



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

## D-RAIL

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#### RAMS analysis and recommendation (technical focus)

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## Executive Summary

The main objective of the D-Rail project is to make the recommendations to reduce derailments by 8-12% and an associated cost reduction of 10-20% within Europe. Selecting the right measures to obtain the maximum safety benefits requires an unbiased and objective process. This deliverable describes the findings of risk assessment and RAMS analysis based on the developed conceptual framework on RAMS and LCC.

In respect to the risk assessment, the top derailment causes set out in WP1 and the effects on derailment reductions from WP2, as well as the assessment matrix for most promising technical interventions from WP4 were combined to derive a shortlist of possible measures. 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). No other techniques were studied in WP7, because they lack effectiveness compared to the studied interventions. For hypothetical new interventions, no input data for RAMS, LCC and risk assessments could be provided by the relevant work packages.

In the next step, the actual risk assessment and risk analysis with reference to the Common Safety Method on Risk Evaluation and Assessment have been conducted. Since no European reference implementation exists, the risk assessments were independently carried out using the SBB and RSSB methodologies. Key inputs considered were the estimated increase of freight traffic towards 2050 from WP3 and potential implementation scenarios and estimated implementation costs from WP5. Risk figures related to freight derailment and risk reduction benefits due to the proposed risk control measures have been calculated using actual SBB and RSSB safety risk data.

It was initially elaborated that none of the three measures would be considered reasonable under the ALARP principle – or any other standard. The outcome of both risk assessments would appear to disagree with current railway practice in many EU states, where HABD's, ALC's and measurement cars are widely in use. However, this apparent contradiction is an artefact of the D-RAIL scope limited to freight derailments, which denies economies of scale as well as synergies with reduction of passenger risk typically exploited by infrastructure managers. A reduced case, based on the amount of additional systems deployed for freight only, was subsequently evaluated which shows a positive outcome for ALC and TGMS.

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. Due to lack of data, TGMS were excluded and only Hot Axle Box and Hot Wheel Detection system were studied.

In order to protect against derailment due to a hot axle condition, high level reliability performance of HABD is vital. Higher reliability of HABDs 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.

A migration approach is described, based on two initial scenarios. One scenario is traffic with high density and/or high speed reflecting the situation to highly utilized mixed traffic lines or high speed passenger traffic, whereas the second scenario is traffic with low density and/or low speed represented by secondary lines. The starting point is also different for European countries: many use technology-intense monitoring and intervention due to high traffic density, others rely on human monitoring. It seems likely that an increase in traffic as predicted in WP2 will shift most countries to technological solutions.

In addition to this RAMS analysis with its technical focus, the LCC report will cover the economic view, answering the question of the reduction of derailment costs and the economics of the monitoring systems.

In D7.4 recommendations for the economic use of monitoring systems and reliable implementation scenarios are summarized.

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## Glossary

ALARP	(Risk) As Low As Reasonably Practicable
ALC	Axle Load Checkpoint
CSI	Common Safety Indicator
CSM-RA	Common Safety Methods for Risk Assessment
CST	Common Safety Target
CHF	Swiss currency
DNV	Det Norske Veritas
DOW	Description of work
ECM	Entity in Charge of Maintenance
ERA	European Rail Agency
FOA	Brake Blocking System
FME(C)A	Failure Mode Effect (and Criticality) Analysis
GAMAB	Globalement Au Moins Aussi Bon
GB	Great Britain
GRP	Generalized Renewal Process
HPP	Homogeneous Poisson Process
HOA	Hot Axle Box
HABD	Hot Axle Box and Hot Wheel Detection
HRMS	Harmonization – Running Behaviour and Noise on Measurement Sites
IID	Independent and Identically Distributed
IM	Infrastructure Manager
K	Stress intensity
LCC	Life Cycle Cost
MEM	Minimum Endogenous Mortality
MGT	Million Gross Tonne
MRR	Monetized Risk Reduction
MTBF	Mean Time Between Failure
MTTR	Mean Time To Restore
NHPP	Non-Homogeneous Poisson Process
NRV	National Reference Value
ÖBB	Austrian Federal Railways (Österreichische Bundesbahnen)
QRA	Quantitative Risk Assessment

RAMS	Reliability, Availability, Maintainability and Safety
RCM	Reliability Centered Maintenance
RFID	Radio Frequency Identification
RP	Renewal Process
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
T	Temperature (current)
Tn	Neutral temperature
TDR	Track Decay Rate
TGMS	Track Geometry Measurement System
TSI	Technical Specification for Interoperability
SFAIRP	Reducing risk “so far as is reasonably practicable”
VPF	Value for Preventing a Fatality
WIM	Wheel Impact Monitoring
WLID	Wheel Load Impact Detector
WP	Work package
WTMS	Wayside Train Monitoring System

# 1 Introduction

Work Package 7 of the D-Rail project provides an overall assessment in terms of technical and economic evaluation of inspection and monitoring systems related to derailment based on RAMS and LCC analyses. The evaluation includes recommendations of analysis methods and implementation of mitigating concepts to prevent the various derailment scenarios considered.

In relation to the RAMS and LCC assessment it is worth to stressing the related input required from other WPs. This includes prediction of additional derailment risks based on the future freight system in 2050 and the impact on RAMS (WP2), cause-consequence chains and necessary infrastructure improvements (WP3), functional and operational requirement specifications for monitoring equipment (WP4) and monitoring concepts including number and locations of measurement sites as well as implementation scenarios (WP5). Outcomes with relevance for WP7 from previous work packages, the recent study by DNV for the ERA, as well as recent research projects have been considered in this work.

As this deliverable focuses on RAMS analysis from a technical perspective, the LCC part is mainly excluded and considered in the related deliverable D7.3. The present deliverable aims to assess the impact of derailments to identify which mitigation measures would be affordable and efficient enough to achieve the reduction of the occurrences of freight train derailments between 8–12% and cost reduction of 10–20% within Europe as defined in the D-Rail targets.

D7.1 provided a survey and analysis of existing investigation methods regarding RAMS and economic studies on derailments associated with derivation of methods and key parameters for risk analysis, RAMS and LCC assessment and decision-making. This builds the basis for the framework and related boundaries for RAMS and LCC analysis, which is presented in the first part of this deliverable.

In section 2 the developed conceptual 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 is presented. This should ensure the common understanding in terms of terminology, methodology, relevant key input data, requirements and related standards for the evaluation of RAMS and LCC. Following this, well developed and established methodologies and appropriate models and tools in terms of RAMS, risk analysis and risk assessment have been used.

Given the conceptual framework, selected case studies consisting of the three most implemented monitoring systems have been assessed as examples to demonstrate the functions and application of the developed framework. But the application of the conceptual framework of RAMS and LCC analysis can be employed for all type of monitoring systems. However, the assessment can be done for any monitoring system to investigate in order to evaluate the economic benefit to the IM's and RU's.

The technical view including RAMS analysis, Risk analysis and risk assessment is presented in the subsequent sections of 2 and 3. In section 2 the focus is on the required key input data and safety targets for RAMS and LCC analysis and the approach for risk analysis and risk management according to CSM-RA.

The RAMS analysis, the risk analysis and risk assessment are employed in section 3 of this deliverable. The RAMS analysis includes the risk assessment considering the number and location of monitoring systems for the pan-European network and the current and estimated increase of freight traffic as well as the impact of future carrier demands on RAMS. In addition, the relevant parameters influencing the probability of occurrence of derailment are represented by a developed formula. This helps to understand the impact of monitoring systems on RAMS of the system itself and of the railway track system. However, the availability of the track depends on the availability and the reliability of the detection measurements.

The case study risk assessments carried out by SBB and RSSB for GB used as a basis data and assumptions derived in WP2 and WP5. The effectiveness of each of the proposed systems in reducing frequency of freight derailments, and the associated reduction in risk were taken from WP2. The potential implementation scenarios and estimated implementation costs were taken from WP5. The risk assessments consider the number and location of monitoring systems for the pan-European network and the current and estimated increase of freight traffic up to 2050.

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. 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.

Additional topics referring to the use of monitoring systems in maintenance procedures as well as the issue regarding the technologies targeting several types of derailment causes are presented in section 4.

Finally conclusions and recommendations derived from the RAMS analyses are indicated.

In addition to this RAMS analysis with technical focus, the LCC report D7.3 will cover the economic view. In D7.4 recommendations for the economic use of monitoring systems and reliable implementation scenarios are summarized.

## 2 RAMS- and LCC management and related boundaries

### 2.1 Common understanding of LCC and RAMS

RAMS according to EN 50126 is an abbreviation describing a combination of Reliability (R), Availability (A), Maintainability (M) and Safety (S):

- Reliability is defined as the probability that an item can perform a required function under given conditions for a given time interval.
- Availability: the availability of an object being in a condition in order to fulfil a required function under given terms and given period or during an alleged span of time provided that the required auxiliary materials/external tools are available.
- Maintainability: the feasibility that a certain maintenance measure could be executed for a component under existing boundary conditions within a defined span of time, if the maintenance will be made under defined conditions and defined process and auxiliary materials will be used.
- Safety: the non-existence of an unacceptable damage risk.

A major requirement when carrying out RAMS and LCC analysis is to have a common understanding of definitions and terminologies regarding RAMS and LCC.

Considering the data flow and interactions of WP7 with other WP's in this project a common understanding of RAMS and LCC is necessary to have a consistent base, particularly in terms of the definitions of the terminologies, relevant parameters and needed data. For that reason in the following section detailed reference is taken to RAMS and LCC definitions, since these are crucial for the analysis purpose carried out in WP7. In this context the developed framework (see chapter 2.2) sets out the procedure of the collection of the key input data taking into account the background, detailed explanation of key issues and goal setting for RAMS and LCC analysis.

The RAMS management is a comprehensive and systematic approach to ensure the availability and safety of systems over the entire life time. However RAMS management ensures the definition of systems, the performance of risk analysis, identification of hazard rates, detailed tests and safety certification. Thus RAMS should be used during the development and implementation of new products or the planning and realisation of new assets since RAMS assists the avoidance of failures already in the planning phase of projects.

RAMS technology is a recognized management and engineering discipline for the purpose to predict the specified functionality of a product over its' complete life cycle. RAMS technology keeps the operation, maintenance and disposal costs at a predefined accepted level, by establishing the relevant performance characteristics at the beginning of the procurement cycle and by monitoring and controlling their implementation throughout all project phases. The RAMS characteristics determine essential parameters of the system such as the usability and acceptability of the system, the operation and maintenance costs, and the users' safety and health risk when operating the system.

