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 the overall objective of **increasing safety levels** regarding derailments even though traffic levels are expected to rise as well. This is quantified by a target of a proposed LCC reduction by 10 - 20% for all derailments and a reduction of severe events by 8 - 12 % in 2050.

D-Rail shows that more than half of all derailments (and a share of 75% of the costs) are addressed by only three types of interventions: hot axle box and hot wheel detectors, axle load checkpoints and track geometry measurement systems. While new technologies and their application were studied, notably regarding onboard devices, **the targets are achievable with existing technologies**, if properly deployed, developed and coordinated. The RAMS analysis includes decision making on selection of equipment according to the reliability and maintainability, evaluation of an applicable and effective maintenance strategy and assignment of the optimum and cost effective interval.

D-Rail in WP7 performed a **risk assessment** with reference to the Common Safety Method on Risk Evaluation and Assessment. Since no European reference implementation exists, the risk assessments were independently carried out using the SBB and RSSB methodologies to estimate the numbers and sites of systems that could be deployed from a freight perspective.

Based on the outcome of **LCC analyses**, axle load checkpoints and track geometry measurement systems show a good ratio between costs and benefits. The outcome of cost-benefit analyses considering hot axle box detection are not favourable due to the density-based placement strategy, the already widespread use and the low maintenance benefits.

The divided role and responsibilities of IMs and RUs poses new questions due to the use of monitoring systems. Installed WTMS owned and managed by the IMs are increasingly stopping non-compliant vehicles of the RUs and ECMs, principally with the aim of protecting the infrastructure from damage (i.e. not to prevent derailments). The present legal framework has to be adapted for future needs since **roles and responsibilities of the actors** like IM, RU and ECM **change**. Most notably the IM gains better insight into individual vehicles requiring maintenance than the RU and ECM, whereas the impression arises that RU/VO lose their technical competence in the field of wheel-rail interaction.

This should however not be construed as a risk transfer, because that would have a damaging effect on safety. Infrastructure managers could evade the risk transfer by not deploying WTMS and thus miss an important tool in augmenting safety. A **regulatory climate** that facilitates and does not hinder WTMS deployment is necessary. Additional legal risks relate to intentional acceptance of residual risk (by less restrictive thresholds or less than perfect system densities) or unintentional risks due to human error, deficient equipment, maintenance windows.

Every country is facing different challenges due to the diverse legal framework and safety management approach, but also other relevant boundary conditions are significantly different due to geographical conditions, such as curve radii and track steepness, track utilization, low temperatures, occurrence of natural disasters or the amount of

infrastructure elements such as tunnels and bridges. This translates into infrastructure-specific alarm and intervention thresholds and intervention actions, for which a **full harmonization** is **unlikely**.

Railway undertakings and vehicle owners suffer from this situation, which can only be addressed by **data exchange**. The generic approach developed in D-Rail, based on exchanging raw data and a recommended interpretation, is a simple solution for the required exchange between IMs as well as from IM to RUs and ECMs. From the IM perspective, it allows integration of different existing equipment and multiple types and generations of WTMS. All actors can also derive non-safety benefits such as information on the quality of the operated rolling stock, reducing delays, certification, maintenance cost optimization, intervention planning after defect detection and providing delay estimations to customers.

Basic questions to data exchange such as transaction protocols, safe communication interfaces, firewalls and server solutions are solved. The remaining problems lie in the **assignment of the operational to the technical data**, e.g. matching a vehicle ID to the measurement from a wayside train monitoring system or identifying the same section of track from multiple TGMS inspections. This topic is not sufficiently treated in the existing regulations or even in any of the Technical Specification for Interoperability (TSI), although technical solutions, e.g. based on RFID are available.

Currently, many systems are already deployed in Europe. Some countries rely heavily on **automated techniques**, where others are only beginning to see the potential for automation. Those that heavily use automation are more interested in getting the biggest leverage out of their investment and want to 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. It seems likely that the increase in traffic as predicted in D-Rail will shift most countries to technological solutions.

The cost-benefit analysis reveals the **significant potential maintenance cost optimization** based on the efficiency gains of using monitoring data to perform Condition-Based Maintenance instead of Time- or Interval-Based Maintenance. It is noteworthy that the quantitative results agree with operational experience in the U.S., where maintenance plays a very prominent part in the business cases for monitoring systems. Given the provided data, findings and assumptions in D-Rail, the LCC analyses demonstrate that HABD and ALC bring financial benefits in terms of 20% LCC reduction. This as set out as one of D-Rail targets can be achieved by TGMS provided that a measuring accuracy of 90% is ensured. But TGMS has the highest potential maintenance cost optimization

The economic pressure is challenging for the railway sector. As shown in D-Rail, 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. Since these discussions lie on the interface between infrastructure managers bearing the costs and railway undertakings/entities in charge of maintenance deriving the benefits, an **active role of**

supranational bodies would help develop these potentials within a short timeframe for the railway system and society as a whole.

It is noteworthy, that the implementable results from WP1 to WP6 are referred to in the introduction part and presented in chapter 3 extensively. In fact, the WP5 findings are considered as essential input for the present deliverable, since the development and implementation of monitoring concepts are the core issues of WP5. For that reason the WP5 results related to implementation scenarios are described in detail. These coupled with the findings and recommendations from WP1 to WP7 ensure the needed input for the proposed guideline in terms of recommendations and description of the reliable implementation scenarios for the use of monitoring systems.

Given that, this deliverable should not be considered as a guideline even though the title might imply. However, this deliverable does not meet the requirements of a guideline fully, but serves as a good base for that, according to the DOW and common understanding within the D-Rail project.

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Glossary

ALARP .... (Risk) As Low As Reasonably Practicable
ALC........... Axle Load Checkpoint
BLS .... Berner Lötschbergbahn AG
CBS........... Cost Breakdown Structure
PBS........... Product Breakdown Structure
CSI .... Common Safety Indicator
CSM-RA..... Common Safety Methods for Risk Assessment
CST .... Common Safety Target
DNV.......... Det Norske Veritas
ECM .... Entity in Charge of Maintenance
ERA .... European Rail Agency
FOT........... Federal Office of Transport
GB .... Great Britain
GRMS.........Gauge Restraint Measurement System
GPS .... Global Positioning SystemHOA Hot Axle Box
HABD .... Hot Axle Box and Hot Wheel Detection
HRMS .... Harmonization – Running Behaviour and Noise on Measurement Sites
ICT............ Information Communication Technology
IM .... Infrastructure Manager
LCC .... Life Cycle Cost
MGT .... Million Gross Tonne
MRR .... Monetized Risk Reduction
MTBF .... Mean Time Between Failure
MTTR .... Mean Time To Restore
NPV........... Net Present Value
NRV........... National Reference Value
NSA .... National Safety Authority
ÖBB........... Austrian Federal Railways (Österreichische Bundesbahnen)
OMD .... On-board Monitoring Device
P2P........... Peer-to-Peer connection
RAMS .... Reliability, Availability, Maintainability and Safety
RFID .... Radio Frequency Identification
RSD .... Directive on Safety of Community Railways 2004/49/EC
RSSB.......... Rail Safety and Standards Board
RU .... Railway Undertaking

SBB............Swiss Federal Railways (Schweizerische Bundesbahnen SBB AG)

SIL ....Safety Integrity Level

SMS...........Safety Management System

SOA ....Struck Brake Detector

SRM ....Safety Risk Management

SMS...........Safety Management System

TGMS ....Track Geometry Measurement System

TSI ....Technical Specification for Interoperability

VO ....Vehicle Owner

VPF............Value of Preventing a Fatality

WTMS ....Wayside Track Monitoring System

1 Introduction

The D-RAIL project aims to significantly reduce freight derailments in the future, through improved understanding of the causes of derailment and the methods for anticipating derailment through measurement of appropriate system parameters. Moreover, the project investigates how independent minor incidents combined could cause a derailment.

More specifically, the main objective of the D-Rail project is to make recommendation to reduce derailments by 8-12% and a cost reduction of 10-20% within Europe. Selecting the right measures to obtain the maximum safety benefits requires an unbiased and objective process.

The goal of this deliverable is to prepare input for the guideline “The implementation of monitoring techniques” based on the related findings in D-Rail. Given that, this deliverable should not be considered as a guideline even though the title might imply. But it serves as a good base for the guideline, according to the DOW and common understanding within the D-Rail project.

However, this deliverable focuses on the recommendations and description of the reliable implementation scenarios for the use of monitoring systems, which is supposed to serve as input for the proposed guideline. Since WP5 deals among other issues with system integration and implementation of monitoring systems, the WP5 findings are considered as very important input for the present deliverable. Furthermore the concerned deliverables of WP5 are confidential. Such being the case the present deliverable is not just referring to the WP5 deliverables, but it synthesizes the WP5 findings related to implementation scenarios in detail.

The first part of this deliverable, section 2, synthesizes the findings based on technical and economic assessments through RAMS anlysis, risk analysis together with risk assessment, the cost-benefit analysis and LCC analyses, performed in WP7. Given that, recommendations for the use of monitoring systems considering the estimated increase in freight traffic by 1.5% annually towards 2050 from WP2 and potential implementation scenarios and related number of additional installation sites from WP5, are provided.

The second part of this deliverable, section 3, summrizes the main findings from the work packages in D-Rail with relevance for the implementation of monitoring systems (national/international). These include the most common causes of derailment but also combinations of causes identified by WP1, the future trends and demands towards 2050 analysed by WP2, the derailment analysis and prevention considering potential mitigation measures assessed by WP3, the assessment of current inspection and monitoring systems by WP4, the development of wayside and on-board monitoring concepts with integration into a wider European system including migration and implementation scenarios by WP5 and finally the field testing and evaluation by WP6.

The third part describes the reliable implementation scenarios for the use of inspection and monitoring systems considering for both national and international needs. This section sets out from the description of cases and concepts, the number and location of inspection and monitoring systems across Europe based on the defined scenarios in WP5, preconditions and framework for implementation, migration aspects, harmonization and system integration at EU level.

Finally, open points and further research recommendations are presented in the last section of this deliverable.

As this deliverable summarizes all of the D-Rail findings, synthesizing the actual conclusions and recommendations, and in order to avoid repetition, this deliverable does not contain an additional chapter on conclusions and recommendations.

2 Summary of the technical and economic findings of WP7

In this section the main findings of WP7 based on technical and economic assessments are presented. These finding result from the risk analysis, risk assessment, RAMS analyses, cost-benefit analysis and LCC analyses. The recommendations for the use of monitoring systems based on the achieved technical and economic results are presented in chapter 3.7.

WP7 developed a systematic data-, RAMS- and LCC-framework to assess inspection and monitoring systems related to derailment based on reliability, availability, maintainability and safety (RAMS) and lifecycle cost (LCC) analysis. With this general know-how, the application of the conceptual framework of RAMS and LCC analysis can be employed for all types of monitoring systems and hence can be used to investigate and evaluate economic benefits to IM's and RU's. To demonstrate the functions basically the three most implemented monitoring systems have been assessed as case studies.

As more than half of all derailments (and at a 75% share of the costs) are addressed by three types of systems, the LCC analysis has been applied as an example. These systems are:

- Hot axle box and hot wheel detection system
- Axle load checkpoint and
- Track geometry measurement system

2.1 Summary of the findings based on technical analyses of WP7

2.1.1 Summary of the findings based on risk analysis and risk assessment

D-Rail is considering a number of possible future "changes" or "systems" with the intention of reducing derailments by 8–12%. In the context of Common Safety Methods for Risk Assessment (CSM-RA) this value might be considered as the equivalent to a safety criteria for acceptability of risk. The risk assessment of these proposed systems was carried out in parallel using GB and Swiss methods of application of the CSM-RA by RSSB and SBB, respectively. Comparison of the results of these two different but comparable methods allows us to draw conclusions on the suitability of the proposed systems.

At this stage the "system definitions" of the proposed methods are relatively high level, and the results of the risk assessment are at a similarly appropriate level of detail. Hazards relating to derailment of freight trains, and in particular those which are affected by the proposed systems, have been investigated and quantified using proprietary GB and Swiss risk data taken from the RSSB Safety Risk Model for GB and the SSB equivalent for Switzerland.

The effectiveness of each of the proposed systems in reducing frequency of freight derailments, and the associated reduction in risk, has already been estimated in D-Rail report D2.3. These estimates have been used as the basis for the risk assessments carried out in D7.2.

The results of the risk assessments indicate which proposed systems would normally be recommended for implementation under the respective safety decision-making frameworks for GB and SBB. However, as these risk assessments have been made using a number of assumptions, and have been generalised for European wide implementation, the unrefined results require further qualitative consideration and rationalisation before final conclusions can be made.

Both SBB and RSSB use similar methods to analyse risk in order to inform a risk based decision making process when considering implementing changes to the Swiss and GB rail network systems. Both are based on using the ALARP principle to compare costs and benefits of a change and using a specified safety criteria associated with an anticipated risk reduction. In GB, for example, this takes the form of the “Value for Preventing a Fatality” (VPF) which indicates the level of justifiable cost expected in order to prevent a fatality. Both the SBB and GB methods are similar and comparable and this is why they were selected to perform a case study risk assessment on the proposed risk reduction measures for D-Rail.

The case study risk assessments carried out by SBB and RSSB for GB used as a basis assumptions derived in WP2 and WP5 regarding potential implementation scenarios and estimated implementation costs. Risk figures related to freight derailment and risk reduction benefits due to the proposed risk control measures have been calculated using SBB and RSSB safety risk data. An assumed timeline of 2020 to 2050 has been considered as the period over which the costs and benefits would be realised. The risk reduction systems considered were:

- Hot axle box and hot wheel detection
- Axle load checkpoints
- Track geometry measurement systems

By applying both SBB and RSSB safety risk assessment methods within the scope of D-Rail, i.e. limited to freight trains, and limited to derailments, and assuming the numbers of equipment installations as laid out in WP 5, it becomes obvious that none of the three measures would normally be considered reasonably practicable under the usual ALARP principle – or any other standard – for wide scale implementation. This is even the case if we assume that the derailment rate increases in line with assumed traffic increases between now and 2050; in this case, therefore the proportional benefits of derailment reduction similarly increase, but the overall ALARP conclusions remain the same. However, if a more focussed strategy for targeted implementation of the measures is considered then the safety case is improved and, in particular, Axle Load Checkpoints and Track Geometry measurement systems become more easily justified as the benefits are higher than the costs. More detailed discussion of the risk assessment results methods and results are given in D7.2.

The outcome of both SBB and GB theoretical risk assessments would appear to disagree slightly with current railway practice in many EU states, where HABDs, ALCs, and measurement cars are widely in use, and considered to be beneficial and appropriate. However, this apparent contradiction is easily explained; limiting the theoretical scope of D-Rail to only freight denies economies of scale as well as synergies with reduction of passenger risk which would typically be exploited by infrastructure managers in justifying a safety case for implementation of a new measure. Considering additional safety benefits beyond the scope of D-Rail would enhance the safety case for implementation of these measures further. The D-Rail scope corresponds much closer to the US situation than the European one. In the US, the business case for WTMS is typically based on maintenance, not safety, which applies to the railway undertaking respectively entity in charge of maintenance and not the infrastructure manager.

Some important conclusions can be drawn from the risk assessment results:

- Synergies between freight and passenger trains should be exploited as much as possible, since the derailment costs and safety impact for passenger train derailments are much higher than for freight, especially when passengers come to harm. As a large part of the freight corridors is used by mixed traffic, freight can benefit from the business case for reducing passenger train derailments.
- Most WTMS are deployed based on the maximum line speed, i.e. a higher density of WTMS will be found on a high-speed line than a line at 120 km/h. There is a trend, notably in France, to separate the high-speed traffic from the rest of the traffic with completely separate tracks, which weakens this correlation, but in most countries freight trains will be found on high speed tracks, allowing them to benefit from the WTMS deployed there. Since this even applies to new constructions such as the new Gotthard tunnel in Switzerland, we do not foresee a trend that would find in 2050 a complete separation. Additional WTMS for freight are required on pure freight corridors. The total number will be much lower than assumed under full-scale scenarios, which will favour the business case.

In addition to the above, it should be remembered that the ALARP conclusions of the case study risk assessments are based on average national freight derailment risk levels currently estimated for Switzerland and Great Britain. It is likely that in states, or specific locations, where risk levels are higher than these assumed levels, the potential for improvement in safety is likely to be higher and therefore more easily justified due to the proportionally higher safety benefits due to implementation of proposed control measures. This might be the case where higher derailment rates have been locally observed, or there is a higher than average density of mixed traffic, or for dangerous goods corridors where potential consequences of a derailments are higher.

2.1.2 Summary of the findings based on RAMS analyses

Within W7, a conceptual framework on “RAMS (Reliability, Availability, Maintainability and Safety) and LCC Analysis” has been developed (see Fig. 1). The proposed RAMS and LCC framework deals with failure management, prevention, elimination, and the reduction of the consequences of derailment, to an acceptable level. Different disciplines are used in the proposed RAMS framework, e.g. reliability theory, reliability science, maintainability, optimization and Life cycle costing.

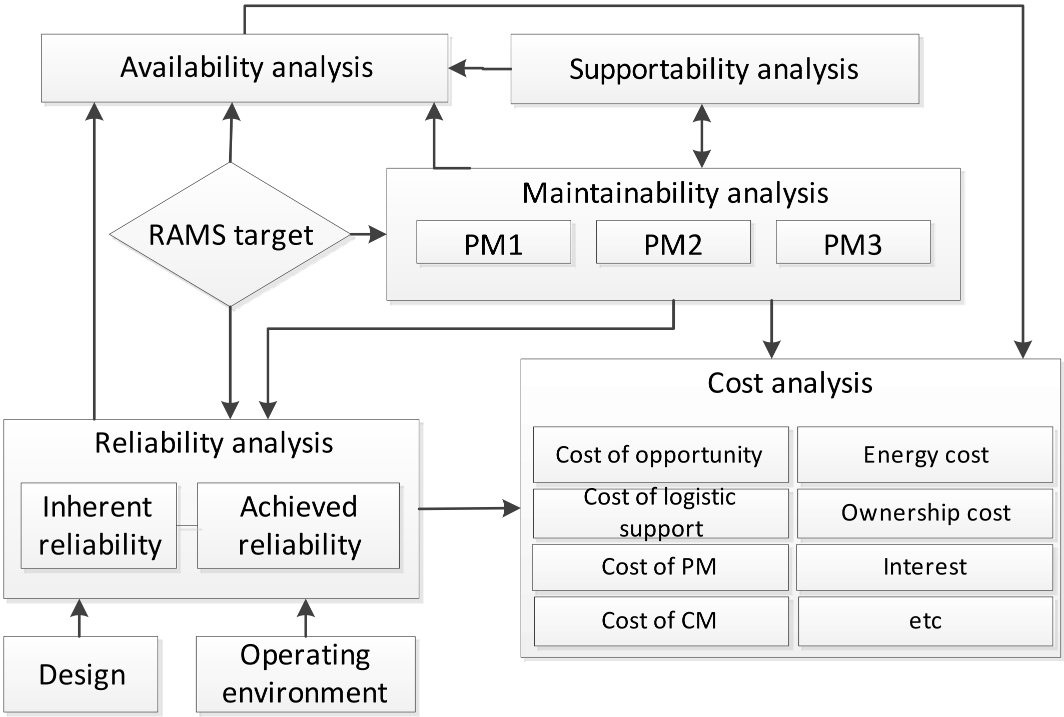


Figure 1: RAMS data analysis framework

The framework set out the concepts that underlie the approach of RAMS and LCC analysis, and explains the key factors, concepts, assumptions, variables, and the presumed relationships and interactions among them.

Within the deliverables of D7.2 and D7.3, a RAMS and LCC analysis process has been proposed which includes the following steps:

- Statement of the problem, definition of objectives, scope and system requirement and specifications
- Identification of RAMS management and related boundaries
- Definition of the boundary conditions, system description and operational and environmental conditions
- Establishment of the basics definitions and target values
- Data collection and preliminary assessment
- Implementation of RAMS modeling, analysis, and validation of RAMS results
- LCC and Cost-Benefit analysis
- Documentation of data and analysis process

The data analysis process for proposed RAMS assessment is also introduced and discussed. In order to verify the developed framework, it has been applied through a case study approach. D-Rail project WP7 D7.2 focuses on RAMS analysis for protective devices. Significant effort has been made by the partners to collect the required data associated with HABD, ALC and Track geometry, to apply the proposed framework.

The data required for RAMS analysis were made available by SBB, and included data from operation and maintenance of HABD's installed at the three sites over a period of two years.

The data includes: Time between failures, operational conditions, type of scheduled and unscheduled maintenance interventions, cost and time associated with scheduled and unscheduled maintenance interventions.

The study presented a flow for data analysis process which includes e.g.: preliminary data analysis and selection of associated appropriate techniques, extraction of information from preliminary data analysis, Identification of appropriate model for reliability, availability, maintainability and safety evaluation, see Fig 2.

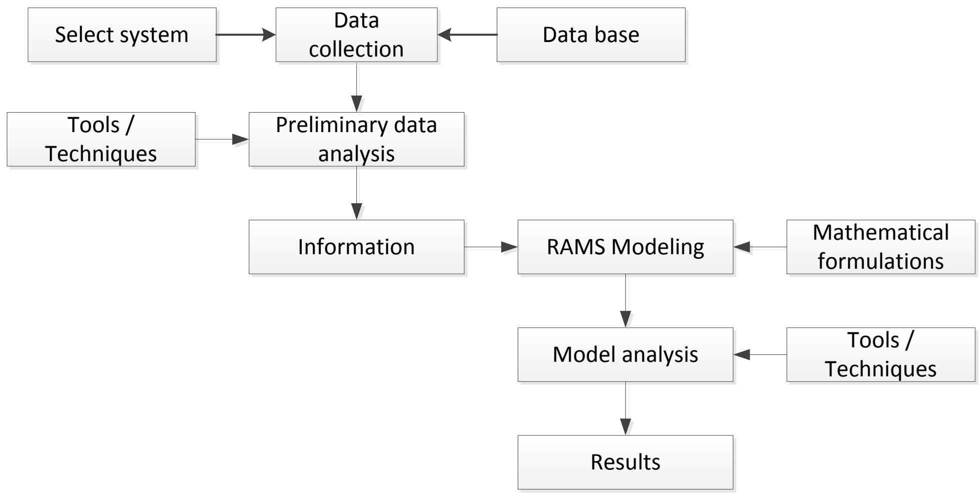


Figure 2: Data analysis process

The preliminary data analysis has been performed to identify the most appropriate reliability model. In the reliability analysis, theories and methodologies from reliability of repairable units and life data analysis has been used to model the reliability behavior of HABDs. In the analysis, appropriate software is used to estimate the reliability model parameters.

