OPE	Technical Specification for Interoperability relating to the 'OPERation and traffic management'
VMD	Vehicle Monitoring Device
VO	Vehicle Owner, Wagon Keeper
WTMS	Wayside Train Monitoring System

1 Introduction

This report describes different measures for derailment prevention and their framework for implementation. It combines results from D 5.1 and other deliverables of D-Rail. Different business cases based on these results and some others are discussed, prerequisites are developed and discussed here.

Starting from the foreseen changes in the railway cargo sector up to 2050 and the possible influence on derailment prevention measures a discussion follows. How to group different derailment causes and mitigation measures in order to evaluate which technologies that could be used for detecting a higher risk of this specific derailment cause is investigated. Different monitoring concepts for on-board devices are introduced in chapter 4.

Due to the high complexity of the task and in addition to D 5.1, a discussion about some boundary conditions is followed. This implies not only questions regarding how to link measurement and/or assessment values to individual vehicles and their components (WTMS-perspective) or to individual locations (OMD-perspective), but also discussions about different intervention scenarios.

All this input influences the development and discussion of different business cases and a discussion about their implementation. Although only an average situation in Europe can be examined, every individual party in the railway sector gains widespread information, when evaluating their individual risk situation.

2 Change of the general framework

The future development of rail cargo traffic has been analyzed in WP2. There estimated values were based on two scenarios of the White Paper of Transport. The two WHITE PAPER SCENARIOS (LOW and HIGH) follow the trends shown by the White Paper of Transport, published in 2011 by the European Commission, as this defines the basis for a significant shift in freight demand from road to rail until 2050.

Due to economic development the freight volume transported on rail will totally increase by approximately 1.53% per year. Furthermore, some shifts in modal split based on additional measures are assumed so that the freight volume may double until 2050. At the same time the commodity split will change generating the need for a different wagon fleet, optimizing loading procedures and the railroad transport itself. Last but not least the share of dangerous goods has to be observed in order to keep transport risks at a low level.

Future rolling stock break down analyzed in D 2.2 addresses different factors that may influence future kind and numbers of freight wagon derailing. These are commodity types, productivity changes, total fleet size and geographic rail freight and rolling stock break down. They are discussed in the following together with two additional topics like new rules in general contract of use and mitigation towards new brake blocks.

2.1 Commodity types

WP2 identified six basic wagon types as dominant for transporting previously clustered commodity types.

- Open wagons
- Covered wagons
- Covered hopper wagons
- Flat wagons
- Tank wagons and
- ISO Tank Container, which is no extra wagon type and therefore combined here with the flat wagons.

Since the work of WP2 does not identify the need of a new wagon type, all improvements of wagon technology will concentrate on optimizing the existing types. Investigations in light weighting of vehicles to reduce tare weight will also be necessary as will improving wagon construction for more flexibility, optimizing logistic process and handling of the wagon.

These changes in transport technology will have a very small influence on the probability of derailing, as they mostly do not affect running behaviour or loads of the running gear. However some changes of monitoring technology have to be expected. For example the efforts to reduce the weight of the running gear will lead to new construction concepts. The wheelset bearings can be situated in between the two wheels, where common hot box detectors cannot monitor their temperature. As long as these developments are applied to a small number of vehicles, not all monitoring systems will be adapted but the vehicles will have to monitor themselves. When it becomes a broadly used technology, monitoring systems will have to be changed.

2.2 Productivity changes

The overall productivity changes are clustered in the two topics “capacity” and “speed” (see D2.2).

To describe the use of existing loading capacity, the load factor is an important characteristic number. This factor shows how often existing wagons are used for transport in a time period. Reducing down time and empty running to raise the load factor may cause poorer maintenance conditions of the wagons due to mainly time based maintenance activities. This may have to be compensated for with adopted maintenance activities of the ECM.

Another possibility to improve available capacity is to light weight freight vehicles to raise possible net weight. This requires new technologies and materials leading to lower wagon weight. The influence on probability of derailing light weight vehicles is not predictable, because vehicle caused influence can be changed in different ways depending on car body stiffness combined with gear characteristics and unsprung masses.

Rising loading capacity can also be achieved by reducing necessary maintenance time. Wheelsets and bogies are among the most costly components of freight wagons regarding maintenance. Track friendly bogies will help to reach this goal but the higher necessary costs inhibit usage of this technology. Adaption of economic boundary conditions will help.

2.3 Speed

Concerning freight transport the term “speed” includes all time consuming steps of the logistic process, like ordering, allocating the wagon or loading. Reducing time needs of every single step improves total “speed”.

Train speed is also one of many possibilities to raise the load factor. But this has to be balanced with other operating needs. The locomotive performance is generally limited by friction coefficient (at low speed) and installed power. Due to increasing driving resistance the maximum gross weight of the train has to be reduced for raising train speed (given a loco operating at max capacity). That causes reduced haul capacity, so that individual solutions have to be found for every transport task.

At least shortening the attendance time in terminals before and after travel is as effective as that.

Effects relating to raised load factor are therefore similar to those mentioned above.

2.4 Fleet size

In Europe the existing fleet of about 718.000 vehicles will increase to more than 2,1 million (white paper high scenario) or at least 1 million vehicles (reference scenario) assuming no change in efficiency or load factors. Under these conditions the influence of the fleet size on derailing probability can be presumed as linearly dependent.

2.5 Geographic rail freight and rolling stock break down

In D 2.2 the most prominent origin-destination pairs on a tonnes lifted basis were identified. This information may also be used for finding the optimal place for monitoring systems to cover maximum running trains with determined financial costs.

2.6 New limit value for wheel flats

There are discussions, to reduce the maximum length of tolerable wheel flats in the General Contract of Use. Today a length of 60 mm is allowed for larger wheels. In the future this length will be reduced to 40mm. A better wheel quality of the entire cargo fleet is expected, because the wheel-inspection has to be performed in a stricter way – and perhaps not only wheel flats will be treated, but other types of wheel irregularities as well. Therefore the number of wheels with high dynamic impact loads will decrease as well as the level of impact forces due to wheel irregularities. The framework developed at WP 3, looking for high impact loads summarizes the effect of all wheel failure, because the correlation between wheel flat length and impact load is not perfect.

2.7 Changing of brake blocks

Using of composite brake blocks instead of cast iron blocks is a European topic in railway freight operation, see [26]. Switzerland discusses a prohibition of cast iron blocks beginning in 2020 in order to reduce the sound pressure emission from cargo trains. The complete Swiss cargo fleet is already operating with composite brake blocks. Due to the same issue, all German VO are converting their fleet also to composite brake blocks until 2020. Operating this brake system, the maintenance interval for checking the cross profile is shorter than for cast iron blocks. Therefore it's assumed, that the wheel quality of the new equipped vehicles will be better than today. That influences much the riding stability as well as additional wheel forces from wheel defects and may reduce therefore the probability of derailments. In parallel there could be a potentially increased risk of thermal wheel fracture and loss of friction during snowy conditions for composite blocks

3 Reduction of derailments and their consequences

This chapter summarizes the main results of Task 3.1 where mitigation matrices have been developed for all eight major root causes for derailments defined by WP1. Furthermore possible mitigation measures are briefly described to show which kind of data from various monitoring systems might be delivered and has to be processed within the framework of a European monitoring solution.

3.1 Root causes

As there is no hierarchy for all elements of the railway system developed so far, the level of detailing and grouping of components is a very crucial aspect when analysing accident data bases. Thereby the grouping and splitting of accident causes (and especially derailment causes) is very sensitive to any ranking which might be done later on to argue priorities for different topics to be investigated in detail. As this problem is well known to the railway experts of the D-RAIL consortia, WP 1 decided to take into account experts opinion when setting the major derailment causes which have to be analyzed more in detail in the following WPs. The major causes are:

- Axle rupture
- Excessive track width
- Wheel failure
- Skew loading
- Excessive track twist
- Track height/cant failure
- Rail failures
- Spring and suspension failure

Following the expert's opinion and their naming Table 1 shows the separation of derailments into

- wheel climb related derailments: happens typically due to dynamics in wheel-rail interaction
- abrupt derailments due to a structural failure: are caused by structural failures of any material involved
- wheel drop derailments: one wheel of an axle drops off the rails without wheel climb of the other wheel
- Of course there are several cause consequence chains where more than one of these derailment types are possible. Those have been indicated as well in this table (e.g. derailments due to crash: the application of a force during a crash with external objects induce a derailment)

Table 1: Causes of the cause-consequence chains, which may lead directly to the state 'derailment' and corresponding type of derailment

causes	type of derailment
broken axle	abrupt derailment (structural failure)
breakage of stub shaft	abrupt derailment (structural failure)
broken wheel	abrupt derailment (structural failure)
faulty flange of wheel	dynamic derailment (wheel climb)
faulty suspension	dynamic derailment (wheel climb) or abrupt derailment (structural failure)
unbalance	dynamic derailment (wheel climb)
variation of width of track gauge	dynamic derailment (wheel climb) or wheel drop
broken rail	wheel drop
blocked brake or wheel	dynamic derailment (wheel climb) or abrupt derailment (structural failure)
violation of clearance gauge	derailment due to crash
faulty buffer	dynamic derailment (wheel climb)
overriding of buffers	dynamic derailment (wheel climb)
objects within the clearance gauge	derailment due to crash

This categorisation is strongly influencing the monitoring concepts because it already indicates the dependency of frequency to check certain parameters. Even for one cause there might be two different mechanisms.

3.2 Inspection and monitoring techniques

For each of the eight major derailment causes in Europe, which were identified in WP1, and for reasonable subcategories of these causes a distinction has been carried out in Task 3.1. Based on this, mitigation measures in terms of systems or technologies, which allow monitoring of these subcategories of derailment causes, have been presented. Thereby not only systems available on the market have been considered but also well-known developments (prototypes, etc.) as well as future monitoring approaches, which seem to be promising from a present-day perspective.

An example from D3.1 is Table 2 which shows the matrices created there to show all various kind of monitoring activity.

Axle rupture is a structural failure of the axle which results in complete fracture of the axle component and the inability of the wheels to support the bogies or vehicle. Axle rupture includes fatigue failure of the axle due to repeated overloads, static and/or dynamic, and thermal failure of the axles, usually in conjunction with an overheated bearing and bearing/axle burn-off.

This estimated cost represents the cost of acquisition of these mitigation /monitoring systems. In addition, there will be annual operating and maintenance costs as well as amortization of the acquisition costs over a defined life cycle.

Table 3: Ranking of the mitigation measures according to estimated costs

Mitigation measure	Mitigation measure type	Estimated costs
Trackside crack detection	Track side	High
Vehicle profile measurement	Track side	High
Acoustic inspection	Track side	High
Optical monitoring of loading	Track side	High
Stress detector	Vehicle side	High
Track strength testing	Recording car	High
Acceleration/force measurements on wheel sets	Recording car	High
Geometry measurements	Recording car	High
Video inspection of rail, sleepers and fastenings	Recording car	High
Magnetic flux or eddy current	Recording car	High
Ultrasonic inspection	Workshop	High
Axle load checkpoint (Q)	Track side	Medium
Axle load checkpoint (Y and Q, resp. Y/Q)	Track side	Medium
Hot box detection (infrared-based)	Track side	Medium
Hot wheel detection	Track side	Medium
Acoustic bearing detection	Track side	Medium
Laser-based wear measurement	Track side	Medium
Simulation based evaluation of geometry measurements	Recording car	Medium
Laser-based wear measurement	Recording car	Medium
Ultrasonic rail inspection	Recording car	Medium
Acceleration/force measurement (lateral)	Vehicle side	Medium
Acceleration/force measurement (vertical)	Vehicle side	Medium
Broken rail detector (signalling system)	Track side	Low
Visual Inspection	Shunting yards	Low
Visual Inspection	Workshop	Low

3.3 Potential mitigation measures

3.3.1 Track side measures

In this section a list of possible track side measures are mentioned. Certain mitigation measures were already investigated in the former project INNOTRACK (www.innotrack.eu).

Axle load checkpoint (Q)

Track side (track based) measurement system for measuring the vertical wheel/rail force Q of each wheel or each wagon passing over the checkpoint.

Axle load checkpoint (Y and Q, resp. Y/Q)

Track side measurement system for measuring the lateral wheel/rail force Y, the vertical wheel/rail force Q, and the ratio of Y/Q of each wheel or each wagon passing over the checkpoint.

Trackside crack detection

Track side measurement system to detect cracks in the wheels and/or axles of each wagon passing over the measurement system site.

Hot box detection (infrared-based)

Track side measurement system for measuring the temperature of each bearing (for each wheel) as the wagon passes over the measurement site. Infrared systems use non-contact infrared temperature measurement technology to measure this temperature.

Hot wheel detection

Track side measurement system for measuring the temperature of each wheel as the wagon passes over the measurement site. Infrared systems use non-contact infrared temperature measurement technology to measure this temperature.

Acoustic bearing detection

Track side measurement system for measuring the condition of each bearing (for each wheel) as the wagon passes over the measurement site. Non-contact acoustic measurement techniques coupled with acoustic signature analysis is used to detect acoustic signatures which represent bearings approaching failure, but before they generate sufficient heat to trigger the hot-box detectors.

Vehicle profile measurement

Track side measurement system for measuring the profile and condition of wagon as it passes over the measurement site. Laser or other non-contact optical technology measures the width, height, and rotation (angle or tilt) of the wagon, to determine if the wagon has excessive movement or rotation (tilt).

Acoustic inspection

Track side measurement system for measuring the condition of each axle, bogie and wagon as it passes over the measurement site. Non-contact acoustic measurement techniques coupled with acoustic signature analysis is used to detect acoustic signatures which represent components approaching failure, but before they are visible or otherwise detectable.

Optical monitoring of loading

Track side measurement system for measuring the load distribution and condition of each wagon as it passes over the measurement site. Non-contact optical measurement techniques are used to detect improper load conditions or conditions of shifted load.

Broken rail detector (signalling system)

Track side measurement system for monitoring continuity of the rail usually by sending an electrical signal through the rail. In the event of a rail break, the continuity of the rail is disrupted and the signal detects the presence of the break, providing an indication of the rail break. Used when traditional, track (rail) based signal systems are not present in the track.

Laser-based wear measurement

Track side measurement system for measuring the profile and wear condition of each wheel as the wagon passes over the measurement site. Laser or other non-contact optical technology to measure the width and height of the wheel flange, and the depth and profile of the wheel tread.

3.3.2 General vehicle side measures

Lateral acceleration/force measurement

Wagon based measurement of acceleration and/or forces to determine if, for each wagon, excessive lateral dynamic forces or excessive movement of the vehicle is being generated.

Vertical acceleration/force measurement

Wagon based measurement of acceleration and/or forces to determine if, for each wagon, excessive vertical dynamic forces or excessive movement of the vehicle is being generated.

Stress detector

Wagon based measurement of stress in key wagon component (e.g. wagon body, bogie structural elements, axles, etc.) for each wagon, to determine if excessive stress of the wagon components is being generated.

3.3.3 Vehicle side measures on recording cars

Track strength testing

Measurement of the gauge widening resistance (gauge holding strength) of the track using an inspection vehicle that applies a controlled lateral (Y) and vertical (Q) load to the track and measures the gauge widening of the track under this known load (together with the unloaded gauge of the track).

Acceleration/force measurements on wheel sets

Instrumented wheel sets on an inspection vehicle that measure wheel rail forces (using strain gauged wheel sets or alternate technologies) and/or accelerations (using vertical/lateral/longitudinal accelerometers mounted on the axles or bogies) to detect track locations that generate high levels of force or acceleration.

Geometry measurements

Inspection based measurement of the geometry of the track to include measurement of all of the key track geometry parameters of gauge, alignment (lateral), profile or vertical

alignment, cant or cross-level, twist, curvature, etc. Usually using non-contact based systems to generate a space curve or chord offset measurement or a direct measurement of the parameter as appropriate. Also used to measure an integrated value of each parameter over a defined length for track to provide a condition index for each section of track.

Simulation based evaluation of geometry measurements

Establishing a dynamic simulation model on the track geometry recording car in order to perform a real-time analysis by using a continuous input stream of track geometry data. The model generates response predictions for the car body bounce, roll angle, pitch angle, vertical acceleration, and vertical wheel forces. These values are determined on a step-by-step basis for every part of supplied input geometry data. Using established thresholds for these values, response predictions are assessed to determine if the rail vehicle is well behaved, or if it exhibits adverse dynamic behaviour and derailment potential. The answer can be used to identify locations producing unsafe vehicle performance in the field and provide the railroad with a defect report that will allow them to take fast corrective action.

Video inspection of rail, sleepers and fastenings

Inspection based system for using video camera and related optical imaging technologies to record the condition of the track and its key elements, which are visible to an inspection vehicle. This includes rail surface condition, rail profile, fastener and sleeper condition, ballast surface condition, etc. The inspection also includes the use of detection algorithms to aid in the detection of track and track component anomalies.

Laser-based wear measurement

Inspection vehicle based measurement system for measuring the profile and wear condition of rail at a predefined interval. Laser or other non-contact optical technologies are used to measure the width, height and profile of the rail.

Magnetic flux or eddy current

Vehicle based testing of the internal condition of the rail using magnetic field technology introduced into the surface of the rail to detect the presence of internal defects in the rail. Usually used as a complement or supplement to ultrasonic technology.

Ultrasonic rail inspection

Vehicle based testing of the internal condition of the rail using ultrasonic wave technology introduced into the surface of the rail (from ultrasonic crystals embedded in a fluid filled wheel or sliding shoe via a couplant medium). The reflected ultrasonic waves are used to detect the presence of internal defects in the rail.

3.3.4 Measures in shunting yards

Visual inspection

Inspectors perform visual inspection of both wagons and track in the shunt yard to detect defects or unsafe conditions.

Using of WTMS

In some cases, the weight of the approaching vehicles is measured in order to actuate the external wheelset brakes, so that the subsiding vehicles run towards the correct track but don't collide with the already stopped ones. The precision of those devices is in the range of

5 – 10%, so heavily overloaded vehicles can be identified. The precision for load imbalances of individual axles has to be proved. Also a comparison with the weight data in the train composition list is possible (and if needed a correction).

Due to the low speed it seems very challenging, to find and to evaluate the severity of wheel defects. A minimal solution could be to give some hints about affected axles to the wagon inspector

3.3.5 Measures in workshops

Visual inspection

Inspectors perform visual inspection of wagons in workshop to detect defects or unsafe conditions.

Ultrasonic inspection

Use of fixed ultrasonic measurement techniques to measure the integrity of key wagon components such as axles and bogie frames in the workshop. Wagons or individual components are brought to the inspection system located in the workshop for testing.

Magnetic particle inspection

Magnetic particle inspections are typically carried out at axles and solid wheels in workshops. Thereby axles or wheels are magnetized. Metal discontinuities (cracks, etc.) cause a magnetic flux leakage, which can be made visible by the means of ferrous iron particles. Therefore this technique helps to detect fatigue cracks and other defects at early stage of their development (surface micro cracks with width from 0,001 mm and more, depth from 0,01 - 0,03 mm).

3.3.6 Systems defined by WP 4 to be used in D-Rail

Detection of wheel defects (WTMS)

Automated system using visual inspection of the wheel (the wheel checker, part 5.1)

Running stability monitoring (on-board)

For inspection of the wagon and bogie behavior (running stability monitoring): An embedded specific monitoring system – the Derailment Prevention Device (DPD) for inspection of the wagon and bogie running stability in order to identify potential fault detection in service., see chapter 4.1

4 On-board monitoring concept

This part aims at developing and integrating different on-board monitoring concepts taking into account the survey, assessment and suggested improvement of monitoring techniques from the work undertaken in WP4.

The basis of this work is the list of eight major root causes of European main line derailment (ranking with respect to cost and number):

1. Axle ruptures
2. Excessive track width
3. Wheel failure
4. Skew loading
5. Excessive track twist
6. Track height/cant failure
7. Rail failures
8. Spring & suspension failure

These root causes have been listed and evaluated by experts. The corresponding work and output data are set out in an assessment matrix (see D-Rail D4.1).

Considering all these events, it is common evidence that they can't suddenly come out of nowhere: these physical phenomena are generally the result of a degradation or degeneration process, due to natural ageing or to hidden defects.

WP5, making the best use of the potential mitigation measures considered in 3.3.2 (General vehicle side measures) and 3.3.3 (Vehicle side measures on recording cars), has developed several concepts for on-board monitoring for the purpose of following these degradation or degeneration processes, and possibly identifying limits (thresholds) in order to provide information before the failure occurs.

They can be divided into two main categories:

- On-board sensing devices to monitor the vehicle,
- On-board sensing devices to inspect the infrastructure.

4.1 On-board devices monitoring the status of vehicles (self-diagnostic)

The purpose of this concept is to improve the operational safety and efficiency of freight trains through continuous monitoring of their mechanical components in order to detect defects and to alert train crews before breakdowns and accidents occur.

Thus, the availability of freight trains and wagons can be ensured during the whole lifetime, using condition based maintenance procedures.

Contrary to WMTS, on-board systems have to be installed on each rolling stock that needs to be monitored. As a consequence, all devices must be easy to install, and requiring minimum maintenance during their operation. The sensitivity of the systems must also be taken into account, as well the cost of installation. The financial viability of this kind of concept has to be studied and justified, first attempts are done in the framework of D-RAIL WP7.

Nonetheless, the technology involved remains exciting, and as long as their cost can be justified there will be a market for them. The real question is what scale this market will have.

4.1.1 State of the art and new proposal

At the present, the railway market offers vehicle mounted devices, specifically dedicated to the Freight rolling stock, in a position to detect a derailment once it has occurred, and to stop the train through a direct action on the brake system.

- The operation of such devices is based on the mechanical principle of mass-spring, sensitive to a given acceleration level, but unable to discriminate the event according to the time duration.
- The device operates once the derailment has occurred
- On the other hand, there is a risk of undue intervention, resulting in undue blocking of the train in line

Faiveley proposes to develop a monitoring concept based on a **bogie stability sensing device**:

- Integrated on-board systems aiming at monitoring the vehicles (self-diagnostic)
- One DPD is fitted per bogie or per wagon
- The device is able to detect abnormal running conditions at bogie or vehicle level
- Signal / information can be conveyed to the locomotive (possibly with display to the driver) for action
- The objective is to integrate the D-Rail product into a range of products with different abilities, from simple to complex

4.1.2 A new technology

Through the use of accelerometer /gyroscope sensors, derived from the automotive, and attached electronic technologies, a better performance can be achieved:

- Measurements along the three axes, mainly vertical and lateral, and angular rotation measurements, allow to better isolate the event of derailment.
- The features of a microprocessor allows to filter in real time accelerations, isolating specific frequencies, and above all allows inserting temporal filters such as to discriminate a single pulse (not symptomatic of a derailment) from continuing events (symptomatic of a real derailment).
- The extent of lateral accelerations and rotations, allows the assessment of any unintended lateral oscillations of the wagon: an intelligent analysis of such events can anticipate a derailment
- Real-time analysis of the accelerations in the frequency domain identifies damaged wheels for example by flats, which may induce derailment if not detected

The DPD is working on the base of the information / signals of a 3D accelerometers and 3D gyroscopes, in response to moves, accelerations and shocks generated when operating a wagon.



Figure 1: Derailment Prevention Device (DPD) and electric connection

The DPD is of the very low consumption type and includes a rechargeable battery ensuring a significant operational life. Its concept will limit the consumption to the “only necessary”, thanks to modern technologies (energy saving, sleeping mode, wake up, sampling, delayed calibrations ...).

One sensor is placed on each bogie (See Figure 2) or – depending on the results of the tests on wagons – somewhere on the body shell (See Figure 3)

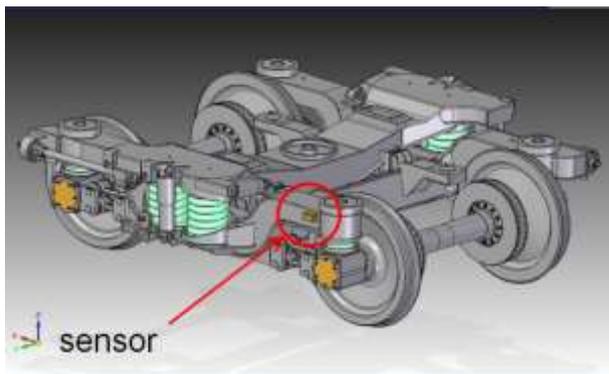


Figure 2: Position of a sensor on bogie

The accelerometer and gyroscope in the 3 directions x, y and z permanently generate signals which are acquired and sampled into size, amplitude, time, frequency ... and the bogie accelerations and displacements in three directions can be continuously calculated, logged and verified.

The obtained results are compared with a processor to reference values and thresholds included into files stored inside the DPD memory.

The target is to be able to detect:

- Abnormal pitching
- Abnormal rolling
- Abnormal yawing
- Wheel problems (flats)
- Bogie abnormal hunting

- Rail defect
- Derailment

When abnormal conditions which could lead to derailment are detected, an “exceeding limit” message is generated by the DPD, ready to be sent and transmitted.

The DPD generates a prevention signal when thresholds are passed during service. The threshold can be specified according to one unique criterion or, if needed, in conjunction with several criteria, such as maximum acceptable displacement in one degree, or as an acceptability mask in the frequency spectrum. The aim is to be able to detect instability significantly before the derailment event.