The corresponding standard is the EN 50126 (Specification and the proof of the reliability, availability, maintainability and safety (RAMS) of rail applications) is issued by the CENELEC.

The standard describes the engineering, construction, use and demolition of a railway system from the perspective of RAMS. Rail infra projects executed by Infra Managers must meet standard EN 50126 (CENELEC, 1999).

The European Standard EN 50126 provides Railway Authorities and the railway support industry, throughout the European Union, with a process which will enable the implementation of a consistent approach to the management of Reliability, Availability, Maintainability and Safety (RAMS). The cornerstones of this standard are the processes for the specification and demonstration of RAMS requirements.

Besides this European Standard aims to promote a common understanding and approach to the management of RAMS. It can be applied systematically by a railway authority and railway support industry, throughout all phases of the lifecycle of a railway application, to develop railway specific RAMS requirements and to achieve compliance with these requirements. The systems-level approach defined by this European Standard facilitates assessment of the RAMS interactions between elements of complex railway applications.

However, EN 50126 promotes co-operation between a railway authority and railway support industry, within a variety of procurement strategies, in the achievement of an optimal combination of RAMS and cost for railway applications. And the adoption of this European Standard will facilitate European railway inter-operability.

It should be noted that the standard EN 50126 is constantly expanded and modified by the European Commission for electronic standardization CENELEC (Comité Européen de Normalisation Electrotechnique).

In regard to the standards an important addition to the European wide regulatory regime with respect to risk management is the introduction of the Common Safety Method on Risk Evaluation and Assessment (the CSM-RA). The CSM-RA has applied since 1 July 2012 to all significant changes to the mainline railway system – ‘technical’ (engineering), operational and organisational. The CSM-RA defines a common European risk management process. Its use is mandatory for all significant changes to the mainline railway system, and as such may be relevant to the introduction of any of the measures being taken forward for implementation due to the D-Rail project. The section 2.4 and 3.3 provide more detail on this EU regulation and the approach used for the Risk analysis and Risk assessment respectively in D-Rail.

The railway transport industry is large in its operation; integrated, automated and complex, in which providing a dependable service has become a prime objective for both the infrastructure owner and operator.

Over the past years, substantial developments in safety and services have taken place in railway system. However, passengers and authorities still expect a more dependable service which is on schedule. This has made safety and punctuality of railway operation key factors in fulfilling the requirements of authorities, passengers and their business. Therefore, railway operators are continuously under pressure to improve their safety and availability level to fulfil their requirements.

However, railway systems degrade with age and usage and can fail. When failure occurs the severity of the consequences can be very significant, leading to higher maintenance, cost, and a reduction in availability, economic loss, damage to the asset and environment and possible loss of human lives.

The prime objectives in the development of a railway system (within the specified constraints, defined by authority, regulation, and maintenance requirements) is to be safe and cost-effective. RAMS and LCC management and assessment provide a comprehensive and systematic methodology to ensure this by considering the whole life cycle.

As depicted in Figure 1, system design attributes and system support elements impact on both the technical and economical sides of the cost effectiveness relationship. In addition, a major projected life cycle cost for a system stems from the consequences of decisions made for reliability and maintainability allocation during both the design and operation phases. Those decisions pertaining to the utilization of new technologies, the selection of components and materials, the identification of equipment packaging schemes and diagnostic routines, the selection of the manufacturing process and maintenance support policies etc., have a great impact on system effectiveness and life cycle cost (Blanchard, 1995).

In this context, the engineers must take in to account the consequences of such interactions in order to achieve the predefined system effectiveness targets and minimize the safety risk and cost. Otherwise, the first factor will decrease and the second will increase, since the performance element is usually emphasized in comparison with other design parameters such as reliability, maintainability, and supportability (D'Addio et al., 1997).

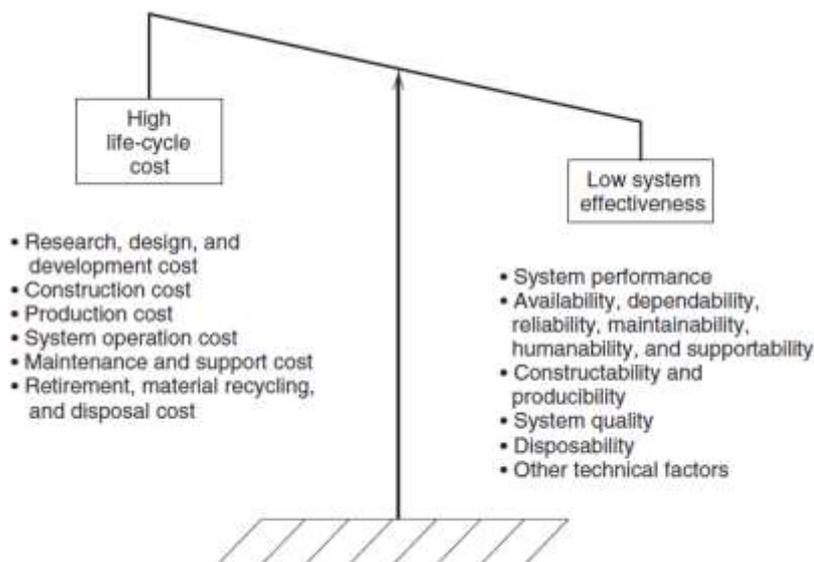


Figure 1: The imbalance between system cost and effectiveness factors (Blanchard, 1995).

To this end, RAMS (Reliability, Availability, Maintainability and Safety) engineering is introduced to deal with failures, failure prevention/elimination, and the reduction of the consequences of failure, to an acceptable level. RAMS models provide a quantitative basis for effective decision making and judging the performance of the railway system through its life cycle. Establishing a RAMS program will help to ensure that the railway system will be free from RAMS-related problems.

So a RAMS analysis consists of several analyses with defined tasks as shown in the following figure (highlighted with an example).

Analysis	Investigation	Study of Variants	Preferred Variant Study	Realisation
Reliability, Availability				
Maintainability				
Safety				
LCC				
RAMS / LCC				
Social Cost & Benefit Analysis				
RAMS/LCC spec				
Degree of detail	Reduction of travel time	Tunnel or Bridge	Ballasted or ballastless track	Continuously embedded rail or precast slab segments

Figure 2: Matrix of different analysis and phases reg. RAMS and LCC analysis

Different disciplines are used in RAMS analysis, e.g. reliability theory, reliability science, maintainability, optimization and Life cycle costing. Reliability science deals with the understanding of the degradation processes. Reliability engineering deals with reliability issues in the design stage. Reliability economics deals with cost analysis of issues relating to design for reliability, and maintenance development. Reliability theory provides an umbrella to deal all facets of reliability: engineering, maintenance, economics, LCC, management, etc.

Maintainability deals with maintenance issues. It is defined as the ability of an item under given conditions of use, to be retained in, or restored to, a state in which it can perform a required function, when maintenance is performed under given conditions and using stated procedures and resources. The main aim of maintainability is to facilitate easy and cost effective maintenance strategies so that the desired reliability, which is aimed at the design stage, can be guaranteed. Some of the essential features of maintainability are: Interchange ability, easy accessibility, easy serviceability, diagnostic and prognostics capabilities and Maintenance task analysis.

Railway systems have grown in complexity. Even though strong focus on performance has been placed, however, realizing a high level of achieved reliability has been a great challenge over the time. Simultaneously, the life cycle costs have been increasing. With increasing complexity, higher traffic demand, and limitations in budget, the importance of developing an effective solution for technical failure management of railway systems, 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.

Therefore, application of RAMS engineering coupled with LCC management for railway systems is vital, to deal with failures proactively and to reduce the consequences of failure, to an acceptable level. Implementation of a RAMS analysis is a complex task and requires proper understanding of the underling concepts, factors, and the interaction among them, to arrive at an effective decision.

However, to deal with derailment and prevention/mitigation of derailment a robust framework is required underlying the RAMS concept and building the base for proposed RAMS analysis.

In the course of the development of the framework for RAMS and LCC analysis all the relevant RAMS and LCC issues and key parameters has been defined and explained. The RAMS and LCC template for data collection of the inspection and monitoring systems shall serve as an integral part of the developed framework for RAMS and LCC analysis to provide an understanding of the RAMS and LCC of derailment detection. Besides the advised RAMS approach complies with the related standards being relevant for the RAMS analysis. Thus it can be stated that an agreement on the same and consistent definitions has been established in order to have a common understanding of the terminologies regarding LCC and RAMS.

A general overview of currently in progress and recently completed related EU projects concerning RAMS and LCC was presented in the report D7.1 of WP7. An additional section on these projects with relevance for RAMS and LCC analysis is dedicated in chapter 2.3.8.

The tasks including the framework and the boundaries conditions for RAMS and LCC analysis are described in the following section

## 2.2 Development of framework and boundary conditions for RAMS & LCC analysis

The aim of this study is to develop a conceptual framework on “RAMS and LCC Analysis” to assist when developing and revising RAMS and LCC characteristics of the protective measures against derailment. The framework sets out the concepts that underlie the implementation of RAMS and LCC analysis, and explains the key factors, concepts, assumptions, variables, and the presumed relationships and interactions among them. The development of a framework for traceable and reliable RAMS and LCC analysis ensures that the whole process and decisions have a cohesive goal. It should be pointed out that the framework is developed at high level for the purpose of D-Rail.

It is essential to show that the developed framework is operational, comprises all the relevant features and is applicable for the aimed analysis. For these reasons case studies have to be defined to refine the analysis of the impact of the selected inspection and monitoring systems and to evaluate the procedure.

The task 7.2 in WP7 sets out the baseline for RAMS and LCC analysis with the related reports D7.2 (RAMS analysis), D7.3 (LCC analysis) and D7.4 (recommendations and findings) since the task shall include:

- Development of a framework and boundary conditions for RAMS and LCC analysis
- Definition of key input data and safety targets for RAMS and LCC analysis
- Approach for risk analysis and risk management according to CSM
- Adaption/Definition of migration scenarios
- Supports in collection of RAMS & LCC relevant data for monitoring systems

Particular emphasize should be given to the definition of the boundary conditions in order to have a common sense on this. In the context of carrying out RAMS and LCC analysis the definition of boundary conditions is two-fold: the necessary framework, available methodologies, knowledge, models, software, data input etc. for RAMS and LCC management and the boundary conditions concerning the technical system or sub-system or component aims to define the operation under which the technology/system is used (e. g. curves, track category, speed, loading, environment, system interfaces, temperature, specific boundaries etc.), which affect the RAMS and LCC of the technology/system. The latter is explained in detail in section 2.3.1. It should be ensured to have a common understanding of the boundary conditions both for RAMS and LCC analysis and for the technical system.