Following the results of the analysis it has been identified that the time between failures in some installation sites become shorter after each maintenance intervention indicating that the unit is under aging. The results also show that in one of the other installation sites the time between failures after each maintenance intervention are becoming longer, indicates that which the system is improving. The plotted data for another installation site also indicates that the time between failures of installed HABD is free of trend. Following these results, it can be concluded that the HABDs installed in different installation sites behave differently and making a general conclusion is not valid.

It should be noted, that the preliminary data analysis includes statistical test for identically and trend within data as well as dependency test (these tests have been mentioned in D7.2).

The results of the case studies also show that the reliability model of HABD units within may follow a mixture of different stochastic models. Therefore, considering a single model representing the behavior of the whole fleet may not be valid.

There are two major options to compensate for unreliability. These include increasing reliability through design or, implementation of an effective maintenance program. Increasing reliability will lead to fewer failures and may decrease maintenance costs in the operation phase. Lower reliability means increased unscheduled repairs and increases cost.

In order to identify the most cost effective decision, application of RAMS and LCC are needed. Within D7.2, a case study was completed to identify the cost effective maintenance strategy for the HABD installed at the Zgraggen site by SBB. In order to discuss the effect of reliability and maintenance decision on cost, three cases have been selected. Case 1, represents the existing HABD installed at Zgraggen site from SBB, and case 2 and 3 represent an arbitrary HABD with different reliability, but with the same cost parameters as case 1.

Based on the cost model developed within the D7.2, cost per unit of time has been computed for each case along with their associated reliability pattern.

In order to perform reliability analysis, one should consider the quality of maintenance as well as residual life after each maintenance intervention.

Reliability-Centered Maintenance methodology has been used, to identify the applicable and effective maintenance policy. This has been done in collaboration with the experts from SBB. In order to assess the optimum preventive maintenance interval, a “cost-based risk constrained” maintenance optimization model has been developed to identify the most appropriate maintenance interval of HABDs.

Figure 2 shows the variation of restoration cost versus restoration interval for three different HABD’s with different reliability values. The important results are also tabulated in Table 1.

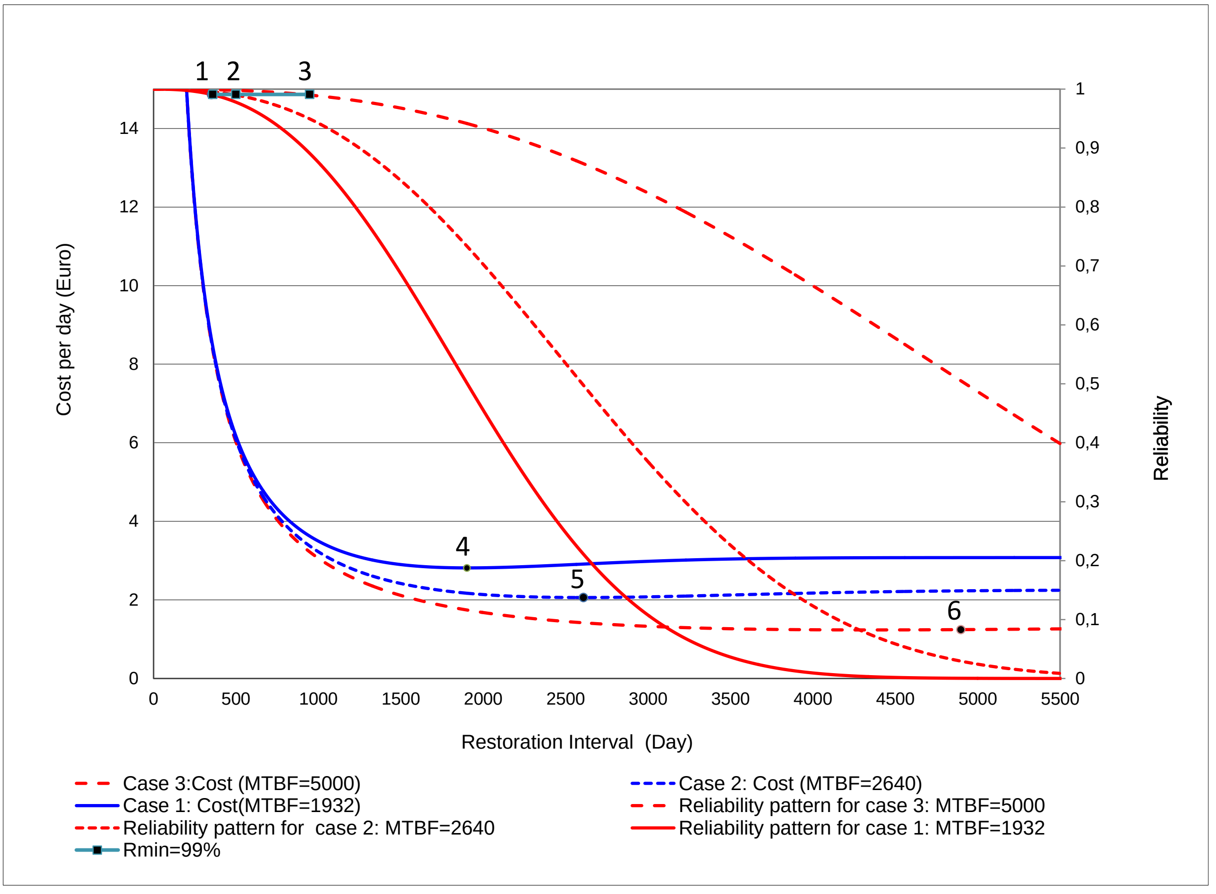


Figure 2: Variation of restoration cost versus restoration interval for HABDs

Table 1: Corresponding MTBF wit and without Reliability limit

	Weibull scale parameter η	Weibull shape parameter β	Corresponding MTBF	Without reliability limit		With reliability limit Rmin=99%	
				Optimum cost/unit of time (Euro)	Optimum Interval T (Days)	cost/unit of time (Euro)	Interval T (Days)
Case 1	2196	2.57	1932	2.81	1908	8.3	366
Case 2	3000	2.57	2640	2.06	2607	6.07	500
Case 3	5681	2.57	5000	1.08	4936	3.22	948

Following the results of the case study, the cost associated with discard is a decreasing function with operating days and an optimum interval does not exist. This is due to the high cost of investment (i.e. 250KEuro) for replacing the old HABD with a new one. Therefore, discard is not an option for decision making. In addition, It was found that under the restoration strategy, there is a specific restoration interval (T=1908 Days) that results in an absolute minimum value of cost function (Cost=2.81 Euro/day).

However, reliability analysis shows that applying the restoration strategy at interval T=1908, exceeds the reliability limit (R(T=1908)=50%) and cannot be selected due to safety limits. Considering Rmin=99.99% as a minimum reliability for HABD system, it has been found that the essential reliability limit does not allow to select the optimum restoration interval, i.e. T=1908 and C=2.81 Euro/days. Therefore, the maximum restoration interval allowed by reliability constrain would be T=366 and C=8.3 Euro/days. This is exactly what the SBB is doing today.

As seen in the figure, higher reliability of HABD (i.e. higher MTBF) will lead to higher safe-life length, when a minimum reliability level (R=99%) is required, see corresponding time in Figure 2 for points 1, 2 and 3, and the values in Table 1. In addition, it is evident that the higher the reliability, the lower the maintenance cost that can be achieved.

It is also evident that when there are no minimum reliability requirements, higher reliability of HABD will lead to achieve an optimum restoration time at longer intervals, and even lowest cost per unit of time, which will lead to the most cost effective LCC, see corresponding cost values in Figure 2 for points 4, 5, and 6 and the values in Table 1.

In fact these portions of cost reduction due to higher reliability of HABD (by design or application of maintenance) might have significant economic consequences, and need to be considered during design and maintenance development activities. This is where the manufacturers and operators can bring all their expertise for further improvement of HABD.

It can be stated that only inspection and monitoring systems with high detection accuracy and availability can provide support in terms of benefit for the infrastructure monitoring and maintenance planning.

As the study shows, application of RAMS and LCC analysis is vital to achieve an efficient and effective decision when dealing with management of protective measures against derailment. This includes decision making on selection of equipment according to reliability and cost figures, evaluation of an applicable and effective maintenance strategy, assignment of the optimum and cost effective interval, and postponement of maintenance, when it is applicable.

Based on the outcome of the D7.2, it is noticed that there is lack of reliable and valid data. Although much effort is done to record the events, the content of the records have not been properly sorted so that they can be used. Hence, it is recommended that in order to have more robust results, one needs to collect more data concerning failure of monitoring systems (e.g. HABD) as well as maintenance.

Since data collection is a time consuming issue, it is recommended to apply the use of Information–communication technology to save time, money and to enhance the results of RAMS analysis.

RAMS analysis also provides a scientific footing for safety and LCC management. The method can also be used for other similar units. If data are available, the effectiveness of maintenance actions can also be considered in the model, with some adjustments.

Summing up, by the integration of adequate modeling the safety and LCC management can be considerably enhanced. Thereby, not only are the safety requirements fulfilled, but a lower maintenance cost might also be obtained simultaneously. This becomes more important when one considers the risk and consequence of derailment e. g. due to HABD and the unreliability of HABD's. By this approach, it is possible to recognize the contribution of RAMS and LCC analysis towards railway operation.

2.2 Summary of the findings based on economic analyses of WP7

Within the economic analysis of the inspection and monitoring systems WP7 performs two 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) considering the predicted increase in freight traffic by 1.5% annually.

The first approach presented is cost-benefit analyses 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) analyses are performed for the three proposed inspection and monitoring systems to evaluate the number of additional inspection and monitoring installations needed to achieve the 10-20% LCC reduction.

2.2.1 Cost-benefit analyses

The safety benefits based on derailment cost reduction (monetized risk reduction) were analysed in D7.2 for hot axle box and hot wheel detection, axle load checkpoints and track geometry measurement systems, which remain as three classes of interventions after short listing within the aims of the D-RAIL project.

All cost figures from LCC and safety benefits on risk assessment cost data were taken from D7.2 based on the cost figures given in deliverable D2.3 (Table 3.4 and 3.5). Additional numbers of installation sites for further cost and benefit categories were developed in close cooperation with WP5 as they were not provided from other work packages.

The cost figures regarding additional benefits result from assumptions - since it is difficult to quantify the additional benefits e. g. from maintenance cost optimization- based on SBB data, experiences from North America and on the study on Heavy Haul Transport in Sweden (see Condition-Based Maintenance for Effective and Efficient Rolling Stock Capacity Assurance [1] and [2]). In this regard it is worth mentioning that there is an EU research project launched in December 2010 called ACEM-Rail (Automated and Cost Effective Maintenance for Railway) in the field of railway infrastructure maintenance organization and planning supported by the European Commission.

An assumed timeline of 2020 to 2050 has been considered as the period over which the costs and benefits would be realised. The monitoring systems considered for the LCC and cost benefit analysis are Hot Axle Box and Hot Wheel Detection (HABD), Axle Load Checkpoints (ALC) and Track geometry measurement systems (TGMS). The reason for that is that more than half of the derailments (and a share of 75% of the costs) are addressed by these three systems and thus they have the biggest impact on derailment reduction.

It must be noted that the avoided costs per derailments, as taking into account in the cost-benefit analyses, should only be considered if these costs are not already included in the derailment costs. For instance the DB data on derailment costs, provided by D1.2 of WP1, are already included in the costs related to derailment and thus don't need to be considered. In contrast to this, the costs for the implementation (in terms of the establishment of the required infrastructure e. g. precise proof of measurement data and needed personal for taking decision on action, real-time data exchange and communication, connection between operation and intervention, vehicle identification by RFID if applicable etc.) are not considered in these analyses.

It should be noted that both in the cost-benefit analyses and the LCC analyses the mentioned optimum scenario defined in WP5 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 overall results of the quantitative evaluation of LCC and cost-benefit analysis referring to the three proposed measures are shown in Table 2 below:

Table 2: NPV of the accumulated costs and NPV of the additional benefits for the two scenarios indicated in [Mio €]. Blue columns correspond to costs (negative NPV's), green columns to benefits (positive NPV's)

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 sceanrio	high scenario	low sceanrio	high scenario	low sceanrio	high scenario	low sceanrio	high scenario	low sceanrio
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 results can be interpreted as follows:

- The methods employed are similar to those used for the risk assessment in D7.2. The cost data have mostly identical components as the same numbers and site placements as in D7.2 were used, but some costs in relation to data exchange were added. The benefit columns contain the expected safety benefits, but as discussed previously the total benefits are much wider than safety alone, so additional financial benefits were added.

- Considering hot axle box detection, the costs in both scenarios are very high in relation to the benefits and thus unfavourable, due to the following reasons:
    - The placement strategy is a density-based approach, i.e. a HABD every xx km. This strategy is required due to the rapid progression of a HAB from a safe to a critically unsafe state.
    - The safety benefits are rather low, which can be explained by the already widespread use of HABD in many countries. Derailments due to hot axle box are less frequent than the occurrence of hot axle box since efficient detection and intervention are possible. It is thus likely that safety benefits are underestimated in the current risk models.
    - Other benefits, especially maintenance, are low, because the detectors target few components of the vehicle, namely the axle box, brakes and wheel temperature, of which only the axle box allows for trending analyses
- Axle load checkpoints have a remarkably good ratio between cost and benefits. The safety business case (see D7.2) is already marginally efficient on its own, but combined with maintenance effects the business case becomes comfortable, since ALCs deliver actionable data on interesting components from a maintenance perspective, namely wheels, spring and suspensions.
- Track geometry measurement systems show an even better efficiency ratio. The safety business case (see D7.2) is already marginally efficient on its own. In addition, the track is the most interesting part for maintenance optimization as it is the biggest single cost block of an infrastructure manager. Minimal improvements in this area act on a very large financial lever.

It is worth mentioning that the IM’s spend the resources for the deployment of monitoring systems, but the RU/VO gain the maintenance benefits. The owner of the monitoring devices (IM) provides in case of alarm, the aggregated monitoring systems data free to the RU, the RU can react to the fault and save the costs for the maintenance, speed up the maintenance process etc. The relevant aggregated data may be used by the RU to improve the vehicle maintenance and to reduce the probability of a hazardous event. This effect is not calculated into the cost model, since an analysis from a safety or societal point of view clearly favours this type of financing.

2.2.2 LCC analyses

In the second approach the Life Cycle Costs (LCC) analyses are performed for the three proposed inspection and monitoring systems to evaluate the number of additional inspection and monitoring installations needed to achieve the 10-20% LCC reduction.

To ensure LCC reduction, many factors in additional to the number of installation sites have to be considered. The related sections (3.6.2 and 3.6.3) of D7.3 demonstrate that many factors and aspects influence the whole life costs of the inspection and monitoring systems. Thus not only the additional number of installation sites, but the efficient deployment of the installations create added value.

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 HABDs, would not reduce LCC automatically, since the associated whole life costs for investment, re-investment, maintenance, operation and disposal have to be considered.

The economic benefit can be ensured by aiming a density based approach and risk-related decision considering important aspects (legal, financial, safety management (SMS, CSM-RA), directives and regulations, requirements of the concerned infrastructure manager, traffic volume, specific boundary conditions etc.). Therefore a way of efficient placement of the installation sites on the concerned network could be e. g. at loading sites (referring to skew loading), border-crossings, neuralgic locations for protection of the infrastructure elements) of major traffic corridors and traffic flows.

However, this approach is more applicable and expedient for the objective of LCC reduction than installation of additional monitoring systems. Given that, a causal link between the required number of additional monitoring systems and life cycle costs (LCC) is not absolutely definitive.

However, the aim of the following LCC analyses is to obtain an order of magnitude in terms of the required number of additional monitoring system in order to achieve the 20% LCC reduction.

Similarly, the cost data used for risk analysis including risk model according to CSM-RA performed in WP7 are taken as input for the LCC analysis. A major requirement when performing LCC analysis is to define and document firstly the boundary conditions and used key input data including the sources of these data. This makes the LCC analysis traceable and clarifies what is within or outside of the calculation, which aspects and data have been considered and those that will not be taken into account due to certain reasons respectively. For this purpose the In/Out frame can be used to document the relevant boundary conditions, as described in the LCC approach in section 2.2 of D7.3 deliverable.

The scenarios defined in the business cases of WP5 regarding the number and placement of additional installations takes account for the reduction in derailments for each of the three proposed monitoring systems including the percentage of the measuring accuracy for maximum, optimum and minimum scenarios (see more details in chapter 4.2 and D5.2 of WP5).

Within the defined scenarios of WP5 the measuring accuracy and the additional number of installations for the three proposed monitoring systems have been assumed. Given that, the assumed measuring accuracy (measuring accuracy) of each monitoring system has an impact on the costs savings as well as on the LCC. This is shown for the two considered (high and low) scenarios including the relevant costs by the Table below:

Table 3: Assumed risk reduction and linked costs due to the measuring accuracy for the high scenario

	Monitoring System	derailment cause	EU27 Frequency (events /year) GB SRM v7.2 scaled for EU27	EU27 Risk (FWI/year) GB SRM v7.2 scaled for EU27	Assumed % reduction in derailments due to system D-Rail WP5	Assumed number of additional units (cf.2014) D-Rail WP5	Specific costs per cause of derailment per year D-Rail D2.3 Table 3.5	Share of avoided derailments for the cause per intervention (cf 500 derailments p. y.) D-Rail D2.3 Table 3.5	Annual number of avoided derailments (cf 500 derailments p. y.) D-Rail D2.3 Table 3.5	Annual cost savings of avoided derailments based on specific cost per cause of derailment D-Rail D2.3 Table 3.5	Annual number of avoided derailments (considering the detection effeciency)	Specific costs per cause of derailment (considering the detection effeciency)	Annual cost savings of avoided derailments per cause of derailment (considering the detection effeciency)
1	**Hot axle box and hot wheel detection**	Hot axle box and axle journal rupture	4,60	0,11	91,00%	790	1 282 575 €	12%	60	76 954 500 €	55	6 412 875 €	70 028 595 €
2	**Axle load checkpoints**	Wheel failure	3,02	0,07	98,00%		1 879 471 €	10,3%	52	96 792 757 €			
		Skew loading	3,28	0,08	98,00%		833 144 €	5,95%	30	24 786 034 €			
		Spring & suspension failure	4,95	0,12	98,00%		1 865 570 €	5,62%	28	52 422 517 €			
	subtotals		11,28	0,28	98,00%	300	4 578 185 €	21,9%	109	174 001 308 €			
	mean value						1 526 062 €			58 000 436 €	107	3 052 123 €	6 215 500 705 €
3	**Track geometry measurement systems**	Excessive track width	15,62	0,24	60,00%		474 966 €	8,60%	43	20 423 538 €		34 501 480 €	
		Excessive track twist	12,71	0,21	60,00%		552 627 €	6,58%	33	18 181 428 €		26 397 644 €	
		Track height/cant failure	5,82	0,12	60,00%		281 922 €	3,40%	17	4 792 674 €		13 640 120 €	
		Rail failures			60,00%		587 025 €	2,87%	14	8 423 809 €		11 513 866 €	
	subtotals		34,14	0,57		20	1 896 540 €	21,5%	107	51 821 449 €		86 053 110 €	
	mean value						474 135 €			12 955 362 €	64	20 387 805 €	833 677 562 €

Table 4: Assumed risk reduction and linked costs due to the measuring accuracy for the low scenario

	Monitoring System	derailment cause	Assumed % reduction in derailments due to system D-Rail WP5	Assumed number of additional units (cf.2014) D-Rail WP5	Specific costs per cause of derailment per year D-Rail D2.3 Table 3.5	Share of avoided derailments for the cause per intervention (cf 500 derailments p. y.) D-Rail D2.3 Table 3.5	Annual number of avoided derailments (cf 500 derailments p. y.) D-Rail D2.3 Table 3.5	Annual cost savings of avoided derailments based on specific cost per cause of derailment D-Rail D2.3 Table 3.5	Annual number of avoided derailments (considering the detection	Specific costs per cause of derailment (considering the detection effeciency)	Annual cost savings of avoided derailments per cause of derailment (considering the detection effeciency
1	**Hot axle box and hot wheel detection**	Hot axle box and axle journal rupture	9,00%	160	1 282 575 €	12%	60	76 954 500 €	5	70 028 595 €	6 925 905 €
2	**Axle load checkpoints**	Wheel failure	90,00%		1 879 471 €	10,3%	52	96 792 757 €			
		Skew loading	90,00%		833 144 €	5,95%	30	24 786 034 €			
		Spring & suspension failure	90,00%		1 865 570 €	5,62%	28	52 422 517 €			
	subtotals		90,00%	120	4 578 185 €	21,9%	109	174 001 308 €			
	mean value				1 526 062 €			58 000 436 €	98	16 687 484 €	5 708 112 893 €
3	**Track geometry measurement systems**	Excessive track width	45,00%		474 966 €	8,60%	43	20 423 538 €		34 501 480 €	
		Excessive track twist	45,00%		552 627 €	6,58%	33	18 181 428 €		26 397 644 €	
		Track height/cant failure	45,00%		281 922 €	3,40%	17	4 792 674 €		13 640 120 €	
		Rail failures	45,00%		587 025 €	2,87%	14	8 423 809 €		11 513 866 €	
	subtotals			10	1 896 540 €	21,5%	107	51 821 449 €		86 053 110 €	
	mean value				474 135 €			12 955 362 €	48	27 968 038 €	625 258 171 €

Both tables above present the effect of the reduction of derailments related to each monitoring system for the two scenarios. The resulting cost savings due to avoiding derailments and the costs due to remaining (non avoided) derailments are indicated in the two tables. These can be interpreted as an example for the high scenario such as: with the assumed measuring accuracy of 91% (high scenario) a maximum of 55 derailments can be avoided with potential cost savings of 70 Mio € by HABD, whereas 6 Mio € remain as costs due to not avoided derailments. Taking ALC about 6 kMio € can be saved due to reduction of 107 derailments with assumed 98% measuring accuracy, while 3 Mio € remain as costs due to non avoided derailments. The resulting cost savings of avoided derailments by using TGMS with assumed 60% measuring accuracy is about 833 Mio € and 20 Mio € remain as costs due to non avoided derailments. Similarly, the interpretation can be done for the low scenario.