3 levels of information are foreseen according to the complexity of the product and the requirements of reliability (Safety Integrity Level, SIL):

1. Minor defects => information for maintenance, something may be degraded or is degrading on a bogie; information for maintenance (may be transmitted to the loco/driver and from there to RU and ECM)
2. Major defects => decision by driver: continuation/ influencing: something wrong is occurring on a bogie or concerning the dynamic behavior of the vehicle (to be transmitted to the driver for decision: continue / stop)
3. High risk of derailment => immediate stopping: Detection of derailment according to the criteria of UIC 541-08, with ability to trigger locally a valve for exhaust of the Brake Pipe, initiating an emergency brake.

4.1.3 Benefits, disadvantages, opportunities of electronic technologies

BENEFITS:

- Ability to store events in non-volatile memory device
- Ability to transfer this information to a user Maintenance mediating means of information access
- Through appropriate architectures, achieving a high Safety Integrity Level (SIL)

DISADVANTAGES:

- requires the existence of an on-board source of energy, as an electric generator battery charging in depot

OPPORTUNITIES:

- on-board energy provides power to any other monitoring devices, electronic security (temperature sensors, bushings, or active diagnostics of the braking system)
- axle generator can be used as a speed sensor, it can measure the cumulative distance traveled by the vehicle (important data for conditional maintenance)
- microprocessor allows you to turn the Electronic Stability sensor in a concentrator of information (through its non-volatile memory) for all other information collected as set out above, and their transmission in wireless information systems

4.1.4 High sensitiveness for detection and fine tuning

The device is technically promising with a high level of sensitivity for detection. Before the work in D-Rail WP 6 started, the existing experience was only based on tests achieved in a laboratory with available simulations.

On-track tests are necessary to confirm expectations and preliminary lab tests.

Under the framework of D-Rail, WP 6 performed tests in Velim in collaboration with VUZ in June 2014, with the target to record the shocks and vibrations in all possible speeds and rolling conditions.

Three configurations (see figure 3) have been tested for comparison, with full recordings:

- Installation of the DPD on bogie
- Installation of the DPD on the body frame
- Installation of the DPD on the top floor of the wagon, above one bogie

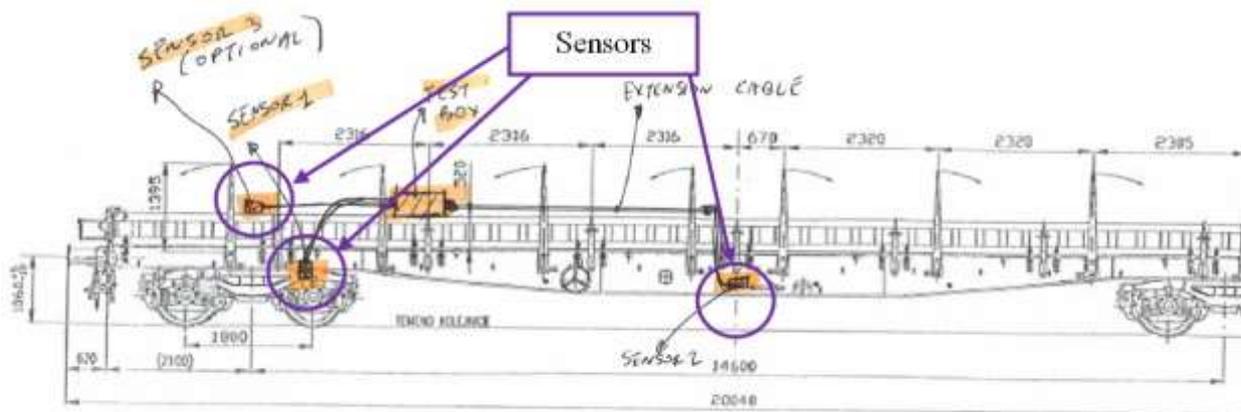


Figure 3: Position of the sensor on wagon for Velim test

Post treatment and comparisons should provide a significant batch of information and data to decide if monitoring on the body frame only is realistic.

The results presented in WP 6 allow an evaluation of the current status after the lab tests.

After field tests in Velim, the recorded information - real data coming directly from the field, and consequently fully trustable - will be used on a test bench, where the measured accelerations will be simulated in order to improve the system by fine tuning.

4.1.5 Wireless transmission to locomotive

The DPD, taken as an isolated device among vehicle devices, already provides a significant improvement to the present situation in the Freight rolling stock. Nevertheless, the equipment is much more attractive when the information is relayed to the locomotive.

In order to reduce the installation cost of the DPD, and not to complicate the operation of the single wagons (in marshalling yards etc), the propagation mode of the prevention message is of a wireless type.

- The process is presently ruled / restricted by existing patents on the markets, and applicable standards (ETSI= European Telecom Standard Institute).

- Faiveley Transport has engaged a patent analyst for the current situation and patenting is in process.

The technology would allow that one wagon out of two is “out of service” or not equipped.

In the locomotive the info / signal can be displayed on a screen, or light a lamp, or – if highly critical conditions are detected – activate a ring or other noise signal. After developing such a device tests have to be performed regarding the safe signal-transmission among all vehicles including near-network-generation under railway surroundings.

4.1.6 Enhancement for the future

By including some “intelligent” devices, together with an additional logging unit located in the locomotive, the data can be logged with GPS position and transferred by GSM-R (or similar) to a server on an internet connected network.

This could be used for example to determine the location of track faults, in cases where a track condition caused the output from several sensors (approximately at the same position) to exceed the limiting criteria.

This information can then be used by the infrastructure manager to inspect the track condition at the location indicated, and repair any derailment hazards if necessary.

The technology for transmission of messages is independent from the detection process, and may be - in further developments - associated / used for transmission of any other kind of information (hot axle boxes, vehicle identification, etc ...).

However, that will need additional sensors of a different type, more electrical connections on the wagon, and higher electronic and software capacities.

4.2 On-board concepts monitoring the status of infrastructure

The purpose of this general concept is to improve the safety and efficiency of the infrastructure dedicated to freight trains or to mixed traffic, by embedding some monitoring devices on rolling stock that are able to inspect the track (and more generally the infrastructure) when they are running, in order to detect defects and to make the best use of these data to alert the relevant persons before breakdown and accidents occur.

Innovative diagnostic systems are at the early stage of their introduction in railways. The concepts described here are not only safety instruments, but also aim to assist taking the right action at the right time, in order to optimize the maintenance of the infrastructure.

Indeed, the collected infrastructure condition data can be automatically stored, and can be used to predict trends in the degradation of track. Measured data and inspection reports should be retrievable immediately to take immediate measures. The collected data can be used to pinpoint and predict trouble spots in the track and be used to plan maintenance scheduling.

The wagons equipped with on-board monitoring devices must be able to run at track speed in order to save time and not to disrupt freight traffic. Thus, they can reduce or even replace manual inspection (save resources, increase personal safety, potentially improve accuracy, minimize traffic interruption).

4.2.1 Measurements and data collection

Two different concepts are highlighted in this section:

- Advanced recording cars
- Embedded monitoring systems on freight trains in regular service

Concept of Advanced Recording cars

Infrastructure inspections were originally made by human inspectors walking along the railroad and visually inspecting every section of track. This was hazardous as it had to be done while trains were running. Manual instruments had to be used to measure various parameters of the track.

The concept of recording cars has already been described in a previous document. It consists in gathering several monitoring systems on a dedicated measuring train, in order to make a high number of measurements at the same time, see Figure 4 and Figure 5.

Today, the main instrument used to obtain information (such as geometry data) about the track are dedicated recording cars. These vehicles are equipped with one or multiple measurement systems to collect data. The different use cases may be roughly divided in the following categories:

- Change-driven measurements relating to changes (e.g. upon completion construction work, acceptance measurements, ...)
- Event-driven measurements ,e.g. confirming existence of a defect after a report
- Scheduled measurements, e.g. a bi-weekly safety inspection as required by the track operating permit, against thresholds
- Individual measurement campaigns, against thresholds.

Advanced recording cars could consist in improving existing monitoring systems installed on dedicated trains, or integrate innovative and promising technologies, for example those described in D4.2.



Figure 4: SBB recording car, Roger 1000, MERMEC

For example, nowadays, a measuring train can generate more than 100 parameters and 1 TB of data every month.

Such a train requires dedicated train paths, and so it is of interest that it can run and make its inspections at service speed, so that it can be included in the regular traffic without major disruption.



Figure 5: Doctor 'Yellow', high speed Japanese measurement train

The primary benefits of recording cars are the time and labour saved when compared to doing manual inspections of the track.

They are able to improve the railway infrastructure inspection and maintenance by means of:

- Self-propelled railway vehicle, allowing efficient installation and seamless integration of diagnostic systems
- Leading-edge measuring systems
- Data management system, high-performance data analysis software.

Inspection of the infrastructure is mainly done by track geometry measurement vehicles. Excessive track gauge and track twist are primary defects to detect to prevent derailment.

Some improvements have been highlighted in WP4 (see D-Rail D4.2) regarding the possible technological innovations that will be developed and designed in the future.

To extend track geometry measurements to also cover system integrity, the measurements should be made close to or under a test wheel with controllable vertical and lateral loads. This would make it possible to test the track with loads that reach or even exceed maximum expected operational load. Such a measurement cannot be made by general vehicles but requires special dedicated vehicles. From a track engineering point of view, it would be extremely beneficial to have geometry data for both loaded and unloaded track as measured by the same vehicle. Here is an area for improvement.

Vertical track alignment should be measured with an applied load and a high sample rate to also cover short defects like dipped rail joints. This is an area for improvement both regarding measurements and analysis. Comparisons with unloaded measurements will enhance some existing regulations. In this case, track stiffness has to be taken into account.

Concept of embedded monitoring systems on in-service freight trains.

Another innovative proposition is to embed monitoring systems on freight trains in service.

As for advanced recording cars, the trend is towards compact non-contact monitoring systems to be installed on nearly any vehicle and used at high speeds. This will make possible

to use shorter inspection intervals without affecting track availability, and so give track managers access to frequent inspection data, without affecting network availability.

So, to reduce the track occupancy time of vehicles inspecting for rail condition, a higher inspection speed is required. A solution could be to move some inspection from special inspection trains to regular trains in revenue operation. If the equipment is compact enough, and the inspection can be carried out at the operating speeds of vehicles in a revenue earning service, then these vehicles could be used to detect infrastructure defects. This would reduce track occupancy for defect detection, and could potentially increase the inspection interval (depending on the number of vehicles fitted).



Figure 6: Rail testing equipment (ground penetration radar, ultrasonic and rail profile laser scanner), Network Rail

As for on-board devices monitoring the status of vehicles, three levels of diagnosis can be defined for on-board devices monitoring the status of the infrastructure in accordance with the European standard EN 13848:

- 3 stages of limits: Alert limit, intervention limit, immediate action limit
- Don't define limit values for the measuring signals (using the results only for information).
- Defines intervention limits: allow to plan the maintenance policy in good time and well in advance.
- The alarm thresholds are not determined by maximal acceptable values, but by the intention to detect any anomaly or fault via pre-alerts at an early stage to permit countermeasures or plan inspections.



Figure 7: Track surface inspection system, Mermec

Two complementary concepts

These two concepts are complementary and could bring an added value to the monitoring policy of infrastructure managers. The introduction of monitoring systems on regular trains would not replace dedicated recording cars.

Equipped regular trains allow more frequent inspections, as they could run on the track several times a week, compared to some times a year for dedicated recording cars.

This could bring much more monitoring data because in-service trains, by definition, are running more frequently on the railway network and on the European freight corridors on which D-Rail focuses.

Moreover, the recording car is of a given vehicle type. Extrapolating the dynamic measures from this vehicle is thus reasonable for other vehicles of this type, although a different class of vehicle may show radically different dynamic behaviour. Examples of extreme cases are tilting trains and high-speed trains. It is not feasible to buy a recording car for every type of train. Installing monitoring devices on in-service trains could bring relevant information for several kinds of vehicles.

However, the cost of such installations must of course be taken into account, and basic, cheap, robust monitoring sensors and systems should be considered to fit out part of a freight fleet.

Even if the precision of this kind of measurement would be lower, the information could be very useful for infrastructure managers. For example, in order to predict track degradation, it is much better to have a lot of points, even if there are more errors. For proper use of the results in statistical analysis has to be performed to distinguish between systematic and random errors.

In this case, the regular trains equipped with monitoring systems would be able to detect some previous indication about the condition of the infrastructure (track geometry parameters, cracks, missing assets...). At this point, the suspicion of a fault detection could lead the infrastructure manager to send a recording car to make more targeted measures on the considered part of the track.

Recording cars require special train paths, which are a huge operational constraint for network exploitation. Using measurements from in service trains could allow recording cars to focus on critical targets and optimize the scheduling of recording cars inspections.

Indeed, in areas with high usage - where measurements are actually of huge interest - tracks are increasingly difficult to obtain due to traffic density. In addition, scheduled measurements are increasingly relegated to non-operating hours, when maintenance activities are also scheduled.

For all these concepts, the track can be considered as a system. Measurements can be analyzed in a combined way. That makes the concepts of data storage, data communication, and condition based maintenance planning tools in order to make an optimized use of all the data that could be recorded by these different propositions even more important.

This requires the application of robust, high-precision and available measuring systems in combination with an appropriate on-board and off-board analysis system.

Finally, the collected monitoring data, indicators and video monitoring results can serve increasingly as a basis for decision making for safety decisions, maintenance and renewal work to be carried out on the track.

“Real behaviour”, dynamic measurements

Another advantage of integrating monitoring systems on commercial trains is that in this manner, the train from which the measurement is made has a real behaviour, and so for example the different interactions and forces between the track and the vehicle are realistic.

Moreover, some recording cars are not able to run at high speed in curves, so are not able to take dynamic measurements, only static ones. The use of equipped freight trains could solve this issue.

Localization issue

Getting inspection and monitoring data is not trivial of course. But even when those data have been acquired successfully by the relevant techniques, they are useful only if they are precisely localized, and associated to the right railway asset.

Recording cars are equipped with localization sub-systems required to provide accurate track measurements. It can consist in an odometer, or based on GPS technology.

Likewise, monitoring systems embedded on regular trains need a localization system. The solution must have sufficient accuracy with a reasonable cost.

More details are discussed in chapter 5.1

4.3 Data: from collection to usage

Railway infrastructure condition monitoring allows railways to frequently collect a wide range and huge amounts of data. And in the future, more and more data will be collected.

When the data are available, validated and stored, then comes the questions of their legal ownership and of their use.

4.3.1 Data ownership

The introduction of monitoring systems on in-service trains raises the issue of the data ownership. Indeed, the systems installed on regular trains would belong to railway operators running on a network. We can imagine that an operator having monitoring systems embedded on some of its trains and who shares those monitoring data with the infrastructure manager could get a reduction in track fees.

All railway operators using a network have to pay some fees proportional to the number of kilometers covered by its fleet. Of course, this concept depends of the structure and the organization of the railways in each country. This solution is already used by many European countries, and since the D-Rail project deals with European freight corridors, the cross border interoperability must be taken into account.

4.3.2 Use of data

The first use of such data would be to ensure and improve safety. When a critical defect is found, an alarm is created and sent to the relevant person, who will take the right decision to respond to this problem.

But too often asset condition data is collected and used only once, just to check if safety parameters are met. This valuable information is then left to die in so-called 'data graveyards'.

Data must not be lost, but can be used to build degradation trends and optimize the inspection policy and the maintenance strategy.

As railways are (and will more and more) collecting and storing increasing amounts of asset condition data, inspection data could be increasingly used to define condition based maintenance, in order to increase the railways' competitiveness.

Unless their processing systems are properly upgraded and integrated, the full benefits of holding this data may not be realized.

So more measurements and inspections could be available, and they could allow a better organization and optimization of the inspection and maintenance policies, shifting from corrective to condition-based/predictive maintenance, the most efficient existing approach to maintenance engineering.

4.3.3 Condition-based maintenance

All data that have been acquired and recorded by monitoring systems give information in order to manage, schedule and perform maintenance tasks.

Sharp differences of extent and maturity in the way condition data is used exist among railways.

Some railways are indeed making advanced use of their data, whereas others are only beginning to explore the possibilities. Condition data are still analyzed in many cases:

- Only once (without time based comparison) with the aim to mainly check safety and quality levels for sections of track ranging from some centimeters (e.g. for the defect calculation) to fixed segments of some meters (e.g. for the calculation of quality indicators at 100 meters)
- By comparing a survey with the previous one to detect the rate of change
- In isolation or with very limited data correlation (e.g. correlation with master asset data)

The adoption of low-cost massive data acquisition and storage technologies makes large amounts of data available for analysis.

In order to optimize the railway infrastructure maintenance management and eliminate the risks of failure occurrence, the ideal solution is to plan maintenance in a "condition-based" manner, determining whether, when, where and how to intervene. This eliminates "too early" preventive and "too late" corrective (after a fault already occurred) interventions and thus produces optimized plans for maintenance.

The railways that are capable of making full use of such data graveyards and transforming them into useful information can take advantage and obtain a more effective decision-making process.

However, corrective maintenance cannot be eliminated; it can only be reduced to a minimum level by implementing planned preventive/predictive maintenance.

This is a radical change in how diagnostic data are used, not only as a function of control, but also as a driver for maintenance activities. Moreover, diagnostic data can also be used to drive (in an objective way) renewals, in fact advanced planning methods can be used to balance maintenance and renewal activities and determine the optimal renewal time.

Railway infrastructure asset collection

Condition data are collected by measuring systems installed on-board dedicated or service vehicles/trains. Other data such as master asset and Geographic Information System (GIS) data can be collected with different modalities ranging from on-site data harvesting to LIDAR surveys oriented towards a more automatic object extractions.

Operational data such as speed restriction and infrastructure usage data usually are managed in systems for the traffic operations, whereas financial data are managed in Enterprise Resource Planning/Asset Management systems.

Comprehensive analysis of asset registry and condition data offers new opportunities to indicate performances of maintenance expressed as an achieved or expected result. In fact, condition data allows measuring the status of an asset during its entire life so detecting historical behaviour and predicting future evolution.

Decision support systems

One of the main purposes for decision support systems is to make the best use of these asset condition data. On these results are built maintenance planning and scheduling. It enables planning of maintenance interventions even before any faults come to light, so maintenance crews can stop scheduling time dependent work because they can foresee the future evolution of their networks.

Some systems are already on the railway market: Enterprise Asset Management (EAM), Computerized Maintenance Management System (CMMS) and Enterprise Resource Planning (ERP).

These kinds of systems are inevitable to support the practical use of such maintenance concepts, in the case of complex, linear assets such as railway networks. This is because different railway assets, such as track segments are economically and structurally interdependent. Scale effects are involved in their maintenance and renewal, while their degradation is often structurally related; moreover, because operations have to continue on the rail network. All kinds of constraints have to be considered in the planning of infrastructure maintenance.

In the railways, the first systems were developed in the 1980s and 1990s, focusing on track maintenance; early examples are MARPAS, BINCO, GEV, REPOMAN, TMS, TMAS, and SMIS. Some of these systems assign priorities to maintenance and renewal work, through projecting the years, in which track quality in a given track segment will first fail to comply target standards.

In recent years there has been a trend towards more of the planning process occurring with data support. Information technologies (IT) tools for optimization are used primarily for materials, personnel and maintenance planning. According to Hansen and Paschl [1], the following success factors are important in order to create good schedules:

- well established overview of all aspects of railway infrastructure including tracks, stations and operating rail farms

- detailed overview of the design and function of signal systems
- overview of the capacity of the network, based on modern methods
- good runtime estimates
- established standards for energy-efficient power trains
- active use of robustness analyse, with special focus on conflict points and bottlenecks
- use of various types of simulation
- monitoring and analysis of punctuality, and other traffic

To be able to plan the maintenance for the Infrastructure Manager (IM) there is a need to know about the interacting technical systems, i.e. traffic companies' vehicles and how the assets are used, how the track is operated, what type of vehicles are used, what is their condition (bad maintenance, bad functioning, increased degradation), how many of them are there, what speed and what axles load. Due to, for example, climate and unexpected events in terms of storms, floods may occur causing unexpected outputs such as train delays. This information about asset condition, traffic operation and so on is collected into different Information and Communication technologies (ICT) systems.

All actions and changes to the asset are reported back to the system for all maintenance actions, also for corrective maintenance where a deviation can be seen.

But there is a need to direct a reactive management attitude towards a proactive management. The key to the proactive approach is the successful implementation of a continuous improvement process. This is usually combined with maintenance strategies like Reliability Centered Maintenance (RCM) or Total Productive Maintenance (TPM). These techniques provide strategic frameworks that support the continuous improvement process.

In a complex environment situation, there is a need to focus on those variables that can affect and promote a value increasing output. A decision support tool can facilitate the management, and Multi Criteria Decision Analysis (MCDA) can be used.

MCDA is a methodology for evaluating options on individual, often conflicting criteria, and combining the separate evaluations into one overall evaluation. MCDA consist of several stages:

- Consider context
- Identify options
- Establish objectives and criteria
- Score option on the criteria
- Assign importance weights to the criteria
- Calculate overall scores
- Examine results, sensitivity analyses and sorts

Nevertheless, the weaknesses of the current railway infrastructure management systems are:

- Few infrastructural aspects covered (e.g. only track geometry analysis, only grinding, etc.). In some cases, data are gathered isolated in different independent systems

- Suppliers of asset management systems cover a narrow field of expertise (only information technology, no condition monitoring experience or data interpretation)
- Typically decision support tools provide only data visualization
- The analysis of railway lines shows fixed segmentation and lack of flexibility
- Short term and long term planning are addressed in separate applications

However, none of these systems has the ability to manage railway asset and condition data (resulting from diagnosis systems) in an efficient and integrated manner.

Railway Asset Management System (RAMSYS, See ANNEX) has been developed by the MERMEC Group in order to provide a system that fully supports condition-based maintenance and renewal management.

RAMSYS was developed by the MERMEC Group specifically for the railway industry, and supports the management of all data related to railway infrastructure and also rolling stock maintenance (assets, defects, work history, measurements, and operational data). Its purpose is to be a decision support for condition-based and predictive maintenance and renewal.

4.4 Related projects:

The European Commission has supported some research projects in the field of railway infrastructure maintenance organization and planning.

ACEM-Rail (Automated and Cost Effective Maintenance for Railway)

The need to optimize maintenance of railway infrastructure was also addressed by the ACEM-Rail project launched in December 2010.

The main goal of the ACEM-Rail project was to reduce costs, time and resources required for maintenance activities, and increase the availability of the infrastructure including both conventional and high speed lines.

This project is an important step forward in railway infrastructure maintenance techniques for the following reasons:

- Development of several technologies for automated and cost effective inspection of the track (Subgrade and superstructure).
- Development of predictive algorithms to estimate the rail defects evolution.
- Development of algorithms for an optimal planning of railway infrastructure maintenance tasks integrating the scheduling of preventive and corrective operations.
- Development of models and tools in order to monitor the proper execution of corrective and preventive maintenance tasks.
- Development of a novel technology for the optimal management of all the subsystems in the whole railway infrastructure system.

AUTOMAIN (Augmented Usage of Track by Optimization of Maintenance, Allocation and Inspection of railway Networks).

This project ended in January 2014. The major goal of the AUTOMAIN project was to optimize and automate maintenance and inspection where possible, and also to introduce

new planning and scheduling tools and methods. AUTOMAIN project aimed at reducing the possession time to around 40%. To achieve this goal, AUTOMAIN project advances in railway maintenance through five main areas: new methodology by applying best practice from other industries, higher speed infrastructure inspection methods, higher speed track maintenance methods, modular infrastructure inspection methods and improvement of the automatic maintenance scheduling and planning systems, so as to reduce the disruption to scheduled traffic and to increase useful capacity.

OPTIRAIL (Development of a smart framework based on knowledge to support infrastructure maintenance decisions in railway corridors)

This project launched in October 2012 and develops new complementary tools based on Computational Intelligence techniques, such as fuzzy logic, for managing information and knowledge, modeling infrastructure behaviors and decision making regarding maintenance tasks. This maintenance decisions takes into account performance, regulations, standards and other aspects from several networks that allow multi-objective optimized decisions for maintenance management along rail corridors.

4.5 Conclusion

The purpose of diagnostic systems is usually twofold. The first, immediate reason is obviously the detection of the irregularities that could endanger safety and reliability of the railway traffic. However, in addition to this, if a monitoring technique is continuous and fast enough to allow consecutive monitoring runs to be performed in regular time intervals, an extremely important temporal aspect is obtained which is of essential importance for a successful condition-based asset management.

When a measuring system is commissioned and starts producing data according to the frequency of inspection, the entire history of data becomes available and this is of essential importance for a successful condition-based asset management. The analysis of measurements and defects over time can provide detailed insight into the infrastructure assets' behavior over time, enabling condition-forecasting and predictive maintenances.

The concepts presented previously, enhanced on-board devices monitoring the status of vehicles, advanced recording cars and regular trains equipped with monitoring devices could change the way data are collected and used for maintenance activities. Considering the increased demand for higher availability, safety and the reduction of the maintenance budgets, benefits expected include:

- More efficient and effective monitoring of the railway infrastructure and rolling stock
- Transition from corrective maintenance to enhanced condition-based and predictive maintenance
- Better control, planning and balancing of maintenance and renewal activities

All the above benefits will directly lead towards significantly better control of the railway infrastructure condition and behavior at any given point in time, together with the rolling stock health, thus enhancing traffic safety and line availability at a minimum maintenance cost.

5 Boundary conditions – required framework

This chapter describes features needed for exchanging data among parties and cross borders.