The framework and the approach on carrying out RAMS and LCC analysis including the required key input data are presented in the following section and depicted in Figure 3.

In principle the following steps are indicative of the scope to perform an effective RAM study, but should not be regarded as exclusive.

### 1. Definition of

- objectives and scope
- responsibilities and time schedule

- RAMS management and related boundaries
2. Establishment of the basics
    - definition of RAMS parameters and targets
    - definition of the boundary conditions, system description and operational and environmental conditions
    - definition of variant study
    - definition of System Requirement Specifications
    - collection of all required and relevant data
  3. Data assessment
    - processing of data
    - analysis and assessment of data
  4. RAM analysis
    - calculation tool for RAM analysis
    - RAM modelling, review of RAM models
    - RAM analysis incl. selection of analysis methods (FMEA, ETA etc.)
    - risk assessment as one part of RAMS
    - interpretation of results
    - taking reference to the defined specifications, compare the achieved results with expectations and demands
    - validation of RAM calculation
  5. RAM results as input for combined RAMS & LCC analysis
  6. Social cost-and-benefit analysis
  7. Documentation of input and output parameters and follow-up of the gathered data

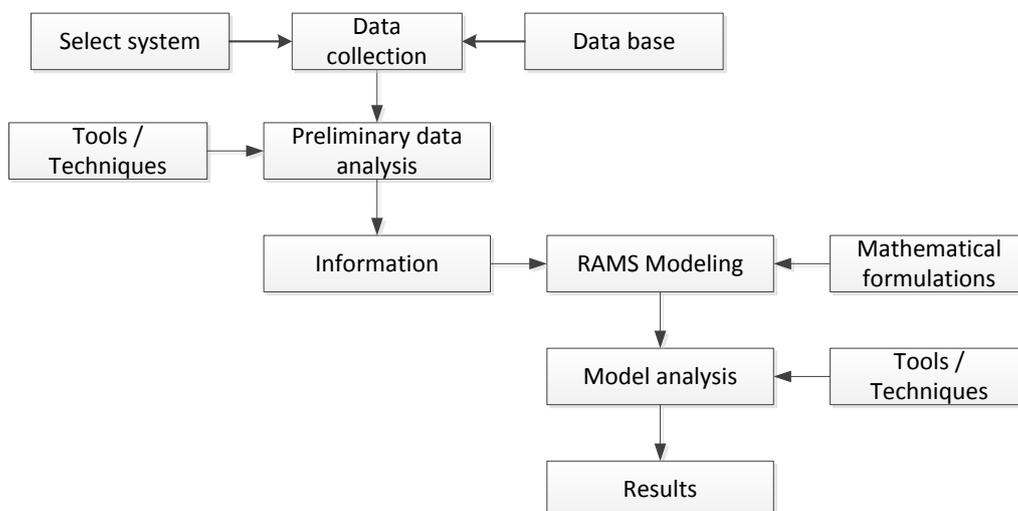


Figure 3: Data analysis process (Blichke and Murthy, 2011)

### **Regarding objectives and scope**

D-Rail focuses on prevention and has to consider derailment detection. In this context, the main aim is to prevent derailment rather than wait until derailment occurs and just mitigate.

The scope of WP7 is to perform technical and economical assessment of inspection and monitoring systems through RAMS- & LCC-analysis. Further, it should support a common understanding of LCC & RAMS and give recommendations for the use of monitoring systems.

Concerning the scope of D-Rail it is worth mentioning that axle failures are not explicitly out of scope of the entire project. However WP3 excludes the analysis of axle brake induced derailments due to the on-going parallel efforts in the EC funded project EURAXLES. In contrast hot axle box and axle journal rupture – being one of the top derailment causes – is used in WP7 as a case study of the evaluation procedure (see more in section 2.3.4)

### **Regarding RAMS management and the related boundaries**

As a next step for RAMS analysis it is necessary to identify and to ensure boundaries for RAMS management. It can be stated that the involved partners in WP7 have the required knowledge and tools to perform RAMS and LCC analysis such as:

- systematic approach with holistic methodologies including defined processes
- appropriate models for Risk analysis and Risk assessment (see section 2.4, 3.2), RAMS (see section 3.1) and LCC (see D7.3) namely
  - SBB methodology (Schlatter, Einer, Spörndli, 2008), The risk concept for evaluation of technology risks to protect travellers and employees, internal SBB document; Ernst Basler und Partner (2009) Risk-oriented prioritization of technology deployment for safety at SBB infrastructure, internal SBB document) as described in D7.1
  - RSSB methodology (GB Rail Industry Guidance Note GE/GN8643 Guidance on risk evaluation and risk acceptance)
  - DB methodology Risk evaluation based on the DB guideline Ril 451 (guidance for operational and technical risk management in the railway system which has currently been re-drafted to align more closely with the latest requirement of CSM-RA)
- Application related software for conduction the Risk analysis and assessment, RAMS analysis and LCC analysis e. g.
  - RSSB Safety Risk Model v7.2.
  - RSSB Taking Safe Decisions Analysis Tool v1.1
  - Reg. RAMS: Variety of software are used for RAMS and LCC analysis e.g. Reliasoft, Catloc, and Simloc.
  - LCC calculation by D-LCC used within DB
- Standardized templates for documentation of input and output parameters

The evaluation of the procedure with respect to risk assessment and RAMS analysis will be validated in the following sections.

### **Regarding the establishment of the basics**

By establishing the basics for RAMS analysis it's necessary to define the RAMS parameters, boundary conditions and the required input data. Besides, the variant study/case study has to be determined in order to collect all the required and relevant RAMS data for the data assessment and analysis purpose.

Such being the case the developed RAMS and LCC template as one core part of the framework is aimed for:

- establishing of common understanding of RAMS and LCC parameters
- description of the selected inspection and monitoring system with technical data
- definition of the related boundary condition the system is used
- description of the expected functions of the system (system RAMS performance)
- current inspection and maintenance strategy and activities with the linked costs
- recurrent failure event data for the selected inspection and monitoring system failure
- time between failures (MTBF) for the selected inspection and monitoring system
- LCC relevant parameters

The workflow and main parts of the RAMS and LCC template may be described as follows:

1. Explanation of relevant RAMS and LCC parameters:
  - Explanation of relevant LCC parameters:
  - Explanation of relevant RAMS parameters:
2. Explanation of the used inspection and monitoring systems:
  - Type of system (wayside, vehicle)
  - Description of the technique (function, system configuration, complexity e. g. number of sensors)
  - Direct measured values, i. e. values that are measured in terms of freight train derailment risk reduction and how these values are measured
  - Level of implementation
3. Detailed description of the used system in terms of:
  - Short description of the used system in terms of: prototype / widely used, design/configuration, number of operational systems, number of installation sites, locations in the network, interfaces with other systems, distinction between measuring system and the associated vehicle etc.)
  - Detailed description of the boundary conditions under which the system is used

- What are the boundary conditions that affect the Availability, Reliability and Maintainability of the system most? How are these parameters affected?
  - What are the boundary conditions that affect the influence the cost level of the system most? How are these parameters affected?
  - Does the system have any redundancy? Consequences if there is no redundancy?
  - Quality of measuring, how is the effectiveness of the detection system/technology [high, moderate, low]
  - What is the impact of non-detection, e .g. unnecessary train stoppage?
4. Regarding RAMS input data for inspection and monitoring systems (see definitions in the annex)
- Reliability parameters
    - Mean Time Between Failure (MTBF)
    - Failure rate
    - Reliability of detection (e. g. time for detection of failure)
  - Availability
    - Availability of the system itself
    - Impact on Availability of the entire system
  - Maintainability
    - Mean time To Restore (MTTR)
  - Safety
    - Number of accidents,
    - Safety Integrity Level (SIL)
    - Redundancy
  - Quality of RAMS data
5. Regarding LCC input data for inspection and monitoring systems (see definitions in the annex)
- Life time
  - Investment, Re-Investment
  - Disposal cost
  - Inspection cost
  - Operation cost
  - Maintenance cost
  - Quality of LCC data (estimated, verified, by experts)