The Net Present Values for the status quo (2014) and for the two scenarios regarding the three proposed monitoring systems are calculated in the LCC analyses. As a discounting factor 4% is taken for the analysis as there is no specification on this in the D-Rail project. The LCC analyses also include the forecast of 2050, i. e. increase of freight traffic by 1.53% annually up to 2050 according to the finding of WP2 (see D2.1, D2.3).

But it should be noted that there are different developments of the freight traffic volume registered in the EU Member States. Some countries in the EU have an increase of freight traffic volume up to 5-10% on specific corridors, while other countries record stagnation and even decrease of the freight traffic volume.

The costs for the implementation of the additional monitoring systems are not included in the LCC analyses, since verified cost data are not available. The impact of the issues in terms of the risk landscape of the IM (own risk assessment, risk management for the concerned boundary conditions and requirements), the effect of higher increase of traffic volume (more than 1.53% per year) as well as the decrease of derailments by 10-20% by 2050 (as taken into account in WP2, D2.3, chapter 3.1) are not considered in the LCC analyses. Contrary to the cost-benefit analysis, LCC analysis considers only expenditures but not additional benefits (such as avoided cost per derailment e .g. operational, preparedness, recovery after derailment, avoided train delay costs per derailment, maintenance cost optimization due to condition-based maintenance strategy).

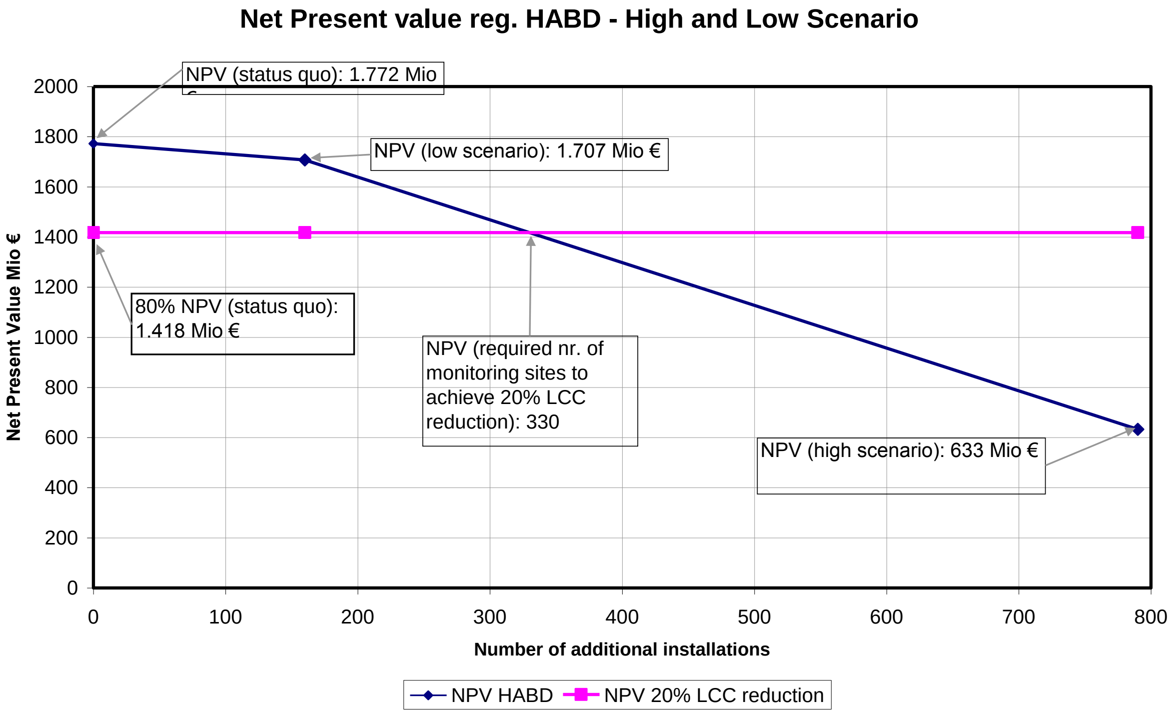


Figure 3: NPV reg. HABD with assumed measuring accuracy of 91% (high scenario) and 9% (low scenario)

Figure 3 as an outcome from the LCC analysis shows that the objective of 20% LCC reduction can be achieved by ca. 330 additional HABD devices.

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

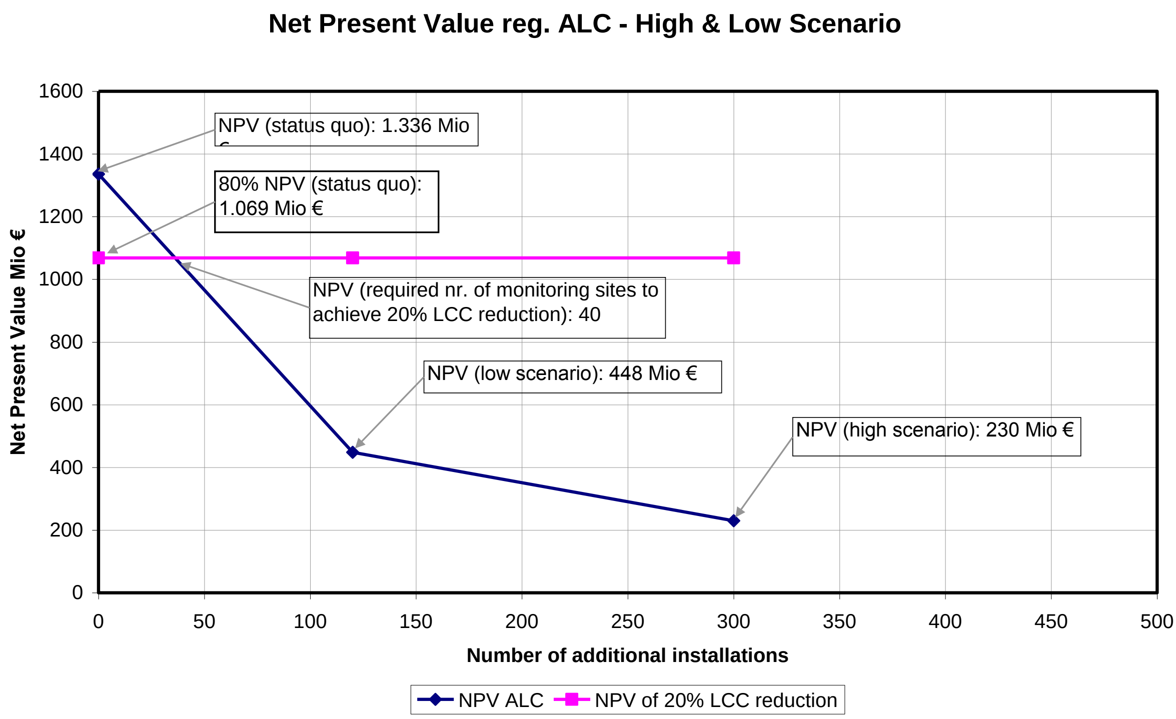


Figure 4: NPV of ALC with assumed measuring accuracy of 98% (high scenario) and 90% (low scenario)

A general remark needs to given regarding the assumed measuring accuracy of 98% for ALC. The assumed measuring accuracy 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 sharply and consequently 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. Costs for false positives (operational disruptions) are not included in the LCC.

Taking the number 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 related 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 is the case now. To demonstrate this effect, a second LCC analysis is carried out for a more realistic value of risk reduction would be 50% measuring accuracy. With the assumed measuring accuracy of 50% about 210 ALC devices are required additionally for 20% LCC reduction, which is presented in the following Figure.

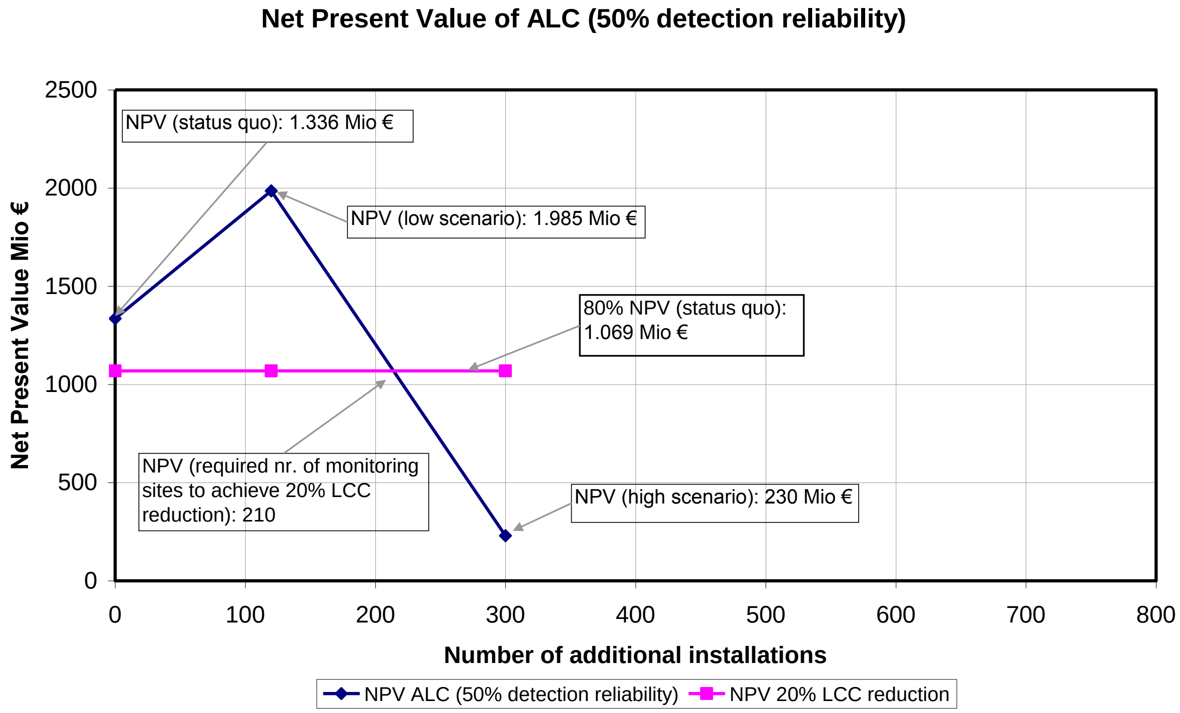


Figure 5: NPV reg. ALC with assumed measuring accuracy of 98% (high scenario) and 50% (low scenario)

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

The outcome LCC analyses regarding TGMS shows that the LCC reduction by 20% can not be achieved, mainly due to the less measuring accuracy of 60% assumed for TGMS. But a higher measuring accuracy of 90% and associated derailment reduction ensures the benefit in terms of 20% LCC reduction. The measuring accuracy means that e. g. 60% of cases that should result in derailments is found and that there are no false positives (i.e. cases where derailment risk is indicated without any derailment occurring, e. g. due to false measurement or wrong limits). Following this, WP3 has made much work is made to get more precise limit values.

Given that, 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 measuring accuracy is the more efficient approach to achieve the required benefits, as presented for TGMS see Figure 6 and Figure 7 below.

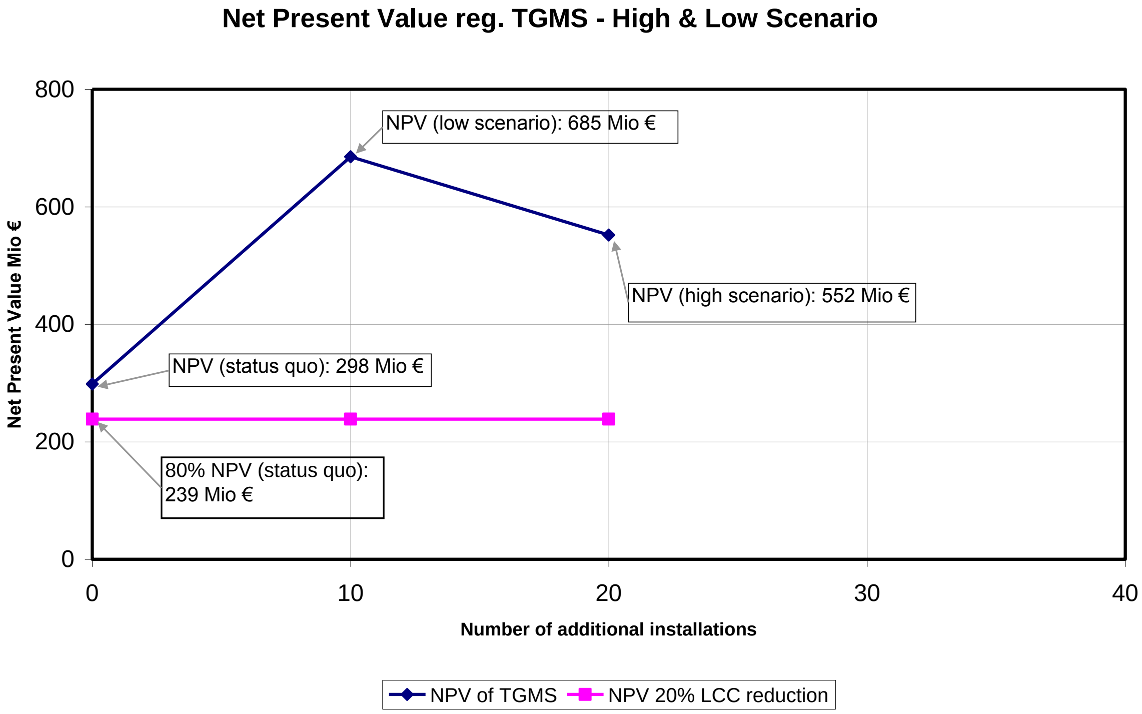


Figure 6: NPV reg. TGMS with assumed measuring accuracy of 60% (high scenario) and 45% (low scenario)

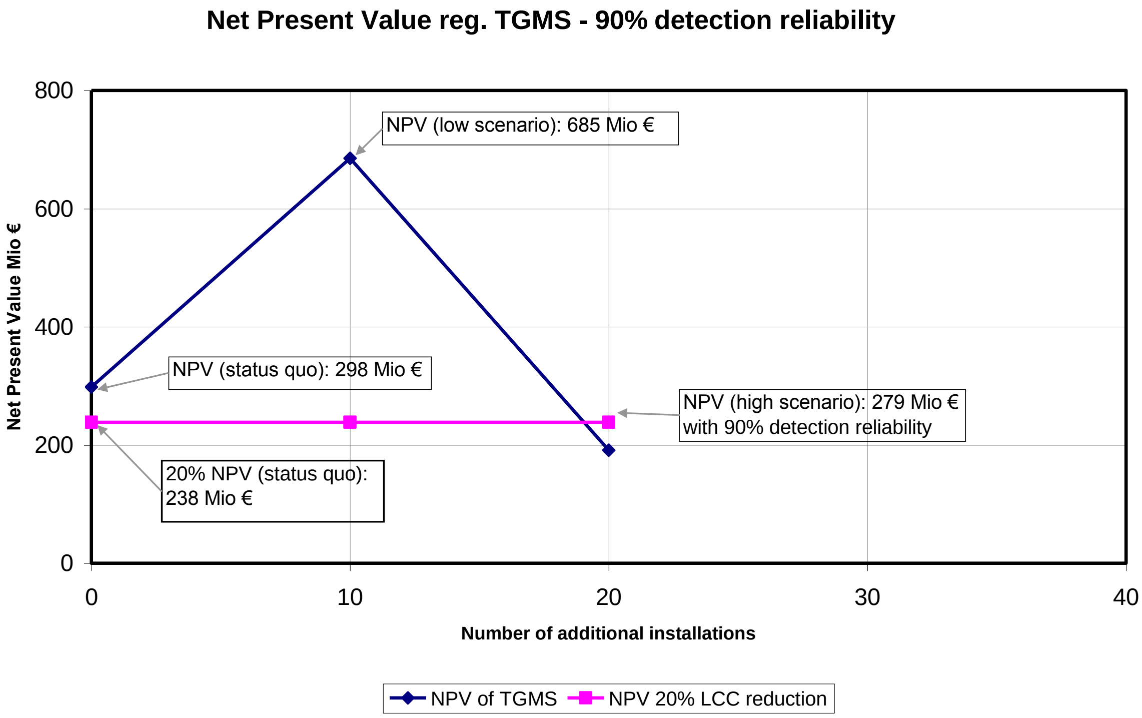


Figure 7: NPV reg. TGMS with assumed measuring accuracy of 90% (high scenario) and 45% (low scenario)

The following Table 5 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 5: Summary of the NPV's based on LCC analysis and additional installations needed for 20% LCC reduction

Monitoring systems	**Scenario**	**Assumed nr. of additonal 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 shall 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 (see section 2.2 and 3.6.3).

The presented cost-benefit analyses demonstrate that the two monitoring systems (ALC and TGMS) are beneficial by considering additional benefits. As an outcome of the LCC analyses HABD and ALC bring financial benefits in terms of achievement of 20% LCC reduction set out as one target in D-Rail. The LCC analyses are based on the used data and assumptions, particularly regarding the potential derailment prevention linked with the assumed measuring accuracy of the monitoring systems.

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

- Regarding HABD: with a measuring accuracy 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 measuring accuracy of 98%) and 210 ALC devices (by measuring accuracy 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% can not be achieved which is owed mainly to the fact of the assumed measuring accuracy of 60%. Thus a break even is not given in the LCC analysis. But a higher measuring accuracy of 90% and associated derailment reduction ensures the benefit in terms of 20% LCC reduction.

Note that the above presented LCC analyses are one way to demonstrate the achievement of 20% LCC reduction. There are certainly more options to achieve this objective. But the key aspect to create added value is the efficient deployment of the installation sites on risk-based decision considering important aspects (legal, financial, safety (SMS, CSM-RA), requirements of the concerned infrastructure manager, traffic volume, specific boundary conditions etc.).

Given the placement of HABD, a density based approach and risk-related decision shall be aimed 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 step increase for 36° to 95° (Schöbel, Karner, 2005), whereas a steeper temperature increase as a non-linear behaviour requires a higher density of HABD.

2.2.3 Socio-economic effect

- Direct consequences of derailments cover injuries and death of railway personnel, damages to vehicles and infrastructure elements.
- Indirect consequences of derailments include
  - immediate follow-up events (collision with another train after derailment, damage from explosions, fires and release of noxious substances, damage to environment)
  - effects from track unavailability (passenger delay minutes, freight delay minutes, lost connections, vehicle rerouting, passenger information)
  - costs to return to normal operations (disaster recovery operations, infrastructure repair, vehicle recovery).
- Long-term effects cover
  - loss of public confidence in railway safety
  - loss of confidence from funding providers (state and local governments)
  - loss of customer satisfaction regarding punctuality
  - shifting of traffic to other transport modes (road, air).

Typically, costs from derailment figures include only direct consequences and partial costs from immediate follow-up events. However, follow-up event costs are usually precise in respect to damage from subsequent collisions and direct damage but tend to approximate and underestimate environmental consequences.

The effects from track unavailability, costs to return to normal operations and all long-term effects are typically not included at all or roughly approximated, despite their possibly large effects. The monetized effects regarding track unavailability, costs to return to normal operations can be quantitatively approximated.

It is unlikely that a meaningful quantification of the loss of public confidence in railway safety, the loss of confidence with funding providers (state and local governments) and the loss of customer satisfaction regarding punctuality can be found. Except some rare and catastrophic events – usually in combination with dangerous goods – a single derailment will have no effect on public perception. Rather it will be a series or accumulation of events that may propel the subject to public consciousness. Experience shows that such situations will create a momentum for action by the railway industry that is almost impossible to control and stop. These actions may not seem reasonable in the context of the enterprise risk analysis, but the financial impact may be profound. The recent history of the UK railway infrastructure may serve as an example.

In the context of D-RAIL, the effect of all these factors on the modal split is the most worrisome. Whatever the exact cause may be, shifting of rail traffic to other transport modes (road, air) will have significant negative consequences on all actors in the railway industry and in a societal perspective. This effect is not limited to freight: if freight trains are perceived as being dangerous or unreliable, passenger transport will also suffer from it. The figures from WP2 will serve as a warning in that respect – the loss of a single percent of modal split creates significant higher adverse impacts compared toall other direct and indirect costs.

2.2.4 Additional benefits of monitoring systems

Regarding cost benefit analysis of WP2 the benefits are accounted only for the technical benefits from avoiding derailments (e.g. infrastructural, operational and rolling stock). They do not include ancillary benefits from maintenance activities, other freight-related benefits (e.g. reputation of the railways transportation) or benefits for the passenger transport.

The benefits associated with inspection and monitoring systems (e. g. WTMS) should include both safety related benefits in terms of derailment reduction and maintenance (non-safety) related benefits.

The economic benefit of monitoring systems also lies in “spill-off” effects, e. g. that you get a better condition monitoring, knowledge where the wagons on the network are, and on reducing maintenance, decreased fuel costs, increased lifetime of rail tracks etc.. Thus the focus shouldn’t be only on the derailment effects, but also on other aspects with associated benefits that are indicated in this section. Important information is the input in improving maintenance procedures to prevent derailment but also decrease degradation to achieve the potential benefits.

However the focus shouldn’t be only on the derailment impact but also on reducing maintenance and providing a reliable operation with higher operation frequencies (operation issue: slots of track – non-availability of track – costs).

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 unused data storage and transforming them into useful information can take advantage and result in 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.

Data exchange between infrastructure managers and railway undertakings and entities in charge of maintenance may provide significant economic benefits.

A recent investigation on iron ore cars suggest that condition-based maintenance strategies may offer LCC benefits in the range between 33% 50% over interval/time-based maintenance strategies, simply by optimizing the re-profiling and re-wheeling operations. In another study it was shown that wheel wear strongly depends on outside temperature and/or attendant meteorological conditions, in some cases varying by a factor of 5 between summer and winter. This is an ideal scenario for condition-based maintenance, which could provide up to 40% of optimization in this scenario. The results are consistent with results from Switzerland concerning wheel re-profiling optimization of locomotives based on ALC data, which show about 50% benefit.

The current limitation to the use of condition-based maintenance lies in the precise vehicle identification. For locomotives, where the identification problem is solved, railway undertakings are highly interested in obtaining WTMS data for maintenance. As the figures above suggest, a solid business case can be formulated as soon as vehicle identification can be addressed, e.g. by RFID tags.