5.1 Reliable allocation of measurement data

To measure and to assess values is one part of the task. In order to use them for data exchange with other parties (e.g. cross border data exchange, data determined by IM but used by ECM, etc.) additional information has to be mapped. Those pre-requisites are described in the following.

5.1.1 Use case: on-board devices

Running vehicles equipped with measurement devices are collecting data during their operation. Independently, if assessment values are generated online, offline or only in the case of exceeding thresholds, a correlation is needed between these assessment values and their place of measurement in the infrastructure.

Using GPS data might be one possible solution. Although GPS localization is widely used today there are still some limiting factors when using it in a railway environment. It might happen, that the amount of satellite reference signals is not sufficient enough during the train passage due to mountains, canyons, tunnels, etc. It might provide sufficient accuracy to localize the track section and its kilometer but not on which track number the train is operating (in multiple track situations). This would require a representation of the railway network as a graph to know also about the topology of lines and stations. Moreover a time stamp has to be taken into account as the network is changing over time. On the one hand new lines are opened but on the other hand also the existing infrastructure is sometimes modified, e.g. number of station tracks, switches.

Dedicated recording cars attempt to overcome these challenges by utilizing data from many different inspection systems, combining GPS, odometers, switching core identification and deflection to obtain a reasonable guess on positioning in the graph. If the graph is wrong, e.g. due to recent changes or data quality in the asset management systems, the problem becomes unsolvable for some segments and a break in the chain of measurement data occurs. This may result in valuable measurement data being discarded. The problem is compounded by the fact that inspections are frequently scheduled after major inspections, i.e. recording cars will encounter these situations much more frequently than regular scheduled trains.

Onboard systems in regular scheduled trains are simpler in nature and cannot usually combine output from many different sensors, but must rely on fewer. This may be compensated in part by the fact that these trains usually run on scheduled courses with well-known trajectories, so that only deviations from the norm need to be recognized. In practice, the problems will likely be limited to parallel sections of tracks and to the precise location in major railway stations and yards.

Additional information could be provided from the infrastructure and its components. Those components could be bridges, tunnels, switches, isolation joints, signaling equipment, track alignment components, etc. As an example: accelerometers obtain characteristic signals, when the train passes e.g. switches or insulation joints. A consistent knowledge about those components and their exact localization in the infrastructure can be used for adjusting this referencing task.

More precise triggering points are given by e.g. balises and RFID-tags mounted in the infrastructure. As an example, DB started installing passive RFID-tags in switches. Recording cars are using the RFID information for localization issues as well as for connecting assessment values directly to the correct infrastructure component. Here the specifications of the GS1 group *RFID in Rail* are used. Discussions are ongoing, if also other infrastructure elements will be equipped in the future.

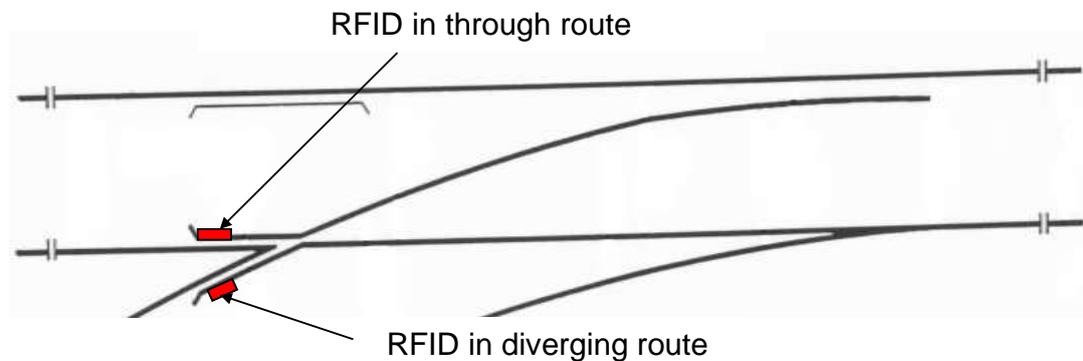


Figure 8: Example of DB: Installation of RFID in switches for localization issues

5.1.2 Use case: WTMS

Using data from WTMS for further actions requires a correct allocation of measurement data to the vehicle ID, the axle number, the side (left/ right) and perhaps even specified to further components (e.g. springs). Even if many IM enforce the RU to report vehicle lists, the question is, if this list is consistent with the in situ situation. Even if the list is (correctly) provided, no information about the travel direction of the individual vehicles might be available, so the results from WTMS can't be connected to individual axles and the side of the wheel sets.

Therefore a certain vehicle identification system is needed. Today's approaches are using e.g. optical systems, like video systems combined with pattern recognition, or vehicles equipped with RFID-tags. In the past, only few RFID systems, which could detect vehicles at track speed, were available. Development in the logistic sectors led to a bigger variety and a dramatic price cut. Unfortunately there was no final decision in the railway sector about harmonized specifications. Recently started activities from the group *RFID in Rail* initiated by

GS 1 and some railway members try to fill this gap. One technology developed by TRV and some partners fulfilling the *RFID in Rail*-specifications was tested within WP 6, see D 6.3.

Mounting two RFID-tags one on each side of the vehicle allows to determine the ID and travelling direction of the vehicle. Therefore assessment values from WTMS can be correctly connected to individual components of an individual vehicle. But therefore, the VO or ECM has to specify relevant components of the vehicle in their data base. If the different readings over time are stored in this way, the history of actions for individual components can be followed easily. In this case the benefits of using WTMS-data for maintenance purposes can be achieved.

In the past a lot of national driven RFID solution were tested and/or used in practice. Even if it is out of the scope of D-Rail (derailment prevention of cargo vehicles), the following example of DB shows the complete chain from detection until action, see Figure 9. The complete high speed fleet and most of the passenger vehicles of DB are equipped with RFID. The individual components of the vehicles are described by the vehicle owner in a configuration management system. Data from WTMS are sent via an exchange protocol to the data gateway of the vehicle owner. From there the data are integrated into the wheelset-database. Maintenance actions are taken under the responsibility of the vehicle owner by observing the development of assessment criteria (here: number of exceeding of dynamic value of wheel force depending on the number of observations).

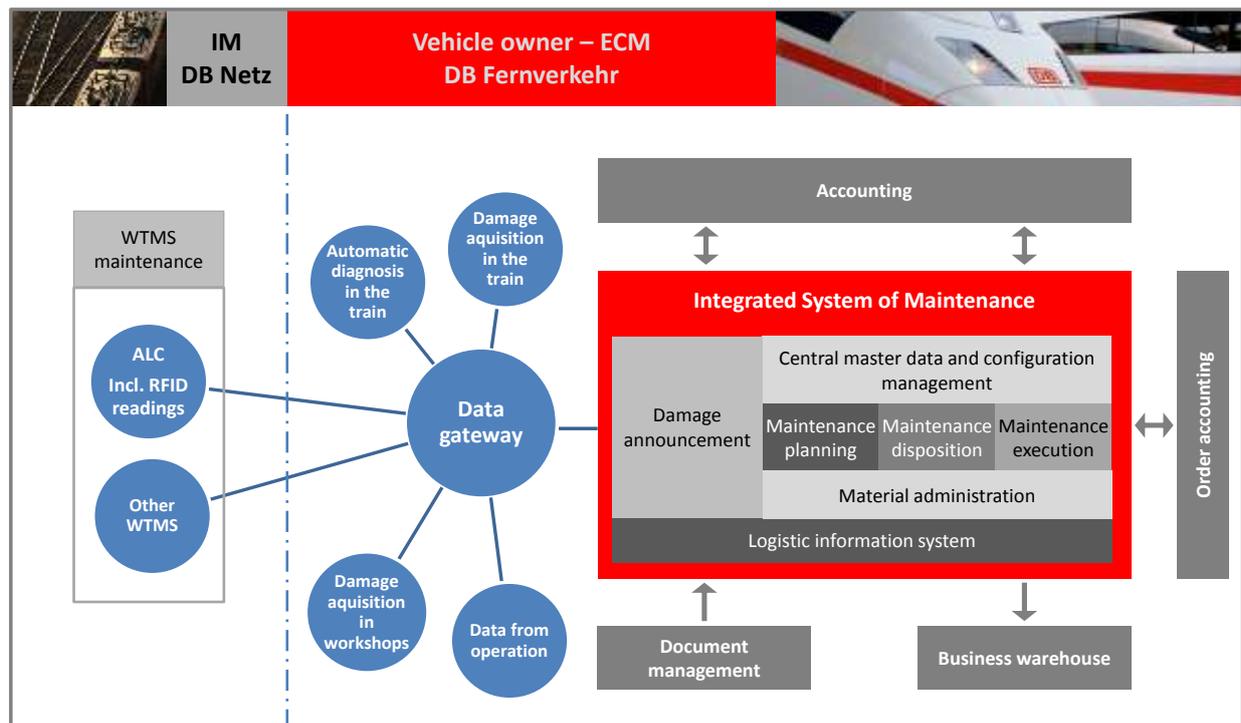


Figure 9: Example from DB about integrated vehicle maintenance. Data from ALC and RFID-readings acquired by IM are transferred to ECM, where they are connected with master data and vehicle configuration in order to plan maintenance actions for individual vehicle components, see [25].

5.2 Intervention concepts

5.2.1 General

Risk-related decision-making is a well-regulated area in railway operations. It deals with taking decisions in a way to shield those taking the decision from legal consequences if an accident occurs. This requires the decision to be taken according to well-documented processes that are consistent with good practices in the industry, such as documented in frameworks such as CSM-RA. For the foreseeable future, risk-related decision making will thus be on the level of every single (national) actor in the railway industry. Mandatory decisions by a higher supra-national authority are only possible if this authority shields the individuals implementing the decisions from legal consequences (while following their decisions) in their respective countries.

A second aspect is the national financing of investments. Risk-related decision-making is intrinsically linked to available funding, which is always limited. The most economical use in the case of safety is also the most ethical one: getting the highest safety benefit per amount of money spent. Since trains are 50-100 times safer than road traffic, this is an investment into the safest transport system.

The boundary conditions differ from country to country: meteorology, topography, traffic composition, track utilization are all factors in this respect. This leads in practice to different intervention thresholds per country. These aspects can only be harmonized if meteorology, topography and all other aspects are also harmonized. This leads in practice to a risk-oriented approach, where every IM must take decisions on intervention thresholds based on his specific risk landscape. The only theoretical alternative is to standardize on the strictest

limit across countries, since otherwise an IM could become liable due to accidents caused by the looser standards. This would increase prices of the railway industry across the board and reduce competitiveness against road transport, which would result in a sub-optimized safety since road transports are 50-100 times less safe. Further train disruptions will lead also to increased road traffic and more accidents and fatalities.

5.2.2 WTMS

When a WTMS detects a condition on a vehicle, several options are theoretically possible:

- immediate stop
- immediate stop at next station/side track
- stop at next maintenance site or border station
- continue under observation
- mark for later maintenance
- no actions

Which option does apply in each case depends on a series of factors:

- severity of the alarm (hot versus warm axle box)
- applied thresholds and rule set/operations manual
- intervention options (availability of side track)
- type and configuration of the WTMS
- remaining distance to travel
- decision-making process (simple, algorithmic, human)

Several possible concepts for intervention can thus be derived:

1. Immediate train stoppage, then decision taking
2. Case-by-case decision-making e.g. by operations centre, intervention centre, algorithms
3. No immediate decision making (only maintenance)

Each intervention concept has requirements and consequences.

Concept (1): Immediate train stoppage

This concept is the easiest to implement and defaults to a safe behaviour, i.e. stopping of a potentially unsafe vehicle. The main drawback is the false positives problem. Not every train stopped presents a problem. Since every immediate stoppage, be it a false or true positive, blocks not only the train, but also the track, operational pressure will immediately ensue to restore at least the track to normal operations. The decision-making will thus occur under time pressure, and it cannot be guaranteed that a train with a serious defect will not be allowed to continue if the problem is not readily apparent. The key question is the way of decision-making. The only person immediately on site is usually the train driver that would need to take this decision, which may not be in the infrastructure managers interests. If an inspector needs to be dispatched on site, this process can be prolonged dramatically. If the

equipment is networked and alerts are processed in a central facility, more efficient and safe decision-making could be implemented there.

Concept (2): Case-by-case decision-making

This case, poses more requirements on the WTMS side. The usual implementation would be in a networked environment with a central decision-making facility (either by human or by algorithmic decision making processes), but decentral algorithmics are theoretically possible. The first possible problem is that a condition may be detected, but no action taken, since the system does not default to a safe action. Cross checks between individuals, clear business rules and logging are actions to remedy this problem.

The main difficulty with case-by-case decisions lies in inconsistencies between individual cases, or ensuring *unité de doctrine* between individual decisions. This should be addressed with a set of business rules that are submitted for authorization to the relevant authorities. These rule sets will describe in the minimum possible detected conditions and the action(s) to be taken. D5.1 contains an example of such a regulation as applied in Switzerland.

The key benefits are the reduction of obvious false positives, e.g. due to faulty sensors, and the ability of tailoring actions to the situation at hand. A train that is only kilometres from a repair yard could be allowed to continue to that destination without stopping under surveillance, while a train with a marginally unsafe condition could be stopped before entering a long tunnel.

Concept (3): No immediate decision making

This concept proposes no immediate decision making. This allows targeted maintenance optimization, but the safety benefits are much lower. Trains in an unsafe or dangerous state will be allowed to run and potentially derail, causing damage to infrastructure and vehicles. Despite its apparent simplicity, implementing such a system is not trivial, since vehicle identification is a must to target maintenance activities on a given vehicle. Axle counters and databases may help in many cases, but data quality in these databases is not optimal, especially where those vehicles are concerned that are also badly maintained.

If traffic disruption is not too much, a second opportunity is possible: In some cases a speed reduction will help, not to exceed intervention thresholds.

5.2.3 On-board

In the area of onboard monitoring, two possible targets are to be discussed: (a) devices measuring the state of the vehicle and (b) devices measuring the infrastructure.

Measuring the state of vehicles

The options for information on the state of the vehicle are in principle the same as discussed in chapter 5.2.2, but the implementation is more difficult. An immediate train stoppage is simple by communicating directly to the driver or by acting on the train brake. Most other options will present a dilemma to the driver: He is informed that one vehicle is in a state that required him to stop at the next possible site due to safety reasons. Looking from the perspective of an IM, possibly the train stands at an inconvenient site and blocks the route. Communications with the IM will be required to find a proper intervention site, but the time is not there, if a derailment has to be prevented. The train driver's reaction has to be ensured, although the affected vehicle belongs not the RU, or the commercial pressure

regarding the other vehicles is high, or there has been a few false positive alarms. Transmitting maintenance advice from a RU to an ECM is another potential pitfall. The only problem that is solved convincingly is the identification of the vehicle.

Measuring the state of infrastructure

Regarding information on the infrastructure, a set of possible intervention applies:

- immediate measures (lower track speed, track closure, ...)
- reactive maintenance
- planned maintenance
- no actions

The point should be stressed that information must flow to the IM as ECM for the infrastructure. This is trivial when dedicated recording cars are concerned, but more difficult as soon as equipment is placed on regular scheduled trains belonging to a RU. This may even be compounded by cross-border operations. Another relevant problem described in chapter 5.1.1 is the localization of the recorded data on the rail network.

Reactive maintenance after passing a threshold is in principle straight-forward, although maintenance may require extensive lead times that may require track closures or speed reductions. Detecting the condition is mainly dependent on three factors:

- detection occurrence frequency
- defect detection threshold (e.g. minimal size of a defect required for a detector to identify the defect)
- detect progression speed

From these three parameters a required inspection frequency may be derived as well as a set of thresholds and limit values. This has direct consequences on the number of required recording cars. It is in this area that onboard devices on scheduled trains may prove extremely useful as they could provide the intermediate points between scheduled inspection campaigns by dedicated recording cars (even if they are not in the same accuracy class).

Predictive or planned maintenance requires additionally trending of individual recording over time. More extensive knowledge on damage types and patterns is required to formulate algorithms for prediction.

Finally, onboard devices on scheduled trains could also give information on dynamics, e.g. conditions that only become apparent with certain types of vehicle/track combinations. Thus, the type of vehicle on which an onboard system is installed should always be recorded. As mentioned in D7.3, some occurrences of derailments were observed, where both vehicle and track were in proper condition (albeit marginally). Onboard devices could offer insights into this behaviour.

5.2.4 Legal framework

Legal documents regarding data exchange

This chapter gives an overview about the EU documents, which are relevant for data transfer and exchange and for the monitoring concepts developed within the D-Rail project. For further detailed information please refer to the relevant documents.

The regulation No 62/2006 of 23 December 2005 concerning the technical specification for interoperability relating to telematic applications for freight subsystem of the trans-European conventional rail system (further TAF TSI) belongs to the most relevant documents dealing with train monitoring. The scope of the TAF TSI covers among others "applications for freight services, including information systems (real-time monitoring of freight and trains)". Beside the train monitoring also wagons are included in the TAF TSI. In the Annex A of the TAF TSI the following specifications are given (see Table 4), which are also mandatory for data exchange purposes within the D-Rail project.

Table 4: List of mandatory specifications included in TAF TSI

Index	Reference	Document name	Version
1	AEIF_TAF_MesData_V11_041021.doc	CR telematic applications for freight: data definitions and messages	1.1
2	AEIF_TAF_DbsData_V10_040322.doc	CR telematic applications for freight: the infrastructure data and the rolling stock data	1.0
3	AEIF_TAF_ConData_V10_040622.doc	CR telematic applications for freight: the consignment note data and description	1.0
4	AEIF_TAF_Patdata_V10_040622.doc	CR telematic applications for freight: the train path data and description	1.0
5	AEIF_TAF_FigSeq_V10_040622.doc	CR telematic applications for freight: figures and sequence diagrams of the TAF TSI messages	1.0
6	AEIF_TAF_CofMgt_V10_041012.doc Pending	TAF configuration management, concept and generic requirements	1.0

Two Regulations regarding the Common Safety Methods for supervision and monitoring have been issued by the European Commission on 16 November 2012 and shall be applied from 7th June 2013 and onwards [11][21].

The Regulation (EU) No 1078/2012 is on "a common safety method for monitoring to be applied by railway undertakings, infrastructure managers after receiving a safety certificate or safety authorization and by entities in charge of maintenance" while Regulation (EU) No 1077/2012 deals with "a common safety method for supervision by national safety authorities after issuing a safety certificate or safety authorization." Both Regulations can be considered complementary and are hence discussed here, however the CSM for monitoring seems exclusively relevant to D-Rail and Train Monitoring Systems.

Regulation No 1077/2012 focuses on the supervision by the NSAs of the RUs and IMs to obtain assurance, from the National Safety Authorities' perspective, about RUs/IMs effectiveness in managing a safe operation and maintenance of the railway system through implementation and compliance with their respective Safety Management System. This supervision is based on a supervision plan, which shall collect data of safety-relevant indicators to reveal safety performance of the railway system as a whole. This supervision may be done on an annual base or whatever frequency is considered appropriate to achieve the defined supervision strategy. This supervision plan should identify areas for targeted supervision activity on the various sector organizations. The data/information can come from a variety of sources, e.g., NSA's own experience, accident reports/recommendations, Annual Reports, complaints from members of the public etc. Possible techniques for conduction such supervision are interviews with people of RUs and IMs, reviewing documents and records, audits, on-site inspections or train rides on a random base. So from a perspective of D-Rail and Train Monitoring Systems this Commission Regulation is considered not primarily relevant since it does not deal with technical sub-systems and their performance in details. There are no direct technical requirements regarding TMS associated to this Regulation.

A more specific Regulation is 1078/2012 which is even named "Monitoring", however monitoring is not used exactly in the same sense as in D-Rail. Monitoring according 1078/2012 "means the arrangements put in place by railway undertakings, infrastructure managers or entities in charge of maintenance to check their (safety) management system is correctly applied and effective." Hence a very thorough analysis regarding the relevance of this regulation for D-Rail is required.

The Regulation on monitoring is dedicated to defining the internal activities to be undertaken by the RUs and IMs themselves on whom, as duty holders, the responsibility for the safe operation of the railways rests.

The primary goal of this regulation is to "... enable to identify as early as possible non-compliance in applying a management system in ways that may result in accidents, incidents, near-misses or other dangerous occurrences. To manage these forms of non-compliance during operation and maintenance activities a harmonized process for monitoring activities should be used" [11]. In order to effectively monitor the management system a strategy, priorities and plan(s) for monitoring shall be set up. Adequate information shall be collected and analyzed in order to assess whether the management system is effective. In case unacceptable non-compliance with requirements is found an action plan shall be defined and implemented. Finally, the effectiveness of action plan measures is to be evaluated. In summary an adequate process shall be defined to detect deficiencies in technical and/or organizational processes which can lead to an unsafe situation.

This regulation does not put any requirements on a specific technical system or sub-system but helps establish a process to monitor whether the safety management system is applied in an adequate way. If found a safety management system (SMS) or parts therefore is not appropriate to discover safety-relevant issues remedial action shall be taken by modifying the SMS.

Article 4 of Regulation 1078/2012 seems relevant from a technical point of view or may at least address the operation and maintenance of Train Monitoring Systems. This article is dedicated to the "Exchange of information between the involved actors". According to this article: "Railway undertakings, infrastructure managers and entities in charge of

maintenance, including their contractors, shall ensure through contractual arrangements that any relevant safety-related information resulting from applying the monitoring process ... is exchanged between them, to enable the other party to take any necessary corrective actions ... “

Clause 2 of this Article puts even more stringent requirements on data exchange if safety risks are identified: “If, through the application of the monitoring process, railway undertakings, infrastructure managers and entities in charge of maintenance identify any relevant safety risk as regards defects and construction non-conformities or malfunctions of technical equipment ... they shall report those risks to the other parties involved to enable them to take any necessary corrective actions ...”

The primary rationale for this required data exchange is the fact, that the stakeholders responsible for a defective component may be different from the stakeholder who detected the faulty component.

The ERA guide on the monitoring CSM clearly explains: “If the actor who detects the problem cannot take any corrective action, because the application of the related risk control measure is up to another railway actor, the CSM for monitoring requires this actor to inform the risk owner (as it should be defined in the contractual arrangements). The risk owner is then able to undertake or to manage the implementation of the necessary corrective actions.”

Since the Train Monitoring Systems are primarily installed to detect defects or non-compliant conditions of track and rolling stock (the hot axle of a specific freight wagon), the information which is gathered from such systems must be considered safety-relevant and should hence be exchanged with other effected parties. Practically, the basic idea is to share safety-relevant information if such information is available.

Apart from the Regulation there is a more detailed “Guide for the application of the Commission Regulation (EU) N° 1078/2012 on the CSM for monitoring” which is issued by ERA and provides detailed examples [20].

The next important document is the regulation No 1078/2012 of 16 November 2012 on a common safety method for monitoring to be applied by railway undertakings, infrastructure managers after receiving a safety certificate or safety authorisation and by entities in charge of maintenance (further CSM for monitoring). As described in the Article 1 of the CSM for monitoring "this Regulation establishes a common safety method (CSM) for monitoring, enabling the effective management of safety in the railway system during its operation and maintenance activities and, where appropriate, improving the management system". The mentioned wording "monitoring" does not mean monitoring in a technical sense (as used within the D-Rail project) but in the sense of audit processes in safety related applications etc. In this regulation also the exchange of safety related information between stakeholders as RU, IM, ECM and others is defined. This is important for instance in case of transfer of safety relevant detection information, produced by wayside or on board monitoring devices. Beside the basic document "CSM for monitoring" other relevant documents, e.g. "ERA Recommendation on CSMs for monitoring and supervision" or "Guide on CSM for monitoring" shall be considered too.

The next relevant document is the description of the HERMES system in the leaflet UIC 917-5. This leaflet describes the data transmission rules, which shall be used as carrier for

international IT applications in railway operation. This data transmission system is subsequently referred as the "HERMES system". In order to make it interoperable, it is necessary to make obligatory specifications of the connection characteristics for network access and security of protocols and functions, of regulations at user level, of message structure etc. These regulations must strictly be adhered to by all users of the HERMES system. The HERMES system is used among others in the Raildata application ISR (Internal Service Reliability), which may be exemplarily recommended for data exchange between the railway stakeholders also for monitoring purposes.

For completeness the leaflets UIC 419-2 (Systematic numbering of international freight trains), UIC 404-2 (Compendium of the data to be exchanged between Railway Undertakings for the purpose of conveying freight traffic) and UIC 407-1 (Standardised data exchange for the execution of train operations, including international punctuality analysis) should be mentioned.

Legal documents regarding the implementation of Train Monitoring Systems

In general, there are no specific legal documents, that refer to the implementation (technical standards similar to TSI) and operation (rules for data to be collected, exchange rules etc.) of wayside or on-board train monitoring systems. Hence, this chapter analyses related legal documents which are assumed relevant. These are basically the TSI, general legal framework for railways (national law) and specific national documents concerning the implementation of WTMS, if any.

From the D-Rail perspective the regulation No 1236/2013 of 2 December 2013 concerning the technical specification for interoperability relating to the subsystem 'rolling stock - freight wagons' of the rail system in the European Union and amending Regulation No 321/2013 (further TSI freight) is relevant regarding the technical parameters of freight wagons, running safety, maintenance rules, interoperability etc. Unfortunately, there are constraints in this TSI freight for implementation and operation of on board wayside monitoring devices such as recommendations for installation, operation or definition of data, which shall be collected.