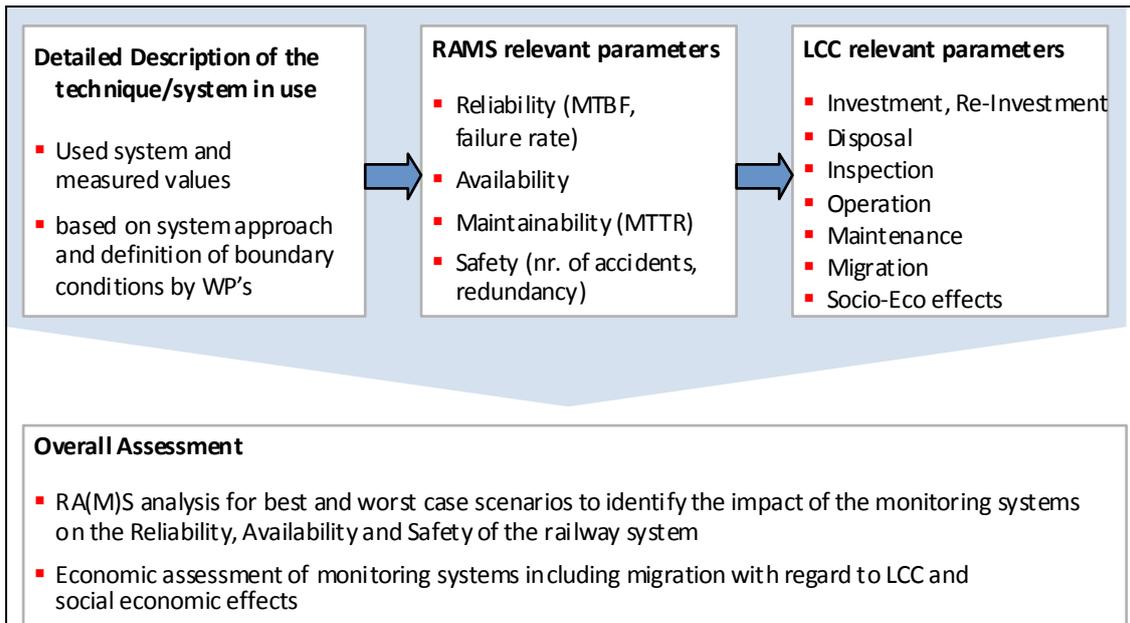


Figure 4: workflow of the RAMS and LCC template for data collection

Parameter	Description
Quality of data	Please indicate the quality of data like verified or estimated <b>Please take care of high quality of data</b> In the case of unknown data a sensitivity analysis might indicate the economic impact of the parameter(s)
Life time [year]	Mean technical life time of system in years, after the life time replacement is necessary
Investment cost [€]	Total cost for investment in a new system/modul/technology. This includes all costs for ready to use, i. e. costs referred to planning and preparation, material, transport, installation (time, construction procedure), access to the site etc.
Re-Investment cost[€]	Cost necessary for Re-installation or Renewal of system or parts of system (sub-system) after the end of the life time
Disposal cost[€]	Cost needed for disposal / recycling ...
Maintenance activity	Short description of maintenance activity
Maintenance interval [year, months]	Interval between two specific maintenance activities, different maintenance activities may have different intervals
Maintenance cost [€]	Cost for maintenance activit in case of preventive or corrective maintenance
Inspection activity	Short description of inspection activity
Inspection interval [year, months]	Interval between two specific inspection activities, different inspection activities may have different intervals
Inspection cost [€]	Cost for maintenance activit in case of preventive or corrective maintenance
Operation cost [€]	Cost per year necessary for operation, labour costs should be given in hour
Cost on operating line [€]	Cost for operating complications that arise from track closures for installation or maintenance work
Non-Availability cost [€]	Cost arised due to malfunction, train delay or less serviceability in terms of planned and unplanned maintenance activity.
Migration cost [€]	Cost for Migration considering the whole migration process management starting from installation to operation till implementation of the new system.
Design & system support cost [€]	Cost for Verification, Monitoring and Support
Service testing and Certification cost [€]	Cost for the needed work to ensure system integration and acceptance, i. e. the system can be brought safely into serviceable order in line with the design intent/requirements and contractual obligations.
Public & Environment Economics [€]	Cost related to public and environment impact

Table 1: Explanation of relevant LCC parameters

Parameter	Description
Quality of data	Please indicate the quality of data like verified or estimated <b>Please take care of high quality of data</b>
MTBF [days]	Mean time between failure given in days. Also indicate the environmental, operational/functional strains, failure criteria and period of use of the system.
MTTR [days] or [hours]	The average time that a device will take to recover from any failure. It's the ratio of total corrective maintenance time divided by the total number of corrective maintenance.
Failure Rate [hour] or [1/t]	Failure Rate is the frequency with which an engineered system or component fails, expressed for example in failures per hour.
Technical Availability A [%]	Availability is the proportion of time a system is in a functioning condition. The Availability depends on the technical performance of the system/component and the Repair rate and both parameters influence also the Life Cycle Costs of the system. A = Uptime / (Uptime + Downtime) Downtime means the system does not work/ is non-operational due to maintenance or unplanned event; Uptime is the time that a system is operational and works error-free.
Safety Integrity Level [SIL]	Safety integrity level of a system (0) 1 to 4 according to the EN 50129 (Railway applications - Safety related electronic systems for signalling). The standard [EN 50129] defines five Safety Integrity Levels (SIL) with SIL 0 being non-safety related. The required Safety Integrity Level shall be decided on the basis of the level of risks identified in hazard analysis or elsewhere. SIL shall be defined at a functional level and functional module level. Similarly, all Systems, Sub-Systems and Components shall have a Safety Integrity Level defined. The design, implementation techniques and measures shall be defined depending on the SIL of the function to be performed by each individual System, Sub-System or Component.

Table 2: Explanation of relevant RAMS parameters

Detailed indication regarding RAMS and LCC key input data is given in chapter 2.3.

M RAMS and LCC template is presented in the annex of this deliverable.

Within the RAMS and LCC template for data collection, assistance in filling out the template has been given to the WPs to ensure that correct data are introduced. The assistance includes for example:

- As far as possible don't change the number and name of the selected techniques in the template; in case of another system/technology just add it
- Make a note if the availability of data is limited or if it is not possible to deliver
- If a range of costs is indicated then describe it and also the reason
- If there are different suppliers of the system then take the mean value of the (investment) costs and make a specific note
- A detailed description of the costs is required, i. e. indicate what is included in the costs (particularly in the investment costs); also state the source of the given data
- The quality of provided data should be indicated using the categories of estimated, assumed, verified, experts
- When the spreadsheet is circulated start with a rough estimation of the values (but with good quality) and then refine the data if needed
- Since the data collection has to be done in the WPs, the template will be circulated to the WP leader and the WP leader is responsible to forward the template to the responsible persons within his WP to fill in the template. WP7 can support in collection of RAMS & LCC relevant data for monitoring systems.

For the partners within D-Rail the framework seems rather clear in structure.

To strengthen the common understanding of RAMS and LCC, WP7 has offered additionally special meetings or training on RAMS and LCC if needed by the partners in this project.

### **Regarding definition of case study**

As indicated in the previous section, the verification of the framework and the evaluation of the procedure will be done through case studies. Among the top derailment causes, hot axle box and axle journal rupture failure, wheel failure, spring and suspension failure and skew loading are selected by WP7 D7.2 among partners to be focused for further RAMS analysis of the associated protection systems. Among protection systems, Hot Box and Hot Wheel Detection Systems as a combined system (HABD) and the dynamic Axle Load Checkpoints have been selected as highly populated types of wayside-monitoring equipment which are presently in use and target the top derailment causes. The hot axle box, axle journal rupture failures, and to some extent wheel failures can be covered by the protection system of Hot Box and Hot Wheel Detection Systems (HABD). Spring and suspension failures, skew loading, some types of wheel failure, and rail failures are covered by dynamic Axle Load Checkpoints (ALC).

### **Regarding collection of required and relevant data**

A special remark needs to be given to the collection of RAMS & LCC relevant data for inspection and monitoring systems within D-Rail. It is well known that the collection of the needed data for RAMS and LCC should be done by the WP's and provided for WP7. Clearly this requires the provision of the needed data for WP7, while WP7 can support the partners in collecting the data (see section 2.3.5 of the present deliverable and D7.1).

### **Regarding definition of the boundary conditions**

Given the fact that the (technical) boundary conditions under which the technology/system are used affect the RAMS and LCC of the technology/system, it is essential to define what is inside and what is outside of the analysis and the accurate context the system is operating in. More details is given in section 2.3.1

The next step in the process of establishing the basics is the process of data assessment and RAM analysis.

Figure 5 presents an overview of the main processes and decisions within the proposed RAMS framework and to show the interactions between different concepts. As shown, in Figure 5, the proposed RAMS analysis process is divided into five main segments: "Reliability analysis", "Maintainability analysis and allocation", "supportability (logistic support) analysis and allocation", and the "Estimation of operational availability".

Each process and decision contains a set of processes, which in turn encompass a number of tasks that must be done to carry out the RAMS analysis.

The arrows in Figure 5 illustrate how data, information and/or decisions flow from one process to another. It should be emphasized that there are many interactions between the various processes. However, in order to increase the clarity this sort of interaction loop is ignored in Figure 5.

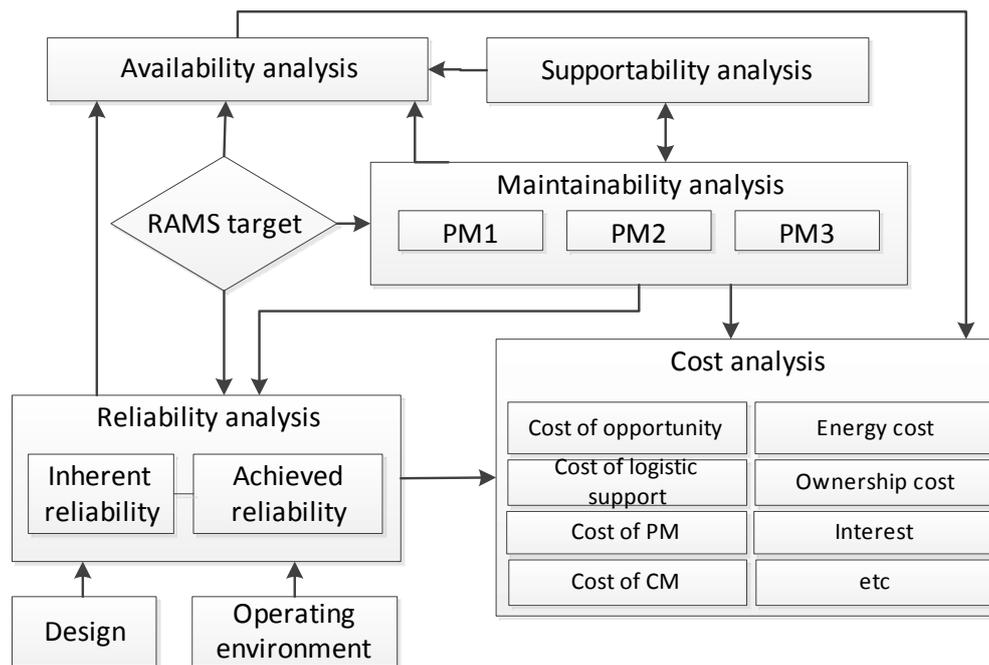


Figure 5: RAMS data analysis framework

### Reliability analysis of railway units

The highest reliability which an item/unit can achieve is established during the design and manufacturing process and is called the inherent reliability. However, the achieved reliability includes the addition of a function of the operating environment of a product, which comprises factors such as the surrounding environment (e.g. temperature, humidity and dust), condition-indicating parameters (e.g. vibration and pressure), and human aspects (e.g. the skill of the operators).

Two options exist to cope with this low reliability, i.e. increasing reliability through design or implementation of effective maintenance program. Increasing reliability will lead to fewer failures and may decrease maintenance costs in operation phase. Lower reliability means increased unscheduled repairs and decreased availability.

When it is not possible to build in the desired level of reliability due to technological and economic issues, an effective maintenance program can be used to compensate for this shortcoming. Hence a common practice is to perform maintenance to compensate for unreliability. The reliability level obtained by performing maintenance is called achieved reliability. It should be noted that by incorporating a more applicable and effective maintenance strategy, one may increase the achieved reliability up to inherent reliability.