3 Recommendations for the use of monitoring systems based on technical and economic findings

In chapter 2 of this deliverable the results of (Task 7.2 to Task 7.4) of WP7 are summarized highlighting out the balance between technical and economic benefits. This chapter summarizes the main findings from work packages 1 to 5 focusing on recommendations for the use of monitoring systems regarded as important for the implementation scenarios. More details on the results from each WP are available in the concerned deliverables.

3.1 Summary of WP1 (derailment impact) findings

WP 1 gathered information on numbers of derailments and their causes from countries in Europe and around the world, and associated costs where available. The objective was to identify the major causes of derailment as a starting point for the detailed analysis of derailment causes in WP3.

The review of project partner countries' mainline freight train derailments focused on the six-year period 2005-2010. The statistics collected for this period showed that the number of derailments occurring each year is in general declining. Derailment data was collected from safety databases in the USA, Russia, and several European countries, as well as UIC and ERADIS, categorised and brought together in a single database. Causes were ranked according to the proportion of derailments occurring within each category, and this provided the following ranking of derailment causes for Europe:

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

Breakdown of derailments into causes, and rankings of these causes, were presented in deliverable D1.1 both for European countries (in particular Austria, France and Great Britain) and as a comparison between Russia, the USA and DNV / ERA (representing Europe).

It was identified that infrastructure and rolling stock are responsible for most derailments on open line and in stations, while operations are the dominant cause in shunting yards. Countries differ in their infrastructure, rolling stock and operation parameters which can create wide variation in the key derailment causes.

Although regulations covering reporting of accidents are now in place in the European Union, there is still significant variation in the quality of reporting across the Member States. Detailed information on derailments, their causes and costs, is often available only from private databases in each country. Costs, in particular, are very difficult to estimate since different financial procedures are implemented in different countries, and the impact of derailments can often be over several years.

Deliverable D1.2 provided details on the impact of freight derailments, including an assessment of the economic impact. Data sources were European databases EUROSTAT and ERADIS, information from D-Rail project partners' databases and information from previous reports, studies and papers.

From the analysis of derailment impact, a number of observations were made for modelling derailment costs:

- There are 500 derailments per year, of which 7% (35 derailments) involve dangerous goods.
- There are, on average, 2 fatalities per year and 3 serious injuries per year, at costs of 1.5M€ per fatality and 0.2M€ per serious injury, so the human cost is 3.6M€ per year. This is equivalent to a human cost of 7200€ per derailment on average.
- Environmental clean-up costs are negligible except in the 7% of derailments involving dangerous goods. If the minimum cost per dangerous goods derailment (250000€) is assumed here, this is equivalent to 17500€ per derailment on average.

Based on this, the human cost and environmental cost add a fixed cost of 24700€ per derailment, independent of the type of derailment. However, this is an average value, and could be thought of as, for example, six severe derailments per year, each incurring costs of 2M€ (rather than 500 derailments per year, each incurring the cost of 24700€ per derailment).

In data collection, the costs were split into two major groups:

- Direct costs, meaning just railway asset costs of infrastructure and rolling stock that are damaged during or after a derailment.
- Indirect costs, including e.g., disruption cost (delay minutes, etc.), fatalities and injuries costs, legal and litigation costs, third party damage, environmental (could include post-accident clean-up operation, etc.), attendance of emergency services, public dangers (hazardous cargo), loss of cargo and freight.

The data collected in D-Rail indicates an 80%/20% split of direct costs between infrastructure and rolling stock.

For calculating the total impact in cases where only direct costs were known, the direct cost should be multiplied by a factor – ERA's cost benefit analysis model gives a factor of 2.5. Data for the USA indicate this factor to be 1.8-2.0. Analysis of the data provided by infrastructure managers in the D-RAIL project suggests that this factor may be much lower (only 1.33) but likely varies considerably between countries.

Analysis of shunting yard derailments, where costs of derailment are comparatively much lower, showed the main cause to be operational, with the 'human factor' as a significant contributor. It is not recommended that subsequent WP studies focus on this area any further.

Based on this analysis of derailment statistics, we can conclude that: developing new technologies and improving existing ones to aid the detection of major causes, improved planning and optimisation of inspections, where greater risk causes are tackled first, would result in fewer derailments.

Furthermore, by understanding the fundamental mechanisms and the key influencing parameters, it may be possible to redeploy or modify existing technologies to more effectively reduce the risk of these derailments.

3.2 Summary of WP2 (freight demand and operation) findings

The D2.1 report investigated the EU27 rail freight potential demand trajectories to 2050, over a range of future scenarios based on specific socio-economic trends extracted from an extensive literature review. More specifically, three options were developed: the reference option, where no major policy change occurs in the future and two White Paper options, which adopt the assumption that there should be a significant freight demand shift from road to rail in the period to 2050.

The EU White Paper, published in 2011 by the European Commission, defines the target scenarios Reference scenario, White Paper Low Scenario and White Paper High Scenario. In the Reference Scenario there is no policy change whereas the other two scenarios assume a partial (30%) and a full (50%) shift of freight from road to rail as per the goals set by the EU 2011 White paper on Transport for modal shift.

D2.1 predicts an increase in total freight demand in the EU of 1.53% per year due to economic activity, and also considers the effects of policies aimed at shifting a greater proportion of freight onto rail for all or the long haul part of the journey (increase in rails modal share). This average growth rate increases significantly only for the High White Paper scenario, affecting strongly on the modal split and doubling the rail demand. Regarding the Low scenario, the total demand is increased by almost 20% over the present position. These results in the prediction that of freight tonnages moved by rail is expected to double by 2050 if rails modal share remains the same, and triple if the policies are effective in moving a higher proportion of freight to rail. The actual increase in freight tonnages moved by rail is likely to be somewhere between these predictions.

Growth in the total tonnages of all types of commodity carried by rail is predicted, however differences in the predicted rate of growth for different commodities results in a change in the proportions of each type of commodity that constitutes rail freight. The predicted change in the proportion of commodity types is greater when increases in modal shift, due to policies are taken into account in the predictions, as well as a general increase in freight demand. The proportion of rail freight made up of the commodity type which includes containerised and co-modal freight is expected to rise by the most, followed by the foodstuffs commodity type.

The forecast and breakdown the future rolling stock based on three scenarios: Reference Scenario, White Paper Low Scenario and White Paper High Scenario.

Changes in the proportional split between different types of commodities carried by rail would impact the proportion of freight traffic made up of specific types of vehicles. The predicted increase in co-modal transport (containers, swap bodies, and semi-trailers carried on rail vehicles) would lead to an increase in the proportion of freight traffic made up of vehicles suited to this type of traffic (flat and pocket wagons). In the same way an increase in the foodstuffs commodity type would lead to an increase in the proportion of freight traffic made up of vehicles suited to this type of traffic (standard or refrigerated co-modal units, or covered wagons with a high loading volume but low payload mass). The transport of foodstuffs and commodities which use co-modal transport is generally more time-sensitive than the transport of bulk commodities.

There is a predicted trend towards reducing wagon weight to increase efficiency, this combined with and increasing proportion of freight being commodities which use co-modal transport and foodstuffs implies that there will be a change in the proportional split between different types of trains. These predictions imply an increased demand for services where the loaded vehicles have a lower average gross mass, carrying lighter weight but higher value and more time-sensitive commodities. This means that there is expected to be an increase in the proportion of trains consisting of freight vehicles with a lower gross mass travelling at higher speed, which has implications for the derailment risk.

The implications for the rail freight sector in terms of wagon fleet capacity and capability are significant. There are also implications for the available infrastructure in terms of line capacity and train paths to accommodate the much higher demand. It has been demonstrated that should the EU come close to achieving its objectives as set out in the Transport White Paper 2011 there will be significantly greater demand on the rail freight infrastructure and rolling stock with a large and significant increase in the number of wagons in operation and a much anticipated increase in productivity and asset utilisation.

Of special note is the fact that it is very likely that the increase will not occur uniformly, but to a higher degree along freight corridors. It will be difficult to assess the actual freight corridors used in 2050, but it can be assumed that measures should be targeted preferably along these corridors. These effects were considered in D7.2 to show the effect of traffic increase on the risk modelling. In general and assuming no other parameters are changing, the linear traffic increase will lead to a linear increase in the number of derailments and thus improve the business cases linearly.

While it is unlikely that the increase in freight traffic will influence the choice of measures, it is certain that an increase will improve the business case for each measure if all other boundaries remain unchanged. Thus, a measure that is marginally inefficient today, could become feasible assuming an annual increase of 1.53%. This shall be accounted for by calculating a case with and without increasing traffic.

To turn to the effect of traffic increase on the WTMS themselves, the following conclusion can be drawn. The useful life of WTMS mainly depends on the weather conditions (snow, rain, ice) and possibly occurring pollution (lost freight). An increase in maintenance costs due to increased train density is not expected.

Higher mechanical wear, caused by increased train density, can lead to an earlier replacement of rail, which automatically means that exchanging the sensor system of the ALC (Axle Load Checkpoint) installations also will be necessary.

An LCC analysis should take into account and evaluate a system not only in terms of economic effects but also with the capability for significant improvement to future needs. Future requirements like the prognoses of increasing load in the near future have to be part of the decision making process.

This deliverable (D2.3 – Cost/Benefit analysis for intervention to reduce freight derailment) focuses on assessing the impacts on derailment from possible interventions using Cost Benefit analysis.

The effectiveness of each of the proposed systems in reducing frequency of freight derailments, and the associated reduction in risk, has already been estimated in D-Rail report D2.3. Given that, safety benefits based on derailment cost reduction were analysed through risk assessment in D7.2.

The top derailment causes set out in WP1 and the effects on derailment reductions from WP2, as well as the assessment matrix for technical interventions from WP4 were combined to derive a shortlist of possible measures, presented below.

Table 6: Results of cost and benefit analysis performed in D-Rail D 2.3 concerning major derailment root causes,

D-Rail top derailment cause	**Total costs (costs per cause)**	**Set of intervention**	**Impact on derailment reduction per intervention**
1. Hot axle box and axle journal rupture	1.282.575 €	Hot box & hot wheel detector systems	12%
2. Excessive track width	474.966 €	Track geometry measurement systems	8,60%
3. Wheel failure	1.879.471 €	Axle load checkpoints	10,30%
4. Skew loading	833.144 €	Axle load checkpoints	5,95%
5. Excessive track twist	552.627 €	Track Geometry measuring systems	6,58%
6. Track height/cant failure	281.922 €	Track Geometry measuring systems	3,40%
7. Rail failures	587.025 €	Track internal inspection systems (NDT: Ultrasound, Eddy Current, Magnetic flux)	2,87%
8. Spring & suspension failure	1.865.570 €	Axle load checkpoints	5,62%
Average derailment cost for the specified causes	1.094.639 €	Total impact from interventions	55%

their total costs, set of intervention procedures and potential impact

The following conclusions can be derived from the table above:

- Use HABD to reduce all derailments due to hot axle boxes by 12%.
- Use ALC to reduce all derailments due to wheel defects, skew loading and spring and suspension failure by 22%.
- Use TGMS to reduce all derailments due to excessive track width and twist, track height/cant failure and rail failures by 21%.
- Any combination of these measures to achieve 20 % reduction (thereby fulfilling the D-RAIL target).

So 55% of the total impact from interventions can be achieved with the examined monitoring systems, namely Hot Box and Hot Wheel Detector systems (HABD), Axle Load Checkpoints (ALC) and Track Geometry Measurement Systems (TGMS). Given that, more than half of all derailments (and at a 75% share of the costs) are addressed by these three systems.

This short list of proposed inspection and monitoring systems has been used as starting point for the RAMS and LCC analyses in WP7.

3.3 Summary of WP3 (derailment analysis and prevention) findings

In WP3 all mitigation measures for the given major derailment causes were identified. Thereby well-known and already introduced measures are considered as well as prototypes and technologies currently under development. Finally the potential for new measures is also indicated.

Cause-consequence chains related to the eight major derailment causes identified in WP1, as well as further chains directly leading to a derailment were described. Based on this, mitigation measures in terms of systems or technologies, which allow monitoring of these subcategories of derailment causes, were analysed. Thereby not only systems available on the market were considered but also well-known developments (prototypes, etc.) as well as future monitoring approaches, which seem to be promising from a present-day perspective.

A rough estimation of the application level of mitigation measures was based on experts directly involved in T3.1. This estimation has been more detailed for OEBB, SBB and SNCF, following the established standard for Technology Readiness Assessment. In Task 3.1 an overall evaluation approach for mitigation measures was developed. This approach has been applied to make a cost-benefit-analysis for the implementation of on-board and wayside train monitoring systems as well as recording cars based upon prevented damages of superstructure, vehicles, etc.

3.3.1 Inspection and monitoring systems

A top-down analysis is carried out where cause–consequence chains are established together with matrices linking potential mitigating actions to their current level of implementation. Results are presented in D3.1.

Example from D3.1 of 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.

Table 7: Example of mitigation measures for derailment cause “axle rupture” (source: table 5-1 from D3.1)

				T	T	T	T	T	T	V	Y	W	W
number of subcategory	subcategories of derailment causes	monitoring target type	monitoring target	axle load checkpoint (Q)	axle load checkpoint (Y and Q, resp. Y/Q)	wayside crack detection	hot box detection (infrared-based)	acoustic bearing detection	vehicle profile measurement	stress detector	visual inspection	visual inspection	ultrasonic inspection
1	axle rupture (in general)	preceding causes	cracks on axle			c						a	c
2	axle rupture (in general)	preceding causes	faulty running surface	a	b					c	a	a	
3	axle rupture (in general)	preceding causes	faulty suspension	a	b				b	c	a	a	
4	axle rupture (in general)	preceding causes	faulty frame	a	b					c			
5	axle fatigue	preceding causes	overloading	a	b					c			
6	axle fracture	preceding causes	overloading	a	b					c			
7	axle rupture due to thermal stress	preceding causes	faulty bearings (before overheating)					b					
8	axle rupture due to thermal stress	preceding causes	faulty bearings (overheated bearings)				a						

Legend:

T - track side
V - vehicle side (in general)
R - vehicle side (recording car)
Y - (shunting) yard
W - workshop

a - measures, which are well known and widely used
b - measures, which are already known but not widely applied (prototypes, etc)
c - measures, which might be relevant for the future

In the following the costs of the acquisition of mitigation measures are roughly estimated and categorized into:

- High: > 500.000 $
- Medium: 100.000 $ - 500.000 $
- Low: < 100.000 $

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 8: 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

3.3.2 Potential measurement/detection approaches

It is worth to mention that the content of this section comes from WP4 and WP5.

3.3.2.1 Track side measures

In this section 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 tradition, 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 measures the width and height of the wheel flange, and the depth and profile of the wheel tread.

3.3.2.2 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.

3.3.2.3 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 these 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. These values are determined on a meter-by-meter basis for every meter that input geometry data is supplied. 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, 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 measures 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.

3.3.2.4 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

3.3.2.5 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).

3.3.2.6 Systems defined by WP4 to be used for field testing 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 of D5.2.

3.3.2.7 On-board monitoring concept

In D5.2 the on-board monitoring concept is described extensively, thus this section focuses more on the benefits to be gained by monitoring systems equipped on regular trains.

There are two complementary concepts that 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, against 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 DRAIL 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, however a different class of vehicle may show radically different dynamic behaviour. Examples of extreme cases are tilting trains and high-speed trains. It seems not feasible to buy a recording car for every such type. 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.

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 the network exploitation. Using measurements from in service trains could allow recording cars to focus on critical target and optimize the scheduling of recording cars inspections.

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

For all these concepts, the track can be considered as a system. Measurements can be analyzed in a combined way. That make even more important 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.

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 decision, maintenance and renewal work to be carried out on the track.

3.3.3 Potential modifications to minimize derailment risks

A bottom-up approach has then been adopted in Tasks 3.2 and 3.3. Here numerical simulations have been adopted to facilitate detailed analyses of derailement scenarios. The aim has been to define threshold operational conditions for derailments. Details on these investigations are presented in D3.2.

As outlined in Deliverable 7.1, D-Rail's work-package 3 – Derailment analysis and prevention identified 37 potential modifications to decrease the risk of derailment have been identified. The costs of these potential solutions are roughly estimated as:

[**A**] – very low

[**B**] – moderate
[**C**] – high

Below, a condensed description of potential solutions and means of influencing is provided. Please note that details are available in D3.2. Thus statements that may seem obvious (e.g. "Monitor and assure acceptable levels of tread wear") are elaborated and (to a varying extent) quantified in D3.2.

Flange climbing on the line and in switches & crossings

- Implementation of improved skew loading limits. [A]
- Improved definition of vehicle maintenance and handling limits. [B]
- Improved recommendations of allowed wheel/rail friction limits. [B]
- Extend track geometry assessment criteria. [A]
- Improved side bearer vertical bump stop clearances. [B]
- (Vehicle dependent) optimised primary suspension stiffness. [B]
- Improved definition of allowed amplitude and length of isolated track defects. [A]
- Review and improve derailment assessment criteria in GM/RT 2141 and EN 14363. [A]
- Avoiding too high wheel/rail friction. [C]
- Inspecting for, and mitigating chassis twist. [B]
- Reduced levels of allowed track twist. [B–C]
- Reduction in allowed wheel force imbalance and/or tougher maintenance demands for wagons in risk of experiencing sloshing. [B]
- Improved accuracy in monitoring (average) wheel loads. [B–C]

Wheel failures

- Improved definition of monitoring needs including needed level of precision. [A]

Wheel failures due to excessive tread braking

- Design guidelines of wheels to improve resilience towards thermal loading. [A]
- Monitor and assure acceptable levels of tread wear. [B]
- Operational avoidance of subsequent brake cycles. [A–B]
- Monitoring of hot wheels to prevent accidental thermal loading. [B–C]

Wheel failures due to mechanical fatigue of the wheel rim

- Maintain the surface roughness of the wheel disc at acceptable levels. [B]
- Design guidelines of wheels to improve resilience towards impact loading. [A]
- Wheel flat detection. [B–C]
- Monitor and assure acceptable levels of tread wear. [B]
- Maintain thermal loading at reasonable levels through operational procedures and monitoring. [B–C]

Wheel failures due to subsurface initiated rolling contact fatigue (RCF)

- Improve the definition of acceptable vertical load magnitudes with respect to subsurface RCF. [A]

- Maintain acceptable vertical load magnitudes by preventing / monitoring rail corrugation and wheel out-of-roundness. [B–C]
- Maintain and monitor a good wheel / rail contact geometry. [B–C]
- Ensure the non-existence of large material defects (at manufacturing). [A–C]
- Ensure a proper contact load position (avoid contact close to the field side). [B]

Rail breaks

- More exact definitions on needed inspection intervals and allowable crack sizes. [A]
- Improved limits on allowable wheel loads (maximum). [A]
- Improved definition of monitoring needs including needed level of precision. [A]
- Better evaluation of consequence of introduction of monitoring of rail foot cracks. [A]
- Maintain and monitor a rail without major material defects. This includes head checks, rail foot cracks, squats etc. [B–C]
- Maintain acceptable vertical load magnitudes by preventing / monitoring rail defects and wheel out-of-roundness. [B–C]
- Maintain a proper stress free rail temperature and monitor deviations from this temperature. Further assure that the rail steel maintains a high strength at cold temperatures. [B–C]
- Maintain proper track stiffness. [B–C]
- In cases where the last four conditions have not been fulfilled, additional monitoring is recommended. [B]

3.3.4 Parameters that influence the risk of derailment

In addition, the findings of WP3 have been employed to identify 29 crucial parameters that influence the risk of derailments as follows. Also here details on the influence of the different parameters are elaborated in detail in D3.2.

Infrastructure parameters

- amplitude and length of isolated track defects, especially track twist
- rail friction
- rail corrugation
- support integrity

Vehicle parameters

- side bearer vertical bump stop clearance
- primary suspension stiffness, especially transitional behaviour between tare and laden loadings
- friction coefficient of sidebearer and centre bowl
- chassis twist
- improved wheel design limits w.r.t. wheel breaks

Operational parameters

- braking practices (power, time, repetitions etc.)

Monitoring possibilities

- More accurate measurement of wheel forces

    - average force – flange climbing
    - peak force – rail break, wheel tread fracture
- Profile measurements
    - wheel profile measurements – flange climbing, wheel tread fracture, rail break
    - rail profile measurements – flange climbing, wheel tread fracture, rail break
- Temperature measurements
- wheel temperature – wheel fracture
- rail temperature – rail break
- Defect (crack) detection
- rail head
- rail foot
- "special structures"
- wheel

Improved criteria for allowed conditions

- wheel load imbalance – flange climbing
- peak vertical wheel forces – rail break, wheel tread fracture
- lateral wheel forces – flange climbing
- reduction in allowed wheel force imbalance and/or tougher maintenance demands for wagons in risk of experiencing sloshing – flange climbing
- more exact definitions on needed rail inspection intervals and allowable rail crack sizes during these intervals
- improved limits on allowable wheel loads (maximum)
- improved definition of monitoring needs (maximum vertical wheel force, track stiffness, hanging sleepers, potentially lateral wheel force) including needed level of precision
- consequence of introduction of monitoring of rail foot cracks
- improved definition of monitoring needs regarding wheel break (wheel temperature, maximum wheel force, wheel flat position, wheel and rail profiles etc) including needed level of precision

3.3.5 Limit values for wheel loads for implementation in ALC

In synergy with the UIC-funded HRMS project, analysis data from D-RAIL have been employed to propose alarm limits for wheel loads. The intent is that these alarm limits will be included in a UIC leaflet as a measure to harmonize allowed wheel loads in Europe. Such a harmonized framework will greatly simplify for operators and train operation managers (that have one set of limit values to consider), and also for infrastructure managers and maintenance contractors (that can base inspection intervals *etc* on a firmly established set of alarm limits).

As elaborated in deliverable D3.2, the alarm limits have a very strong foundation in that they are based on a structured limit assessment approach. Here established numerical models (validated from full-scale field test) are employed to analyze influencing parameters. In the next step “bad case scenarios” (corresponding to very poor, but realistic, operational conditions) are defined. Finally limit values on measured parameters are suggested and operational consequences may be assessed.

While this approach allows for future modifications of established alarm limits, it steers towards that consequences of any such modifications need to be evaluated within the structured framework. In other words: the taken approach avoids the establishment of limit values based on “opinions” and instead allows the limit values to be based on an informed decision that balances operational disturbances (that increase with lower alarm limits) towards the size of cracks that are required to be found at inspections. Note that also e.g. consequence of any future modification of allowed track geometry deviations (e.g. track twist) can be assessed through the established framework.