For completeness the national regulation documents are also mentioned in this chapter. They are different in every country, but the general structure may be the same or very similar. From the D-Rail perspective, the national definition of interfaces and responsibilities between railway undertakings, vehicle owners, infrastructure manager etc. are of interest. In Europe, the content of the national documents may be similar and e.g. consists of these aspects:

- definition of stakeholders such a RU, IM and Notified Bodies,
- technical requirements (installation and maintenance) for infrastructure and rolling stock (beside the relevant TSIs),
- qualification of stakeholder (health, financial, professional),
- infrastructure access conditions and pricing

They are defined in national law, rules, leaflets and other national documents, specific to every European country (and compliant with the EU railway regulations).

All the above requirements may be relevant and shall be considered when implementing monitoring systems to prevent derailments. The most important topics may be the cost sharing for installation, maintenance, operation, type approval and homologation process of

monitoring devices, responsibilities between stakeholders and technical requirements and their approval by notified bodies. After the implementation the safety responsibilities shall be clarified. Since these general legal aspects are different in every European country and it is out of scope of the D-Rail project to analyze and compare the legal state across the Europe, some examples are demonstrated in chapter 4 of D5.1.

The last group of legal documents are specific national documents regarding the WTMS. For example the German leaflet 501 or the Swiss procedure I-50099 may be mentioned.

The German leaflet 501 "Merkblatt 501 Sichtbarkeit der Fahrzeugradsatzlager für ortsfeste Heißläuferortungsanlagen (HOA)" (in English: Visibility of the vehicle axle boxes for wayside hot box detectors) deals with the rules for the visibility of the axle boxes for the fixed wayside hot axle box detectors. This leaflet covers rolling stock as well as wayside infrastructure and defines conditions for the implementation of hot axle box detection systems in Germany.

The Swiss procedure "I-50099 Handbuch Zugkontrollenrichtungen" [17] (in English: Handbook wayside train monitoring systems) deals with the installation of different train monitoring systems and defines alarm classes, alarm maintenance, monitoring device maintenance, operational procedures etc.

These handbooks may be used as examples for IM in other countries, where similar leaflets do not yet exist. A future extension and unification of such a procedures and leaflets is desirable and may lead towards an appropriate TSI. This TSI may be a part of the TAF TSI and / or Rolling stock TSI (freight).

Summary

The above analyzed legal aspect for installation and operation of wayside or on board train monitoring systems may give these conclusions:

- Sufficient legal base for data exchange between stakeholders exists, it is comprised by the TAF TSI, CSM for monitoring and the definition of the Hermes system, which is today successfully used in different applications (e.g. Raildata "Orfeus", "ISR" or "UseIT")
- Apart from partially separate national rules, a unique basis for the implementation and operation of Train Monitoring Systems does not exist. There is a need for creation of common recommendations, which could lead in the future to a specific TSI. This TSI may be a part of the TAF TSI and / or of the Rolling stock TSI (freight wagons).

5.2.5 Roles and responsibilities

The roles and responsibilities are basically described and discussed in the Chapter 4 "Consequence of legal aspects" of D 5.1. This chapter covers the following complementary topics:

- the actual trend of supposed risk transfer from the RU to the IM
- the question of responsibilities by the definition of density of WTMS and setting of threshold values
- availability of WTMS

- demonstration of a practical approach for implementation from Switzerland.

The main conclusion of this chapter is the necessity of appropriate national laws or regulations, which would define the interfaces between (national) IM and RU (and/or ECMs). These aspects are mainly discussed in the following text.

To analyse the data exchange and responsibilities across the borders, in the first step these simplifications and presumptions are made:

- The stakeholders are reduced to RU and IM. This presumption may be justified by the fact, that the RU is responsible for the railway operation and only the RU is the direct partner for the IM. The relations between RU and ECM or vehicle owner (depending on the concrete business case) are not important from the point of view of this discussion.
- The existence of WTMS (wayside train monitoring systems) and / or OMD (on-board train monitoring systems) is assumed, without detailed specification of the used technology, without the knowledge of their density and threshold values (e.g. defined at the national level).
- The subject responsible for data collection is assumed to be IM or RU, indifferent of the technique WTMS / OMD¹ (defined by the national system).
- Only one cross border is analyzed.
- Only the safety relevant data exchange is considered (in case of alarm, if train shall be stopped), the exchange of maintenance data is not analyzed in this step, but may have similar consequences.

To demonstrate the complexity of the TMS related cross border data exchange (in this example over one border), some examples for combinations of stakeholders are demonstrated in the Tables below.

Table 5: Case 1, IM in both countries provides the data collection

Country A: TMS device / data owner (note)	Country B: TMS device / data owner (note)
WTMS / IM	WTMS / IM
OMD / not applied	OMD / not applied

Table 6: Case 2, RU(s) in both countries provides the data collection

Country A: TMS device / data owner (note)	Country B: TMS device / data owner (note)
WTMS / not applied	WTMS / not applied
OMD / RU(s)	OMD / RU(s)

Table 7: Case 3, RU(s) in one country and IM in other country provides the data collection

¹ In some cases also the RU may be responsible for wayside device, e.g. the installation of ATO balises by the RU in the Czech Republic.

Country A: TMS device / data owner (note)	Country B: TMS device / data owner (note)
WTMS / IM	WTMS / not applied
OMD / not applied	OMD / RU(s)

Table 8: Case 4, RU(s) and IM in both countries provides the data collection

Country A: TMS device / data owner (note)	Country B: TMS device / data owner (note)
WTMS / IM	WTMS / RU(s) (e.g. installation of WTMS in RU's responsibility by missing IM interest)
OMD / RU(s) (e.g. additional proper OMD installed by RU)	OMD / IM (e.g. special monitoring vehicle for infrastructure)

From the Tables above it is evident, that in a worst case, data transfer between all stakeholders must be performed (see Case 4). Also in Case 1 or in Case 2 at least at the next border the necessity of data transfer between different stakeholders (similar to Case 3) may appear. With a new technical solution, the data exchange between different stakeholders would be theoretically possible, but would increase the organizational and operational demand (communication between all RU and IM). Based on our experience, the communication between RU only or IM only may be much easier and may be supported by already existing collaboration. For these reasons, the EU-wide definition of unique stakeholders responsible for exchange of TMS data may be preferable. This may lay in the competence of IM only or RU(s) only and may be mandatory and unique for all European countries. The national data transfer to this stakeholder may remain in the competence of every country and may be organized in a different way country by country (similar to other national values).

Demonstration of cross border data exchange

We suppose for example RUs responsibility for EU wide cross border data exchange of Train Monitoring Systems data. The above mentioned tables would change accordingly (see below).

Table 9: Case 1, IM in both countries provides the data collection

Country A: TMS device / data owner (note)	Country B: TMS device / data owner (note)
WTMS / IM -> data transfer to RU (if alarm)	WTMS / IM-> data transfer to RU (if alarm)
OMD / not applied	OMD / not applied

Table 10: Case 2, RU in both countries provides the data collection

Country A: TMS device / data owner (note)	Country B: TMS device / data owner (note)
WTMS / not applied	WTMS / not applied
OMD / RU(s)	OMD / RU(s)

Table 11: Case 3, RU in one country and IM in other country provides the data collection

Country A: TMS device / data owner (note)	Country B: TMS device / data owner (note)
WTMS / IM-> data transfer to RU (if alarm)	WTMS / not applied
OMD / not applied	OMD / RU(s)

Table 12: Case 4, RU and IM in both countries provides the data collection

Country A: TMS device / data owner (note)	Country B: TMS device / data owner (note)
WTMS / IM-> data transfer to RU (if alarm)	WTMS / RU(s) (e.g. installation of WTMS in RU's responsibility by missing IM interest)
OMD / RU(s) (e.g. additional proper OMD installed by RU)	OMD / IM (e.g. special monitoring vehicle for infrastructure) -> data transfer to RU (if alarm)

For the data transfer for example the established Raildata "International Service Reliability (ISR)" tool may be implemented. RAILDATA is an international organization of European Cargo Railway Undertakings and established as special group of the UIC. The objective of RAILDATA is "to develop, implement and run IT services, as cost-effectively as possible and in total compliance with the rules governing competition, to improve data exchanges and thereby promote rail freight traffic development between the Railway Undertakings of Europe". The ISR is a common tool of RAILDATA railway undertakings (founded by former "national railways" but open for all RU) for concentration and exchange of information about movements of freight wagons in international traffic through a central platform (installed in Aubervilliers and Paris in France). It makes possible to track both loaded and empty freight wagons and consignments across significant part of Europe. Beside others the ISR monitors wagons during train run and enable exchange of relevant wagon events. Already defined wagon events are e.g. "WagonDamaged - technical problem occurred on the wagon, is out of service" or "WagonRepaired - wagon is restored, it can go again". The basis for the messages is the XML, also other events, e.g. TMS alert, may be easily implemented. The application covers a significant part of Europe (see Figure 10) and is interoperable with other RAILDATA tools (Orfeus, UseIT). For further information please refer to: <http://www.raildata.coop>.

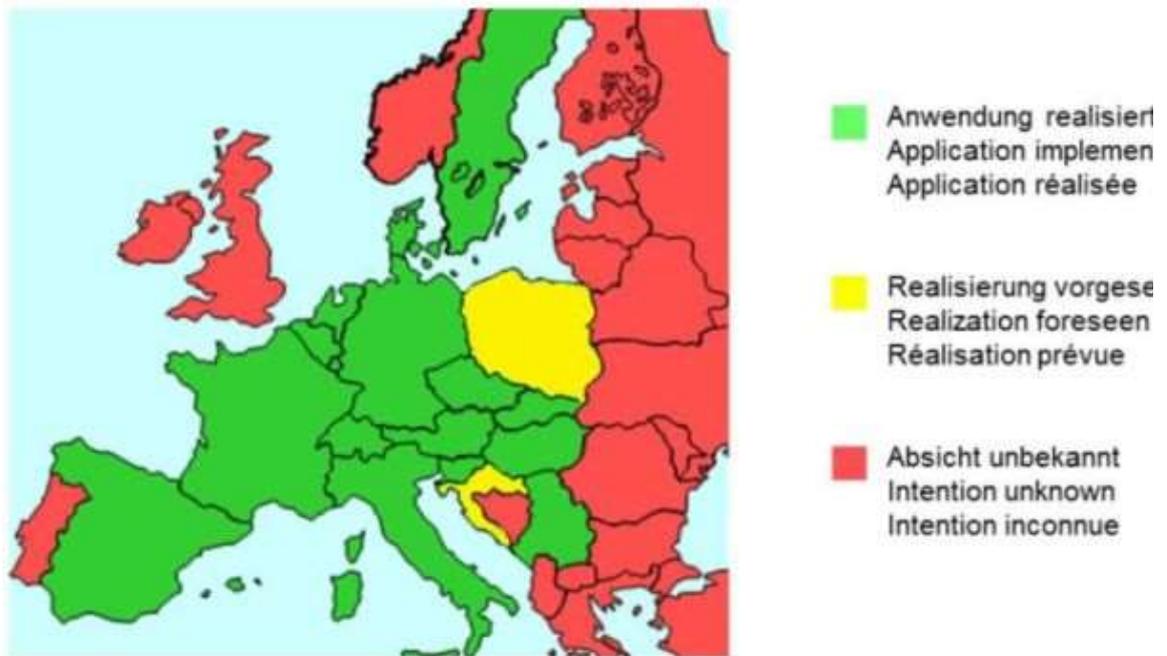


Figure 10: International Service Reliability (ISR) coverage in Europe in 2013

Summary

The basic topics related to the general problems with responsibilities by the implementation of Train Monitoring Systems are described in the chapter 4 of D 5.1. For this reason mainly the cross border related aspects with data exchange are analyzed in D 5.2. Under the presumption that the national applications of Train Monitoring Systems would not be regulated, different stakeholders for data exchange in different countries may appear. For this reason the prior aim of the further TMS development shall be the European wide assessment of cross border responsibilities for data exchange to infrastructure managers only or to railway undertakings only. This responsibility may be more crucial than for example IT solutions for cross border data exchange. Examples of European-wide applications, such as the HERMES system are supported by a sufficient legal base. One suitable solution is presented as an example: the authorization of RUs with the EU wide cross border data exchange and the usage of the existing Raildata ISR tool for data exchange.

5.2.6 Background and experiences from the “e-maintenance” pilot project

Based on the report from WP 2, and the prediction of a significant increase of freight transports in the railway sector until 2050, some IM are planning to upgrade the WTMS concept and the approach for actions after exceeding alarm limits.

As a result of a pilot project the IM and RU have demonstrated that preventive maintenance based on data from WTMS, and especially WILD, reduces the number of traffic disturbances caused by exceedance of high level alarms described in table 5 in chapter 2.2.4 “Activities in Sweden” of D 5.1. Preventive maintenance also reduces the deterioration of both the track and the vehicles and reduces costs both for the IM and RU. It also reduces the risk of derailment (loading process, better wheel quality) and it supports maintaining the existing safety standard by the help of automatic generated data.

Project organization

Partners in the pilot project were Trafikverket (IM), Green Cargo (RU), AAE (VO), SSAB (Steel company/ end customer) and EuroMaint (ECM). The project started 2013-06-01 and ended 2014-05-31.

Combination of WTMS and RFID

Green Cargo transports steel slabs from the steel plant in Luleå for further processing in the rolling mill in Borlänge. All wagons in the fleet are tagged with RFID tags and it's possible to combine data from the wheel impact load detectors with vehicle identification. After integrating the combined data in the database of TRV, RU and ECM has access to it as well, so it enables them to perform queries to follow the status of the fleet, see the figure below.

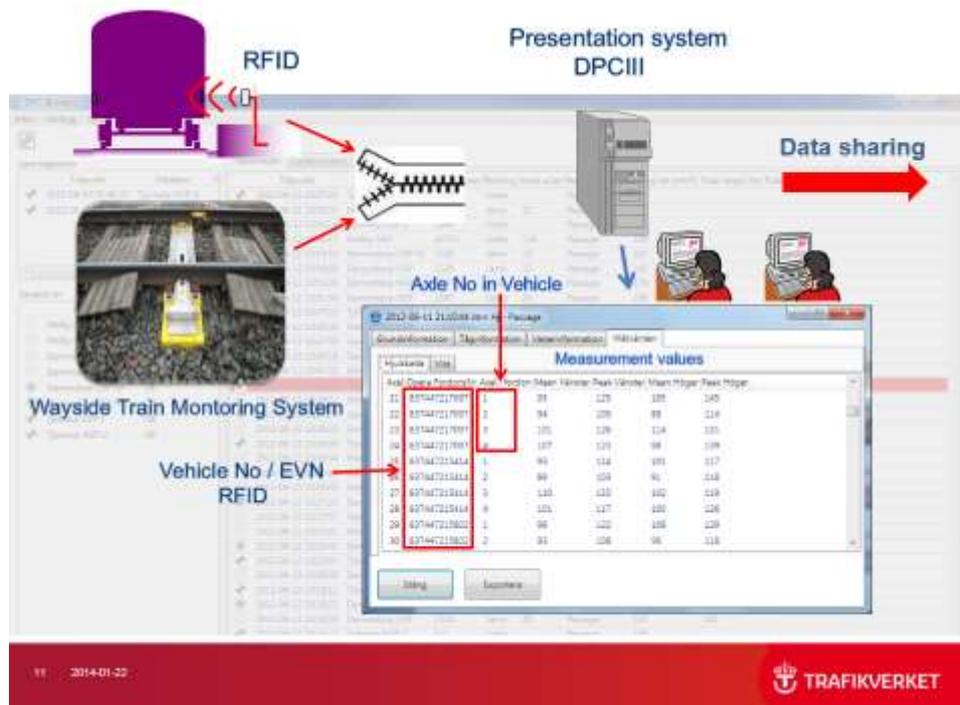


Figure 11: Detector data in combination with vehicle ID (RFID) as input for e-maintenance

The ALC that were used in the project were installed at Sunderby Sjukhus, Degerbäcken, Jörn and Bodsjön. There are RFID readers installed at each detector site. The location of the ALC and the RFID readers can be studied in Figure 12 below.

Pilot project 2013/2014: Location of wheel impact load detectors and alarm limits



Figure 12: Location of ALC and alarm limits used in pilot project

Criteria for vehicle maintenance in the pilot project

The partners of the project agreed to act on early warnings from the ALC. In this case the warning alarm level was between 300-320 kN (Peak). The vehicles with wheel defects exceeding that level were labeled in the database, so that the ECM could easily observe which vehicle that might have a defect. In parallel they were allowed for transport to the workshop after arrival and unloading at the final destination. That deviate from the normal process described in table 5 in chapter 2.2.4 “Activities in Sweden” of D 5.1. The work shop and the RU got the information in an early state, so that they were able to plan the maintenance process.

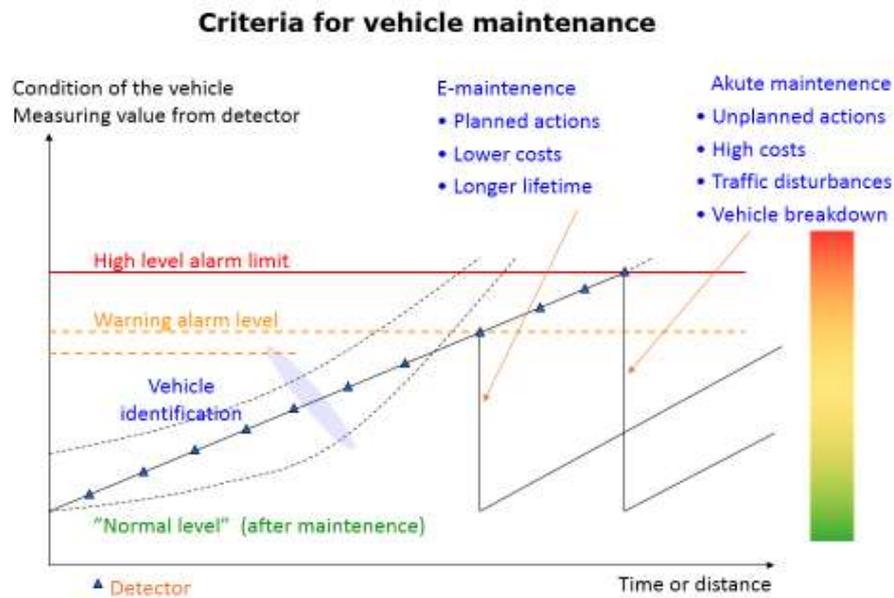


Figure 13: Criteria for vehicle maintenance

After the maintenance process the ECM sent documentation to the IM describing the type and extent of the damage, which was found at the specific vehicle. All data was saved in a data base for further analysis to translate between wheel forces and the actual size of the wheel damage.

Outcome of the project

The RU collaborating in the pilot project could reduce the number of severe wheel defects during the project phase. As a consequence the number of high level alarms exceeding (> 350 kN, Peak) was reduced as well: From 21 in 2013 to 7 in 2014 for the RU that was partner in the pilot project. For the other RU operating at the same track the numbers of exceeding was comparable in both years, see Figure 14.

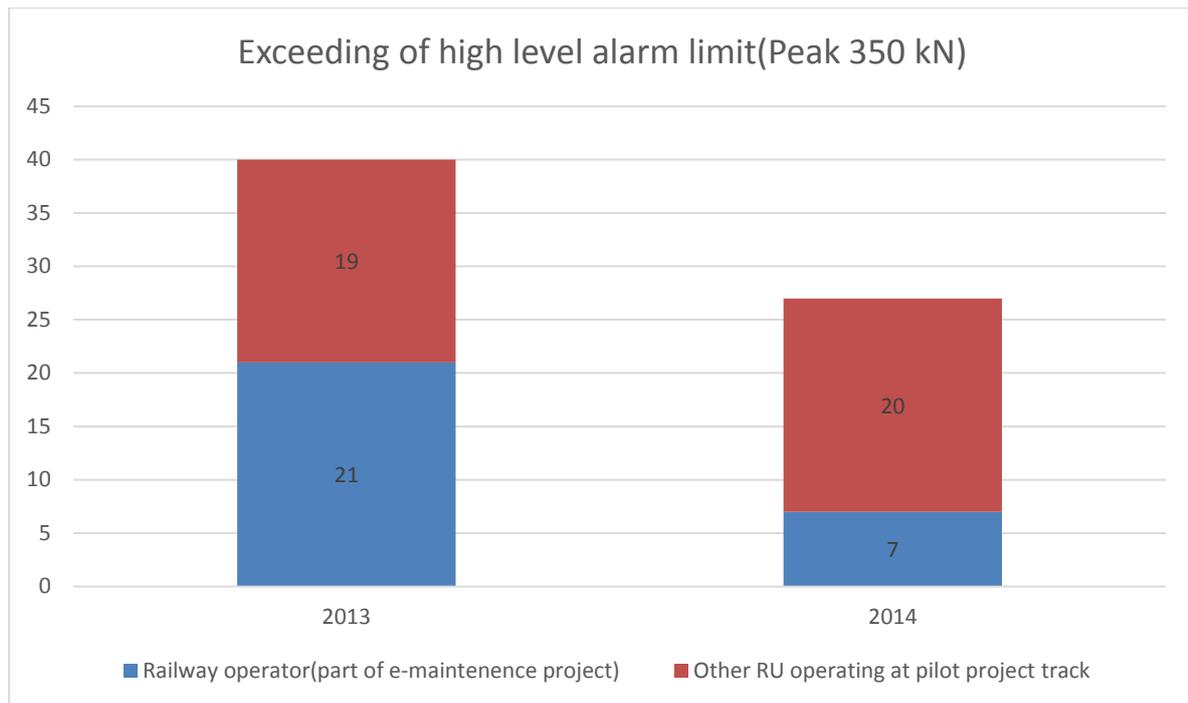


Figure 14: The number of exceeding high level alarm limit was reduced from 21 to 7 for the RU in the pilot project.

The key factors for success in the approach with preventive maintenance have been that:

- the vehicles with wheel defects can be identified with RFID, so RU and ECM know the affected components
- RU and ECM receive information in an early state for planning of actions
- commissioners of transport, RU, wagon keepers are commercial matured and utilizes the effects and benefits of preventive maintenance. In this case the general contract for use of freight wagons AVV 2006 can be an obstacle for preventive maintenance
- usage of customized warning alarm limits for different types of vehicles
- the procedures, rules and practices to prevent wheel damages are strictly followed

5.3 Approaches for data exchange

There are three approaches possible:

1. National driven (= business as usual)
2. Bilaterally harmonized
3. EU-wide harmonized

Technically, the implementation of these approaches was discussed in D5.1, where the “generic approach” (=harmonized interpretation procedure for exchanged data) was recommended. Additionally, it was discussed that this approach can be implemented in a central or a distributed architecture.

In the following sections, the three implementation approaches are discussed followed by requirements for implementation of the generic approach.

5.3.1 National driven (= business as usual)

If data exchange activities are driven by each IM in his own approach, only very limited use cases are available. An IM could exchange data with RUs operating on his network, although RUs operating on several networks might have to implement different data exchange models. An exchange with neighboring IMs would only be possible along the lines of one IM setting the standard and the other IM converting the data, if at all possible.

To successfully improve maintenance of vehicles, the allocation of WTMS data to the vehicle ID is a very crucial aspect which has been discussed in one of the previous chapters of this deliverable, see chapter 4.2 and chapter 5.1.

5.3.2 Bilaterally harmonized (non-unified data transfer)

A European-wide exchange of monitoring data without unification means that there are no standardizations regarding the interfaces, the transmission protocols and the data-format. Typically, the data exchange takes place only between two parties, who specify the transfer within bilateral agreements. For parties who would like to get access to monitoring data of many providers (infrastructure managers) in different countries there will be a huge entry barrier, because they will be confronted with a plethora of different exchange specifications.

This simplest of all concepts would be the practical outcome of an uncontrolled growth of a European network for monitoring data exchange. Due to its disadvantages, this concept should not be seen as a European solution.

5.3.3 Fully harmonized (unified data transfer based on harmonization)

Another approach was discussed in chapter 4.3.3 of D 5.1: a full harmonization of the European wide train monitoring, which is based on two cornerstones (see Figure 15):

(a) Monitoring data exchange

The harmonization of the data exchange has to guarantee, that monitoring data which is acquired by any harmonized system in Europe can be exchanged to any qualified data user without necessity of translation, interpretation or other adjustments. Thus a general transfer protocol for all kinds of measurement data has to be developed. This definition has to be done independently of the specific monitoring systems, which is a fundamental prerequisite for the extensibility of the monitoring by new systems. This will be a major advantage in a mid- and long-term view, where the requirements for monitoring will change due to changes in the general framework of railway (wagon constructions, etc.) and due to technological progress in measurements and sinking prices of measurement components.

(b) Monitoring systems

The harmonization of systems is independent of the harmonization of data exchange, even if an implementation of harmonized monitoring systems without an implemented harmonized data exchange reduces the advantages dramatically (due to different and/or system specific protocols big efforts have to be made for exchange comparable measurement data to all qualified data users in Europe).