Hence, by maintenance we may increase an item's operational reliability, but not its inherent reliability. Therefore, the organisation providing maintenance plays an important role in achieving the inherent reliability of equipment at the lowest possible cost in its service life. Examples of the organisation's responsibilities include selecting proper subcontractors, using a skilled staff for correct removal and installation, repair and testing, and providing a proper inventory environment and packaging schemes, etc.

However, all these decisions concerning RAMS should be based on a reliability analysis that provides a fact/data driven platform for further RAMS decision. A short summary of the reliability analysis follows.

Reliability analysis of Railway units can be classified into reliability analysis of non-repairable and repairable units. Non-repairable units are those which are not repaired when they fail to perform one or more of their functions satisfactorily, and are instead discarded. The discard action does not necessarily mean that the unit cannot be repaired. In some cases repair actions are not economically effective since a repair would cost almost as much as acquiring a new unit. Repairable units are those which, after failing to perform one or more of their functions satisfactorily, can be restored to satisfactory performance by any method other than replacement of the entire system (Ascher and Feingold, 1984). The reliability analysis of repairable units includes modelling the number of recurrent failure events over time rather than the time to the first failure, and the reliability of such units strongly depends on the effectiveness of the repair action.

There are two main methods for selecting and evaluating the reliability models using observed failure data i.e. Nonparametric or empirical methods and Parametric methods. The non-parametric method provides a non-parametric graphical estimate of the number of recurrences (repairs/failures) versus the utilization/age. The method is called non-parametric in the sense that it does not use a parametric model for the population. This estimation involves no assumptions about the form of the mean function or the process generating the system histories.

The parametric method assumes that the data has come from a type of probability distribution (e.g. Exponential, Weibull, Normal distributions) or stochastic point process (e.g. Non-homogeneous Poisson Process and Renewal Process) and makes inferences about the parameters of the models.

Reliability analysis of the non-repairable units deals with modelling the time to first failure, i.e. methods deal with units that experience only one event, end of life. Methods such as life data analysis (LDA) is proposed to model the time to first failures. In LDA, it is assumed that events (failures) are independent and identically distributed (iid). Readers are referred to (Ebeling, 2004), (Modarres, 1992), (Kececioglu, 2002) for further study and discussion of reliability life data analysis.

The parametric method used to model reliability of repairable units entails stochastic point processes, including the homogeneous Poisson process (HPP), the non-homogeneous Poisson process (NHPP), the renewal process (RP) and the generalized renewal process (GRP), the last of which was introduced by (Kijima and Sumita, 1986). The quality or effectiveness of the repair action is categorized as follows (Rausand and Høyland, 2004), (Ascher and Feingold, 1984):

1. Perfect repair, i.e. restoring the system to the original state, to a “like–new” condition,
2. Minimal repair, i.e. restoring the system to any “like-old” condition,
3. Normal repair, i.e. restoring the system to any condition between the conditions achieved by perfect and minimal repair.

Based on the quality and effectiveness of the repair action, a repairable system may end up in one of the following five possible states after repair (Rausand and Høyland, 2004) and

(Ascher and Feingold, 1984): 1) as good as new; 2) as bad as old; 3) better than old but worse than new; 4) better than new and 5) worse than old.

Figure 6 depicts the model selection framework for reliability analysis of repairable units/systems. As seen in the figure, the trend and dependency test is the most important step towards selection of the right reliability model.

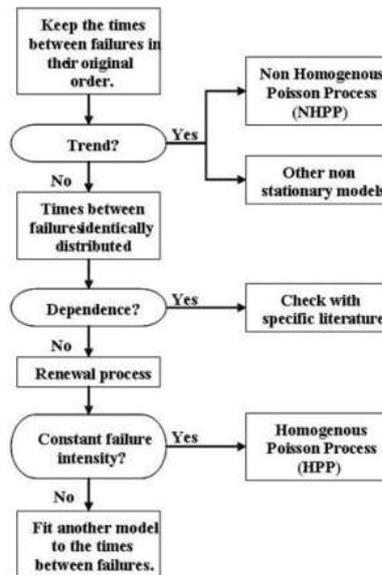


Figure 6: Model Selection Framework for Reliability Analysis of Repairable Systems [Adapted from (Ascher and Feingold, 1984)].

## Maintainability Analysis

Maintainability is an inherent characteristic of system or product design. It pertains to the ease, accuracy, safety, and economy in the performance of maintenance actions. A system should be designed in such a way that it can be maintained without large investments of time, at the minimum cost, with a minimum impact on the environment, and with the minimum expenditure of resources (e.g. personnel, material, facilities, and test equipment). One goal is to maintain a system effectively and efficiently in its intended environment, without adversely affecting the mission of that system. Maintainability is the “ability” of an item to be maintained, whereas maintenance constitutes a series of actions necessary to retain an item in, or restore it to an effective operational state. Maintainability is a design parameter. Maintenance is required as a consequence of design (Blanchard et al.), (Blanchard, 1995), (Blanchard et al., 1995).

High maintainability performance and, in turn, high availability performance are obtained when the system is easy to maintain and repair. . Some design features of maintainability characteristics include interchangeability, easy accessibility, easy serviceability, and diagnostic and prognostic capabilities. The inherent maintainability is primarily determined by the design of the equipment and can be greatly enhanced if fault detection, isolation and repair procedures are worked out during the design stage itself in advance. In general, the maintainability is measured by the mean repair time, often called Mean Time To Repair (MTTR), which includes the total time for fault finding, and the actual time spent carrying out the repair.

Maintenance task analysis is one of the most important parts of maintainability analysis and includes a detailed analysis and evaluation of the system to (a) assess a given configuration relative to the degree of incorporation of maintainability characteristics in the design and compliance with the initially specified requirements and (b) determine the maintenance and logistic support resources required to support the system throughout its planned life cycle (Blanchard, 2004).

Maintenance actions, if used properly can control the degradation and reduce or eliminate the likelihood of the occurrence of failures and to restore a failed system to operational state. However, maintenance involves costs and these can be significant fraction of the operating budget. Hence the applicable and effective maintenance requirements have to be defined to achieve the desired reliability and availability and reduce the total life cycle cost.

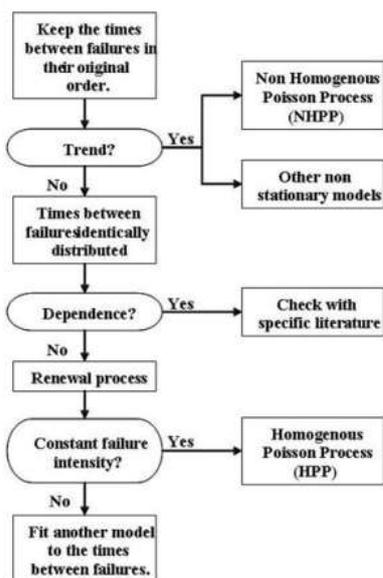


Figure 6 conveys an example of the relationships and interactions between selected reliability and maintainability tools, which should be considered during maintainability analysis (Blanchard, 2004). Varieties of methodologies are introduced to define the maintenance requirements of an equipment among them reliability centred maintenance (RCM) within railway sector.

Reliability-Centred Maintenance (RCM) is a well-structured, logical decision process used to identify the policies needed to manage failure modes that could cause the functional failure of any physical item in a given operating context. The RCM methodology is used to develop and optimize the preventive maintenance and inspection requirements of equipment in its operating context, to achieve its inherent reliability where, inherent reliability can be achieved by using an effective maintenance programme. The methodology is based on the assumption that the inherent reliability of equipment is a function of the design and the built quality (Nowlan and Heap, 1978), (Moubray, 1997), (Smith and Hinchcliffe, 2003).

### Cost analysis for Maintenance activities

If the maintenance and repair effectiveness follows as-good as-new process, the maintenance cost per unit of operating time, considering maintenance task every T Unit of operation, can be expressed as:

$$Cost_T = \frac{C_{PM} \cdot R(T) + C_{CM} \cdot F(T)}{\text{Expected operating length}}$$

Where

T: Inspection interval

Cost<sub>T</sub>: cost of maintenance per unit of time per maintenance

C<sub>PM</sub>: Cost of preventive maintenance

C<sub>CM</sub>: Cost of corrective maintenance, and may include potential cost of accident, and loss of revenue

R(T): Reliability at time T

F(T): probability of failure at time T

The expected cycle length can be estimated as follows:

$$\text{expected maintenance cycle length} = T \cdot R(T) + [M(T) \cdot F(T)]$$

Since the state of the units/systems after repair derives the residual life and the costs, it is vital to consider maintenance effectiveness and reliability after maintenance intervention in the cost modelling. Further readings on the subject can be found in (Ascher and Feingold, 1984), (Rausand and Høyland, 2004), (Ebeling, 2004) and (Pham, 2003).

### Availability performance

The most frequently used availability measure is the *steady-state availability* or *limiting availability*, which is defined as the mean of the instantaneous availability under steady-state conditions over a given time interval and is expressed by  $A = \lim_{t \rightarrow \infty} A(t)$ .

This quantity is the probability that the system will be available after it has been operating for a long time (e.g. 10 years in case of railway track) and is a significant performance measure for a system. Often steady-state availability is also defined, depending on whether the waiting time or preventive maintenance times are included in or excluded from the calculation. Therefore, depending on the definitions of uptime and downtime, there are three different forms of steady-state availability: inherent availability, achieved availability, operational availability (for a detailed discussion see e.g. Blanchard and Fabrycky; (Blanchard 1995); and (Kumar and Akersten, 2008). It is important that these metric be well defined to properly tailor them to railway operation and needs.

**a) Inherent availability (A<sub>i</sub>):** inherent system availability is the probability that the system, will operate satisfactorily when called upon at any point in time under specified operating conditions, in an ideal logistic support environment (i.e., readily available tools, spares, maintenance personnel, test equipment etc.) (Blanchard and Fabrycky). It excludes logistic delay time, administrative delay time, and does not consider preventive or scheduled maintenance tasks. Inherent availability may be expressed as.

$$A_i = \frac{MTBF}{MTBF + \overline{M}_{ct}}$$

Where the MTBF is the mean time between failure and  $\overline{M}_{ct}$  is the mean corrective maintenance cycle time.

As stated by (Ebeling 2004), inherent availability is solely based on the failure distribution and repair-time distribution. Therefore it is viewed as a design parameter.