The proposed alarm limit primarily focuses on avoiding derailments due to rail breaks (vertical impact loads) and flange climbing (load imbalance). In addition they may decrease derailments due to axle failures (by preventing axle box breakdown) and wheel failures.

The introduction of higher precision alarm limits will not only decrease derailments through more accurate monitoring, they will also increase overall transport safety by arresting only derailment critical vehicles. This will decrease operational disturbances and costs and improve the competitiveness of railway in comparison to road traffic (which is a mode of transportation that is about 50–100 times less safe than the railway).

Below is a short summary of the proposed alarm limits. Wagons that exceed the proposed limits should not be allowed to continue unless continued operation below limit values can be assured.

Proposed alarm limits for vertical peak loads to prevent rail breaks

A suggested limiting peak wheel load of Q_{max} = 350 kN is proposed. For temperatures more than 20°C below stress free temperature, the limit is ramped down to a limit of Q_{max} = 250 kN at 40°C below the stress free temperature.

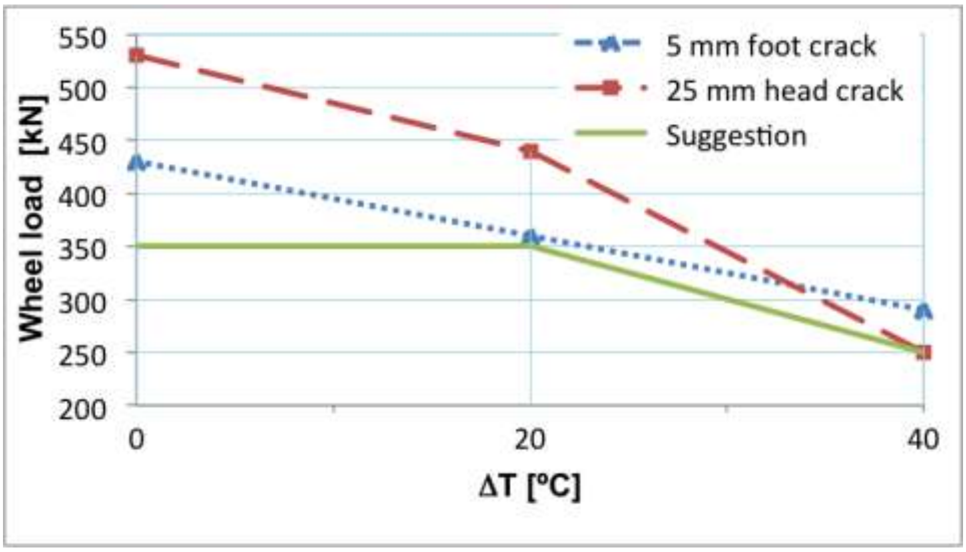


Figure 8: Proposed alarm limits for vertical peak loads, and corresponding critical loads for selected lengths of foot and head cracks. Here ΔT = T0–T where T is the current and T0 the stress free temperature.

Limit values related to skew loading to prevent flange climbing

A limit value for skew loading is proposed as

$$I_{\mathrm{alo}} = \frac{I_{\mathrm{a}}}{k \times I_{\mathrm{lo}} + m} \pounds 1$$

Where is the maximum axle load imbalance (maximum quotient between forces on left/right and right/left wheels for all axles of a wagon) and the longitudinal imbalance (largest of the quotient between sums of forces on front/rear or rear/front bogie of a wagon). Further *k*= –0.25 and *m* = 2.05.

In addition a maintenance limit for skew imbalance for unloaded vehicles is proposed as $I_{\mathrm{d}} < 1.3$, and a stop limit as $I_{\mathrm{d}} < 1.7$ where I_{d} is the largest quotient between forces on diagonally mounted wheels. This is to detect twisted vehicle frames for maintenance proposes.

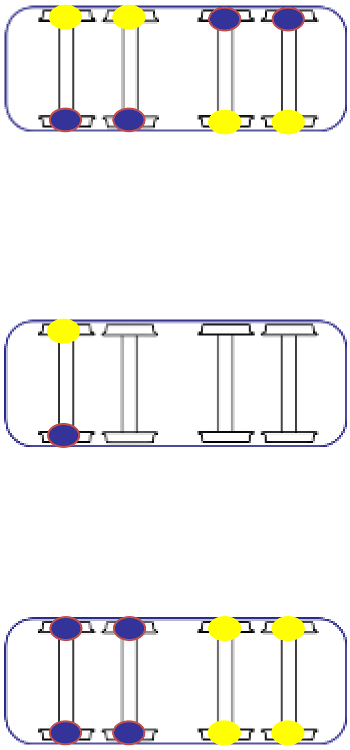


Figure 9: Illustration of force quotients, from left to right Id, Ia, Ilo.

For wagons in risk of additional sloshing loads, the limit values should be decreased by 20% to account for a worst-case scenario. Potential reductions in limits for two-axle wagons are currently being investigated.

3.4 Summary of WP4 (inspection monitoring techniques) findings

WP4 has provided a detailed review and critical assessment of current inspecting and monitoring techniques relating to derailment prevention and mitigation. Inspection and monitoring must be considered for both the freight vehicle and track aspects and the interaction, the 'freight system'. The technology assessment also included existing technical solutions currently available related to derailment prevention and mitigation.

This study performed in D4.1 includes, along with a selection of case studies:

- Track-based inspection and condition monitoring equipment,
- Vehicle-based technologies and specific recording cars with on-board systems, and
- Vehicle identification using video or Radio Frequency Identification (RFID).

An assessment of selected monitoring systems was presented to determine their ability to capture key derailment parameters, including some features, advantages and limits of the selected systems. A set of evaluation parameters was generated and a rating scheme developed in order to quantitatively evaluate the systems.

Based on this assessment, a gap analysis was performed to determine what functions are missing and what technologies require development in order to improve derailment prevention. These results are described in Deliverable D4.2 ('System enhancements, developments and functional system specifications').

As mentioned, an assessment matrix presenting methods to prevent or reduce the most common derailment risks was generated by the D-RAIL project team in WP3 and WP4. Ranking of the effectiveness and efficiency of each method has in next step been made by the project team. Results are presented in Table 9. There are 8 rows presenting the most common root causes to derailment and 13 columns presenting techniques to detect these root causes. Also added are columns that cover effectiveness and potential for improvement.

In WP7 it was found out that the approach regarding the use and value of monitoring systems are in line with the conclusions of the assessment matrix.

Each of the 8x13 cells is then divided into 9 sub cells. Each sub cell represent an assessment parameter indexed A-I. The colours in the sub cells reflect the assessment ranking. A green field means the technique is performing well on that parameter, a yellow field means the technique fulfil moderate expectations and a red field that it gives low or none contribution.

The interpretation of this matrix is difficult to generalize. The selection of preferable techniques to implement in a target environment is strongly affected by e.g. the technology level in that environment, the track standard, the traffic volume and also the maintenance routines in use.

Table 9: Assessment Matrix ranking monitoring and inspections methods regarding their ability to prevent or reduce risk for derailment

Detection method & implementation level
=well known and widely used
=already known, but not widely applied

Assessment parameter
A B C
D E F
G H I
A = hardware ruggedness
B = technology platform
C = standards, engineering acceptance requirements
D = cost
E = operational limits
F = cross border interoperability
G = diagnostic alerts and data communication systems
H = measurement effectiveness
I = derailment prevention efficiency

Assessment ranking
=high
=moderate
=low

Platform: T=Track-side / V= Vehicle carried		T	T	T	T	T	T	T	V	V	V	V	V	V			
		axle load checkpoint (Q)	axle load checkpoint (Y and Q, resp y/Q)	hot box detection (infrared based)	hot wheel detection	acoustic bearing detection	vehicle profile measurement	laser-based wear measurement (WPDS)	track strength testing	track geometry measurements - includes simulation	video inspection of rail, sleepers and fastenings (rail failure)	laser based wear measurements (rail profile)	ultrasonic rail inspection	magnetic flux or eddy current	Overall Effectiveness Using All Technologies, 1=none / 10=High	Potential for Improvement, 1=none / 10=High	
Cause of Derailment		C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13			Areas for Improvement
Hot axle box and axle journal rupture	R 1														7	4	Ability to aidentify additional failure mechanosms with accoustic bearing detectors
Excessive track width	R 2														8	5	Higher speeds for track strength
Wheel failure	R 3														6	7	Cold crack detection, Measuring crack growth
Skew loading	R 4														7	6	Potential for new technology
Excessive track twist	R 5														8	5	Improve simulation based evaluation, Measuring onboard dynamic responses
Track height/cant failure	R 6														8	5	Improve simulation based evaluation, Measuring onboard dynamic responses
Rail failures	R 7														8	4	Higher speed, Find smaller defects
Spring & suspension failure	R 8														7	7	Potential for new technology

An important output of this assessment is to identify what system aspects require to be improved and/or a newly introduced in order to reduce and prevent derailment occurrences.

These results of the assessment are one of the main outputs of this report and can be summarized as:

- Axle load checkpoints are beneficial for checking parameters related to derailment.
- The hot box detectors of today are efficient, but defects detection can be made earlier with acoustic bearing detectors.
- Inspection of wheels from wayside stations could be further improved.
- Inspection of the infrastructure by track geometry measurements tends towards compact non-contact optical systems to be installed on nearly any vehicle and at high speeds in order to allow for shorter inspection intervals without affecting track availability. Moreover, the geometry measurements should be made close to or under a test wheel with controllable vertical and lateral loads to also cover system integrity.
- Rail defect detection would need higher inspection speeds to reduce time in track.

The existing situation in Europe regarding the prevention of freight train derailments through implementation of automatic inspection and monitoring systems is acceptable. However, considering the latest technical innovations and developments, there is a significant potential improvement (see D4.2).

Some functional specifications for improvement of existing monitoring techniques to decrease derailment occurrence is summarized below.

Table 10: Proposition of enhancement for inspection and monitoring systems

Version.	Measuring capability relevant to derailments	Potential improvements		
		Measuring other parameters with added sensors	Accuracy	Range
Axle-load checkpoint	Skew loading, wheel failures, bogie failures	ID vehicle		
Hot box/wheel detectors on wayside	Axle box T° Brake T°	Able to detect failure before overheating, with Hot box detectors on board	Analysis of emissivity coefficient to increase the accuracy	
Wheel profile and diameter systems	Wheel parameters	Cold crack detection, Measuring crack growth, measurement at higher speed,		
Acoustic Bearing Detectors	Axle bearing, condition, wheel flats		Prediction of baring failures several journeys in advance	
Track Geometry Measurement	Track geometry parameters	Improve simulation based evaluation, Measuring onboard	Track geometry parameters measured under load	Higher speeds for track

Version.	Measuring capability relevant to derailments	Potential improvements		
		Measuring other parameters with added sensors	Accuracy	Range
System		dynamic responses	TGMS embedded on regular trains	strength
Rail Profile system	Rail wear	Recognition of the rail reference		
Accelerometer	Longitudinal defects			
Ultrasonic testing	Deep defects		Higher speed	
Eddy current testing	Near surface defects		Higher speed	
Visual inspection	Surface defects Missing/broken assets (fishplates, fastenings…)	Database of components, Mix several technologies (2D, 3D …)	Find smaller defects	

The approach was based on the parameters that need to be monitored highlighted in WP3, and its purpose is the identification of the missing functions in existing monitoring techniques, and the proposal of innovative technologies able to reduce these gaps.

To improve monitoring of vehicle loading conditions, optical vehicle profile measurement systems, already used to check that freight is within loading gauge, are promising techniques used to detect improper load conditions or conditions of shifted load.

For suspension failures, stress detectors might be a relevant monitoring technique for the future. It consists of wagon based measurement of stress in key wagon component for each wagon, to determine if excessive stress of the wagon components is being generated.

Automated wheel tread condition monitoring detectors are needed more and more and need to be developed. Track side measurement systems are designed to detect cracks in the axles (and/or wheels) of each wagon passing over the measurement system site. Such systems are only at a prototype level, but first results are promising, so they might be relevant for the future. Technologies used are non-destructive (High definition cameras and bespoke high intensity illuminating system, Ultrasonic scanning, Electromagnetic scanning).

For internal cracks; there is no effective solution except ultrasonic inspection in workshop, which is not widely applied. Some work has been done in the US to perform ultrasonic inspection under moving wagons.

Regarding track geometry measurement systems, some functions that have been identified as relevant for reducing derailment occurrence are not fulfilled by the existing systems, like poor fastenings or sleepers leading to an excessive track width. This monitoring can be done by automatic video inspection of the railway assets. Systems, which monitor these parameters, are available but they are expensive, and each individual system generally only inspects one or two of these parameters, making systems which cover the whole range of track condition parameters even more expensive. It is proposed that such a system should be able to inspect all the track components and their condition, including rails (rail surface defects) and ballast. So the utilisation of these systems in a "global" track inspection would be relevant as it can deal with several subcategories of derailment causes.

Once again, a potential for enhancement of track strength measurement systems is the capability of measuring at higher speed to cause less disruption of the train service.

One major improvement would be to define precisely the needs of the different users. IM will have different aims than RU. Based on that, the definition of measured values and intervention concepts will follow. From the European perspective it is necessary to harmonize those attempts. This is actually done within the UIC project HRMS (Harmonisation Running behaviour and noise on Measurement Sites).

Only measurement systems with high accuracy and availability can provide support for infrastructure monitoring and for maintenance planning. The on-board monitoring devices must be able to run at track speed in order to save time and not disrupt the freight traffic. Thus, they can reduce or even replace manual inspection (save resources, increase personal safety, potentially improve accuracy, minimize traffic interruption)

3.5 Summary of WP5 (integration of monitoring techniques) findings

WP5 discusses the interactions between the technical components to form the monitoring network of an infrastructure manager as well as communications between infrastructure managers (IM) and railway undertakings (RU) – entities in charge of maintenance (ECM) and vehicle owner (VO) respectively.

By developing business cases with the assumptions regarding the number and placing of the systems considering three different types of scenarios are defined in WP5. These served as input for WP7 for the cost-benefit analyses and the LCC analyses, to demonstrate the derailment risk reduction and the possible achievement of 20% LCC reduction. These scenarios based on the business cases are presented in the table below.

Table 11: Investigated business cases

Business cases	Countries with high automation	Countries with low automation
Number of additional systems	(a) Protection of dedicated infrastructure components (b) Installation at border stations (c) Loading stations (e.g. harbours)	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

In the course of the development and assessment of business cases WP5 has developed a concept for the estimation of the number and placement of inspection and monitoring sites. This concept proposes a categorization to cover all upcoming systems and to answer the question of positioning in the network of an IM by considering the existing experiences of IM with WTMS. And the categorization will in principle also apply to on-board systems monitoring the infrastructure. The details of the business cases are listed in **Error! Reference source not found.**.

The results of the LCC analyses regarding the business cases are presented in D7.3 and in section 2.1.3 of this report.

Particular emphasize shall be given to the fact that every country is facing different needs from their perspective. These arise on one hand from the different legal framework as well as safety management approach. On the other hand, other relevant boundary conditions due to geographical conditions, such as curve radii and track steepness, low temperatures, occurrence of natural disasters or the amount of infrastructure elements such as tunnels and bridges to be protected with WTMS are different, all of which cannot be influenced by directives (safety, interoperability etc.).

The divided role and responsibilities of IMs and RUs poses new questions due to the use of monitoring systems. Installed WTMS owned and managed by the IMs are increasingly stopping non-compliant vehicles of the RUs and ECMs, principally with the aim of protecting their infrastructure from damage (i.e. not to prevent derailments). The present legal framework has to be adapted for future needs since roles and responsibility of the actors like IM, RU and ECM change. Most notably the IM gains better insight into individual vehicles requiring maintenance than the RU and ECM, whereas the impression arises that RU/VO lose their technical competence in the field of wheel-rail interaction. As outlined in CSM for Monitoring, the IM has an obligation to inform the RU/ECM of his knowledge, but the RU/ECM remains fully responsible for safe conditions of their vehicles, be it maintenance or loading.

Thus, the deployment of systems by an infrastructure manager that monitor the condition of a railway undertaking's vehicles should not be construed as a risk transfer, because that would have a damaging effect on safety. Infrastructure managers could evade the risk transfer by not deploying WTMS and thus miss an important tool in augmenting safety. A regulatory climate that facilitates and does not hinder WTMS deployment is necessary. Additional legal risks relate to intentional acceptance of residual risk (by less restrictive thresholds or less than perfect system densities) or unintentional risks due to human error, deficient equipment, maintenance windows. The document presents a simple and tested approach to address these risks.

The infrastructure manager derives significant benefits from deploying WTMS in an integrated approach. These include improving security of the railway transport, improving the infrastructure availability, decreasing the infrastructure damages, lowering the total train delays which lead to better timetable performance, customer relationships, and insight into network by usage statistics and trend analyses.

Railway undertakings and vehicle owners can also derive important benefits if they receive data from the IM: information on the quality of the operated rolling stock, reducing delays, certification, maintenance cost optimization, intervention planning after defect detection, providing delay estimations to customers. Maintenance Optimization, in particular, can have a significant impact in improving railway freight competiveness with road transport but due to difficulties in exchanging data between IM and RU/ECM, however, this is currently an exception. Present data exchanges relate to maintenance optimization, comfort increase or operational simplifications and is not a part of CSM Monitoring.

3.5.1 Approaches for data exchange

Nowadays maintenance on railway vehicles is scheduled without information on the actual conditions of the vehicle since no such data is available to the wagon keepers. Condition based maintenance can decrease costs (by prolonging the maintenance cycles) and improve safety (by shortening the cycle in case of indications of faulty behaviour).

Making data on a vehicles performance such as information collected by axle load checkpoints available to wagon keepers is an important first step towards condition based maintenance.

Today, data exchange across borders is based on bilateral agreements between IMs. To enable pan European use of monitoring data, three different data exchange approaches are presented below, which represent different levels of harmonization:

- National driven (= business as usual)
- Bilaterally harmonized
- EU-wide harmonized

Technically, the implementation of these approaches was discussed in D5.1, where a generic approach to data exchange was recommended. Additionally, it was discussed that this approach can be implemented in a central or a distributed architecture.

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

3.5.1.1 National driven (= business as usual)

If data exchange activities are driven by each IM independently, only very limited use cases are available. An IM could exchange data with RUs operating on the network, although RUs operating on several infrastructures might have to implement different data exchange models. An exchange with neighbouring 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 the maintenance of vehicles, the allocation of WTMS data to the vehicle ID is a very crucial aspect.

3.5.1.2 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 between only 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 European network for monitoring data exchange. Due to its disadvantages, this concept should not be seen as a European solution.

3.5.1.3 Fully harmonized (unified data transfer based on harmonization)

(1) 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 or other adjustments. Thus a general transfer protocol for all kind 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 big 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.

(2) Monitoring systems

The harmonization of systems is independent to the harmonization of the 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 major efforts have to be made for exchange comparable measurement data to all qualified data users in Europe).

Some immediate gain can be obtained by direct intervention on vehicles, but a much higher gain can be obtained by an integrated approach, as it encourages the collection of vehicle characteristics over time, permits an intervention mode that balances needs for safety with operational aspects (eliminating false positives while keeping true alerts) and allows for more robust uptimes and higher system densities at the same cost. In addition, the integrated approach allows for an exchange of data between involved parties. It has to be discussed if the exchange is only between IM or also RU, NSA and/or VO.

The following types of information could be exchanged: measurement data, pre-analysed measurement data, measurement data and interpretation rules and/or operational data. Depending on the data types to be exchanged, conditions on standardization are different (peer-to-peer versus centralized exchange, non-unified versus harmonized protocols). It is understood that many systems are already deployed and in use which restricts the degrees of freedom significantly. The practical experience today is with peer-to-peer non-unified exchange, but protocol harmonization is certainly a desirable step. Use cases for data exchange are border-crossing trains, trend analyses of train operations and infrastructure usage, use of different and new monitoring systems as well as maintenance optimisation.

More relevant findings from WP5 in terms of implementation and migration are presented in chapter 4 of this deliverable.

3.6 Summary of WP6 (field testing and evaluation) findings

3.6.1 Analysis of tests for the validation of numerical simulations

In the D-RAIL WP3: "Derailment analysis and prevention” evaluated the risk of rail breaks. In particular, the evaluation was used to estimate crack growth and conditions that cause rail break. The evaluation was carried out both for rail head and foot cracks. For the foot cracks located at the foot edge, it was identified that also lateral bending of the rail may have an influence that cannot be neglected. However from the available experimental and operational data, it was very difficult to quantify how large this influence was. For this reason it was decided that tests would be carried out in D-RAIL WP6. These tests consisted in measuring the longitudinal strain at the rail foot.

A 3D FE track model was developed and calibrated towards lateral and vertical bending stresses obtained from an experimentally tested rail track section. The calibrated numerical track model allows for the prediction of bending stresses in the outer rail foot also for load conditions outside the studied range. For the conditions studied, the resulting stresses have a close to linear dependence on wheel forces that can be estimated by simple linear approximations.

The high values of the lateral bending stresses predicted under more severe conditions imply that the influence of lateral bending cannot be neglected regarding crack propagation (and fracture) of rail foot cracks.

Further research needs

More rigorous inspections of rail foots in highly loaded track sections (e.g. sharp curves and switch blades) can be motivated.

3.6.2 Analysis of vehicle and wayside monitoring technology field tests

The MERMEC Wheel Checker

The MERMEC wheel defects checker has been proposed in WP4 and has been tested within Task 6.2. It is a wayside monitoring system placed near the track in order to monitor and inspect the running band of the wheel by means of vision systems. The images are captured by a digital camera and a lighting system. The main target of the wheel checker in order to reduce the occurrence of derailments is a detection of defects and breaks on the wheel flange. Other targeted defects are considered to be all included in the running surface of the wheel, such as shelling, spalling, flat spots etc.

Lots of acquisitions have been carried out. Different trains have passed through the system and hundreds of pictures of wagon wheels have been taken. In the second phase of this testing, some artificial defects have been created to assess more precisely the capability of the monitoring system.

The participation on the project and the testing of the wheel checker prototype in Barrow Hill has permitted the assessment of the system TRL. The step forward was to bring a new functionality of the system that is defect detection on the wheel flange.

Further research needs

- Increasing of the robustness of the system in order to avoid even temporary breakdown and to prevent any missing of a train and of any defect on a wheel
- Improving the image processing in order to adapt it automatically to any kind of wheel, any kind of train.