The harmonization of the monitoring systems comprises three steps, which are for each measurement target / system consecutive:

- **Basic requirements:** define the conditions which have to be monitored (e.g. condition of axle bearings) to achieve the overall goal, identify which indicators and their respective measurement parameters are the most suitable for evaluating each of these conditions (measurement targets)
- **Measurement systems:** for each measurement target the determination of measurement principle and the requirements regarding the algorithm to build measurement results has to be specified. This goes with the definition of the measurement target (e.g. for a detailed definition of the measurement target “axle temperature”, it has to be specified the relevant area on the bearing housing, which depends on the measurement geometry of the system)
- **Thresholds:** based on harmonized measurement systems, also the thresholds for critical conditions and/or for maintenance issues can be harmonized. This must not be understood as generally defining only one threshold per monitoring target for the whole of Europe, but rather defining values depending on circumstances of the railway network and/or regularities of the infrastructure manager (e.g. allowed axle loads may depend on specific track properties). Due to this variety of values, the different thresholds together with the areas of application have to be disclosed.

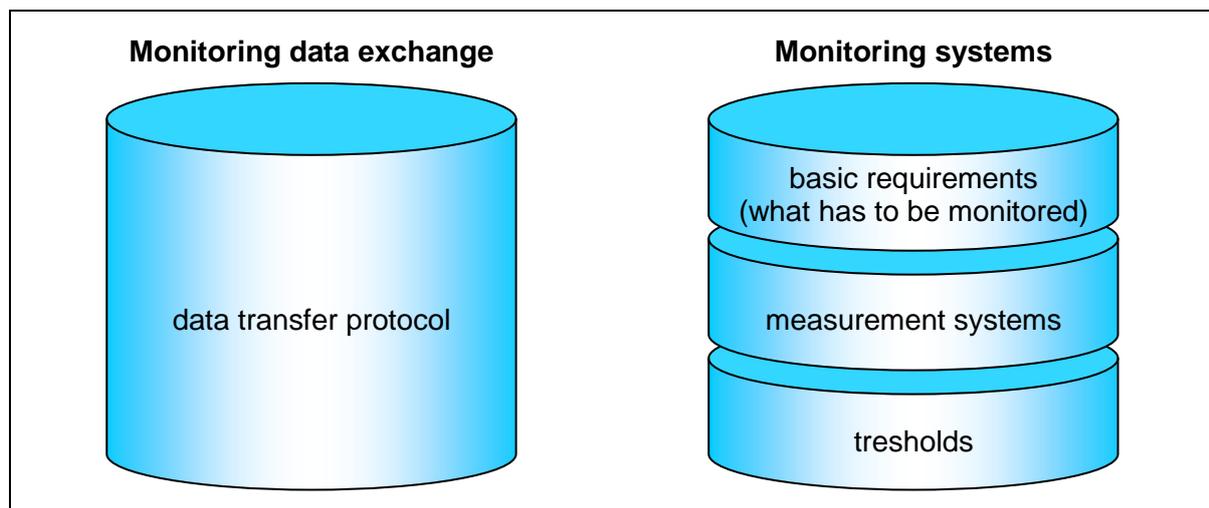


Figure 15: Two independent cornerstones of full harmonization in Europe: monitoring data exchange and monitoring systems

As discussed in D5.1, it is possible to implement a harmonized data transfer with a central data broker or with distributed architectures, although it is likely that only distributed architectures fulfill the requirements as soon as safety relevant applications are considered. Since proven bilateral data exchange models already exist, these could be used as a basis for an EU-wide harmonization.

The generic approach in D5.1, which comprises exchange of data of different treatment levels (including pre-processed output data) as well as a recommended algorithm for the interpretation of the data, solves most issues, see Figure 16. Most notable, the different national thresholds (deriving from the individual boundary conditions and risk landscape) as well as the different installed base of equipment is fully addressed by this approach.

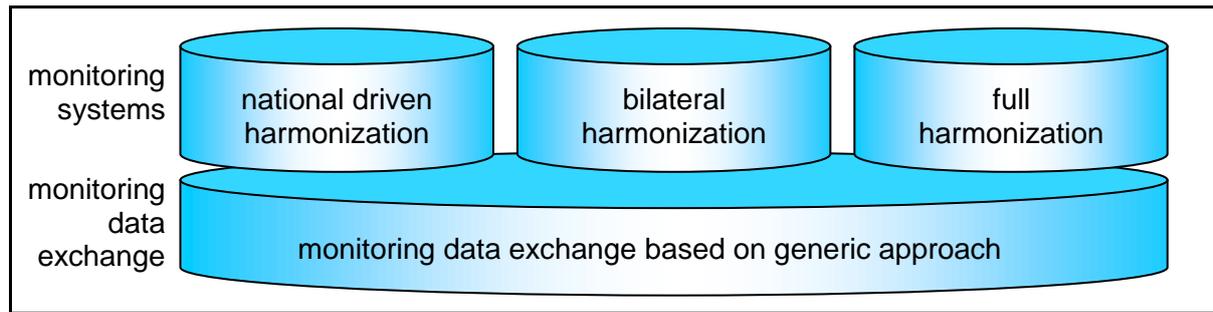


Figure 16: Advantage of generic approach for data exchange: usable with all levels of monitoring system harmonization

5.3.4 Requirements for implementing the generic approach

The conceptual design (see chapter 4 of D 5.1) basically targets the exchange and interpretation of data without detailed knowledge of sensor systems properties. Generally the data should be available for different parties (infrastructure managers, railway undertakings, vehicle owners, etc.). For compatibility with legal constraints of European infrastructure managers or other data users, the concept should also provide configurable access rights and masking of vehicle IDs.

For high acceptance, there should be no changes in safety relevant alarming procedures of infrastructure managers (just forwarding and listening). Furthermore, the application of user-definable thresholds shall be possible to fulfill national recommendations, infrastructure manager requirements, etc. For high flexibility, even the evaluation algorithm has to be modifiable for the data users and depending on provided data.

The approach shall allow an inclusion of different sensor systems for comprehensive trend analysis. Thereby, a universal framework shall be offered for data representation and functionality. It is important to mention that the concept is not a change request for suppliers regarding standardized evaluation content, but providing already existing output data in a different (unified) way.

In general, the following guiding principles have to be considered in the conceptual design:

- Use of existing monitoring systems (almost) independent of their output
- Open for integration of future systems
- If data is available in different levels of detail, prefer more detailed level
- IM are responsible for data provision
- Data users are responsible for their interpretation

With the implementation of a universal framework for data representation and functionality compared to direct linking between monitoring systems and data users the following benefits will occur:

- Less implementation effort for infrastructure managers (as data provider) and for data users to get data from different systems
- Easy integration of further or new systems

A European framework could easily leverage this operational experience and implement the solution in a short time-frame.

6 Development and assessment of business cases

6.1 Introduction

The D-Rail objective is to reduce the LCC from derailments by 10-20% and the number by 8-12% considering an increase in traffic until 2050. Here, the focus is on LCC and not on the number of derailments, as the vast majority of derailments occur in shunting yards with very low damage. The much rarer open-track derailments are much more serious due to higher speed, mixed traffic and expensive infrastructure elements and thus responsible for more than 80% of the costs.

WP2 quantified the increase in traffic with several scenarios. For the present deliverable, a possible traffic increase of 1.53% per year was considered.

An analysis of derailment causes in WP 2 showed that eight causes are responsible for 55% of derailment costs. Furthermore, WP4 determined that three interventions could be used to act on these eight derailment causes, namely:

- (1) Hot axle box detection
- (2) Axle load checkpoints
- (3) Track geometry (as well as ultrasonic inspection systems)

With these three measures, a potential maximum cost-reduction of 55% is possible, see Table 13. Additional benefits can be gained by using on-board monitoring devices (but that was not considered in WP 2 and WP 3). Considering the much more limited 10 ... 20% cost objective of D-Rail, it seems unreasonable to look for additional candidates.

D-RAIL D5.2 Outline system requirements specification for pan European Freight monitoring

Table 13: Costs and Benefits from D-Rail per cause and intervention set of accident (Table 2.1 from D 2.3 including additional information from WP 7). Possible interventions by color: (a) HBDT = yellow: (b) ALC = orange, (c) TGMC = white

Set	D-Rail top derailment causes	Total costs in Mio €	Inspection techniques	Share of derailments for the cause	Annual number of avoided derailments
1	Hot axle box and axle journal rupture	1282.6	Hot box & hot wheel detector systems Acoustic bearing detectors, Impact load detector	12%	60
2	Excessive track width	475.0	Track geometry measurement systems Track strength measurement systems	8.60%	43
3	Wheel failure	1879.5	Axle load checkpoints, Wheel profile and diameter systems, Hot wheel detector systems	10.30%	52
4	Skew loading	833.1	Axle load checkpoints Vehicle profile measurement (Vision)	5.95%	30
5	Excessive track twist	552.6	Track geometry measuring systems	6.58%	33
6	Track height/cant failure	281.9	Track geometry measuring systems	3.40%	17
7	Rail failures	587.0	Track internal inspection systems, Track surface inspection systems, Video Inspection of rails: Track Head Inspection System, Video Inspection of rails: Track Inspection System, Broken Rail detectors, Rail profile measurement systems, Impact load detectors, track stiffness measurements	2.87%	14
8	Spring suspension & failure	1865.6	Axle load checkpoints On-board accelerometer systems, On-board accelerometer systems	5.62%	28
Total share of derailments				55%	277

As discussed in D 7.2 and D 7.3 it has to be noted that this first general estimation is based on a cost benefit analysis performed in D2.3. No influence due to risk based models or any LCC calculation was considered here.

Next in this chapter the following points are presented: Starting from a general assessment of possible intervention scenarios estimating the number of additional needed devices for

(1) – (3) a discussion about a two dimensional approach for (1) and (2) is followed. The additional benefit from using on-board monitoring devices and the data exchange among entities is discussed. Here, the proposed development until 2050 is integrated into the situation of 2014. General remarks and hints for the implementation and migration scenarios are given in the next chapter.

It should be noted that the first general assessment takes only costs into account (based on the results from WP 2), and all following cases afterwards include the risk and LCC analysis performed by WP 7. The detailed LCC assessment results can be found in D7.4.

6.2 Assessment of potential intervention scenarios

This section will discuss different paths to obtain a 20% cost reduction from a more general point of view. Results obtained from D2.3, see Table 13 are used as the basis. There, numbers and costs from the database analysis of WP 1 were taken into account. The values in Table 13 are not influenced by any risk based models, like CSM-RA.

Using the assumptions from WP 2 some estimations concerning a possible cost reduction by 10 ... 20 % can be given. Qualitatively, the following possibilities exist to fulfill the D-Rail objectives based on the derailment causes:

- Use HABD to reduce all derailments due to hot axle boxes by 100%, which will yield a cost reduction of 12% (i.e. 20% cost reduction is not possible with HABD alone).
- Use ALC to reduce all derailments due to wheel defects, skew loading and spring and suspension failure by 91.5%, which will yield a cost reduction of 20%.
- Use TGMS to reduce all derailments due to excessive track width and twist, track height/cant failure and rail failures by 93%, which will yield a cost reduction of 20%.
- Any combination of these measures to achieve a 20 % cost reduction.

Within the D-Rail parameter, any of the solutions above will achieve the intended results, however there are significant ethical and legal aspects to such a decision.

There exist well-established methodologies for this type of risk-related decision making, which are extensively described in D7.1 and applied in D7.2. In principle, every actor in the railway system is obliged to apply these methodologies in his own precise context, and a D-Rail recommendation cannot and is not intended to remove this obligation from the safety management.

6.3 Combination of measures: two dimensional approach

All further investigations include the risk and LCC assessment done in WP 7. Next a combination of measure (1) and (2) – HBDT and ALC - is investigated in order to fulfill the general D-Rail aim of reducing the derailment costs by 10 – 20 %. It is investigated from a more general perspective of how many additional devices that are needed, in order to reach this goal. The number of installed devices 2014 is taken as reference. A graphical display of the results is presented in Figure 17 and Figure 18. Please note that both graphs show linear interpolations of the results from D7.2 and D7.3 and have not been calculated independently for each data point. The results are thus fully consistent with the risk assessment and LCC calculation in WP7.

D-RAIL D5.2 Outline system requirements specification for pan European Freight monitoring

Reduction of derailment damages [%] by deployment of additional WTMS across Europe																
	Number of additional ALC															
	0	20	40	60	80	100	120	140	160	180	200	220	240	260	280	300
0	0	2	3	5	7	8	10	12	13	15	17	19	20	22	24	25
100	1	2	4	6	7	9	11	12	14	16	18	19	21	23	24	26
200	1	3	5	6	8	10	12	13	15	17	18	20	22	23	25	27
300	2	4	5	7	9	11	12	14	16	17	19	21	22	24	26	27
400	3	5	6	8	10	11	13	15	16	18	20	21	23	25	26	28
500	4	5	7	9	10	12	14	15	17	19	20	22	24	25	27	29
600	4	6	8	9	11	13	14	16	18	19	21	23	24	26	28	29
700	5	7	8	10	12	13	15	17	18	20	22	23	25	27	29	30
800	6	7	9	11	12	14	16	17	19	21	22	24	26	28	29	31
900	6	8	10	11	13	15	16	18	20	22	23	25	27	28	30	32
1000	7	9	10	12	14	15	17	19	21	22	24	26	27	29	31	32
1100	8	9	11	13	14	16	18	20	21	23	25	26	28	30	31	33
1200	8	10	12	14	15	17	19	20	22	24	25	27	29	30	32	34
1300	9	11	13	14	16	18	19	21	23	24	26	28	29	31	33	34
1400	10	12	13	15	17	18	20	22	23	25	27	28	30	32	33	35
1500	11	12	14	16	17	19	21	22	24	26	27	29	31	32	34	36
1600	11	13	15	16	18	20	21	23	25	26	28	30	31	33	35	37
1700	12	14	15	17	19	20	22	24	25	27	29	31	32	34	36	37
1800	13	14	16	18	19	21	23	24	26	28	30	31	33	35	36	38
1900	13	15	17	18	20	22	23	25	27	29	30	32	34	35	37	39
2000	14	16	17	19	21	23	24	26	28	29	31	33	34	36	38	39

Figure 17: Effect of the deployment of axle load checkpoints (x-axis) and hot axle box detection systems (y-axis) on the reduction of derailment damages in %, assuming a yearly traffic increase of 1.53%. All combinations color coded in green fulfill the D-Rail objective of 20%.

LCC cost reduction [Mio €] over 30 years by deploying additional WTMS across Europe [%]																
	Number of additional ALC															
	0	20	40	60	80	100	120	140	160	180	200	220	240	260	280	300
0	-	0	1	1	2	2	3	3	4	4	5	5	6	6	6	7
100	4	4	5	5	6	6	7	7	8	8	9	9	10	10	10	11
200	8	8	9	9	10	10	11	11	12	12	13	13	13	14	14	15
300	12	12	13	13	14	14	15	15	16	16	17	17	17	18	18	19
400	16	16	17	17	18	18	19	19	20	20	21	21	21	22	22	23
500	20	20	21	21	22	22	23	23	23	24	24	25	25	26	26	27
600	24	24	25	25	26	26	27	27	27	28	28	29	29	30	30	31
700	28	28	29	29	30	30	30	31	31	32	32	33	33	34	34	35
800	32	32	33	33	34	34	34	35	35	36	36	37	37	38	38	39
900	36	36	37	37	37	38	38	39	39	40	40	41	41	42	42	43
1000	40	40	40	41	41	42	42	43	43	44	44	45	45	46	46	47
1100	44	44	44	45	45	46	46	47	47	48	48	49	49	50	50	50
1200	47	48	48	49	49	50	50	51	51	52	52	53	53	53	54	54
1300	51	52	52	53	53	54	54	55	55	56	56	57	57	57	58	58
1400	55	56	56	57	57	58	58	59	59	60	60	60	61	61	62	62
1500	59	60	60	61	61	62	62	63	63	64	64	64	65	65	66	66
1600	63	64	64	65	65	66	66	67	67	67	68	68	69	69	70	70
1700	67	68	68	69	69	70	70	71	71	71	72	72	73	73	74	74
1800	71	72	72	73	73	74	74	74	75	75	76	76	77	77	78	78
1900	75	76	76	77	77	78	78	78	79	79	80	80	81	81	82	82
2000	79	80	80	81	81	81	82	82	83	83	84	84	85	85	86	86

Figure 18: LCC costs over 30 years in M€ for the deployment of axle load checkpoints (x-axis) and hot axle box detection systems (y-axis).

Figure 17 shows the percentage reduction of derailment costs by adding additional number of ALC and/or HABD, while Figure 18 shows the cumulated cost reduction in M€ for 30 years. Both graphs show linear interpolations of the results from D7.2 and D7.3 and have not been calculated independently for each data point.

A possible interpretation of the intersection from these graphs is that the D-Rail objective can be fulfilled in a most economical way by deploying ALCs. Although a cost reduction of

20% can be achieved by a combination of HABD and ALC (e.g. 140 additional ALC and 1100 additional HABD, see Figure 17), the LCC assessment in Figure 18 shows that focusing more on ALC brings more financial benefits. These results can be interpreted such, that already many HABD are installed, so any additional implemented ALC brings relatively more benefits than installing additional HABD.

Again, it has to be noted that this evaluation does not account for the requirement of each IM to do his own risk assessment e.g. using CSM-RA. The individual national situation has to be taken into account.

6.4 Aspects about number and placement of inspection sites

Based upon previous experience of IM with WTMS the following categorization is proposed to cover all upcoming systems and to answer the question of positioning in the network of an IM. The categorization will in principle also apply to on-board systems monitoring the infrastructure.

Therefore measurement values in the sense of parameter types - connected to WTMS and/or OMD are categorized based on when and how quickly they might change during a train journey, see Figure 19.

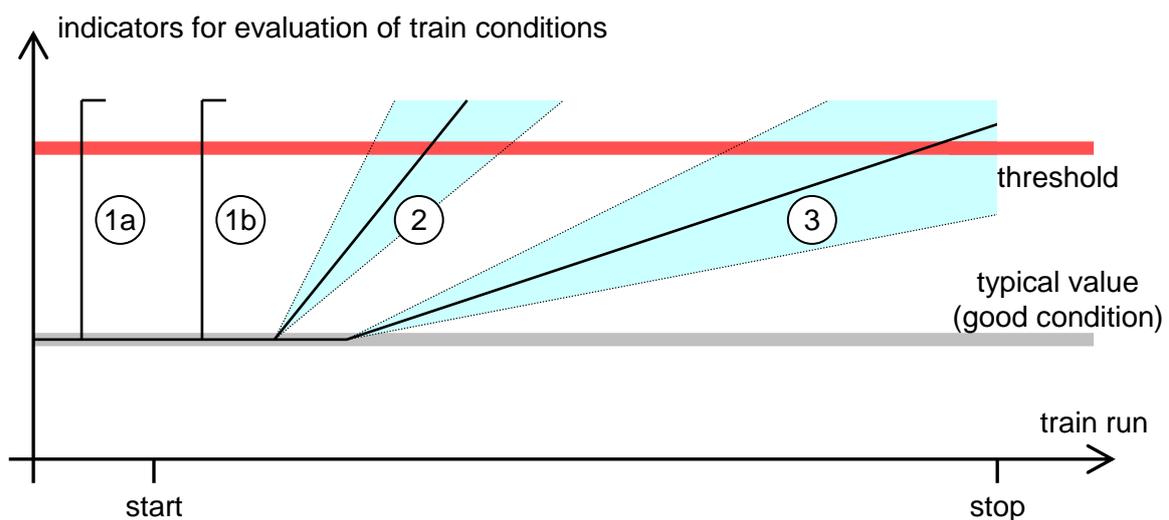


Figure 19: Different parameter types and their possible evolution over time

1. Almost never changing parameters

This category represents all characteristics which are not changing at all or are introduced at a given time by an event. This type of parameter should be checked at places where either the underlying event may occur or where the train enters the responsibility of an IM (strategic placement). The condition is not further worsened over time, but the vehicle is in a potentially unsafe state as soon as the condition is introduced.

Examples: skew loading (occurs at loading), vehicle running with a broken suspension, rockfall

In practice, these conditions may also be introduced by gradual events such as continuous loss of loaded content. These cases will be classified in other categories.

An additional difficulty is the fact that parameters such as skew loading (see 1a in the figure above) are always introduced at a loading site, but that other parameters such as a broken spring (1b) may occur at any time during the train passage.

2. Slow changing parameters:

This category is designed for all dynamic characteristics which can be monitored during usage (vehicle parameters during the run, effect of vehicle dynamics on the infrastructure). Here it's assumed, that those parameters have a linear increase or at least a trend that may be approximated by a linear behaviour.

This category represents all characteristics which are changing very slowly. It may be assumed that the parameter will be measured multiple times by WTMS or on-board monitoring before it reaches dangerous values. Operationally, these may be treated just like static parameters (quasi-static). An essential difference is however those trends can be easily extrapolated from the multiple measurements to predict the moment when the parameter requires preventive or corrective action.

Examples: rail geometry problems due to usage, axle box temperature (except for some cases with exponential/rapidly temperature increase if the bearing breaks down)

3. Fast changing parameters:

This category is designed for all parameters which can change immediately at any location and anytime. Typically there is an initial factor which directly leads to a fast change from safe state to a dangerous state. This category is the most critical one since an increase in traffic is directly increasing the risk of derailment.

Examples: load shifting due to ruptured loading belts

Depending from the trend to be expected for one parameter the distance between two monitoring locations and/or the inspection frequency can be calculated. This calculation requires an already existing data collection to recognize the behaving of the parameter.

Calculating the inspection frequency for on-board monitoring is less straight forward, as the defect progression rate is not the only parameter to account for.

Defect size resp. growth in relation to a detection threshold must be considered. Many defects can only be detected by a sensor if the condition is sufficiently severe. A hot axle box is easy to detect, but an axle bearing that is in the process of being destroyed can only be detected from the point where enough friction is happening to produce heat above the detection thresholds. For complex scenarios such as rail damage, the defect must have a certain size to be detectable with ultrasonic or visual inspection techniques.

The defect appearance rate is also relevant for the inspection frequency, especially in combination with rapidly progressing conditions.

For WTMS, there is usually only a single possible defect to be monitored (e.g. one hot axle box) and a straightforward detection threshold.

However, prediction of a reasonable number of measurement sites is always risk-based, e.g. taking into account the risk landscape of the concerned infrastructure manager. Relevant are:

- Non-technical measures compensating the risk (e.g. train observers and listeners)

- Expected damage from events, which contains many parameters such as track speed, track age, usage patterns (mixed passenger and cargo versus cargo only), high-value infrastructure elements, topology/geography, climate, ...
- Event frequency (based on past events)
- Risk aversion and other risk management factors
- Risk acceptance and financial considerations

It seems safe to assume that these parameters are not readily unified across Europe, but that a risk assessment per IM is required. The following sections describe scenarios that will result in a risk reduction as required in the DRAIL scope.

This risk assessment is not stable over time, as traffic volumes increase and composition changes. Assuming traffic increases as predicted by WP2, a risk assessment at a later stage may lead to different outcomes, especially since automated systems scale better in high-density or high-speed situations than non-technical measures.

6.5 Relevant differences about the situation in Europe

It has to be noted, that WP5 and WP7 perform analyses for all of Europe, based on the derailment figures from WP1. WP1 also showed that derailments are not uniformly distributed over Europe, and WP4 showed that technical mitigation measures for some of the derailment causes are already in wide-spread use in some countries. Thus the outcome of a risk assessment for a country that does not deploy hot axle box detection in a density-based approach will significantly differ from these results. Similarly, topographical, climate and other parameters may produce a different distribution of derailment causes in a given country. As an example, derailments due to natural disasters are among the most common occurrences in Switzerland, while derailments due to hot axle boxes have not occurred for more than ten years due to the deployed WTMS. Thus the SMS will favor deployment of different technologies than a Europe-wide assessment.

Drilling deeper into the heterogeneity, there are two classes of countries in Europe: those heavily favoring automation and those using human monitoring and intervention. Some speculations point towards different financial possibilities and manpower expenses, however a more thorough analysis would indicate that countries with high speeds, high traffic densities and/or high amount of mixed traffic will favor automated intervention out of necessity. Increasing traffic levels as predicted by D-Rail will push all countries towards a higher degree of automation, since the SMS will force the IM to reassess the risk landscape in light of the traffic increases.

In countries with high existing automation, the topics of interest are deploying additional systems, better integration between the systems and exchanging data between IMs, RUs and ECMs. For countries with low existing automation, the first priority is deploying the initial systems and possibly data exchange with neighboring IMs and interested RUs. If the predicted increase in traffic volumes hold true, it may be expected that the traffic volumes in 2050 for countries with currently low automation will approach those with currently high automation.

6.6 Scenarios – use cases

The following cases (see Table 14) will be investigated in order to reduce the derailment costs by 10 - 20 % although the predicted traffic increase of 1.53% per year up to 2050 occurs.

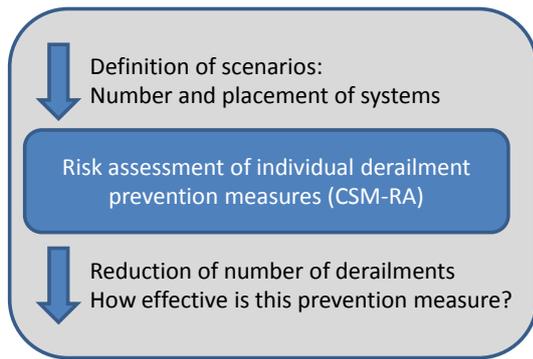
Table 14: Investigated cases.