**b) Achieved availability ( $A_a$ ):** achieved system availability is the probability that the system, will operate satisfactorily when called upon at any point in time under specified operating conditions, in an ideal logistic support environment (i.e., readily available tools, spares, maintenance personnel, test equipment etc.)(Blanchard and Fabrycky). It excludes logistic delay time, administrative delay time. The achieved system availability does consider preventive or scheduled maintenance tasks. Achieved availability may be expressed as.

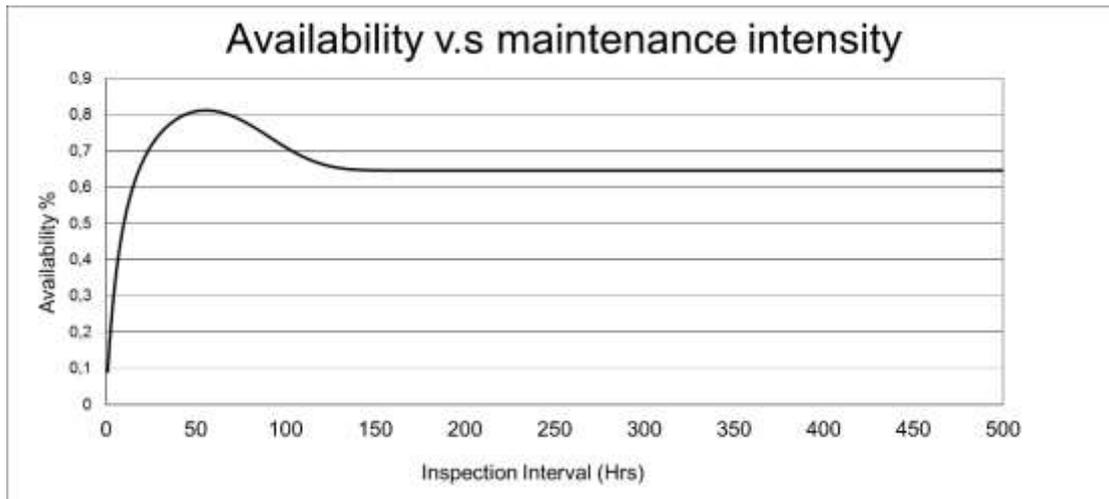


Figure 7: Effect of maintenance intensity of availability performance

$$A_a = \frac{MTBM}{MTBM + \bar{M}}$$

Where MTBM refers to the mean time between maintenance and  $\bar{M}$  is the mean active maintenance time.

As shown in Figure 7, when the intensity of preventive maintenance increases (i.e. shorter interval) it may have a negative impact on the achieved availability even though it may increase the MTBF. This is due to the fact that the shorter preventive maintenance intervals increase the downtime. As the preventive maintenance interval increases, the achieved availability will reach a maximum point and then generally approaches to the value of the inherent availability.

**c) Operational availability ( $A_o$ ):** operational system availability is the probability that the system, will operate satisfactorily when called upon at any point in time under specified operating conditions, in an actual logistic support environment (Blanchard and Fabrycky, 1998). This availability measure is closest to reality since it addresses not only the corrective and preventive maintenance task, but also the logistics and administrative time delays. The operational availability is expressed as:

$$A_O = \frac{MTBM}{MTBF + MDT}$$

Where MDT is the mean maintenance down time and includes maintenance time  $\bar{M}$ , logistics delay time, and administrative delay time.

By reducing the impact of freight derailment on railway users and operation the Availability of the track should be increased in order to achieve less track disruptions due to derailment and its consequences. However, the Availability of the track depends on the Availability and the Reliability of the detection measurements. In the context of RAMS analysis for D-Rail purpose it makes to distinguish between the Availability of the inspection and monitoring system itself and the Availability of the entire railway system (see data collection by the RAMS and LCC template in section 2.2.1).

### **Documentation of input and output parameters**

Once the needed key input data have been collected for the analysis it is recommended to document these data. A clear and standardized documentation of all assumptions and parameters is absolutely essential for a traceable analysis and for comparable results. In the following some recommendations, based on the example of DB, in terms of documentation of the boundary conditions and technical and economic parameters with relevance for RAMS and LCC analysis are given.

In general the standardised templates (used in DB) contain the documentation of:

- Scope, objectives, time schedule and responsibilities of the analysis
- Boundary conditions to be taken into account
- Economic parameters, include the relevant cost items (LCC)
- Technical parameters (RAMS) include the impact on Availability, Reliability of detection, Migration, or how reliable is the detection, systems and entire systems Reliability etc.

It's essential to make clear the boundaries and define the base of the boundary conditions to be analyzed within the LCC and RAMS analysis. Besides the availability and quality of needed data, the more clearly and accurately the boundary conditions are defined and documented the better is the RAMS and LCC analysis will be. This can be visualized for example with the striking diagram, where one can identify those cost elements that will be part of the LCC calculation and, as a result, will require a detailed clarification and possible breakdown.

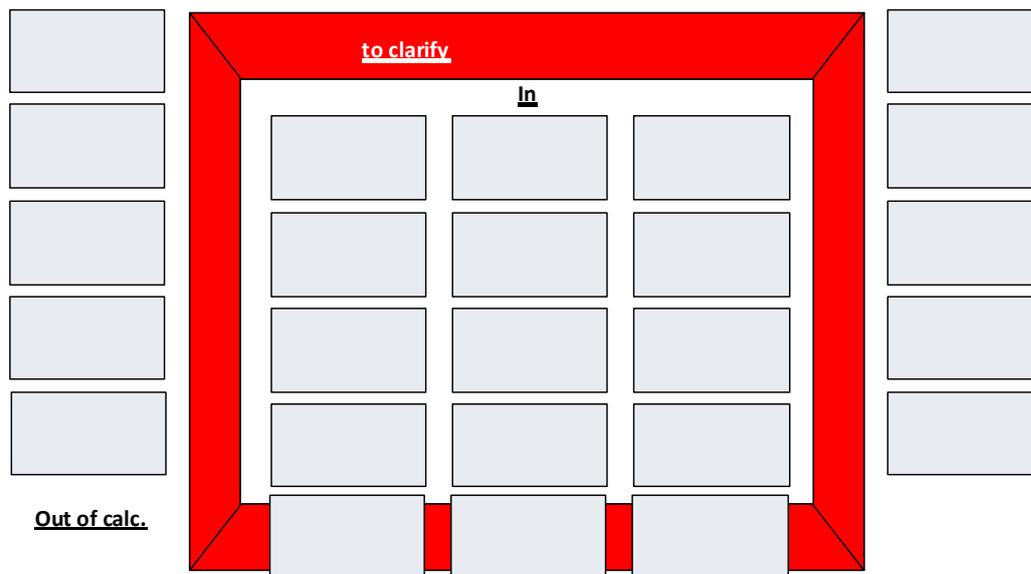


Figure 8: In/Out Frame for the documentation of the boundary conditions

The above In/Out Frame assures that the appropriate boundary conditions are fixed and the question what is within the calculation and what is not are made clear. The In/Out Frame also gives the possibility to put some fields on the frame, which need to be clarified during the LCC analysis and required as essential input for the LCC calculation.

For instance, the subsequent standardized template can be used for the documentation of the relevant technical parameters (RAMS): the technical parameters, which are relevant for the analysis in relation to technical performance and related to costs, should be documented in a table like (to be considered as a proposal):

Parameter	Scenario A	Scenario B	Scenario C	Scenario D
Included detection systems				
Number of detection system				
Reduction of derailments				
Migration				
Impact on Availability system as such & entire system				
Reliability of detection impact of non-detection				

Figure 9: Template for the documentation of the relevant technical parameters (RAMS) as an example

The corresponding template for documentation of the economic parameters (LCC) is presented in the report of D7.3.



## 2.3 Definition of key input data and safety targets for RAMS and LCC analysis

The scope of WP7 is to perform technical and economic assessment of inspection and monitoring systems with RAMS and LCC analysis, to support a common understanding of LCC&RAMS and give recommendations for the use of monitoring systems.

Consequently these expected results need relevant input data. For instance for reliability analysis within WP7 the following data is needed:

- Description of the selected inspection and monitoring system with technical data
- Description of the expected functions of the system (system RAMS performance)
- Description of the associated boundary conditions
- Current inspection and maintenance strategy and activities
- Recurrent failure event data for the selected inspection and monitoring system failure (unit: MGT or frequency of traffic)
- Time between failures (MTBF) for the selected inspection and monitoring system

Besides the following input data are required to perform maintainability analysis and modelling:

- Description of inspection/maintenance tasks
- Corrective maintenance time
- Inspection time
- Repair time (restoration/Overhaul)
- Replacement time
- Logistic delay time
- Administrative delay time
- Active maintenance time
- Trouble shooting time

The key input data required to perform LCC analysis are described in D7.3.

The most important part of a RAMS and LCC calculation is the processing and determination of the relevant RAMS and LCC data. Before collection the relevant RAMS data it's necessary to determine and fix the boundary conditions, which is presented in the next section.

### **2.3.1 Boundary conditions to be taken into account for RAMS and LCC analysis**

First there is a need to be clear about the definition of boundary conditions in this context. In the current context the definition of the boundary conditions are regarded for the technology/system under which it is used and which have implications on the RAMS and LCC of the technology/system.

The identification and definition of boundary conditions that will affect the chosen RAM(S) parameters (e. g. the reliability of system, component) is very important. The environmental conditions in which the equipment is to be operated, such as temperature, humidity, dust, maintenance facilities, maintenance and operation personnel training etc. often have significant influence on the product reliability characteristics and thereby on the maintenance and product support requirement. During the operation phase, manufacturers can benefit from obtaining information about the product's technical health as well as conformance and deviations from the expected performance targets.

Generally boundary conditions are those factors that might change the planning or the contract commitments, beyond what the planner/contractors are able to influence over. It is essential to define and to document the relevant boundary conditions affecting the system. That assures that the appropriate boundary conditions are fixed and the question what is within the consideration and what is not are made clear. In general such factors shall include but not limited to:

1. Traffic:

- type of train and their maintenance standard
- axle weight
- speed
- traffic volume (amount of trains, MGT, mix of traffic)
- load
- type of line
- radius

2. Track related:

- alignment
- track construction
- track quality
- subgrade, structure beneath substructure
- water underpass

3. Quality of initial installation

4. Environmental conditions: solid-borne-sound, sound insulation, atmospheric influence, national requirements, special characteristics etc.