The FAIVELEY bogie stability sensoring system

The Faiveley instability sensoring system has been tested at the VUZ test facility on the small and large circuit within Task 6.3. It is an on-board system designed to detect bogie stability problems and, if required, to issue alarm according to the level of detection. At the actual design level the sensor is able to log the 3 axis acceleration rates and to detect high acceleration pattern in time domain.

The system was installed on a flat car with which five selected types of instabilities in vertical, lateral and longitudinal direction were realized. The gathered data of accelerations were analysed in order to prepare software in the sensor for the detection.

Further research needs

Data treatment includes:

- data review by mathematic analysis software PC based
- algorithm for detection simulation on PC
- implementation of software algorithm in the sensor
- verification in the lab by dedicated test bench.

The DAKO derailment detector

The DAKO detector was also tested at the VUZ test facility. The detector is a newly developed device which is designed to detect derailment and significantly reduce the impact of derailment. The principle of the detector is to measure a vertical acceleration of a vehicle headstock. The detector is mounted on both freight wagon headstocks. When a very high shock occurs on the wagon headstock, the device is activated and makes the train brake.
The functionality of the prototype of DAKO derailment detector was successfully verified during the testing period when the device was not activated during normal operation running and was activated after the vertical acceleration of wagon headstock reached the defined value.

Further research needs

The test results provide a good information for the development of another version of detector which will be primarily designed for passenger coaches. This type is equipped with an electronic indicator.

3.7 Recommendations for the use of monitoring systems based on technical and economic results

In the following the important recommendations for the use of monitoring systems from technical (RAMS analyses and risk assessment) and economic (LCC analyses) perspective are presented.

From a technical point of view

The risk- and LCC-assessment of WP7 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 Europe-wide measures as well as some national based ones have to be taken.

Further, the risk assessments suggest that if a focused strategy for targeted implementation of the measures is considered then the safety case for implementation is improved and, in particular, Axle Load Checkpoints and Track Geometry measurement systems become more easily justified.

Synergies between freight and passenger trains should be exploited as much as possible, since the derailment costs and safety impact for passenger train derailments are much higher than for freight, especially when passengers come to harm. As a large part of the freight corridors is used by mixed traffic, also freight can benefit from the business case for reducing passenger train derailments and vice versa.

In addition, it is likely that in states, or specific locations, where risk levels are higher than the assumed levels - ALARP conclusions of the case study risk assessments (see 2.1.1 and D7.2) are based on average national freight derailment risk levels currently estimated for Switzerland and Great Britain - the potential for improvement in safety is likely to be higher and therefore more easily justified due to the proportionally higher safety benefits due to implementation of proposed control measures. This might be the case where higher derailment rates have been locally observed, or there is a higher than average density of mixed traffic, or for dangerous goods corridors where potential consequences of a derailments are higher.

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.

It must be noted that risk analysis and risk assessment should be conducted in line with the Common Safety Method on Risk Evaluation and Assessment (the CSM-RA) and the CSM for Monitoring. The D-Rail project supports the principles in the CSM for Monitoring in that it is seeking to develop a strategy for improving current operations with regards to freight derailments within a European framework.

As part of a transport operators safety management system (SMS) review processes when individual states decide to implement the strategies recommended by the output from the D-

Rail project they will have to do so in compliance with the CSM-RA if the proposed change is identified as being a significant change.

Railway systems have grown in complexity. Even though strong focus on performance has been placed, realizing a high level of operational availability has been a great challenge over the time. Simultaneously, the life cycle costs have been increasing. With increasing complexity, higher traffic demand, and limitation in budget, the importance of developing an effective solution for technical failure management of railway system, has increased. Hence, due to continuously increasing requirements related to safety, dependability, cost and sustainability, improvements in the methodologies and procedures for failure management is expected.

In order to protect against derailment e.g. due to a hot axle condition, high level reliability performance of HABD is vital. Higher reliability of HABD's contributes positively to detect any hot axle condition, and lower the derailment likelihood and consequence. As shown in the RAMS analysis, field reliability can be improved through an applicable and effective maintenance strategy. The application of selected case studies shows that the framework of RAMS and LCC is operational and provides a robust approach in underlying the RAMS concept and building the basis for proposed RAMS analysis to deal with derailment and prevention/mitigation of derailment.

The objectives of safety and availability in operation can only be realized if the requirements regarding reliability and maintainability are constantly met and the ongoing long-term maintenance as well as the operational environment is being monitored.

From a economic point of view

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 are thus responsible for more than 80% of the costs.

The following clarification in terms of the right interpretation of the presented economic results should be considered. The two approaches regarding the cost-benefit analysis and LCC analyses are different in terms of the boundaries, used input data and outcomes etc. Therefore the results of this two approaches can't be compared and should be interpreted based on the given scope, objective, used data and assumptions concerning each approach.

As stated previously, the cost-benefit analysis calculates the cumulated costs by taking into account the additional benefits and the depreciation by using a discount rate. The outcome of the cost-benefit analysis indicates the economic benefits through the ratio between costs and benefits by saying whether the costs or the benefits predominate. While the LCC analysis assess all costs incurred within a given system during the technical life cycle considered for this system using the discount rate, i. e. all payments – also future payments – needs to be referred to a reference date using the discount rate. Contrary to the costs-benefit analysis LCC analysis does not consider additional benefits.

Commonly both approaches indicate the economic benefits of monitoring systems. For both the cash flow is very important and the future cash flows have to be discounted to the starting point of the study period. However, the discounted cash flow is obtained by multiplying these factors with the annual costs for each year and the result of these accumulated costs is the New Present Value (NPV) for each of the alternatives.

Given that, WP7 used both approaches to demonstrate on the one hand the economic benefits of the considered monitoring systems (through cost-benefit analysis) and on the other hand to prove the achievement of the 20% LCC reduction depending on the number of additional monitoring systems (through LCC analyses). However, the different objectives in the context of D-Rail WP7 imply these different approaches.

Based on the outcome of cost-benefit analyses by considering additional benefits, Axle Load checkpoints (ALC) and Track geometry measurement systems (TGMS) are beneficial. Axle load checkpoints have a remarkably good ratio between costs and benefits. Track geometry measurement systems show a greater 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 becomes much better. In fact, the track is the most interesting part for maintenance optimization as it is the biggest single cost block of an infrastructure manager. Minimal improvements in this area act on a very large financial lever.

The outcome of cost-benefit analyses considering hot axle box detection (HABD) is that the costs in both scenarios are very high in relation to the benefits (see Table 2) and thus unfavourable, due to evident reasons such as: the placement strategy is a density-based approach; the safety benefits are rather low, which can be explained by the already widespread use of HABD in many countries and the low maintenance benefits.

Contrary to this, HABD brings financial benefits in the LCC analysis (see Table 5), considering the whole life costs without additional benefits. The LCC analyses demonstrate that the 20% LCC reduction can be achieved with less number of additional monitoring systems concerning HABD and ALC than assumed numbers by the WP5 business cases. That is to say that ca. 330 additional HABD devices (instead of 790 assumed in the business cases of WP5) are necessary to achieve 20% LCC reduction. The differences is explained by the fact that WP5 estimated the additional number of monitoring systems and the actual needed additional number is based on the LCC outcome. The number of additional ALC installations needed to reduce the LCC by 20% is only ca. 40 (assuming 98% measuring accuracy) and ca. 210 (assuming 50% measuring accuracy) respectively.

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.

Regarding TGMS it was shown, that the LCC reduction by 20% can not be achieved considering the given boundary conditions defined in the business cases of WP5. The reason is mainly the low number of avoided derailments due to the assumed measuring accuracy of 60%. Provided that the measuring accuracy of TGMS is better than (in this case assumed with 90%), the rate of derailment reduction increases and the benefit in terms of 20% LCC reduction can be achieved. But it is difficult to estimate the risk reduction, also because no quantitative data could be provided within D-Rail in this area. The risk reduction can only be estimated as it is not only dependent on detection, but also on intervention.

It can be stated that TGMS has the highest potential maintenance cost optimization (assumed 15 Mio € by performing condition-based maintenance as indicated in D7.3). So TGMS becomes very interesting from a maintenance perspective in terms of better usage of measurement data for prediction of trend analysis and performance of the right intervention. In addition, the transition from corrective maintenance to enhanced condition-based and predictive maintenance would be enhanced.

The results of the performed LCC analyses are supposed to be considered under the provided input data and boundary conditions.

It is necessary to bear in mind, that a causal link between the required number of additional monitoring systems and their life cycle costs (LCC) is not absolutely definitive. Considering these case studies it is not recommendable to increase the number of installations without an (LCC) analysis as this approach does not lead to a LCC benefit automatically.

However, the goal should be to identify cost-effective solutions in terms of an integrated system (prevention and mitigation) that also targets several derailment causes. By doing this, a right balance between the increase of investment, maintenance and operating costs compared with the saved cost due to fewer derailments should be aimed at.

Given that, not only the additional number of installations, but the efficient deployment of the installations at appropriate sites linked with high measuring accuracy (measurement accuracy) creates an added value. In this context a risk-based decision approach considering important aspects (legal, financial, safety management (SMS, CSM-RA), directives and regulations, requirements of the concerned infrastructure manager, operational necessities, traffic volume, specific boundary conditions etc.) and the selection of appropriate locations need to be taken into account.

Regarding number and location of additional installation sites

Hot axle box and hot wheel detection systems are already in wide-spread use. Based on the risk assessment in WP7.2, the benefit from additional systems is limited, however it should be emphasized that some countries have virtually complete coverage and others almost none. In the latter countries, significant benefit can be derived from HABD as it is a mature technology with low entrance hurdles. The general approach in all countries could be the same, namely a density-based approach, i.e. one installation every x kilometres, while the amount of kilometres is defined per country and local conditions, based on the individual risk assessment.

For ALC, a risk-based approach makes more sense than a density-based approach. As such, sites will be chosen at border stations, shunting yards, and major ports as well as to protect expensive infrastructure elements such as tunnels. This leads to an irregular distribution across countries, and it is no surprise that the highest current use is found in countries with many border crossings, shunting yards and tunnels, combined with higher operating speeds. Axle load checkpoints are extensively used in some countries, but have not yet achieved the same overall penetration as HABD. Since they cover several derailment causes, their potential is high.

TGMS detect several types of derailment causes and were shown in D7.2 to be an efficient safety measure. These systems are in wide use in Western Europe, but a significant benefit can be derived in countries that do not make use of this technology.

It’s obvious that more benefit can be derived from a better usage of the collected measurement data for maintenance activities. A way 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 manifest in 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) in all 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 analyses. Thus the focus regarding TGMS should be on obtaining of additional benefits rather than on additional deployment of installations.

The risk reduction (and the increase of safety respectively) regarding TGMS is not only dependent on detection, but also on intervention and on correct limitsas stated before. In addition, the increase of measuring accuracy of TGMS is the more efficient approach to achieve benefit instead of on additional deployment of measurement cars.

However, decision on a reasonable number of measurement sites should always be 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)co
- 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

Currently, many systems are already deployed in Europe. Some countries rely heavily on automated techniques, where 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.

It should be noted that derailment detectors will remain a voluntary measure in RID 2015 (see RID 2013 note in section 7.1.1 kept unchanged for RID 2015) at the condition that the equipped vehicle fulfils the requirements for authorisation on introduction into service and users have appropriate operation measures in their SMS.

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.

Additional benefits:

The benefits associated with inspection and monitoring systems (e.g. WTMS) should include both safety related benefits in terms of derailment reduction, and maintenance (non-safety) related benefits. However, the economic benefit from the monitoring also lies in “spill-off effects” e.g. that a better condition monitoring is obtained and n Maintenance reduced, less

Maintenance of rail tracks and equipment, decreased fuel costs, increased lifetime of rail tracks etc.

Also the consideration of additional benefits - due to avoided costs to return to normal operations after derailments, avoided train delay costs, and maintenance optimization due to condition-based maintenance – are decisive for the outcome of the economic results.

Additional benefits should be derived from the use of on-board monitoring, such as on-board systems to be installed on each rolling stock (that needs to be monitored), recording cars and regular trains equipped with monitoring devices, which could change the way data is collected and used for maintenance activities. By using on-board monitoring, time can be saved (if able to run at track speed), disruption of freight traffic and thus costs and manual inspection can be reduced. Monitoring data can be gained by equipped regular trains allowing more frequent inspections and be used for predicting trends in the degradation of track.

Effectively targeted inspection regimes are a source of potentially significant benefits, where the use the measurement data to optimize and predict maintenance generates benefits in terms of avoidance of derailments, reduced damage to track and equipment, increase component life time and savings in track and equipment maintenance. For instance using profile data to define grinding or lubrication gets more value from the rail steel. All of these benefits give direct cost savings.

Combination of monitoring systems for different derailment causes (combined failure modes)

So far the assessment of effect of combined monitoring systems used for different types of derailments and combined causes respectively is not yet analysed. The study of D2.3 and the view of the assessment in WP7 so far limit to the benefits of interventions per cause, even though the same interventions could be used for different types of derailments.

Given the current practice regarding the HABD, in Switzerland and Germany the Hot Axle Box Detection and Hot Wheel Detection are being used as a one system and are regarded as a one combined system. In addition the Axle Load Checkpoints are targeting several top derailment causes by mitigating wheel failure, skew loading, and spring and suspension failures.

Because of detection of different failure modes, the business cases for ALC and TGMS are significantly improved. The HABD by adding two more sensors can be turned into combined hot axle box and hot wheel and stuck brake detector.

As indicated in WP3, very typical of this class of combined cause derailments are those associated with track geometry defects. In many cases, key additional contributing factors to these types of defects are speed, often within a “critical speed range”, non-uniform loading- which can include under loading of one side or end and overloading of the other side or end, poorly performing bogies, and excessive wheel or rail wear, particularly when they form a shallow angle that makes it easier for a wheel to climb the rail in a curve.

Some functions that have been identified as relevant for reducing derailment occurrence are not fulfilled by the existing TGMS. For example, poor fastenings or sleepers can lead to an excessive track width.

The monitoring of the causes above can be achieved by automatic video inspection of the railway assets. Systems, which monitor these parameters, are available but they are expensive, and each individual system generally only inspects one or two of these parameters, making systems which cover the whole range of track condition parameters even more expensive. It is proposed that such a system should be able to inspect all the track components and their condition, including rails (rail surface defects) and ballast. So the utilisation of these systems in a "global" track inspection would be relevant as it can deal with several subcategories of derailment causes.

In fact Track Geometry Measurement cars have usually video inspection and laser-based wear measurement (e. g. in DB) for mitigating the effects of excessive track width, excessive track twist and track height/cant failure. A proposition could be to use track strength measurement systems such as the Gauge Restraint Measurement System (GRMS) in addition to rail profile and track geometry measurements systems, which actually applies a controlled lateral (and vertical) load to the track and as such measures gauge widening under load (and thus wide gauge under load). This approach has been successful in the USA.

Generally there should be considerable interest in research and study of further potential combinations regarding number and location of monitoring systems that are technically feasible and generate benefits for the sector.

However, some limits to further combinations are to be noted. WTMS often have specific installation requirements (space requirements, requirements on track geometry) that precluded further combinations with other types of equipment. Different target densities and strategies lead to different number of required installations, e.g. many more HABD than ALC will be required, therefore a combined HABD/ALC system would not be economical. In addition, some technologies cannot be combined due to mutual interference or other limitations, e.g. current ultrasonic and eddy current technologies are incompatible.

4 Description of reliable implementation scenarios (national/international) for the use of monitoring systems

This chapter describes the reliable implementation scenarios for the use of inspection and monitoring systems to be considered for both national and international needs. To this end, it includes the following:

1 Description of cases and concepts
2 Current status and establishment of a reference configuration
3 Number and location (density) of inspection and monitoring systems across Europe
4 Preconditions and relevant aspects for implementation
5 Implementation framework
6 Migration aspects
7 Harmonization and system integration at EU level

The above listed issues are based on the achieved results from all work packages, but particularly of WP5 - dealing with integration and development of monitoring concepts (D5.2) and system requirements specification for pan European freight monitoring (D5.1) - and of WP7 from the technical and economic perspective. The deliverable 5.2 of WP5 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 other are discussed pre requisites are described.

When considering the results from a technical and economic perspective, the deliverable D7.2 of WP7 contains RAMS analysis with technical view, whereas D7.3 refers to LCC analyses and covers the economic view.

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.

4.1 Description of monitoring cases and concepts

An analysis of derailment causes in WP 2 - showed that eight causes are responsible for 55% of derailment costs. Furthermore, WP4 defined possible monitoring actions that would address these derailment causes and that three interventions act on these eight derailment causes, namely:

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

With these three measures, a potential maximum cost-reduction of 55% is possible. Considering the much more limited 10 - 20% cost objective of D-Rail, it seems unreasonable to look for additional candidates.

D5.1 analyses possible use cases for monitoring, in which data exchange plays an important role. In D5.2, the individual inspection and monitoring systems are combined to form a monitoring concept. The main degrees of freedom are number of systems per type and location and placement of equipment.

In the course of the development and assessment of business cases WP5 has developed a concept for the estimation of the number and location of inspection and monitoring sites. This concept proposes a categorization to cover all upcoming systems and to answer the question of positioning in the network of an IM by considering the existing experiences of the IM with WTMS. The categorization will in principle also apply to on-board systems monitoring the infrastructure. In the following the results in terms of the estimation of additional monitoring systems and associated measuring accuracy are presented, which are used as input for the WP7 assessments. More details on this can be seen in D5.2 of WP5.

Table 12 Summary of the assumed number of additional units (see deliverable D7.2 and D5.2 of WP5)

Monitoring System	**Assumed measuring accuracy of the considered measure**	**Estimated number of additional units to be installed (cf.2014)**	
Scenario 1: Widespread implementation with "high" level risk reduction			
Hot axle box and hot wheel detection (HABD)	91%	790	
Axle Load Checkpoints (ALC)	98%	300	
Track Geometry Measurement Systems (TGMS)	60%	20	
Scenario 1: Targeted/focussed implementation with lower risk reduction			
Hot axle box and hot wheel detection (HABD)	9%	160	
Axle Load Checkpoints (ALC)	90%	120	
Track Geometry Measurement Systems (TGMS)	45%	10	

The safety benefits based on derailment cost reduction (monetized risk reduction) were analysed in D7.2. The LCC analyses assessed the scenarios based on the defined business cases, as presented above, in order to evaluate the additional number of monitoring systems concerning the three proposed systems to achieve the 20% LCC reduction. This approach enables to determine the reduction in derailments in relation to the number of monitoring systems. All cost figures from safety benefits and LCC were taken from D7.2 and D7.3 respectively based on the scenarios developed in WP5.

Furthermore the assessments performed in WP5 and WP7 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.

Drilling deeper into the heterogeneity, there are two classes of countries in Europe: those heavily favouring 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 favour 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 his risk landscape in light of the traffic increases.

Table 13: Investigated scenarios based on the business cases

Business cases	Countries with high automation	Countries with low automation
Number of additional systems	(d) Protection of dedicated infrastructure components (e) Installation at border stations (f) Loading stations (e.g. harbours)	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

In countries with high existing automation, the subjects 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 subject is deploying the initial systems and possibly data exchange with neighbouring IMs and interested RUs. If the predicted increase in traffic volumes comes true, it may be expected that the traffic volumes in 2050 for countries with current low automation will approach those with current high automation.

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.

Within the D-Rail perimeter, any of the solutions above will achieve the intended results, however there are significant ethical and legal aspects to such a decision. The most important one is the choice not to deploy a given measure and thus consciously accept a preventable risk.

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 relevant context, and a D-Rail recommendation cannot and is not intended to remove this obligation from the safety management.

4.2 Preconditions and relevant aspects for implementation

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 fixing 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 in future among different parties and across borders, 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.

4.2.1 Changes to the roles and responsibilities of actors

In some countries, the role of the infrastructure manager does not contain the possibility of controlling or supervising the railway undertakings using its infrastructures, while in other countries this authority is well established. The role of WTMS to protect the infrastructure is easily contained in any regulatory framework, but the vehicle supervision, monitoring and enforcement aspects are difficult to accommodate in some countries. As part of the regulatory process, the rights and limitations of such vehicle-related activities must be defined if a positive effect on safety is to be obtained. In some countries, this translates to a delegated authority conferred to the infrastructure manager, in other countries a reporting-based framework may be more appropriate, where enforcement rests with the regulatory authority and not the IM; however this second approach may shift time-critical operational duties to the regulatory authority.

Since the regulatory authorities have an interest in increasing safety, a common understanding can usually be found. This understanding of the proper role and use of WTMS as well as principles and limits of the approach should be codified in formal documentation to create a legal climate that facilitates the deployment of technical measures to increase safety.

In Switzerland, this was implemented by two measures.

A new article (Art. 40) was added to the Ordinance on Railways (742.141.1 „Eisenbahnverordnung, EBV"). This article confers the right (but not the obligation) to IMs to use WTMS to check if vehicles meet the requirements for safe operations. The use, type and placement of WTMS are risk-based, respect operational necessities and follow technical and constructional guidelines. The IMs prepare a concept for the use of WTMS and submit it to the Federal Office of Transport (FOT) for authorization.

This concept of WTMS (see [4]) describes the following elements:

1 Definitions and types of WTMS, most notably technical and systemic limitations of WTMS

2 Principles for planning and building WTMS, including the risk-oriented approach, the cost-benefit-ratio, planned network density

3 Principles for operations, including limit and intervention thresholds, allowed intervention measures per alarm type, availability requirements, notification processes and reporting to RU/ECM and FOT

This short document, which is public, addresses all legal aspects and removes the obstacles to a wide-spread use of WTMS. The two-step process seems straightforward and easily transferred to other countries and allows individual countries to specify their own requirements, e.g. threshold values and notification processes.

4.2.2 Use cases for data exchange

4.2.2.1 Intervention at border crossings (data exchange between IMs)

Border stations are well equipped to serve as locations for an intervention of a train. Replacement wagons, cranes and trained personnel can usually be found at border stations.

Since deploying and maintaining a checkpoint on a foreign infrastructure is difficult (different safety regulations, different standards for wayside equipment, custom fees for replacement parts) and since border stations are often located very close to the border, it is often impossible to place a checkpoint between the actual border and the border station. Measurements like hot wheel detection need trains to have covered a certain distance since the last stop before temperature builds up to show defective brakes. Checkpoints therefore get placed well after the border stations. For measurements like hotbox detection, where frequent, repeated measurements are necessary, this is often less than ideal.