Business cases	Countries with high automation	Countries with low automation
Reasons for installation of additional systems	(a) Protection of dedicated infrastructure components (b) Installation at border stations (c) Loading stations (e.g. harbors)	Installation of first systems
Cross border data exchange between IM	Derailment reduction due to pan European data exchange	Derailment reduction due to few bilateral cases
Data exchange in the wider sense of CSM (e.g. between IM and ECM)	Derailment reduction due to data exchange	No actions

The basis for the investigations performed in WP 7 can be seen Figure 20. After creating the risk analysis models (see details in D 7.2) some use cases could be calculated, in order to obtain the derailment risk reduction. Assumptions about the number and placing of the systems had to be taken. Three different types of scenarios where the basis:

1. Maximum scenario
2. Optimum scenario
3. Minimum scenario

Step 1: Risk assessment (D 7.2)



Step 2: LCC assessment (D 7.3)

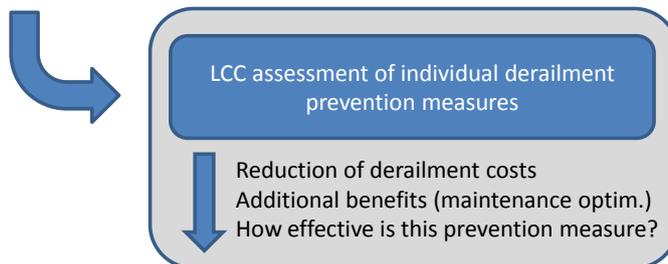


Figure 20: Procedure, input and output for risk and LCC assessment performed by WP 7

Since no European reference implementation for CSM-RA exists, two national implementations of risk assignment methodologies were used independently. Table 15 summarizes the results from the RSSB methodology and Table 16 from the SBB methodology, both of which are theoretically described in D7.1 and practically applied in D 7.2.

For both methodologies, all essential parameters were taken from the national implementations, but scaled to the larger D-Rail scope.

Table 15: Summary of the results of the GB (RSSB) risk assessment

Monitoring System	Assumed % reduction in derailments due to system	Assumed number of additional units installed (cf.2014)	GB ALARP Conclusion
Scenario 1: Widespread implementation with "high" level risk reduction			
Hot axle box and hot wheel detection	91%	790	Not justified to reduce risk to as low as reasonably practicable
Axle load checkpoints	98%	300	Not justified to reduce risk to as low as reasonably practicable
Track geometry measurement systems	60%	20	Not justified to reduce risk to as low as reasonably practicable
Scenario 1: Targeted/focused implementation with lower risk reduction			

Hot axle box and hot wheel detection	9%	160	Not justified to reduce risk to as low as reasonably practicable
Axle load checkpoints	90%	120	Justified to reduce risk to as low as reasonably practicable
Track geometry measurement systems	45%	10	Justified to reduce risk to as low as reasonably practicable

Table 16: Summary of the results of the SBB risk assessment

Measure	Annualized Cost [M€]	Monetized Risk Reduction (MRR) [M€]	MRR with risk aversion [M€]	Cost-benefit ratio	MRR with risk aversion and traffic increase (70%) [M€]	Cost benefit ratio with traffic increase (70%)
HABD: 1 system reference	0.033 [SBB]	0.017 [SBB]	0.019	1.7 (adequate)	0.033	1.0 (effective)
HABD: 2600 additional systems (99%)	85.8	1.28	1.45	59 (not reasonab.)	2.47	34 (not reasonab.)
HABD: 790 additional systems (91%)	15	1.16	1.32	11 (not reasonab.)	2.24	6 (adequate)
HABD: 100 additional systems (9%)	3.5	0.12	0.14	25 (not reasonab.)	0.238	14.7 (not reasonab.)
ALC: 1 system reference	0.037	0.033 [SBB]	37k	1.0 (effective)	63k	0.6 (highly effective)
ALC: 300 additional systems (98%)	6.4	4.49	5.09	1.26 (effective)	8.66	0.74 (highly effective)
ALC: 120 systems (90%)	4.1	4.12	4.68	0.88 (highly effective)	7.95	0.51 (highly effective)

A key finding is that similar conclusions are derived from both methodologies, despite different terminology, details and input parameters:

- Both methods conclude that additional HABD systems are not reasonable according to the ALARP principle used by both methods, even when only a low number of HABD for all of Europe are considered
- The deployment of 120 additional axle load checkpoints is reasonable in both methodologies. 300 additional axle load checkpoints appear reasonable in the Swiss model, but not in the UK model. In this instance, the risk aversion factor in the Swiss model is responsible for more than 50% of the difference, the rest is due to the different risk landscapes in CH and UK.
- Track geometry measurement systems could only be evaluated in the UK model due to insufficient statistical basis in CH (too small number of instances). About ten additional TGMS for Europe appear reasonable in this scope, but not 20. It should be understood that countries such as Germany, France and Switzerland are already above the number of measurement trains broken down by country that is considered reasonable in the D-Rail scope alone (only freight), but other countries are below their share.

Generally, the outcome in D7.2 differs significantly from the result of the national SMS. For reference, Table 16 also shows the values for CH for HABD and ALC ("1 system reference"). Unlike the other rows, these values only apply to CH, including passenger and freight traffic, and consider the total safety impact (not limited to derailments alone). The D-Rail approach does not allow exploiting the synergies that IMs normally seek out in such installations.

Finally, the LCC assessment of D 7.3 derived the results presented in Table 17.

Table 17: Quantitative evaluation of LCC and Benefit-Cost ratio. Blue columns correspond to costs (negative NPVs), green columns to benefits (positive NPVs).

Measure	Net Present Value (NPV)		Cumulative NPV		NPV of avoided cost of derailments		Cumulative NPV of avoided cost of derailments		Benefit/Cost Ratio (of cumulative NPV)	
	high scenario	low scenario	high scenario	low scenario	high scenario	low scenario	high scenario	low scenario	high scenario	low scenario
HABD	4.183.588 €	847.309	406.704.373 €	82.370.506	3.160.816 €	510.078	140.063.570 €	24.927.524	0,34	0,30
ALC	1.997.905 €	799.162	143.097.302 €	57.238.921	10.571.639 €	9.833.234	478.489.452 €	446.416.482	3,34	7,80
TGMS	915.706 €	457.853	74.038.955 €	37.019.478	10.731.375 €	9.204.726	524.623.336 €	458.312.627	7,09	12,38

The LCC assessment differs from the risk assessment as it includes additional costs such as networking of individual units, RFID tagging, but also additional benefits from derailment prevention such as saved rescue and recovery costs, prevention of passenger delays, and benefits from non-safety related aspects such as maintenance optimization. For axle bearings, the maintenance effects are limited, but ALC show massive positive effects on vehicle maintenance and TGMS show massive positive effects on track maintenance.

6.6.1 Hot Axle Box Detectors (HABD)

Temperatures of hot axle boxes are classified as a dynamic parameter (see chapter 6.4). The most frequent case is a linear dynamics, but a small unknown proportion of events present a faster, exponential heat increase.

As discussed in Schöbel, Karner (2005) in a linear case a train can run more than 180 km with a temperature increase from 36°C to 95°C. This result was obtained for cargo vehicles operating in Austria under normal operational conditions (no longer stops during the journey). Placing of HABD every 180 km would still catch every linear case with the same characteristics (a faster linear trend is of course possible). Non-linear behavior will generally present a steeper temperature increase and thus require a higher density of HABD. Placement of HABD must conform to a density-based approach to match the trend behavior.

Table 18 shows the following general scenarios for HABD:

Table 18: General scenario in Europe for hot box detection

HABD	Target and assumptions	Result: Number of devices and risk/cost reduction
Maximum scenario	100% risk reduction, aiming at linear and exponential cases on all tracks. This would require a target density of 65 km, but isolated cases of exponential events remain possible.	3'600 devices for ~100% risk reduction
Optimum scenario	aiming only at linear cases on all tracks, assuming a distance of not less than 150 km between inspection sites, 65 km for main freight lines, and a lower value for high-speed tracks.	1'790 devices for ~91% risk reduction and ~97% cost reduction. This scenario is in line with established practice or target values in countries such as Germany, Switzerland, France and Austria.
Minimum scenario	Aiming only at linear cases on main freight lines, assuming a distance of no less than 150 km between inspection sites.	160 devices for a 9% risk reduction, although a much higher proportion of the costs would be covered.

There is already a strong installed base of about 1000 devices. These costs can be subtracted from the initial cost, but not the OPEX and the renewal costs.

The UIC derailment numbers already reflect the fact that HABD detectors are in use in many countries. This effect must be compensated for, as it will make HABD appear less beneficial than is correct.

In addition, the D-Rail approach differs from established practices in European railways as it limits its scope to derailments and freight only, while all other approaches are concerned with railway safety, of which freight derailments are only a subset. This explains why already more than 1000 devices are in use today, as the need to prevent derailments on fast or high speed lines and concerning passenger trains have much higher derailment costs associated.

It may thus be interesting to focus on the approach used in Switzerland, which does not ask for the effect of a given number of devices on safety, but rather the additional effect on safety from additional devices. In the D-RAIL context, this translates to the following question: assuming freight can benefit from the already established HABD on mixed lines, how many additional systems can be afforded for freight only?

6.6.2 Axle Load Checkpoints (ALC)

Axle load checkpoints deal with several derailment related parameters simultaneously. Skew loading is a static parameter, load shifting a fast-changing parameter, wheel defects may present either characteristic. The static and quasi-static aspects would make a strategic choice of locations feasible, the dynamic effect would require a density-based approach.

Table 19 shows the following general scenarios for HABD

Table 19: General scenarios in Europe for ALC²

ALC	Target and assumptions	Result: Number of devices and risk/cost reduction
Maximum scenario	Any scenario aiming for the dynamic effects will result in very high numbers without eliminating residual risk completely	Not investigated
Optimum scenario	ALCs positioned at shunting yards and ports (1 double system per yard) and border crossings and in front of 1/3 of critical infrastructure elements.	500 devices. This should catch all cases of skew loading and wheel defects and reduce the damage of load shifting due to the protection of critical infrastructure elements by ~35%,
Minimum scenario	ALCs positioned at shunting yards and border crossings,	320 devices ~100% risk reduction for all cases of skew loading and wheel defects.

Due to the heterogeneity in Europe, the placement at strategic sites will result in a very unequal distribution of costs. Small countries have proportionally more border crossings, topography and climate effects are more pronounced in Scandinavia and alpine countries and critical infrastructures are also unequally distributed.

6.6.3 Measurement Cars (MC), specially TGMS

Within D-Rail the data base for a bottom-up estimation is insufficient. A top-down approach would suppose that the inspection intervals are driven by present inspection requirements and that the number of measurement cars is driven by the utilization from the inspection intervals. Based on Swiss and German figures (0.5 ultrasound car per 7'500 km (CH), 3 ultrasonic cars for 61'200 km (D) about 22 ultrasonic cars would suffice for all of Europe. Similarly, 32 geometry recording cars could cover all of Europe, but as today's measurement cars fulfill multiple roles above the pure track geometry inspections, the numbers lie in a range between 20 - 40 cars. The risk reduction can only be estimated as it is not only dependent on detection, but also on intervention.

Successful intervention is dependent on several factors:

² In order to detect elliptic or polygonalised wheels, the installation of ALC should allow a minimum speed of 50 km/h

- Some measures require the right meteorological conditions (i.e. welding is not possible/ difficult in winter)
- Some measures carry significant financial costs or are dependent on critical resources of limited availability (tamping trains, specialized construction crews, ...), which triggers a delay due to planning and non-availability
- The wrong action can result from misinterpretation of data, e.g. a low-hanging catenary might indicate a problem with the track and not the catenary.

No quantitative data could be provided from the D-Rail participants in this area.

6.6.4 Mixture of HABD, ALC and TGMS

Many combinations of HABD, ALC and TGMS deployment numbers would lead to a reduction of derailment costs by 20%.

On one hand, a purely financial approach can be taken, as exemplified for two dimensions in Figure 17 and Figure 18. It seems obvious that HABD come out badly in this approach, but this is not inconsistent with the outcome from the risk assessments (Table 15 and Table 16).

The risk management approach evaluates each measure independently. ALC and TGMS are both reasonable under CH and UK methodologies, although the number of systems may vary. Factoring in maintenance optimization, the outcome for both techniques is even more favorable. TGMS is the most favorable technique by a large margin. Thus the following approach is the most reasonable.

1. Evaluate the target number of "reasonable" – as defined under ALARP or a corresponding national interpretation standard such as GAMAB – systems per country
2. Compare to the number of actual systems
3. If below the target number, additional systems to reach the "reasonable" number of systems are the most efficient step
4. If above the target number, the procedure should be restarted from 1 for the second most favorable technique and further down from there.

This approach takes no note of regional specificities, such as temperatures, mountains, track conditions. For such a detailed analysis, the risk assessment approach contained in the national SMS is a much better approach.

Finally, it must be noted that the financial approach must not be used to evaluate a safety relevant feature. Only risk-related decision making method that is accepted and applicable in the IM's SMS context may be used for that. Such as method could come to the conclusion that all three measures are reasonable (or even mandatory) in the IM's specific risk landscape.

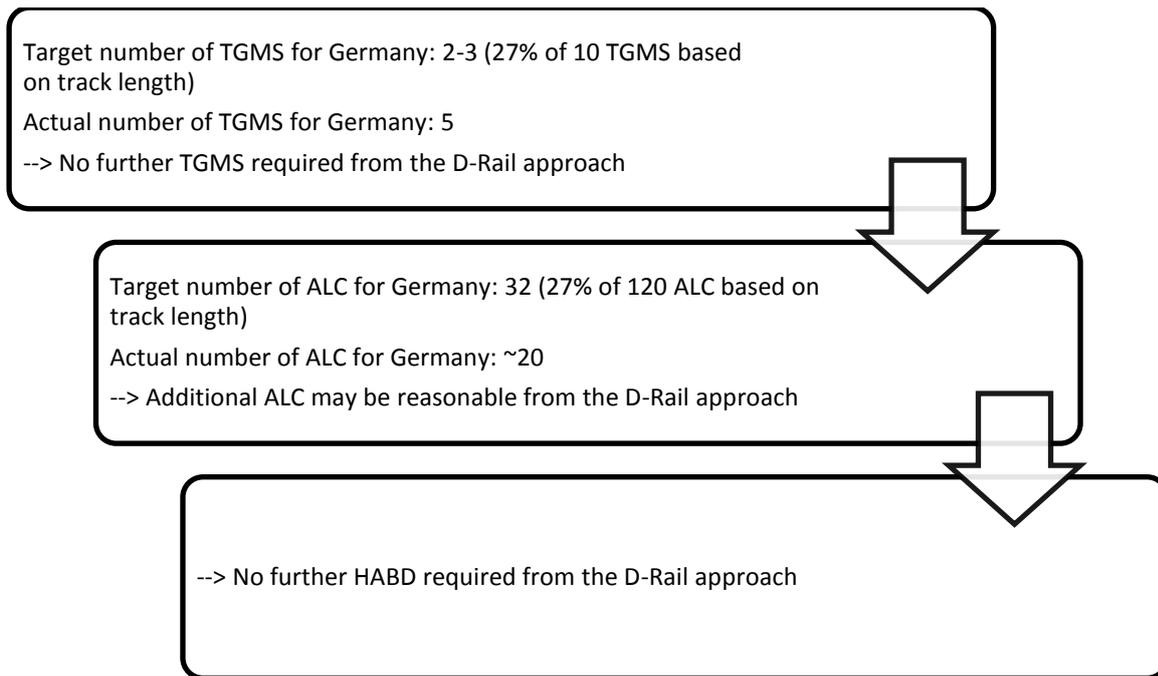


Figure 21: Example of application of the procedure for Germany. The approach takes no note of national specifics and thus probably overestimates the number of required ALC for Germany

6.6.5 On-board monitoring devices (OMD)

There is very limited operational experience with on-board devices. It is therefore assumed, that these devices are defined here as small devices capable of being deployed on a large number of vehicles. The case of installing complex equipment such as TGMS on regular scheduled trains is not covered in this section, as this equipment is similar in price to TGMS and will not be deployed in large numbers across a fleet or even part of a fleet.

As an overview, the following fields are seen:

- (1) Automatic Vehicle Identification (AVI): Devices to enhance the capabilities of WTMS, such as RFID-identification
- (2) Vehicle Monitoring Device (VMD): Devices to monitor conditions of the vehicle, either complementing or replacing WTMS
- (3) Infrastructure Monitoring Device (IMD): Devices to monitor conditions of the infrastructure, either complementing or replacing TGMS and other systems installed on dedicated trains
- (4) Derailment prevention device (DPD) and derailment detection device (DDD): Devices for derailment mitigation, such as mechanical derailment prevention devices as used on dangerous goods trains in Switzerland and the electronic Faiveley derailment prevention device

At first glance, costs for these devices must be borne by the RU/ECM, just like costs for WTMS are borne by the IM. The detailed analysis in Table 20 shows that some cost sharing mechanism with the IM is certainly required for (3) and may be discussed in (1) and (4). This dilemma can't be solved within D-Rail and will thus only consider the aggregated costs and benefits.

Table 20: Categories of On-board monitoring Devices and qualitative benefits

Category	Safety benefit	Benefit for IM	Benefit for RU/ECM
(1) Automatic Vehicle Identification	Indirect, through WTMS	Better vehicle identification	Targeted use of WTMS data for maintenance
(2) Vehicle Monitoring Device	Direct, preventing derailments	Less derailments	Targeted use of VMD data for maintenance
(3) Infrastructure Monitoring Device	Direct, preventing derailments	Targeted use of IMD data for maintenance	-
(4) Derailment prevention device	Direct, mitigating derailment damage	Less damage from derailments	Less damage from derailments

Due to the lack of available data and devices, a bottom-up-calculation for a business case cannot be performed and must thus be limited to a top-down estimation of how much a hypothetical device is allowed to cost.

For this discussion, a fleet of 100'000 vehicles in Europe is assumed. Since the devices are theoretical in nature and no data were available from WP4 and WP-6, we assume that the maintenance costs are 20% per year of the investment cost and a lifetime of 5 years. Furthermore, we assume that the hypothetical VMD will give the same data as an ALC for a given vehicle, and the IMD the same data as a TGMS, i.e. that they can fully replace these devices if the whole fleet is equipped with them. We will furthermore assume that the DPD is able to reduce damages from a derailment by 50% and will never be triggered erroneously. Finally, we assume for (2) VMD and (3) IMD that these devices will only be deployed if they cost less than the corresponding ALC and TGMS. (1) AVI and (4) DPD are additional benefits that do not have a similar correspondence.

The next problem area is getting the data out of the devices to an appropriate actor. For (1) the data exchange is provided by the WTMS and the AVI is purely passive. For (4), the exchange is limited to the driver respectively the train brake.

For (2), the data must be transported from every vehicle to the RU or ECM of that particular vehicle, which means that on some trains as many corresponding parties as vehicles must be addressed. Furthermore, a time-delayed data exchange, e.g. at shunting yards, would suffice for the maintenance requirements, but not the safety benefits provided by ALCs. Thus, some real-time communication is necessary, e.g. by GSM, GSM-R or by a dedicated system with balises along the track. These data would then be aggregated in a central system and provided to the RUs and ECMs, which would need to take appropriate action. Ignoring the problem of a RU/ECM not complying, there is still the problem of getting to a train in motion and take an action such as an immediate stop without access to the signaling equipment as an IM has. It seems likely that the train driver, possibly of yet another RU, would have to coordinate an unscheduled train stop with the IM. This scenario still presents many uncertainties, which are impossible to quantify.

Scenario (3) is more benign, since the only actor interested in the data is the IM responsible for the monitored infrastructure. In addition, real-time data are not required in this instance, and a time-deferred exchange becomes a real possibility.

Table 21: Top-down limits for different modes of on-board devices

Category	Cumulated benefits (from D1.1, D5.1, D7.3)	Upper limit for costs per vehicle based on benefits	Upper limit for costs per vehicle based on alternative techniques	Remarks
(1) Vehicle ID	121.1 M€ ³	101€	-	
(2) Vehicle Monitoring Device	446.4 M€ ⁴	372€	103€ (ALC)	Amount includes real-time communication to the RU and ECM of each vehicle
(3) Infrastructure Monitoring Device	458.3 M€ ⁽⁴⁾	382€	62€ (TGMS)	Amount includes communication to the IM
(4) Derailment prevention device	254 M€ ⁵	212€	-	

Case (1) is a purely maintenance- and efficiency driven case. Dangerous trains will be stopped regardless of Vehicle ID, but this case would allow the RU/ECM a faster identification of the offending vehicle and is the basis for condition-based maintenance.

Case (2) is about half a safety case and half a maintenance optimization case. Since ALCs can provide both effects as well, a VMD is only economic if less expensive than ALCs, which gives an upper limit of 103€ per vehicle. Included in that amount is a totally uncharted new data exchange landscape between many actors that do not exchange presently real-time, safety-critical data. Experience would indicate that the amount is not even sufficient for the data exchange part alone.

Case (3) is about one third a safety case and two thirds a maintenance optimization case. Data exchange is a simpler proposition, with fewer actors and no real-time component. However, the limit is only 62€ per vehicle. However, it could be imagined to sprinkle this device through the fleet, e.g. one vehicle in ten, which would make the technology competitive – provided the data are as good as those from TGMS.

Case (4) will not prevent derailments, but mitigate their damage. The interesting aspect is that this measure will act on all derailments, for whatever cause. This would allow funding of 212€ per vehicle.

In summary, the only cases accessible with current technologies are (1) and (4). There are no actual costs for (4) available, so an upper limit is used as a proposal. For cases (3) and even more so for case (2), a lot of basic questions on usage scenarios are not answered and any business case is premature.

³ Reference: Table 8 of D 7.3, calculated for 30 years, discounted with 2,5%

⁴ Reference: Table 10 of D 7.3

⁵ Reference: Table 4.5 of D 1.1

Even if the following activities don't match completely with the scope of D-Rail, it's interesting to discuss them, since they may fill some open gaps of information. There are sensors available which are mounted on individual cargo vehicles logging the route and mileage and sending this information to the VO, see [03] and [04]. This information looks quite simple, but it gives a lot of chances for enhancing the maintenance of vehicles. In combination with other measurement values, like loading devices (see [19]), axle temperature and or pressure/temperature in a tank can be transmitted directly from the vehicle to anywhere via UMTS. It is expected, that the enhancement in sensor and transmission technology bring new solutions: e.g. RFID which can store time history of axle temperature. This information can be transmitted to a reader at the track side or in a workshop.

6.7 Result of LCC analysis of WP 7

Within the economic analysis of the inspection and monitoring systems WP7 has performed two different approaches to demonstrate the economic benefits of the three proposed inspection and monitoring systems (see D7.3, chapter 3.6.2 and 3.6.3). The first approach performed in D7.3 chapter 3.6.2 is a Cost/Benefit Analysis with the calculation of the cumulated costs by taking into account the additional benefits on avoided costs due to derailments associated to each of the proposed inspection and monitoring system. The used data are consistent with the data used for the risk analysis based on GB and SBB risk data scaled for EU27 (see D7.2 of WP7).

In the second approach the Life Cycle Costs (LCC) of the three proposed inspection and monitoring systems are calculated. Similarly to the Cost/Benefit analysis, the LCC analyses use the same cost figures but not based on GB data, but rather on the given specific costs per cause of derailments (D2.3). Contrary to the Cost/Benefit analysis, LCC analysis considers only expenditures but not additional benefits.

The related sections in D7.3, particularly the sections 3.6.2 and 3.6.3 demonstrate that many factors and aspects influence the whole life costs of the inspection and monitoring system. And not only the additional number of installations, but the efficient deployment of the installations creates added value considering aspects such as legal, financial, safety (SMS, CSM-RA), requirements of the IM, specific boundary conditions (climate effects, curves, tunnels, bridges, natural phenomenon) and many other aspects. The goal should be to identify the cost-efficient solution to prevent and mitigate risk for derailment.

This section outlines the LCC analysis performed to evaluate the additional number needed to achieve the 10-20% LCC reduction.

By identifying the required additional number of installations in order to achieve the target of 20% LCC reduction many factors have to be considered. In general, this issue is more a matter of efficient placement of the installations on the concerned network, for instance at loading sites such as ports (skew loading occurring at loading site), border-crossings, neuralgic locations (bridges, tunnel) of specific corridors. This is a more efficient approach than to build a causal link between the required number of sites and LCC, which might not be applicable and expedient for the objective in terms of LCC reduction.

However, when monitoring installations reach a certain number on a specific network (route) no further decrease of derailments is achievable by intensified monitoring (saturation effect). That is to say that the approach by installing e. g. more HABD would not lead to higher LCC

reduction automatically, since the associated whole life costs for investment, re-investment, maintenance, operation and disposal have to be considered. But the efficient deployment of the installations sites shall follow an integrated approach based on risk-related decision processes and individual national situations with related aspects such as legal, financial, safety (SMS, CSM-RA), requirements of the IM, specific boundary conditions (climate effects, curves, tunnels, bridges, natural phenomenon) and many other aspects. The goal should be to identify the cost-efficient solution to prevent and mitigate risk for derailment.

However, the aim of the following analysis is to get an order of magnitude in terms calculating the required number of monitoring system in order to achieve the 20% LCC reduction, individually or by set of combination.

It must be noted that in the cost benefit analysis and the LCC analysis the mentioned optimum scenario corresponds to the assumed "high" cost / "high" level risk reduction option and the minimum scenario to assumed "low" cost / "low" level risk reduction option respectively.