5. How to establish maintenance logistic (logistic time)

6. Climate issues (cold weather, high temperature, storms, flooding)

7. Unwanted objects in the tracks
8. Sabotage
9. System interfaces with existing infrastructure system/subsystem/component in terms of system compatibility
10. Operation and Maintenance requirements: maintenance actions and strategy / procedures (e. g. how much possession time is available?), linked with logistic, equipment aspects

These boundary factors need to be monitored continuously. There is a need to develop methods for vehicle classification and monitoring of their maintenance condition and how their condition affects the degradation on the infrastructure assets. There is also need to improve ways of getting feedback of how the track is operated, amount of trains, mix of trains. Risk assessments for unwanted events must be included as early as possible in the planning phase.

In an ideal situation the infrastructure assets are in verifiable conditions, i.e. we know how the assets are used and how they break down. This means that we have control and knowledge of the traffic operating the track and degenerate the track. We also have control over the environment in which the facility is located, namely that it is not adversely affected by e.g. corrosion, weather, sabotage.

In reality, however, both unwanted and unexpected events occurs that affect the system and causes adverse and undesirable output e.g. train delays, see figure below. These events can also be called negative boundary condition, and will affect the reliability and availability of the system.

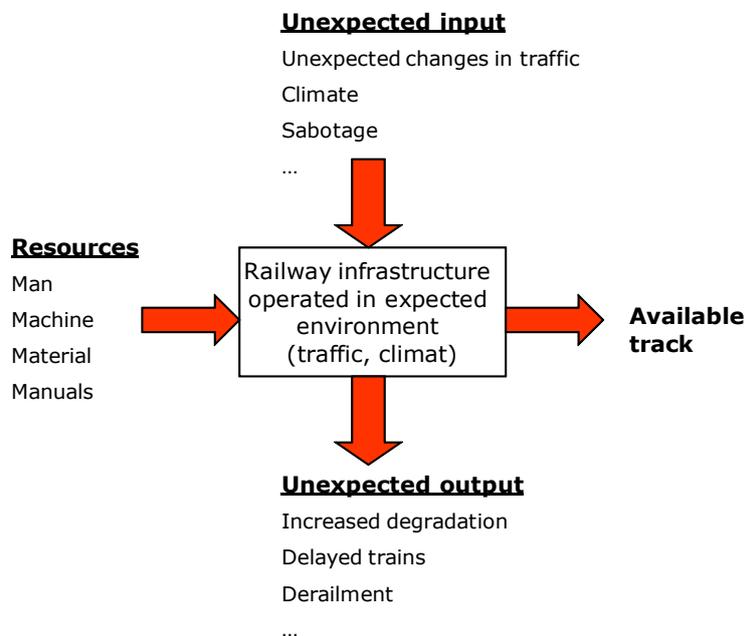


Figure 10: Unexpected input/output affecting the reliability and availability  
(see guideline for RAMS/LCC Analysis in InnoTrack project)

For D-Rail purpose the following boundary conditions are considered to be relevant:

1. Boundary conditions reg. RAMS analysis:

- definition of objectives and scope within D-Rail project (see DOW, D-Rail targets)
- definition of the technical boundary conditions, specific boundary conditions
- definition of the relevant derailment scenarios
- definition of the inspection and monitoring systems to be considered
- required RAMS data (see RAMS and LCC template), assumptions or estimation of relevant reliability parameter, availability parameter, maintainability parameter to be considered in terms of data collection and processing
- existing constraints

2. Boundary conditions regarding LCC analysis:

- Period of consideration
- Discount rate, interest rate
- Relevant cost items (see RAMS and LCC template)
- Constraints, limitations
- see more details for LCC in D7.3 since this report is focused on RAMS analysis

It is essential to make clear the range and define the base of the boundary conditions to be analyzed within the LCC and RAMS analysis. Besides the availability and quality of needed data, the more clearly and accurately the boundary conditions are defined and documented the better is the RAMS and LCC analysis. One possibility for the documentation of the boundary conditions is shown in the previous section with In/Out Frame diagram.

However, the main target in terms of boundary conditions is to answer the question whether the requirements could be met by the Boundary conditions.

When it comes to take into account regionally directives in some countries, e. g. in Switzerland and Austria, specific boundary conditions should be considered.

The risk management of the concerned IM's incorporates already this risk landscape. Of note are all effects that may lead to

1. a higher expected damage from events

- tight curve radii
- steep tracks
- long tunnels
- several tunnels in succession without adequate intervention sites between portals
- high traffic densities (stronger effect of delays on follow-up trains)
- mixed usage patterns of passenger and cargo (stronger effect of delays on follow-up trains)

- natural disasters (rockfalls, slope slides, mountain slides)
2. abnormal equipment behaviour
    - low temperatures (higher wear, limited ability to work on tracks)
    - heavy snowfalls (reduced precision of WTMS)
    - heavy gusts
  3. a different outcome of risk modelling includes:
    - risk aversion and other risk management factors, e.g. the influence of rare high-damage events
    - risk acceptance and financial considerations

It can be stated that there are different reasons for implementing monitoring concepts. It can be noted, that every country emphasises different aspects in a different perspective. Different national driven strategies in combination with other boundary conditions lead to a non-uniform representation usage. Those boundary conditions might be:

1. Climate conditions (e.g. extreme temperatures, snow or rain amount)
2. Track alignment ( e.g. small radii because of geographical circumstances)
3. Amount of steep slopes, i.e. many sections with braking/traction
4. Amount of infrastructure elements to be protected
5. Possibilities of reaction in a disruption
6. Data exchange for improving the vehicle maintenance

It is assumed that WP5 ensures that definition of relevant derailment scenarios and related boundary conditions are in line with WP7 and are reflected in the course of interaction with WP7. That is to say that the best and worst case scenarios for a range of boundary operating conditions are supposed to result from generic requirements for pan European solution and implementation and migration scenario. Task 5.2 of WP5 outlines the system requirements specification for pan European freight monitoring including:

1. Business cases of monitoring concepts
2. Allocation of measurement data (vehicle identification)
3. Ranking: Types, number, places of systems, etc.
4. Intervention concept, roles and responsibilities
5. Generic requirements for pan European solution
6. Implementation and migration concept
7. Future trends

### 2.3.2 Relevant RAMS parameters for Monitoring Systems

Generally the most common RAMS key parameters are:

<p><b>– Reliability</b></p> <ul style="list-style-type: none"> <li>– <math>\lambda</math> (t) - Failure Rate</li> <li>– R (t) - Survival probability</li> <li>– MTTF - Mean Time to Failure</li> <li>– MTBF - Mean Time between failures</li> <li>– MTTF - Mean Time to first failure</li> <li>– MDBF - Mean Distance between failures</li> <li>– MCBF - Mean Cycles between failures</li> <li>– MFD - Mean Failure Detection Time</li> <li>– MUT - Mean Up Time</li> <li>– RBD - Reliability Block Diagram</li> </ul> <p><b>– Availability</b></p> <ul style="list-style-type: none"> <li>– Train delay hours</li> <li>– Theoretical or interior availability considers corrective maintenance</li> <li>– Technical or engrained availability considers corrective and preventive maintenance</li> </ul>	<p><b>– Maintainability</b></p> <ul style="list-style-type: none"> <li>– MMH - Mean Maintenance Hours</li> <li>– MDT - Mean Down Time</li> <li>– MCDT - Mean Corrective Downtime</li> <li>– MPDT - Mean Preventive Downtime</li> <li>– MTTR - Mean Time to Restore (Repair)</li> <li>– MTBM - Mean Time Between Maint.</li> <li>– MLDT - Mean Logistic Delay Time</li> </ul> <p><b>– Safety</b></p> <ul style="list-style-type: none"> <li>– HR - Hazard Rate</li> <li>– THR - Tolerable Hazard Rate</li> <li>– Number of accidents</li> <li>– FME(C)A - Failure Mode, Effects (and Criticality) Analysis</li> <li>– FTA - Fault Tree Analysis</li> <li>– HA - Hazard Analysis</li> <li>– ETA - Event Tree Analysis</li> </ul>
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Figure 11: Overview about the most common RAMS key parameters

In section 2.1 a general overview of RAMS parameters is given. But this section describes the RAMS parameters as being relevant input data for RAMS analysis.

For D-Rail purposes the key values for RAMS and LCC are defined as follows:

Reliability	Availability	Maintainability	Safety
System configuration, boundary conditions	System uptime	MTTR, Mean Time to Repair	Number of incident
System performance data	Availability of system itself	MDT, Mean Down Time	Number of accidents
Failure rate	Availability of the whole system	Maintenance resources	
MTBF, Mean Time Between Failure for corrective maintenance	Train delay hours	Logistic aspects	
Reliability of detection,		Constraints (spare parts)	
Impact of non-detection			
Redundancy			

Table 3: Key values for RAMS related to derailment

The key values required for RAMS analysis will depend greatly on the specific analysis being carried out and specific national requirements. For example if the RAMS data is to be used for a simple life cycle cost calculation where costs of delays and interruption to traffic are not considered then 'Mean Time Between Failure' and the cost to repair and maintain, will be the key RAMS value. However, if the purpose of your RAMS calculation is to consider availability of a line and the impact of delays, then 'Mean Time Between Service Affecting Failure', 'Mean Time to Repair' and 'Mean Time to Maintain' become the critical RAMS values.

Reliability parameters with relevance for RAMS analysis in D-Rail (see also RAMS & LCC template) are defined as following:

#### Failure rate ( $\lambda$ )

The probability of failure per unit of time of items in operation; sometimes estimated as a ratio of the number of failures to the accumulated operating time for the items. Failure rate is usually time dependent, and thus the rates change over time versus the expected life cycle of a system.

Failure rate is the frequency with which an engineered system or component fails, expressed for example in failures per hour.

#### Mean Time Between Failure (MTBF)

Mean Time Between Failures, is a basic measure of a system's reliability. It is typically represented in units of hours. The higher the MTBF number is, the higher the reliability of the product.

Further reliability parameters are MTTF (Mean Time To Failure), MTBM (Mean Time Between Maintenance for preventive Maintenance), MTFE (Mean Time to First Failure) and Train delaying failures.

Availability parameters for the purpose of D-Rail (see also RAMS & LCC template):

The availability could be measured for example in train delay (hours), total train delay, train delay caused by infrastructure, train delay caused by a specified infrastructure asset and punctuality of passenger and freight train. There is also a code for what caused the train delay. In terms of migration and system integration the distinction between the Availability of the system itself and the impact on Availability of the entire system should be considered.