By exchanging data across the border, this situation can be improved. Data from another IM can be used for intervention on trains at the border station. Even if perfect accuracy cannot be achieved, cross border signalling and intervention for WTMS can quickly close gaps in the checkpoint network.

4.2.2.2 Trend analysis of operating trains (data exchange from IM to RU/ECM or between IMs)

Maintenance-related data can need repeated measurements for reliability and trending, e.g. by using multiple passings of the wheel over the same or over several checkpoints. The time between such measurements must not be too long. Waiting for a railway wagon to pass a second time over the same set of checkpoints is a valid option for railway wagons in a regular schedule. This is often the case for passenger vehicle, but it is not as frequent for freight wagons. To measure multiple revolutions, data from multiple checkpoints can be combined. This can be achieved by exchanging data from checkpoints located on a freight corridor.

Precise measuring of wheel defects and intervention based on detections of such defects is not a safety function. It can lead to significant cost reductions for the IM and the RU/ECM: fixing defective wheels lowers the track deterioration and reduces damage to the axle bearings. However, the corrective action must be taken by the RU/ECM and not the IM, requiring reliable vehicle identification by the IM and data transfer to the RU/ECM.

Maintenance on railway vehicles is typically scheduled (time- or interval-based) without information of the actual conditions of the vehicle. Condition based maintenance can significantly decrease costs (by prolonging the maintenance cycles) and improve safety (by shortening the cycle in case of indications of faulty behaviour). Making data on a vehicles performance collected by WTMS available to wagon keepers is an important first step towards condition based maintenance.

Already today, IMs collect data for maintenance of vehicles on behalf of RU. Examples are DB Netz collecting ALC data of the ICE fleet or SBB doing the same for locomotives. Such values are only usable if they are collected frequently and assigned to a vehicle. To get a high enough frequency of measurement for vehicles used internationally – such as freight wagons, national measurements are not sufficient. An international data exchange will be required.

Data can also be exchanged between IMs if an individual measurement is not good enough to take a decision. An example is the detection of hot wheels. To distinguish between wheels heated up due to braking and wheels constantly under heat, measurement data from different locations must be combined to decide whether the brake has a permanent problem. In Switzerland both IMs SBB and BLS use this observation method, and apply the processes even crossing the IM boundaries: axles with block braked wheels with temperatures between 200° and 250° in Heustrich (BLS) get remotely inspected there and rechecked at Münsigen (SBB). The WTMS implementations of SBB and BLS use data exchange to inform each other about the suspicious temperatures.

4.2.3 Generic approach to WTMS data exchange

Many WTMS are already in use in different countries, using different technologies from multiple vendors. Some Infrastructure managers use more than one vendor and have different versions in use dependent on the WTMS installation date. Even the act of measuring the temperature of an axle box can be implemented in several ways, e.g. with different sensor technologies or at different sensor/axle positions, which may lead to different thresholds for condition detection and alarming.

Generally, monitoring systems are designed as standalone systems, which are providing results to allow immediate decision taking. This means that the systems analyse and evaluate measurement data according to predefined rules and/or thresholds.

For usage of such data by end users, the users have to trust the specific evaluation method applied in the system. The assessment of the evaluation method can be difficult or almost impossible, since such detailed system specifications often are difficult to get or even not disclosed by the manufacturer.

If data users could trust in the quality of measurement data evaluation, exclusively exchanging of measurement results would offer the advantages of less data traffic and less implementation effort in case of P2P transmission. On the other hand, in a European wide monitoring network with heterogeneous monitoring systems, it seems to be challenging due to the diversity of systems for data processing to get the same high level of trust for end users to the results of all established and upcoming systems.

In comparison of exchanging simple measurement results, the transmission of pre-analysed measurement data would lead to higher traffic, but with knowledge about the meaning of the pre-analysed data, end users are to do an interpretation according to their requirements. For instance, they are able to vary the applied thresholds or calculate alternative key parameters for evaluation. On the other hand, direct usage of pre-analysed data without implementation of such an interpretation is not possible.

The main idea of the recommended generic approach is to combine pre-analysed data and a recommended interpretation algorithm. The definition of evaluation algorithms is based upon standardized data types (e.g. single value, vectors) and elementary mathematical and logical functions (e.g. addition, mean). This gives the data users the transparency of the recommended evaluation and enables at the same time modifications due to their own requirements.

Data users who trust in the suggested evaluation algorithm have the ability to follow the recommendations without any further knowledge about the measurement system. Those users who have specific expectations regarding the evaluation have the flexibility to apply their own evaluation when knowing the meaning of provided data.

The generic approach can be implemented in a P2P or a centralized architecture. For P2P, only the communication protocol and data to be transferred including its representation in the protocol need to be defined. The storage of the data is left to the participants. The storage can be integrated into existing (legacy) systems. National laws in terms of data privacy can easily be followed. Policies for data retention can be defined according to the participants needs. A P2P architecture is the most flexible communication pattern. It is easy to evolve the data exchange for future needs. The drawback of a peer to peer architecture however lies exactly in that flexibility. The complexity grows with the square of the participants in the network, as partners will start evolving the communication mechanisms.

In an architecture using a centralised data hub, all data is sent to a central clearing house and can be fetched by participants from there. In this scheme, the communication protocol and the data storage need to be defined. It is not possible to exchange additional data between two participants without changes to the central clearing house. The clearing house forms a bottleneck in terms of the data exchanged, the storage retention and potentially also the performance. The big advantage of a centralised approach is the simplicity. All participants have to implement and test towards the standard defined by the clearing house.

4.2.4 Boundary conditions

Every country is facing different needs from their perspective. These arise on one hand from the different legal framework as well as safety management approach. On the other hand, other relevant boundary conditions due to geographical conditions, such as curve radii and track steepness, low temperatures, occurrence of natural disasters or the amount of infrastructure elements such as tunnels and bridges to be protected with WTMS are different, which cannot be influenced by politics.

In addition, there is an important trade-off between false-alarm rate and early detection. In countries with a very intensively used rail network such as Switzerland, the impact of a false positive, i.e. stopping a train without a fault, is much more severe as it may lead to follow-up traffic disruptions. Early warnings for hotbox and hot wheel detection allow more flexibility in choosing the intervention location, which prevents train stops at inconvenient locations that have a severe effect on the network availability. The early warning requirements lead to trade-offs in alarm detection which results in a higher false-alarm rate compared to other countries. SBB copes with that higher false-alarm rate with the introduction of an intervention centre. The intervention centre remotely diagnoses all alarms and supports the intervention process. False alarm messages can be suppressed within 60 seconds. This process is very successful. The overall delays of trains due to false alarms in the whole of Switzerland were 20 minutes in 2012, without any derailments due to hot axle boxes. SBB has an interest in receiving measurement data below the alarm threshold used in its neighbouring countries so that measurement data from trains entering Switzerland can be included in the early warning detection. On the other hand, using the early warning alarm threshold in the whole of Europe would also be wrong. Without implementing an intervention centre, false alarms would lead to unnecessary train stops.

4.2.5 Benefits of integrated approaches

The infrastructure manager derives significant benefits from deploying WTMS in an integrated approach. These include improving security of the railway transport, improving the infrastructure availability, decreasing the infrastructure damage, lowering the total trains delay, better timetable performance, better customer relationships, better insight into network by usage statistics and trend analyses.

Railway undertakings and vehicle owners can also derive important benefits if they receive data from the IM: information on the quality of the operated rolling stock, reducing delays, certification, maintenance cost optimization, intervention planning after defect detection, providing delay estimations to customers. Especially the maintenance optimization holds a large financial lever that can improve competiveness of railway freight compared to road transport, however this is today the exception due to the difficulty of exchanging data between IM and RU/ECM. Current data exchanges relate to maintenance optimization, comfort increase or operational simplifications and is not a part of CSM Monitoring. The actual safety increase will be analysed in D5.2.

Today, exchange across borders is based on bilateral agreements between IMs. To allow pan European use of monitoring data, three different concepts are compared. It is seen that the generic approach shows the most benefits as it allows integration of different existing equipment, multiple families and generations of WTMS and is a simple solution for the required exchange between IMs as well as from IM to RUs and ECMs.

4.2.6 Intervention and limit thresholds

For some types of WTMS, thresholds are defined in the relevant guidelines (“limit thresholds”), see WP3. With practical experience it has become obvious that some of these limits lead to false positives and that a less restrictive limit is advisable, even if the risk of non-detected, but unsafe vehicles increase. Inversely, on some tracks a more restrictive threshold than the limit threshold indicates already an unsafe state. These thresholds that lead to an actual intervention are called “intervention thresholds”.

When the intervention threshold differs from the limit threshold in either direction, this may give rise to problems. Intervention thresholds that are more restrictive than the limit thresholds will create difficulties with the RUs, since trains will be stopped that conform to regulations but that are deemed unsafe by the IM. Less restrictive intervention thresholds present a legal risk in case of subsequent events, since a train should have been stopped according to regulation, but was not stopped due to the higher actual limit.

4.2.7 On-board monitoring

(1) Self-monitoring of vehicles

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, and the cost of installation as well. The financial viability of this kind of concept has to be studied and justified.

(2) Monitoring the infrastructure

The concept of recording cars consists in gathering several monitoring systems on a dedicated measuring train, in order to make a high number of measurements at the same time. 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:

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

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 also allow taking immediate measures. The collected data can be used to pinpoint and predict trouble spots in the track and plan maintenance scheduling.

To complement this infrastructure monitoring, monitoring devices may be embedded on the rolling stock.

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 the freight traffic. Thus, they can reduce or even replace manual inspection (save resources, increase personal safety, potentially improve accuracy, minimize traffic interruption).

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.

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

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

4.2.8 Identification of data points

4.2.8.1 Infrastructure

Running vehicles, equipped with measurement devices, collect data during their operation. Independently, if assessment values are generated online, offline or only in the case of a threshold being exceeded 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 localisation is widely used today, there are some limiting factors when using it in the railway environment. It happens 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 localise the track section and its kilometre, but not the track number on which the train is operating. 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.

Additional information could be provided from the infrastructure and its components itself. Those components could be bridges, tunnels, switches, isolation joints, signalling 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 localisation in the infrastructure can be used for adjusting this referencing task.

More precise triggering points are given by 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 localisation issues as well as connecting assessment values directly with the correct infrastructure component.

4.2.8.2 Vehicles

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 further components (e.g. springs) is necessary.

Therefore a certain vehicle identification system is needed. Today’s approaches are using e.g. optical systems, like video systems combined with a pattern recognition, or vehicles equipped with RFID tags. In the past, only few RFID systems were available, which could detect vehicles at track speed.

Developments in the logistic sectors led to a bigger variety and a dramatic price cut. There was no final decision in the railway sector about harmonised specifications. Recently started activities from the group RFID in Rail initiated by GS 1 and some railway members try to fill this gap.

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 assigned to individual components of an individual vehicle, but the RU/ECM has to specify relevant components of the vehicle in their database. If the different readings over time are stored in this way, the history of actions for individual components can be easily followed. In this case, the benefits of using WTMS-data for maintenance purposes can be achieved.

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 exceedings of dynamic value of wheel force depending on the number of observations). This approach is easily transferred to freight.

4.3 Implementation framework regarding monitoring systems

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 among 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

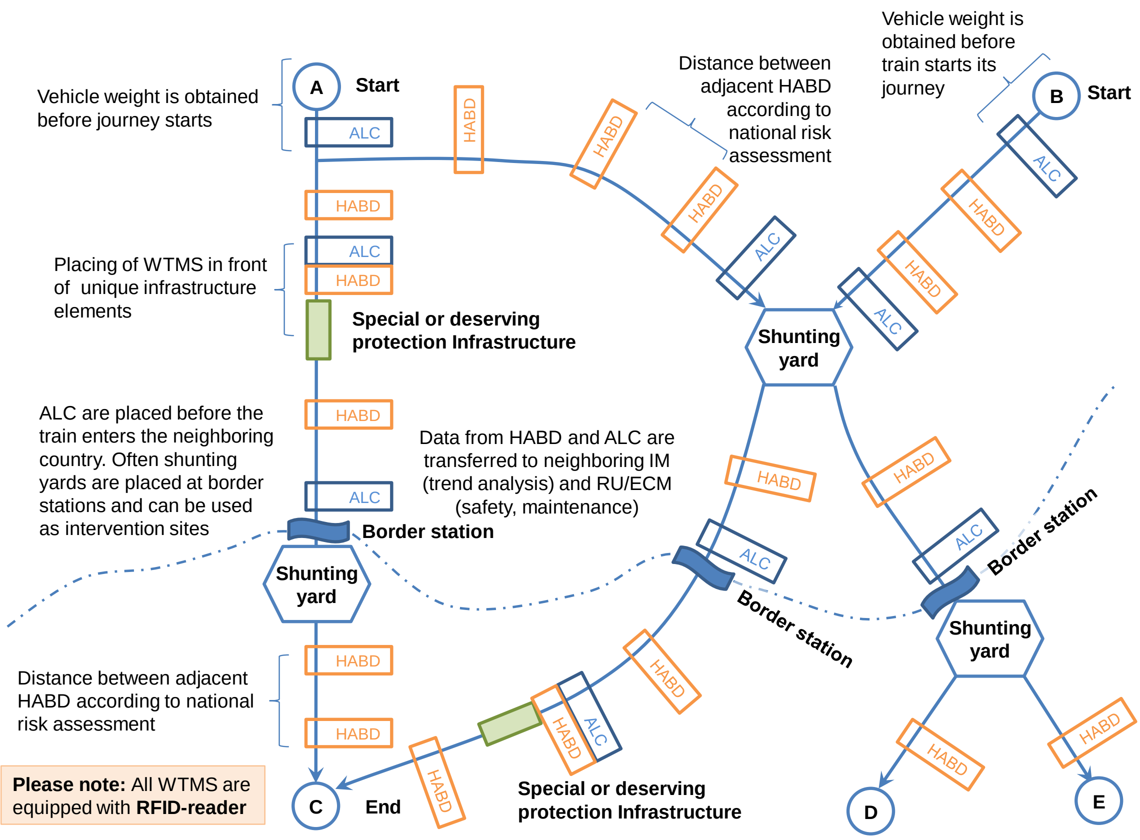


Figure 10: Placing of WTMS for block trains (left) and full-load trains (right) in 2050. It has to be noted, that all WTMS are equipped also with RFID reader. Here only the case of one way-traffic is shown. For bidirectional traffic ALC has to be implemented on both sides of the border

The implementation strategy of WTMS for block trains and full-load trains in 2050 is shown in Figure 10. 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 neighbouring infrastructure, so that the facilities and staff at a border station can be used for eventually required vehicle treatments. **Error! Reference source not found.** 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 of D5.2.

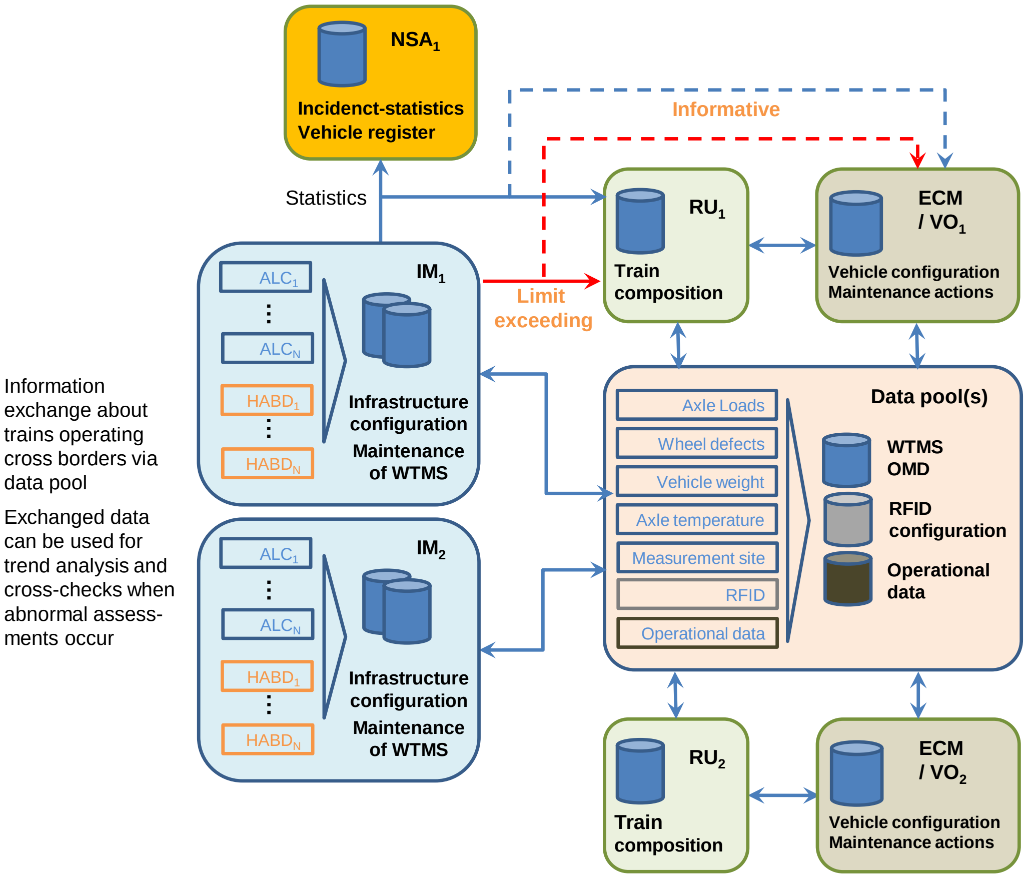
The second key issue is the question of data exchange between different parties. The generic approach for integrating values from different measurement types was discussed in detail in chapter 4 of D 5.1. Further recommendations were given in chapter **Error! Reference source not found.** of this deliverable. A sketch of data flow in 2050 is given in Figure 11. 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 RUs 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. Neighbouring 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



6.

Figure 11: Data exchange procedure for WTMS and OMD in 2050

4.3.1 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 precessing 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 item. Again, financing will be a limiting factor. Network communication facilities have to be built up – or existing ones 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 a 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 in 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 the 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.

4.3.2 Costs

Following D5.5, 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.

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.

4.4 Conclusions regarding implementation

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. A number of different activities have already started in this field. Individual solutions are available following 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 [17]
- Exchanging vehicle maintenance data between RU and ECM via the maintenance regulation VPI 08, see [16]
- Exchanging real time operational data of freight and passenger trains between neighbouring countries via Train Information System (TIS), see [18]
- Implementing RFID in rail, see the requirements defined in [19] and an example of combining them with WTMS in Sweden described in [20]
- Combining different types of WTMS in an intervention center, see an example in [21]

It is seen, that basic IT questions, like transaction protocols, safe communication interfaces, firewalls, server solutions are solved. The interesting fact is that all 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, a transition is 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 **Error! Reference source not found.**). For this reason a generic approach was developed, which enables an integration of all kinds of measurement data.

Based on the risk and LCC assessment a suitable number of additional systems were 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 available as well. A diplomatic and wise political guidance is necessary, in order to focus the lines of development and already existing solutions.

4.5 Migration aspects

Migration is not a trivial issue. In regard of migration costs in investment, operation and maintenance phases needs to be considered. The concept of migration is complex. It can mean both the change in total and each assigned adaptation process of individually components of the system migration; e. g. as part of the implementation an application is replaced by a new one. In migration processes both elements of software migration and data migration come together (e. g. often a new hardware will be required). Therefore a careful planning and implementation are crucial for maintaining data consistency and smooth transition of functionality from the old to the new application. A successful migration needs to meet, but not be limited to, the following requirements:

- to ensure uninterrupted, secure, reliable service
- to perform so many changes as seems necessary in order to cover current and expected future demands
- to perform as few changes as possible in order to reduce the volume and the risk of migration
- to change the old “code” as little as possible to minimize risks
- to change the old “code” to that extent that it supports the migration
- to install a great flexibility as possible in order to simplify future modifications
- to minimize the potential negative effects of the changes
- to maximize the use of modern technologies and methods

The migration should refer to some important issues such as:

1 Technical: special boundary conditions, environment, analysis of system compatibility, comparison of old and new system, adjustment of new system…

2 Professional: staff, compliance with standards and guidelines, field test, qualification and training of staff, migration of database, level of communication, functionality etc.

3 Procedural: operation procedure, reporting chain, responsibilities, documentation etc.

Three different aspects of migration are to be considered:

- Technical migration of equipment
- Migration towards integrated approach
- Shift from manual surveillance towards automated equipment

4.5.1 Technical migration of equipment

WTMS are already in use in many countries. The first generations are only capable of local operations and cannot function in a networked manner. However, they provide a safety benefit already in this state. It seems highly unlikely that this equipment will be removed and replaced with new equipment before its lifecycle is completed for two reasons:

- An authorization procedure was required for the original installation. Changes to such equipment may require new authorization requests and possibly temporary measures to keep the safety level.
- A business case / LCC calculation was required for the original installation. Removing the equipment before its planned life-cycle would require an extraordinary write-off.

Thus, the technical migration costs are in most cases simply negligible as they are accounted for by normal equipment life cycle costs.

4.5.2 Migration towards integrated approach

The integrated approach as outlined in WP5 is the basis for an efficient data exchange within the IM and between IM and all other actors in the railway industry. In addition, it allows for more efficient and rational operations since it places the "expensive" intelligence centrally and allows economies of scale.

This approach requires:

1 Compatible technical equipment
2 Network connectivity between equipment sites and central processing facilities
3 Central processing facilities and decision-making resources (human or algorithmic)
4 Connection to railway operations to implement decisions (e.g. train stopping)

4.5.3 Shift from manual surveillance towards automated equipment

The situation in Europe in the area of vehicle monitoring is inhomogeneous, as discussed in WP5. Every actor in the railway industry performs his own risk assessment and decision-making, and will thus decide on reasonable measures in his own risk context. Some countries already heavily rely on technical measures such as WTMS, while other use more human surveillance. As explained in WP 5, the main drivers towards automation are traffic volumes and speeds (much more than personnel costs).

The shift from manual surveillance towards automated equipment is gradual. It is likely that at first, based on the individual risk situation, a given track such as a high speed or main cargo line will be selected for automated system deployment, hopefully in a configuration that will not need to be migrated to a networked system later on.

As seems clear from this risk-based approach, the speed of the shift will depend on many local factors. Assuming a traffic increase of 1.5% annually, it seems likely that in 2050 all main cargo and high speed lines will be equipped with WTMS and no longer perform manual monitoring in that area. For the rest of the rail network, no such prediction is possible.