The Net Present Values for the status quo (2014) and the three proposed monitoring systems are calculated by the LCC analysis. A discounting factor of 4% is taken for the analysis. The analysis also includes the forecast of 2050, i. e. increase of freight traffic by 1.5% annually up to 2050 according to the finding of WP2 (see D2.1, D2.3). Since verified cost data regarding implementation and migration are not available, these costs are not included in the LCC analysis. Both the risk landscape of the IM and the effect of higher increase as well as the decrease scenarios of traffic volume are not considered in the LCC analyses. Contrary to the Cost/Benefit analysis, LCC considers only expenditures but not additional benefits such as:

- Avoided cost per derailment (operational, preparedness, recovery after derailment, etc.)
- Avoided train delay costs per derailment
- Maintenance cost optimization due to Condition-Based Maintenance strategy

But the business cases on the three proposed systems would be much improved if the additional benefits were considered as shown in the Cost/Benefit analysis of the previous section.

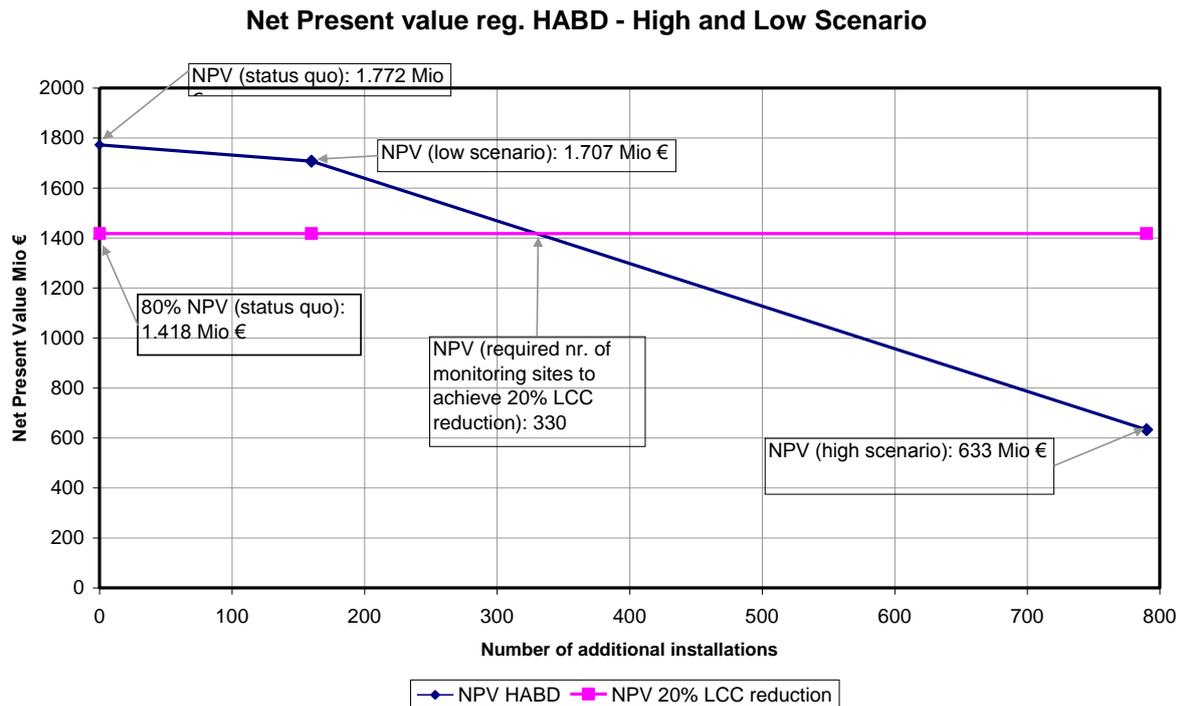


Figure 22: NPV of HABD with assumed detection reliability of 91% (high scenario) and 9% (low scenario)

Figure 22 shows, that the objective of 20% LCC reduction can be achieved by 330 additional HABD devices as an outcome from the LCC analysis.

The LCC analysis regarding ALC shows a beneficial case for both high and low scenario due to the assumed high detection reliability of 98% and 90% respectively. Only 40 additional ALC installations are necessary to reduce the LCC by 20%, which is presented in Figure 23 below.

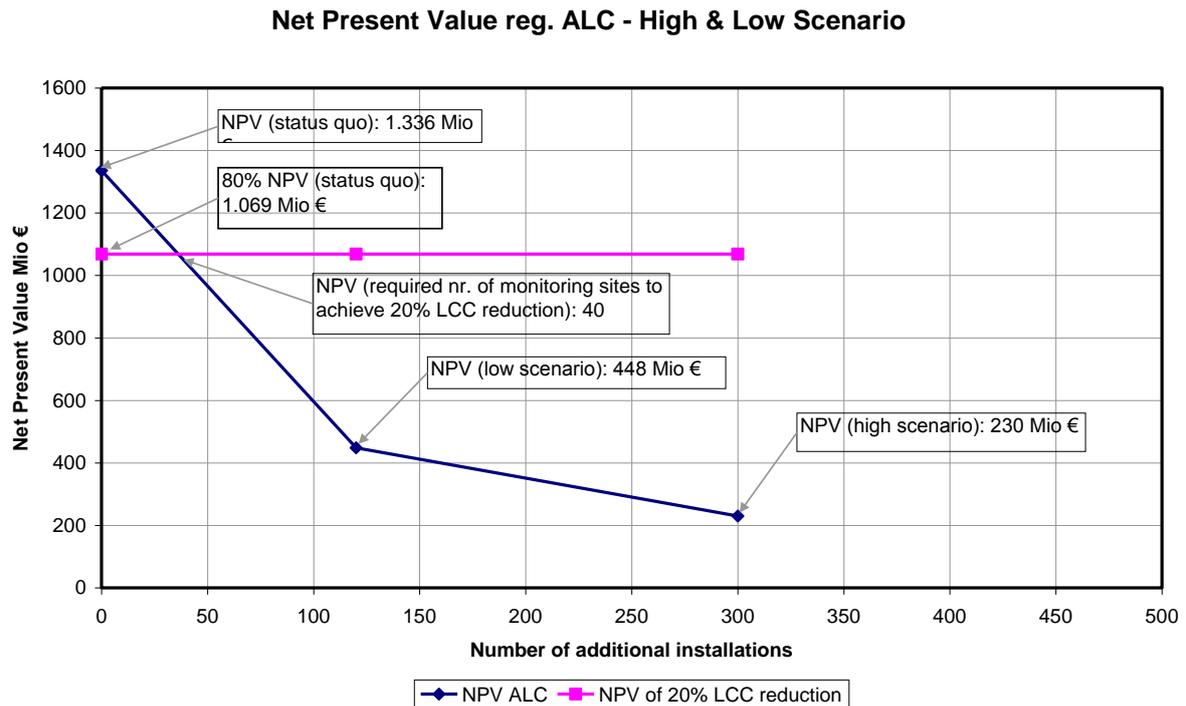


Figure 23: NPV of ALC with assumed detection reliability of 98% (high scenario) and 90% (low scenario)

A general remark is required regarding the assumed detection reliability of 98% for ALC. The assumed detection reliability of 98% and 90% respectively regarding ALC seems to be very high and needs to be proved as this high value implies that the monitoring system measures very precisely and consequently detects all trains being critical in terms of derailment. On the other hand this could be interpreted that also trains with no hazardous state could be stopped due to the assumed sharp detection resulting in higher costs due to unnecessary train stoppages.

Taking the numbers of avoided derailments due to ALC assumed in the analysis so far (109), then not more than 109 trains with risk to derailment have to be stopped. If more than 109 trains are stopped the effect and linked costs respectively of unnecessary train stoppages resulting from track unavailability, checking activities before continuing of the train journey etc. have to be considered. Thus the break-even point in the LCC analysis would be much later than it is the case now. To demonstrate this effect, a second LCC analysis is carried out for a more realistic value of risk reduction, which would be a 50% detection reliability. With the assumed detection reliability of 50% about 210 ALC devices are required additionally for 20% LCC reduction, which is presented in the following Figure 24.

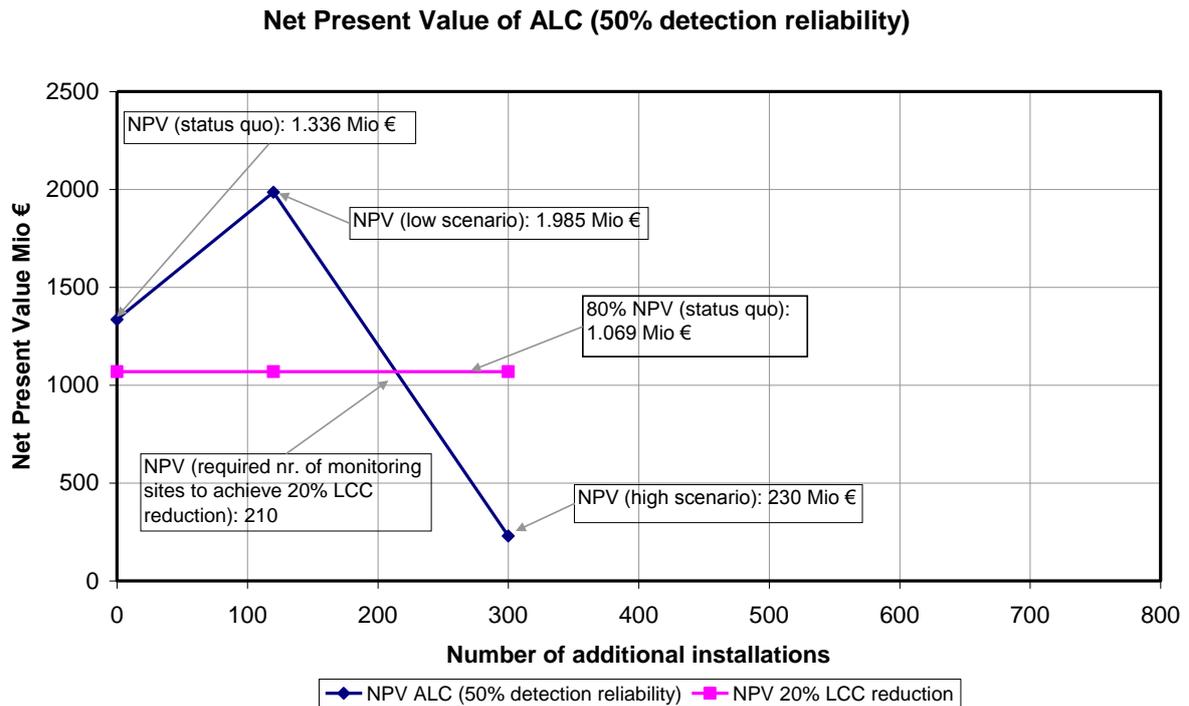


Figure 24: NPV of ALC with assumed detection reliability of 98% (high scenario) and 50% (low scenario)

Generally, due to the heterogeneity in Europe, the placement at strategic sites will result in a very unequal distribution of costs.

The outcome of the LCC analysis regarding TGMS shows that the LCC reduction by 20% cannot be achieved, mainly due to the detection reliability of 60% assumed for TGMS. With a higher detection reliability of 90% and associated derailment reduction ensures the benefit in terms of 20% LCC reduction is obtained. Given this, it can be stated that a causal link between additional number of installations and LCC is not always given. To increase the number of installations does not lead to a LCC benefit automatically, whereas an increase of detection reliability is the more efficient approach to achieve the required benefits, as presented for TGMS, see Figure 25 and Figure 26.

Net Present Value reg. TGMS - High & Low Scenario

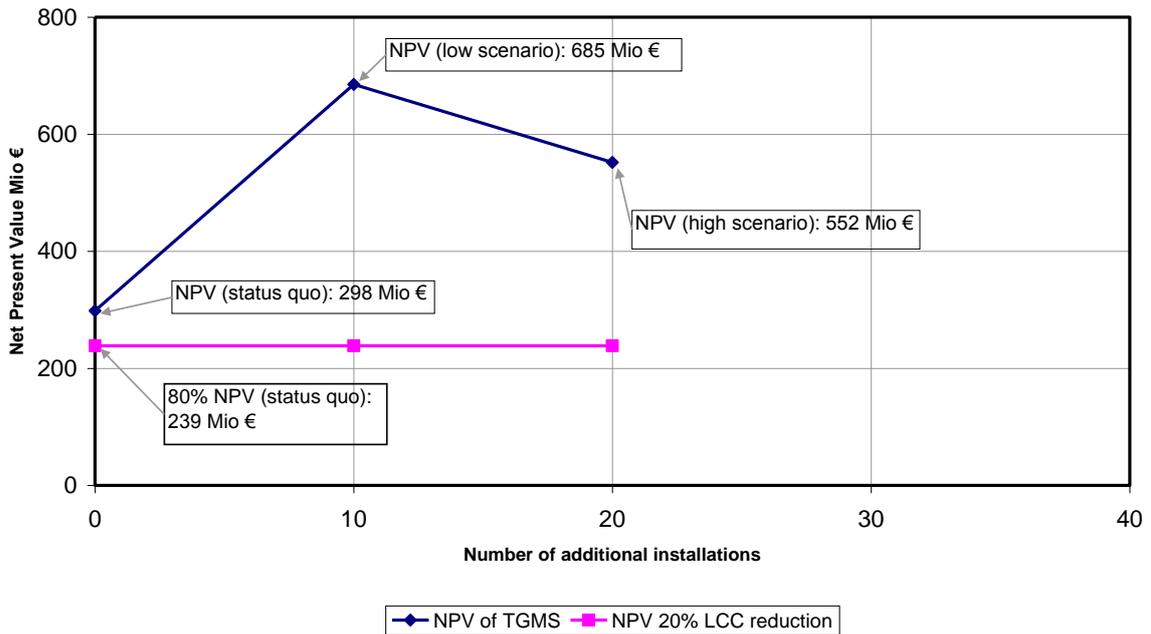


Figure 25: NPV of TGMS with assumed detection reliability of 60% (high scenario) and 45% (low scenario)

Net Present Value reg. TGMS - 90% detection reliability

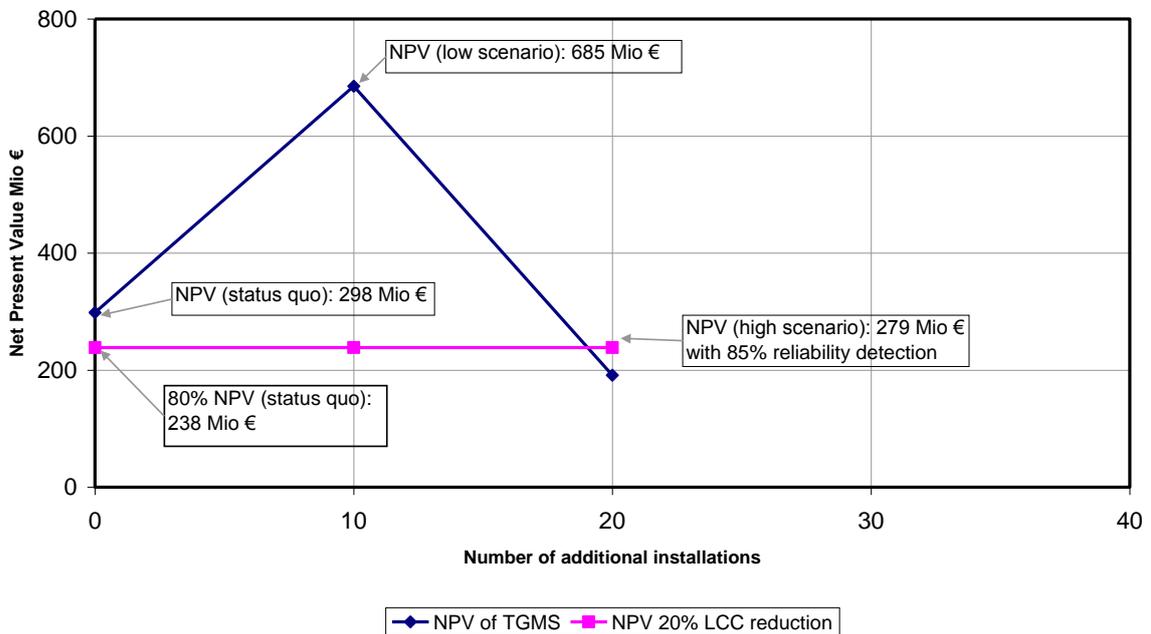


Figure 26: NPV of TGMS with assumed detection reliability of 90% (high scenario) and 45% (low scenario)

The following Table 22 summarizes the LCC results carried out for the three proposed monitoring systems in terms of the evaluation of additional number of installations to achieve the aimed 20% LCC reduction.

Table 22: Summary of the NPV's based on LCC analysis and additional installations needed for 20% LCC reduction

Monitoring systems	Scenario	Assumed nr. of additional monitoring sites	Assumed measuring accuracy of the considered measure [%]	NPV ("status quo") [Mio €]	NPV (80% reduction= 20% LCC reduction) [Mio €]	NPV (up to 2050) [Mio €]	Required nr. of monitoring sites to achieve 20% LCC reduction
HABD	High scenario	790	91	1.772	1.418	633	330
	Low scenario	160	9	1.772	1.418	1.707	
ALC	High scenario	300	98	1.336	1.069	230	40
	Low scenario	120	90	1.336	1.069	448	
	Low scenario	120	50	1.336	1.069	1.985	210
TGMS	High scenario	20	60	298	239	552	not possible
	Low scenario	10	45	298	239	685	
	High scenario	20	90	298	239	191	20

Particular emphasize should be given to the fact, that the performed LCC analysis is based on the provided data by WP1 (D1.1, D1.2) and WP4 (D2.2, D2.3) as indicated in the In/Out frames regarding the definition of the boundary conditions.

The presented Cost/Benefit analysis and the LCC analysis demonstrate that the two monitoring systems (ALC and TGMS) are beneficial based on the used data and assumptions, particularly regarding the potential derailment prevention and the detection reliability.

The findings of the performed LCC analyses demonstrate that the D-Rail objective of 20% LCC reduction can be fulfilled by a certain number of additional installations linked with the needed detection reliability concerning the three monitoring systems, which is indicated in the following:

- Regarding HABD: with a detection reliability of 91% 330 additional installations are needed to achieve a 20% LCC reduction. The break-even point in the LCC analysis can be reached after three years (high scenario) and eight years (low scenario)
- Regarding ALC: with additionally 40 ALC devices (by detection reliability of 98%) and 210 ALC devices (by detection reliability of 50%) respectively the aimed 20% LCC reduction can be achieved. The break-even point can be reached in the first year for both cases (high scenario and low scenario).
- Regarding TGMS: the LCC reduction by 20% cannot be achieved which is owed mainly to the fact of the assumed detection reliability of 60%. Thus a break-even is not given in the LCC analysis. But a higher detection reliability of 90% and associated derailment reduction ensures the benefit in terms of 20% LCC reduction.

Given the LCC outcome regarding HABD, a density based approach and risk-related decision shall be aimed for the placement of HABD to match the trend behaviour. For instance the definition of a minimum target density, e. g. 150 km, would still catch every linear case with a gradual increase from 36° to 95° (Schöbel, Karner, 2005), whereas a steeper temperature increase as a non-linear behaviour requires a higher density of HABD.

However, focusing more on ALC would lead to more financial benefits. So the installation of additional ALC generates more benefit than installing additional HABD, as there are already many HABD in use. And the safety business case (see D7.2) is already marginally efficient on its own. Similarly to HABD, the density approach for ALC shall be risk-related decision based on his (IM) own risk assessment (CSM-RA). However, firstly the placement of ALC shall be

focused at specific corridors with neuralgic points (bridges, tunnels), border-crossings and loading stations. The further deployment can be done iteratively.

The same goes for TGMS since TGMS shows an even better efficiency ratio in the Cost/Benefit analysis. The safety business case (see D7.2) is already marginally efficient on its own, but combined with maintenance effects the business cases become much improved. The track is the most interesting part for maintenance optimization as it is the biggest single cost block of an infrastructure manager. So TGMS becomes very interesting as it has the highest potential maintenance cost optimization (15 Mio € as indicated in section) by performing Condition-Based-Maintenance strategy (see 3.7.3 of this report). In this respect the prediction of trend analysis and performance of the right intervention action can only be ensured through accurate measurement data and reliable assessment. This would enhance the transition from corrective maintenance to enhanced condition-based and predictive maintenance.

It's obvious that more benefits can be derived from a better usage of the collected measurement for maintenance activities. One method of data collection is to enhance on-board devices monitoring the status of vehicles, advanced recording cars and regular trains equipped with monitoring devices. The benefit can be manifested in a reduction of the maintenance budgets by more efficient and effective monitoring of the railway infrastructure and rolling stock and a better control, planning and balancing of maintenance and renewal activities.

Assuming the number of measurement cars to be 20 (high scenario) for all of the member states, an inspection interval of every two year can be performed. This number of additional measurement cars might be sufficient to identify rough failures, but not sufficient enough to catch more relevant failures in order to predict trend analysis. Thus the focus regarding TGMS should be on obtaining of additional benefits rather than on additional deployment of installations.

It may be proven that the risk reduction (and the increase of safety respectively) regarding TGMS is not only dependent on detection, but also on intervention as stated before. In addition, the increase of detection reliability of TGMS is the more efficient approach to achieve benefit instead of increasing the number of installations.

Of course, a combination of these systems is possible, which is more or less shown by the matrix in Figure 17 and Figure 18 of this deliverable.

6.8 Discussion of result

The investigations of the business cases shown in Table 14 in respect of LCC-reduction due to derailments show generally speaking, that HABD are of minor interest in the D-Rail scope. This reflects the fact that countries with focus on high automation in technologies already installed many of them in their network. The number of first installations for countries with focus on low automation is comparably small, as long as the focus is only on derailment prevention for cargo trains. In addition, the effects on maintenance optimization for axle bearings are limited.

Both ALC and TGMS are reasonable from a safety perspective, and both show massive positive effects on maintenance optimization, ALC for vehicles and TGMS for the track. Even though TGMS show financial benefits in the cost benefit analysis, but the target of 20 % LCC reduction can only be achieved as provided that the measurement accuracy is high (about

90%). These outcomes are based on the provided input data mainly from WP 1 and WP 2 and assumptions made between WP 5 and WP 7. More details can be found in D7.3 and chapter 6.7.

The IM may be more interested in the latter, as he pays the costs and collects the benefits, while ALCs are more interesting for the RU/ECM.

In Chapter 6.7, the results from the LCC assessment in WP 7 are presented. This approach differs from the safety assessments in D7.2 in the following aspects:

- Purely financial, e.g. no risk-related decision principles such as ALARP or GAMAB are used
- Use of discounting, which makes the prevention of derailments in future less valuable than preventing derailments today

As the comparison between the RSSB and SBB methodologies already showed, the use of a different standard may come to different numbers of required installations, but the general outcomes are in line.

The final arbiter of the number of systems and their placement must be the risk assessment on the level of every IM. Usually this assessment is a mandatory step to estimate the necessity in the respective risk landscape.

7 Implementation and migration

This chapter will focus on implementing a framework including remarks on the timeline and estimated costs in order to fulfill the aim of reducing the derailment related LCC by 2050 up to 10 - 20 %.

The following topics have to be regarded:

1. European wide harmonized assignment of assessment values from WTMS and/or OMD with individual asset components, e.g. by RFID, GPS, etc.
2. European wide data exchange format for technical data coming from WTMS and/or OMD
3. Implementing an data exchange procedure within Europe including data base management
4. Agreement among all involved parties about assessment and intervention procedures including values, consequences, rules and responsibilities
5. Installation strategy for additional WTMS and/or OMD

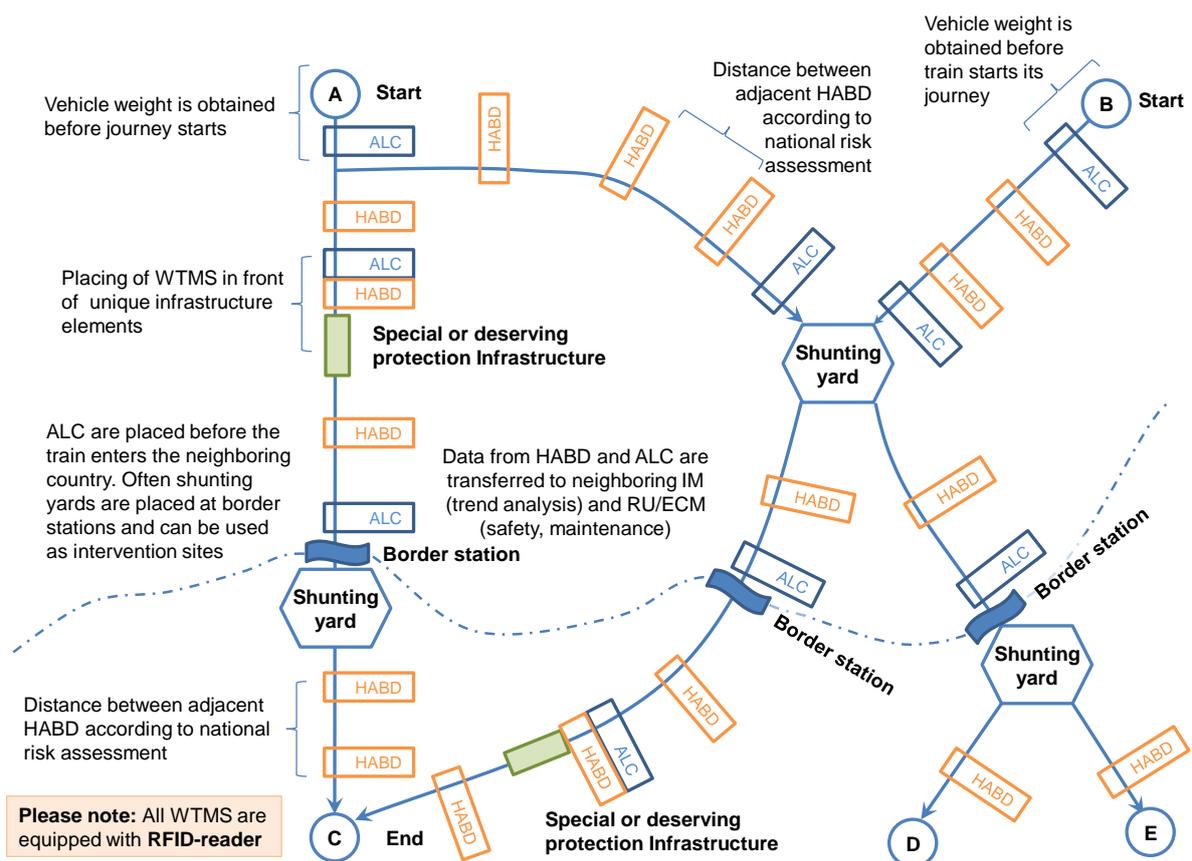


Figure 27: Placing of WTMS for block trains (left) and full-load trains (right) in 2050. It has to be noted, that all WTMS are equipped also with RFID reader. Here only the case of one way-traffic is shown. For bidirectional traffic ALC has to be implemented on both sides of the border.