4.6 Harmonization and system integration at EU level

A key aspect where harmonization is possible and shows a large leverage is the exchange of collected data among interested parties, national and international. 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.

The harmonization of systems is independent to the harmonization of the 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: definition of which conditions have to be monitored (e.g. condition of axle bearings) to achieve the overall goal and which indicator respectively measurement parameter inclusive the required accuracy is 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 go 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 (with reference to WP3): 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 defining only one threshold per monitoring target for whole 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.

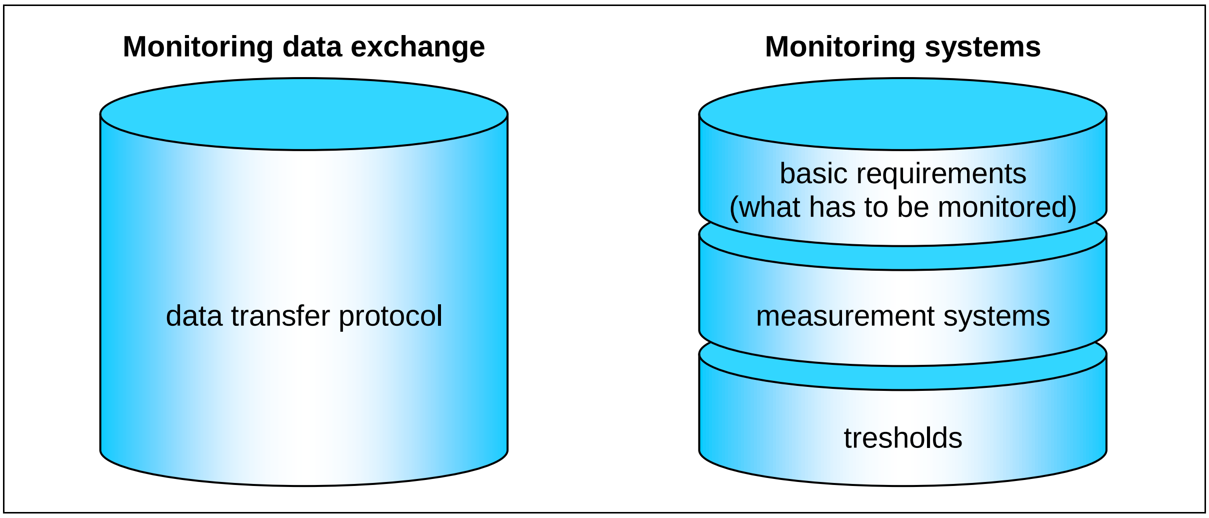


Figure 12: Two independent cornerstones of full harmonization in Europe: monitoring data exchange and monitoring systems

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 13. 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.

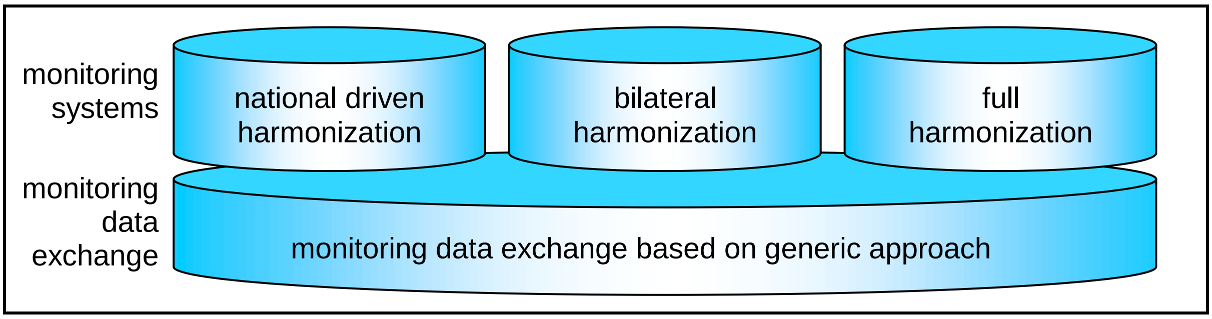


Figure 13: Advantage of generic approach for data exchange: usable with all levels of monitoring system harmonization

4.6.1 Requirements for implementing the generic approach

The conceptual design (see chapter 4 of D 5.1) basically focusses on 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 make it 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 should allow for an inclusion of different sensor systems for comprehensive trend analysis. Thereby, a universal framework could 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 own interpretation

With the implementation of a universal framework for data representation and functionality compared to direct linking between monitoring systems and data users 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.

5 Description of open points and further research recommendations

5.1 Limitations on the inputs recognized so far are as following

WP1: Databases do not allow automated evaluation of derailment-locations regarding track alignment and track condition parameters

WP2: Traffic flow prognosis did not cover developments of bogie types, Prediction of additional derailment risks based on future freight system 2050; Additional requirements for availability, safety and regulations.

WP3: Complex dependency of influencing parameters creates a level of uncertainty regarding the actual derailment risk

WP4: Demand for future development and integration, functional specification for system application aiming to prevent and mitigate derailment occurrences, recommendations for technological improvements and/or new technical feature introduction are still open, but highly required for WP5

WP7: limitation in provision of sufficient RAMS input data by the partners in D-Rail; no European reference implementations for methods such as CSM-RA

5.2 Difference in the member states

There is a lack of consistency regarding recording of detailed derailment data. Data about derailments exist both in European and in individual country databases. They belong to a variety of organisations and are presented in a number of formats differing in structure, information under which criteria is reported and the definition of causes of accidents, etc. Some are public and some are not.

Although regulations covering reporting of accidents are now in place in the European Union, there is still significant variation in the quality of reporting across the Member States. Detailed information on derailments, their causes and costs, is often available only from private databases in each country. Costs, in particular, are very difficult to estimate since different financial procedures are implemented in different countries, and the impact of derailments can often be over several years.

In addition, the dispersion of derailment causes over Europe is not identical to the dispersion of derailment causes in every country. Many factors such as topology, meteorology, traffic density, track ages, vehicle mix and occurrence of natural disasters lead to different prime causes.

5.3 Vehicle identification

The current limitation for the use of condition-based maintenance lies in the precise vehicle identification. For locomotives, where the identification problem is solved, railway undertakings are already highly interested in obtaining WTMS data for maintenance. As described, a solid business case can be formulated as soon as vehicle identification can be addressed, e.g. by RFID tags.

5.4 Combined failure modes

Derailments have major and contributory causes that lead to an accident. Many of these causes have underlying factors. In order to better understand these underlying factors, it would be necessary to review individual investigation reports – many of which are confidential. Most railroads and national agencies tend to report derailments as due to a single cause or to a primary and additional secondary causes. Only when they cannot find such a single cause, they will investigate a combination of effects leading to a derailment. In reality many (if not all) derailments are the result of combined causes (where the combination of several contributing factors are necessary, for the derailment to occur), and a systematic investigation might present key input for additional robustness of the system.

5.5 Combined interventions

Generally there should be considerable interest in research and study of further potential combinations of measurement sites and techniques that are technically feasible and generate benefits for the sector. On one hand, this may address some combined derailment causes, and the other it may prove a cost-efficient way to deploy solutions. Combination is mainly interesting for systems that share similar deployment strategies and similar installation requirements and that do not interfere with each other. As an example, combining axle box checkpoints and hot axle box detection is not reasonable in this logic, as the number of sites and the deployment strategy are different. Ultrasound and eddy current inspection systems interfere and cannot be combined on the same recording car.

5.6 Data exchange

A key aspect where harmonization is possible and shows a large leverage is the exchange of collected data among interested parties, national and international. 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 fixing 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 are transmitted in the future among different parties and across borders, 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.

Apart from this study there should be considerable interest in research and study of further potential combinations regarding measurement sites that are technically feasible and generate benefits for the sector.

So further recommendations for activities concerning the following topics can be given:

- Expanding existing incident reports with data about combined derailing causes and providing European wide statistics.
- Harmonizing thresholds for track and vehicles concerning comparable boundary conditions
- Further research for the purpose of defining additional combined thresholds which can be monitored using existing or new monitoring systems.

5.7 Potential enhancement cross-border operation and harmonization at the European level

The benefits of implemented harmonized monitoring concepts can be realized only when specific cross border topics are considered and implemented. This implies not only aspects of monitoring techniques, but also responsibilities, cross border data transfer and intervention concepts.

Today's data handling is often clearly divided into two different categories: data related with train operation and data resulting from detection devices. Both categories have the need of data exchange when trains operate across borders. At the operational level, new interfaces in terms of data exchange were developed recently in order to fulfil the requirements of different TSIs. It is expected that these protocols are appropriate for measurement data as well. Different use cases have been formulated within D-Rail, including protocols and data formats. A test implementation within D-Rail has shown the possibilities of exchanging data cross border.

In regard of the technical questions (e.g. what, where, by whom, and when to measure), several general questions have to be solved, before this global harmonized monitoring concepts can be implemented. Pragmatic solutions are necessary, so that the legal framework is acceptable for all involved parties, before a common framework can be adopted across the EU. The recent railway law clearly distinguishes between the responsibility for building, maintaining and operating vehicles and infrastructure. Both parties are responsible for their own business area, but more and more infrastructure based monitoring stations detect the state of vehicles, or are operated as checkpoints with a control function and an intervention concept. Here a solution at the legal level is needed, so that the responsibility of RU and IM is clearly regulated.

Furthermore one party has to invest (e.g. IM), so that another party receives the data for their fleet management (e.g. vehicle owner). In this case, a pragmatic and/or politically driven solution has to be developed, so that the cost for the operation of such a monitoring network is carried by all partners.

Migration is not a trivial issue. Therefore careful planning and implementation is crucial for maintaining data consistency and a smooth transition of functionality from the old to the new application. D-RAIL has put forward ideas for monitoring concepts set out from existing technologies. The exchange of measurement data across borders is a new field in many countries which requires new responsibilities and knowledge to be transferred and implemented by different organisations. If not done, the benefit – which lies in the statistical assessment of the data – will not occur. More discussions between IM, RU, vehicle owner, vehicle maintainer, safety and market authorities, and end customers are needed to encourage this new step towards 2050.

5.7.1 Political aspects

Risk-related decision-making may have political and public pressure to contend with. After a severe accident the railway company comes under intense public scrutiny. As every accident is *in principle* preventable, there is always some basis for a prolonged discussion. This leads to sensationalism and pressure for immediate measures, before a railway company and public authorities have concluded their investigations. The main problem here is that the the public falls back on a very simplified risk management approach that is to use all available funds to cover the single risk that led to this particular accident, while dropping all other measures that would cover more probable risks (railways are 50-100 times safer than road transports). Standardized and objective risk management methods are an important part to deflect some of this pressure, but they cannot replace effective corporate communications. Thus, before an accident occurs, those responsible for implementing the communications strategy (senior management and corporate communications) must be sufficiently briefed in the methods, reasoning and consequences to trust in its recommendations and defend them against adversity.

The beginning, operating of international trains requires an exchange of necessary information. With upcoming electronic devices this process runs more automatically and much faster. Specific train vehicle data is already available and is used to provide information as vehicles approach a border crossing and in some cases this information can be provided before the train begins its journey. European networks should harmonise their data interfaces and define a process on how to respond to different limit values. Early coordination with non-EU countries will help to minimize the effort for implementing similar exchange processes at the external border. The benefit is a reduced number of necessary measurement sites – due to saved border-induced redundancies –without any reduction in information quality.

However, different practices in different countries and political aspects complicate the work e. g. regarding data gathering and comprehensive analyses. This is mainly due to the differences between databases in their structure and cause classification, the reporting criteria and approaches for assessment of consequences and evaluation procedures.

To ensure that solutions are cost-efficient there is also the political issue of who is paying for monitoring, mitigating actions, derailments and who benefits from the solutions. Often if one party invests (eg the IM), others, such as the vehicle owner, benefit from this investment by receiving data which assists with fleet management (e.g. vehicle owner for its fleet management). In this case a pragmatic and/ or political driven solution has to be developed, so that all parties carry the cost for the operation of such a monitoring network. In the example above it can also be noted that the IM benefits from the data in terms of improved input to deterioration, infrastructure maintenance and asset management predictions. As a result it is important to decide who pays for what and who benefits as this could influence how investments and benefits are shared.

5.7.2 Safety aspects

With respect to safety, the overall target should not be to generally harmonize boundary conditions even if it increases efficiency potential. For example demanding alarm limits to be the same for all tracks and at all times will not be realistic due to varying technical conditions. Operational conditions, strategies and policies and in particular local boundary conditions such as substructure, track alignment, track characteristic vary from location to location. Although not every track has to respect the same limit values (due to different operational conditions), the establishment of limit values has to be based on scientifically sound principles (as outlined in WP3) following a common framework.

Different ways of measuring a physical quantities leads to different values of the same measured object. To this end reference objects with known measuring quantities would provide a potential for European wide calibrations. This also includes measurement accuracy and uncertainty of measurements. The latter depends on accuracy and reliability of the system and affects the entire system and the costs. In this context it is necessary to have agreement across Europe on what constitutes a 'faulty vehicle'.

Monitoring some vehicle characteristics to prevent derailments has the additional effect, in that the RUs gain information of non-conformal operations of their wagons. The additional effort resulting from restoring the appropriate state of the vehicle leads to improved consideration of operating standards in a short time perspective. But not only exceeding the limits should enable the optimization process. In the interests of the IM, RU and partner companies, a data flow process should be defined, agreed and met *before* starting a train to ensure there is compliance with technical and operational standards.

Trains routinely employ tracks belonging to different infrastructure maintainers. Certification is an attempt to ensure that every combination of vehicle and track will behave in a safe manner. However, it is understood that the management of the different causes that may lead to derailment is difficult if railway and infrastructure operators are from the same region. If they are from different regions, even basic aspects of safety philosophies may differ. Many standards and international regulations attempt to ensure a minimum level of cross-national understanding in these issues, but the regulations must leave leeway to regional authorities, as no region can afford to restart its railway operations from scratch.

These aspects are of practical importance for wayside monitoring equipment. A train may pass wayside monitoring equipment in one country and be within the accepted parameters of that country. After crossing the border, the intervention parameters may be lower and thus the train is stopped. However, as mentioned above, identical parameters Europe-wide are not the solution: already within a region, different intervention values may be reasonable. Nonetheless, better cross-border coordination of intervention parameters would enable a railway operator to know that his cross-border train (in its present condition) will pass all wayside monitoring systems on his route without triggering an alarm – or not, which would enable him to fix the situation close to his own sites. Consequently there is a need for a harmonized alarm limit framework from which operational limits may be established. Such a framework for allowable wheel loads has been developed in WP3 and is further elaborated on the UIC-project HRMS.

5.7.3 Legal aspects

If an accident leads to injury or death, criminal or civil proceedings will be launched in parallel to the accident investigation. The railway and infrastructure operators will need to defend the conduct of their employees, but also their risk management. This becomes critical in situations where a mitigating measure would have prevented death or injury, but the company chose not to implement it. This is even more important if human error of an employee of the same company caused the accident, as it may lead to an impression of a fundamental safety problem.

To defend the decision process that led to this decision of not implementing a measure it must be explained to non-experts such as judges, and it must be shown that the employee taking the decision correctly followed established practice at the company. It is thus very important that the methods are transparent, plausible and objective. Further, the notion of overall societal safety optimization must be widely agreed. In this context rail transportation is an order of 50–100 times safer than car transportation. Further, the risk of accidents is never zero. Thus, focusing huge resources on eliminating the few remaining potential, low-probability safety issues of railways will be counter-productive if it e.g. causes traffic disruptions and/or increases costs, and thereby shifts traffic towards roads.

Another area that concerns wayside monitoring systems is the implied risk transfer. In Switzerland, a decision by the regulator stipulates that the railway operator remains fully responsible for the state of his vehicles, independent of the fact if the infrastructure operator uses wayside monitoring systems to monitor the vehicles' state. Thus, if a WTMS fails or is not detecting a dangerous state, the railway operator remains fully responsible and cannot shift part of the blame on the infrastructure operator, whose equipment failed to detect the problem. This encourages establishment of important safety nets. In other countries, the situation is less clear, which discourages widespread use of WTMS as their use could make the infrastructure operator liable for non-detection of vehicle issues. Regulators in all countries should create a framework that encourages and does not discourage the use of monitoring systems.

Pragmatic solutions are necessary, so that the legal framework is acceptable for all involved parties, before a common framework can be adopted across the EU. Also a solution at the legal level is needed, so that the responsibility of RU and IM is clearly regulated. One part of the common legal framework shall include the issue of data privacy. Since different stakeholders access and operate the system, management of data security policy is necessary. The information and knowledge exchange shall be regulated to guarantee the access, the exploitation of information and data exchange. To this end, the data and information have to be protected by data/information security and access restriction policies built into the system. In this respect, the confidentiality of data is a big issue. In WP1 it was found that a major obstacle could be confidentiality of data i.e. in gathering information. This means that it is not publicly available and data owners are reluctant to supply it. This circumstance implies also the availability and quality of data. In this regard, the question to be solved is how the quality and confidentiality of the data of the measuring systems provided by the different IM and operators in the EU countries can be assessed.

5.7.4 Further research needs from field testing perspective

Analysis of tests for the validation of numerical simulations:

More rigorous inspections of rail foots in highly loaded track sections (e.g. sharp curves and switch blades) can be motivated.

Analysis of vehicle and wayside monitoring technology field tests:

a) The MERMEC Wheel Checker:

- Increasing of the robustness of the system in order to avoid even temporary breakdown and to prevent any missing of a train and of any defect on a wheel
- Improving the image processing in order to adapt it automatically to any kind of wheel, any kind of train.

b) The FAIVELEY bogie stability sensoring system: data treatment includes:

- data review by mathematic analysis software PC based
- algorithm for detection simulation on PC
- implementation of software algorithm in the sensor
- verification in the lab by dedicated test bench.

c) The DAKO derailment detector

The test results provide a good information for the development of another version of detector which will be primarily designed for passenger coaches. This type is equipped with an electronic indicator.

5.7.5 Technical and economic assessment (RAMS and LCC analyses)

One of the findings is that the current state of RAMS practice in railway infrastructure is in a very early stage of development and there is more basic development necessary. For this reason there are no specific existing RAMS studies focussed on derailments, only some studies and projects on specific topics of RAMS with respect to derailments. More basic development is necessary before RAMS analysis can become fully functional in the railway community. Consequently more work and research in terms of establishing of a systematic procedure for calculating RAMS is needed, particularly on derailments. There might be also scope for extensive training in RAMS across Europe

The results of the risk assessments indicate which proposed systems would normally be recommended for implementation under the respective safety decision-making frameworks for GB and SBB. However, as these risk assessments have been made using a number of assumptions, and have been generalised for European wide implementation, the unrefined results require further qualitative consideration and rationalisation before final conclusions can be made.

Based on the outcome of the D7.2, it is noticed that there is lack of reliable and valid data. Although substantial effort is undertaken to record the events, however, the content of the records have not been properly sorted so that they can be used. Hence, recommended that in order to have more robust results, one needs to collect more data concerning failure of monitoring systems (e.g. HABD) as well as maintenance.

Since data collection is a time consuming issue, it is recommended to use application of Information–communication technology to save time, money and to enhance the results of RAMS analysis.

Regulations should enable and not hinder the rapid adoption of systems to prevent derailment. Too high requirements on the reliability of detectors (e.g. requiring the same reliability levels as railway control centres) will result in expensive equipment of low density. In some countries the lack of regulation slows the speed of detector adoption, as the infrastructure operator risks being held liable for non-detected vehicle defects as soon a detector is implemented. The cross-border use of detectors and detector data is starting to appear, but for full success it requires the operator to know the lowest threshold that a particular train will encounter along an operated route. Note that we do not believe that one single threshold makes operational sense. However threshold levels must bebased on a scientifically founded framework (as offered by D-Rail's WP3), and the limits must be coordinated and communicated to permit a railway operator to stop his train early on and remedy a problem close to his intervention site instead of encountering it on the line with the lowest threshold.

Regarding long term effects (as "soft factors"): it is unlikely that a meaningful quantification of the loss of public confidence in railway safety, the loss of confidence with funding providers (state and local governments) and the loss of customer satisfaction regarding punctuality can be found. There could be further research in his area e. g. using stated preference techniques.

References

[1] Palo, M., Larsson-Kraik, P.-O., Lin, J.: Life Cycle cost model for rolling stock freight wheels, submitted

[2] Palo, M., Schunnesson, H.: Condition monitoring of wheel wear on iron ore cars, COMADEM, Vol. 15, No. 2, 2012

[3] D-Rail, D1.1: Summary report and database of derailments incidents

[4] D-Rail, D1.2: Report on derailment economic impact assessment

[5] D-Rail, D2.3: Cost/benefit analysis for intervention to reduce freight derailment

[6] D-Rail, D3.1: Report on analysis of derailment causes, impact and prevention assessment

[7] D-Rail, D3.2: Analysis and mitigation of derailment, assessment and commercial impact

[8] D-Rail, D3.3: Guidelines on derailment analysis and prevention

[9] D-Rail: D4.1: Survey and Assessment of Existing Inspection & Monitoring System

[10] D-Rail, D4.2: Survey and Assessment of Existing Inspection & Monitoring System

[11] D-Rail, D5.1: Integration and development of monitoring concepts

[12] D-Rail, D5.2: Outline system requirements specification for pan European Freight monitoring

[13] D-Rail, D7.1: Existing derailment RAMS and economic studies and D-Rail approach

[14] D-Rail, D7.2: RAMS analysis and recommendation (technical view)

[15] D-Rail, D7.3: LCC analysis and recommendation (economic view)

[16] xsd definition of electronical data exchange format according to VPI 08, available at: http://www.comap.sternico.com/vpi08_en.html

[17] http://www.raildata.coop

[18] RNE TIS: Rail Network Europe, Train Information System, available at http://tis.rne.eu/tl_files/RNE_Upload/TIS/2013/TIS_Brochure.pdf

[19] European guide for the identification of railway assets using GS1 Standards 1-0.pdf, found at http://www.gs1.eu/?page=&tudasbazis=60&lister=224

[20] Samuel Greengard: Swedish transport goes on track with RFID, in RFID journal, Logistics, June 23, 2013, www.rfidjournal.com

[21] R. Schorno, C. Schmidt, U. Nietlispach: Zugkontrolleinrichtungen in der Schweiz, in: Elektrische Bahn, Vol. 109 Heft 9, 2011, p. 448 … 458