The implementation strategy of WTMS for block trains and full-load trains in 2050 is shown in Figure 28. It is difficult to draw a picture, where the placing of additional WTMS is

highlighted due to the fact that many countries already started implementing WTMS. Therefore basic principles for placing, mentioned in the text before, can be seen, e.g.:

- The individual axle loads and vehicle weights of a train are gained, before the train gets into service, either based on information from the loading process, with the help of on-board monitoring devices at every vehicle or due to ALC. This gives not only the correct picture of individual axle loads and vehicle weights, but also an examination about any load imbalances. If too many ALC are needed for that, the devices can be mounted at dedicated sites, where many trains are passing and a shunting yard is nearby to handle trains in a case of a wrong loading regime.
- ALC are installed before trains are entering a neighboring infrastructure, so that the facilities and staff at a border station can be used for eventually required vehicle treatments. Figure 28 shows an example for an already implemented solution of SBB.
- Shunting yards are equipped with ALC, before the train enters the yard, so load imbalances or any other changes compared to the initial values can be detected
- The distance between adjacent HABD is determined by the national risk assessment
- Depending on the national risk assessment further HABD and/or ALC are situated in front of special infrastructure elements like long tunnels, bridges, etc.

A completely different picture could be observed if all vehicles are equipped with on-board diagnostic devices, which are measuring the individual axle box temperatures, brake situation and axle loads in 2050 and send the information directly to the driver, resp. RU and IM. Some disadvantages of this case are discussed in chapter 6.6.5.



Figure 28: Example of SBB: Installation strategy of WTMS for trains, entering Switzerland: Installing of WTMS in a neighboring country and operating WTMS by SBB or the neighboring IM in order to ensure a treatment on shunting yards at the border station and to ensure track availability.

The second key issue is the question of data exchange between different parties. The generic approach for integrating values from different measurement types was discussed in detail in chapter 4 of D 5.1. Further recommendations were given in chapter 5.3 of this deliverable. A sketch of data flow in 2050 is given in Figure 29. Basic principles about safety responsibilities as well as transferring data in a sense of a wider information exchange are integrated. The description starts with pre-requisites followed by relevant data exchange routines and a description of the role of some relevant parties.

The pre-requisites discussed in D 5.1 and in this deliverable are integrated, e.g.:

- A connection between the national vehicle register and RFID-tag of all vehicles is provided by a central data broker. This is a key factor for the following point
- The ECM/VO provides information about the configuration of the individual vehicles. Only then trend analysis or state dependent maintenance of individual vehicle components can be performed, and/or maintenance actions are verifiable
- The IM provides information about the configuration of the railway network
- The train composition including the vehicle ID is provided by RU before the train gets into service
- A unique train operation number, the route and the timetable for the complete journey is generated before the train gets into service. Not only all involved IM, but also all involved RU have to find an agreement.

The following data flow is implemented:

1. The IM obtains data of all WTMS (including RFID readings) and transfer them to a central data service. Additional data is stored for maintenance reasons of the devices, in order to ensure their assessment quality.
2. IM informs in a case of exceeded intervention threshold the RU, who is still responsible for taking actions. Due to enhancements of the general railway law also the IM is allowed to take actions (because of better knowledge about stopping of trains at places with lower disturbances for the rest of the traffic). In any case, the ECM/VO is informed about such incidences.
3. Neighboring IM can use the data of 1., in order to investigate trend alarm behavior of single vehicles or to perform cross checks with historical data, if one vehicle is peculiar.
4. ECM/VO are able to make a query about the mileage and loading history of their fleet in order to enable a state dependent maintenance strategy.
5. IM as well as RU and ECM report severe incidents to the NSA. This information exchange enables an enhancement in the railway sector

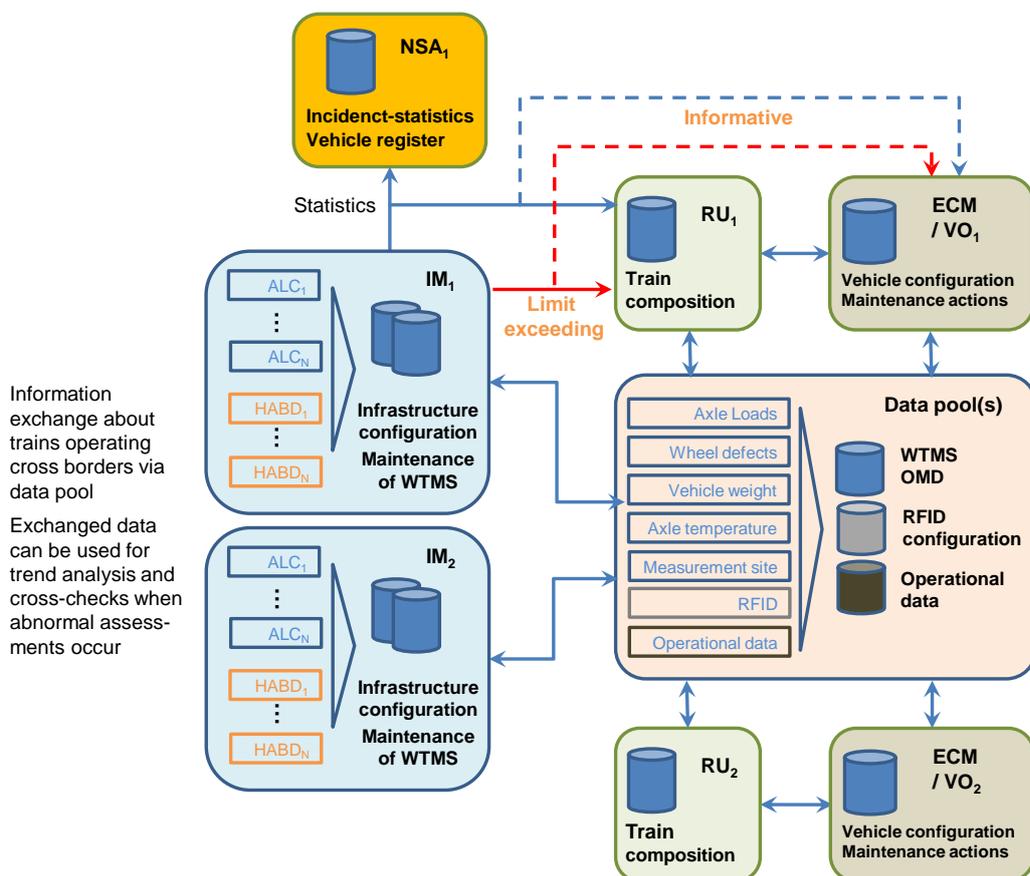


Figure 29: Data exchange procedure for WTMS and OMD in 2050

7.1 Time schedule

Due to the fact that many topics were dealt with in former projects – or in the past missing technological gaps were recently closed with the help of new developments – many of the needed pre-requisites are already available, but were perhaps not used in this more general

way. Therefore it seems finally to be feasible to start with implementing the schemes discussed in D-Rail.

Installation of new and/or additional devices

As shown in chapter 6, new and/or additional devices have to be installed. Countries (a) with a focus on high automation will have a slightly different implementation strategy than those countries (b) with a focus on low automation. Financial aspects are in both cases the limiting factor. None of the railway entities is able to invest at once, so the implementation will take years.

Countries of the group (a) already operate their installed devices. Due to the recommendations of chapter 7 it could be necessary, to install additional devices at single spots. This number will be small compared to the amount of existing devices, so this could be finished within 5-10 years. If the already existing devices have missing functionality (e.g. providing of new protocols, post processing or network access) they will be exchanged at the end of their life cycle. It is expected that no additional financial resources will be allocated, in order to shorten this period. A time span of 15 up to 30 years may be assumed before all devices are changed.

Countries of the group (b) have the advantage that they can implement devices, which enable all needed functionalities. Again, financing will be the limiting factor. The number of needed devices depends on the local risk assessment including network and traffic characteristics and other factors. It is assumed, that the installation period should be finalized in a period of 5-10 years.

The installation strategy for additional WMTS and/or OMD will be a responsibility on a national level. D-Rail can mainly serve to give guidance on reasonable implementations based on practical experiences and theoretical models developed in this project.

Data exchange (protocol types, etc.)

Due to the described fact that many different solutions already exist and are operated, only a short implementation period is estimated for this topic. Again, financing will be a limiting factor. Network communication facilities have to be built up – or existing ones might be upgraded. It is estimated that all resources and implementations should be available in a shorter period than 5 years.

Generic data exchange (harmonization of interpretation)

For countries where no WTMS are currently installed or only first installations are tested the generic data exchange can easily be integrated and should be therefore considered in the procurement procedure for national data and intervention center.

Countries with already existing networked WTMS have the opportunity to upgrade their interfaces by application of the generic approach to overcome the shortcomings of the bilaterally harmonized approach. This helps them to reduce the number of protocols and interfaces and thereby the related costs.

Legal framework

Different aspects have to be regulated, like European regulations, TSI, national laws, technical standards, maintenance processes and regulations, etc. It is difficult to give a correct and valid time span for this item. It depends much on the political power and the

conviction in the railway sector, when they will be implemented. They are often very interlinked with each other, so it is assumed, that the complete process will take more than ten years.

Other aspects

These activities should be based on existing implementations and experiences as a starting point. A Europe-wide harmonized assignment of assessment values from WTMS should be carried out as a starting point. Interested European IM have to agree on the allocation procedure for WTMS data. A European wide data exchange format and a reference implementation for the generic approach developed and described in chapter 4 of D5.1 can be established subsequently. Finally, the data exchange procedure among different parties, including IMs and possibly RU/VO must be fixed.

OMD are not as mature as WTMS, but encouraging signs are visible. The use cases are less straightforward, but the approach developed for WTMS should consider at least the possibility to be sufficiently generic to integrate OMD data when available.

7.2 Costs

Costs for the development of a standard and a reference implementation are difficult to assess. In practice, it depends on the number of active participants, which are those that issue requirements and change requests. Passive participants do not affect budgeting significantly.

As an example a similar EU-project described, the Schengen Information System SIS II. This system shows many similarities to the solution discussed here and contains all the same process steps. Every country has several generations of passports in use, some machine-readable, some with microchips, some with biometrical data. There is no uniform EU passport, but many national implementations. Virtually all countries have developed national databases before SIS and SIS II. Several generations of passport reading devices are in use at airports, border crossings or in mobile devices used by police forces. SIS II contains many different data types about passports, stolen goods, finger prints or arrest warrants. Usually, every country has one or several preexisting other databases for these data and other police matters, which must be integrated. The SLA parameter requirements are high, since millions of passengers use EU airports and other borders every day and a non-functioning SIS or SIS II will impact efficiency and border control times dramatically. The same goes for ID controls performed by police. If a SIS search cannot be executed, it is possible that a wanted criminal will walk away from a police control. Every country has thus opted for a national copy (N-SIS) that is synchronized with a duplicated central instance (C-SIS). No instance, even the central one, is required for the whole to work, and even direct N-SIS to N-SIS connections are allowed, to work around heavy load situations. The data exchange between the N-SIS and C-SIS is strictly standardized while the national use cases and processes remain fully under the national control. Generally speaking, SIS II has many similarities to the requirements discussed in the present chapter, and has certainly a higher daily load than a future railway data exchange would generate.

It has been shown in the Schengen Information System SIS II project that if a high number of participants issue requirements and change requests, the budget will explode from an initial estimation of 14.5 M€ to almost 200 M€. As a practical guideline to estimate such projects,

every active participant will increase the required budget by 30%, which is an exponential increase.

Based on SIS II costs, one active participant will require about 1 Mio €, five will require 3 Mio €, ten about 10 Mio € and thirty about 300 Mio €. A formal consultation process is thus required to obtain reasonable cost estimations, and a professional requirements and project management support is required to stay within the estimate.

As described in the previous section, the installation strategy for additional WMTS and/or OMD, and thus the attendant costs is a purely national matter. However, from an EU point of view, it may make sense to provide additional funding to some countries to accelerate this process.

8 Conclusions

The risk- and LCC-assessment of WP 7 shows, that the proposed LCC reduction by 10 - 20% of all derailments and the reduction of severe events by 8 - 12 % in 2050 is possible. In order to reach this goal some European wide measures as well as some national based ones have to be taken. The implementation of them will change the railway sector to the better. Even if harmonized pan European solutions are preferred, every actor has to assess their individual risk factors. Therefore the proposed installation strategy of additional WTSM and/or OMD can't be homogeneous for all of Europe (not to forget about the already existing variability in Europe). Different national risk assessment criteria and the local conditions will lead to different optimum solutions, like e.g. geography, climate, infrastructure network conditions, traffic mix, speed, vehicle types, commodities of goods, etc. Taking into account further systems installed not only due to safety reasons but also due to customer needs, the variety will increase additionally.

But it is not only the number of installations which counts. Another central key aspect is data exchange among different parties as well as across different countries. Different activities have already started in this field. Individual solutions are available following their specific interests – but they might not focus on this wider D-Rail perspective. Some selected examples may be given, e.g.:

- Exchanging wagon events between RU via ISR, see [19]
- Exchanging vehicle maintenance data between RU and ECM via the maintenance regulation VPI 08, see [08]
- Exchanging real time operational data of freight and passenger trains between neighboring countries via Train Information System (TIS), see [21]
- Implementing RFID in rail, see the requirements defined in [22] and an example of combining them with WTMS in Sweden described in [23]
- Combining different types of WTMS in an intervention center, see an example in [24]

It is seen, that basic IT questions, like transaction protocols, safe communication interfaces, firewalls, server solutions are solved. The interesting fact is that the mentioned examples use protocol descriptions based on xml. This type of protocol is very flexible for any extension. But what is missing today? Operational data has to be combined together with technical data derived from WTMS and/or OMD and last but not least combined with individual assets.

Here shall be the future development. It was shown, that this topic is not treated sufficiently in any of the existing regulations or even in any of the TSI.

Actions due to potentially improper vehicle and/or infrastructure states are only possible and economical beneficial for the whole railway sector if the data exchange includes more than the bilateral contracted parties. Measured and interpreted quantities have to lead to actions, either to prevent derailments or to save money due to state dependent maintenance. One precondition for this is to enhance the legal framework. When implementing the business cases proposed here, every actor needs a clear legal basis for knowing about their duties and responsibilities. Even if a pan European usage of all proposed concepts will take some time, there is a transition needed. The framework of the successfully implemented general railway law needs some extensions, when using data from WTMS/OMD. As discussed, this gap is not filled by the Regulation (EU) N° 1078/2012 on the CSM for monitoring.

Another aspect of data exchange deals with interpretation of the content of the data. Data from different systems, supplier, locations, etc. shall be transmitted in future among all parties and across borders. Although it is expected that the harmonization of intervention concepts and thresholds in Europe will take its time – or is in some cases due to comprehensible reasons impossible, a first interpretation of the data can be harmonized (see 5.3.3). For this reason a generic approach was developed, which enable to integrate all kind of measurement data.

Based on the risk and LCC assessment a suitable number of additional systems was provided in order to reach the proposed aim of reduction in 2050. The installation strategy is then dependent on the individual risk assessment, as pointed out above. Therefore it is estimated, that countries with an already existing detection network will increase the number of installations only marginal until 2050. It is expected that here the emphasis is more on data usage and data exchange. One beneficial action will be to change towards state dependent vehicle inspection and maintenance routines. Enhancements in maintenance regulations will be developed and implemented. Those activities will also be beneficial for countries with a recent low level of automation. They can benefit from these developments when they start installing their detection network.

The economic pressure is challenging for the railway sector. A need for a change is there – and many approaches as well. A diplomatic and wise political guidance is necessary, in order to focus the lines of development and already existing solutions.

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Appendices

8.1 Appendix 1: The Ramsys Platform (MerMec)

MerMec offers a product, in which condition-based maintenance processes can be treated. The platform Ramsys consists in four main steps: data collection, data analysis, planning and control.

8.1.1 Data collection:

Data collection includes condition data from surveys by measuring vehicles and other inspections, maintenance and renewal work data, and operational data, such as number of trains, and tonnage.

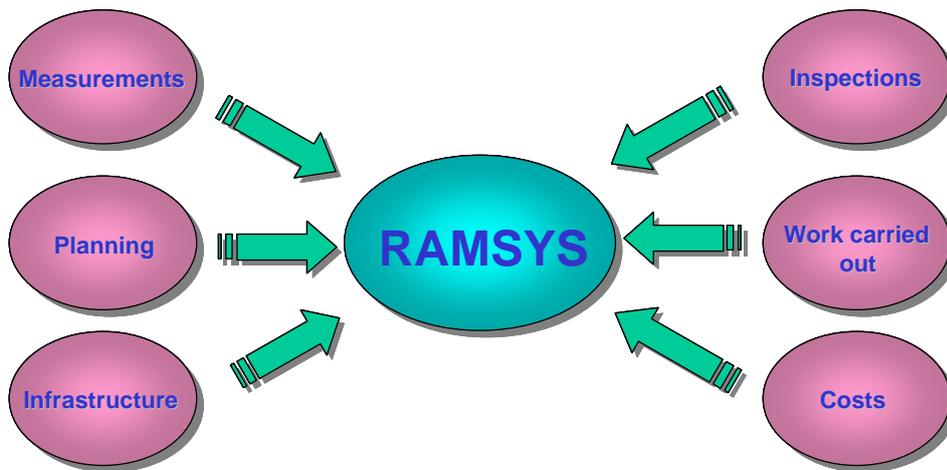


Figure 30: Data input needed for Ramsys (MerMec)

RAMSYS provides a set of data-exchange Tools to import existing data. Direct download of data from monitoring systems, dedicated recording trains, maintenance vehicles eliminates redundant file management and thereby allow the construction of an efficient data base.

Moreover, each data input in RAMSYS is automated and verified as much as possible to have the best data quality and correctness.

8.1.2 Data analysis:

This is the data processing step that produces, from a data alone, or in correlation with other data, new information such as defect, key performance indicators or rate of deterioration.

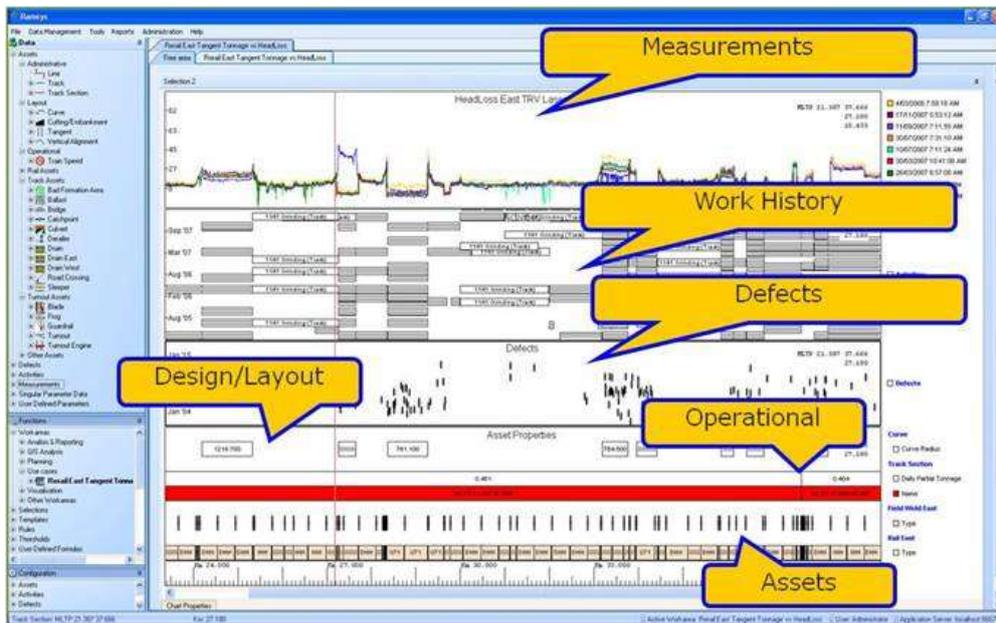


Figure 31: Ramsys analysis results

Typical data analysis in RAMSYS consists in different features, such as measurement localization and data verification, correlation of several data types, generation of derived data such as defects or new parameters and time-based condition data analysis.

Having several consecutive measurement and their analysis over the time allows detection of deterioration trends that enables forecasting of asset behaviour, and therefore planning of action before measured information reach critical thresholds, and so before a defect appears.

8.1.3 Maintenance planning:

It consists in the preparation of maintenance plans to be scheduled requiring additional data to assess where, when and what maintenance is really required. This is based on intelligent business rules and thresholds.

RAMSYS performs automatically various analyses, like deterioration modeling and optimisation in order to reach optimal maintenance and renewal plans.

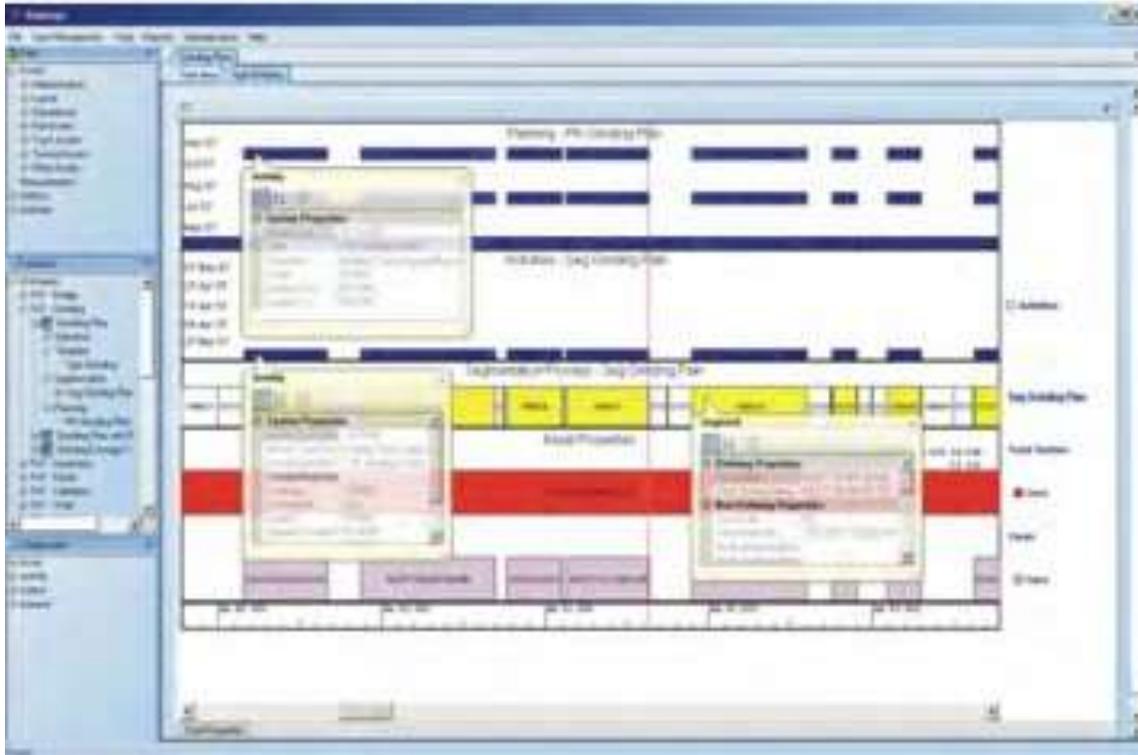


Figure 32: Output: Automatic generated maintenance and renewal plans

8.1.4 Maintenance control:

This phase consists in checking the outcomes of the executed maintenance activities.

It is possible to incorporate and refine existing maintenance strategies and policies defined in official railway standards and specifications. RAMSYS sustains analytical processes that control current maintenance tasks, estimate future maintenance needs, and helps ranking renewals or assess the impact of alternate maintenance scenarios.

RAMSYS is built as a software platform where all the different maintenance processes are designed, with the use of preventive and predictive models. It is composed of modules that can be integrated according to the needs of any application. Some of these modules are listed below:

- Infrastructure modeling
- Inventory of singular assets
- Characteristics of singular assets
- Predictive modules for asset deterioration modeling
- Maintenance planning module
- Resource optimization module