Maintainability parameters with relevance for RAMS analysis in D-Rail (see also RAMS & LCC template):

Mean Time To Restore (MTTR): the sum of corrective maintenance times divided by the total number of repairs within an item. That indicates the average time to fully repair a failed system – it includes detection of failure(s) removal and replacement of the failed component(s) and final check. In order to measure the amount of variation or dispersion from the mean time to repair, standard deviation can be used. A low standard deviation shows that the time to repair events tend to be very close to the mean value; a high standard deviation shows that the data points are spread out over a large range of time to repair values.

Besides Mean Time Between Maintenance (MTBM), Mean Time Between Repair (MTBR), Mean Maintenance Hours (MMH), MDT (Mean Down Time) as well as Mean Logistic Delay Time are further measures of maintainability.

Safety parameters with relevance for RAMS analysis in D-Rail (see also RAMS & LCC template):

Parameters in use are Hazard rate, Number of accidents, Number of derailments, Number of accidents due to external sources, Number of accidents due to internal sources and incidents that could have led to accidents/damage.

However, infrastructure managers should collect a standardized set of RAMS data, as indicated by the RAMS parameters Table 3, and build up and maintain a database of these values, therefore it is important to standardize on a set of key values which can be utilized. RAMS values should be continually reassessed and updated, the greater the sample of data the greater the confidence of the results.

The following list is indicative of methods for estimation of RAMS-parameters, but should not be regarded as exclusive:

<b>Characteristics</b>	<b>Methods</b>
<b>Failure rate</b>	Evaluation of data, statistics, probability method
<b>Consequence of failure</b>	FMECA – Failure Mode, Effect & Criticality Analysis RBD – Reliability block diagram FTA – Fault tree analysis
<b>Availability</b>	Monte-Carlo-Simulation Markoff-Analysis Evaluation of data
<b>Maintainability</b>	Maintenance analysis (Corrective Maintenance) RCM – Reliability Centered Maintenance Evaluation of data
<b>Safety</b>	Risk analysis, Risk assessment, Risk management

Table 4: Methods for estimation of RAMS-parameters

### 2.3.3 Top derailment Causes

Further input data is needed to answer the question ‘which prevention measures should be considered to address the key derailment scenarios?’. The approach is to look at top derailment causes with the biggest impact in terms of frequency of occurrence and linked costs in order to evaluate costs and benefits based on the (set of) interventions which target common derailment causes.

The following list represents the result of very thorough analysis (see [1] and [2] for more information) and reflects the most important (in terms of number and costs of derailments and pertinent consequences) derailment causes in Europe currently. Top derailment scenarios with the biggest impact as identified in D1.1 are:

1. Hot axle box and axle journal rupture (Rolling Stock)
2. Excessive track width (Infrastructure)
3. Wheel failure (Rolling Stock)
4. Skew loading (Operation)
5. Excessive track twist (Infrastructure)
6. Track height/cant failure (Infrastructure)
7. Rail failures (Infrastructure)
8. Spring & suspension failure (Rolling Stock)

The eight European main derailment causes have been re-grouped as follows:

- Top derailment causes concerning track geometry
  - Excessive track width
  - Excessive track twist
  - Track height/cant failure
- Top derailment causes concerning vehicles
  - Axle shaft, journal or bearing failure
  - Wheel failure
  - Skew loading
  - Spring & suspension failure

The data collected in D-RAIL indicates an 80% / 20% split of direct costs between infrastructure and rolling stock. Another finding from WP1 was that infrastructure and rolling stock are responsible for most derailments on open line and in installation sites, 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, as demonstrated in the analyses of WP1 (D1.1 and D1.2).

It should be noted that the impact of derailments in shunting yards is excluded and only the derailments on the open track (outside of the shunting yards) are considered in the analysis

of WP7. However, derailments in shunting yards are relevant in a quantitative way but not from an economic perspective. In addition a high amount of derailments occur in shunting yards due to human failure (and other reasons) but human error is (for various reasons) excluded in D-Rail.

Note that excessive track width is implying a “very excessive track width” due to rail support failure or rail roll-over. This issue was not covered in D3.2, but is included in this report.

### 2.3.4 Proposed Inspection and Monitoring systems for the analysis

A main task in WP7 is to achieve derailment related cost reductions of 10 – 20% and to show the cost saving by the optimum use of inspection and monitoring systems. However, through RAMS and LCC analyses the reduction in derailments in relation to number of monitoring system is determined

The selected inspection and monitoring systems to focus on, which was decided amongst the WP’s and which is in line with the analysis of the assessment matrix of WP4, are:

Table 5: Selected inspection and monitoring systems (wayside and vehicle based)

No	System / module / technology	Type (wayside/vehicle based)
1	Hot Box Detection System	wayside
2	Hot Wheel Detection System	wayside
3	Track Geometry Measurement System	vehicle based
4	Axle Load Checkpoint (ALC)	wayside
5	Wheel Profile and Diameter system (WPDS)	wayside
6	Rail profile measurement system (Laser based wear measurement)	vehicle based
7	Video Rail Inspection	vehicle based
8	Ultrasonic Rail Inspection	vehicle based
9	Acoustic Bearing Detection	wayside
10	Vehicle Profile Measurement	wayside
11	Track Strength Testing	vehicle based
12	Magnetic Flux / Eddy Current Rail Inspection	vehicle based

Regarding the selection of the inspection and monitoring system to be considered for the risk assessment and RAMS analysis it was decided to take the measures that help to achieve the reduction of 8-12% derailment and to ensure that the key derailment scenarios are covered by the selected inspection & monitoring techniques. WP2 has elaborated in D2.3 a cost

benefit analysis per cause and intervention set of accident on nine techniques. Their combinations establish eight sets of interventions, targeting their common causes with the largest impact on derailment. Such being the case and in line with the approach of WP7 analysis, this should serve as a short list of proposed inspection and monitoring systems.

The description of the three proposed inspection and monitoring systems are presented in the appendices of D4.1 of WP4 as well as in the annex of this deliverable.

Table 6: Short list of proposed inspection and monitoring systems to be considered

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%

Some assumptions and constraints of the cost benefit analysis can be taken from the submitted deliverable D2.3.

The cost benefit analysis incorporates nine types of measures and eight causes of derailments. For each individual cause of derailment a set of interventions is allocated. In addition, the potential impact is identified based on the share of derailments resulting from this cause. The basic idea is to attribute the cost to the benefits, i. e. if we apply a specific (set of) intervention(s) what will the effect be.

Furthermore three types of costs are defined for each intervention: the implementation (investment and reinvestment) and maintenance costs, which differ per intervention and are applied for nine types of interventions (resulting from D4.1), and the avoided derailment costs (set out in D1.2) and are identified per cause of accident and frequency of occurrence.

One observation from the above table is that the highest costs are identified for wheel failure (derailment cause Nr 3) and spring and suspension failure (derailment cause Nr 8), followed by hot axle box and axle journal rupture (derailment cause Nr 1) and skew loading (derailment cause Nr 4).

The existing systems deployed on the network to monitor hot axle box and axle journal rupture (derailment causes Nr. 1) are hot box and hot wheel detector systems (HABD). The combination of hot box and hot wheel detector systems as a set of intervention helps to decrease the number of accidents caused by Hot axle box and axle journal rupture (cause), with an effect of maximum 12% of the total number of derailments.

For Monitoring of the derailment causes of wheel failures (derailment cause Nr. 3), skew loading (Nr. 4) and spring and suspension failures (derailment cause Nr. 8), dynamic Axle Load Checkpoints are currently in use. Consequently the use of the dynamic Axle Load Checkpoints leads to mitigation by a maximum of 22% of the derailments (i.e. 110 derailments) annually, attributed to the causes of wheel failure, skew loading and spring and suspension failures.

Track Geometry Measurement Systems are currently used to mitigate the effects of derailment causes reg. excessive track width (derailment cause Nr. 2), excessive track twist (derailment cause Nr. 5) and track height/cant failure (derailment cause Nr. 6). The potential impact of avoided derailments attributed to these causes is up to 19% of the derailments (i.e. 93 derailments) annually.

It can be observed that these top eight derailments causes and their impacts can be covered by the existing techniques, such as that 34% of the total impact from interventions can be achieved with hot box and hot wheel detector systems and Axle Load Checkpoints. Additionally a percentage of 52% of the total impact from interventions can be achieved by adding Track Geometry Measurement Systems (TGMS).

Generally speaking, even though their total share of derailments is 55%, they represent a very high share of the total derailment costs -75% of total annual derailment costs due to their severity.

It should be noted that in this method, it is assumed that the measure can be 100% effective in eliminating the causes that it is targeted towards.

A special remark needs to be made regarding why the above mentioned shortlist is used for the analysis in WP7, but also to clarify to what extent axle box failures are supposed to be out of scope of D-Rail, as these are already covered by the EURAXLE project:

- hot box and hot wheel detectors and Axle Load Checkpoints are the systems where we have the most experience have and therefore good RAMS and LCC data on
- The set of interventions of hot box and hot wheel detector systems and dynamic axle load checkpoints were identified with the highest benefit to cost ratio considering the cumulative benefits. The benefits are expressed as cost savings from derailment costs. For each cost category, these are broken down per derailment type. The actual benefits are derived as a fraction of the total costs, depending on the number of maximum expected avoided derailments and their effectiveness rate (see D2.3). These results match with the experiences of SBB and DB.
- Seven out of the eight techniques coupled with derailment causes listed in the above table can be covered by the existing techniques such as Hot Box and hot

wheel detection (used in combination at SBB and DB), Axle Load Checkpoints and Track geometry measurement systems

- For that reason it is a very good case study / benchmark of the evaluation procedure. This is important to calibrate and assess the accuracy of the procedure.
- Thus, the expected output is two-fold: A refined analysis of the impact of hot box and hot wheel detectors and also the validation/calibration of the procedure, which is not possible to get from any other detector type (due to the long and extensive experience with hot box / hot wheel detectors, but also because there is a correlation between alarms and very high derailment risks (high potential impact on derailment risk reduction) which is among the highest for all detector types.

As stated previously an assessment matrix has been developed in WP3 and WP4 presenting methods to prevent or reduce the most common derailment causes and risks respectively. Ranking of measurement effectiveness and derailment prevention efficiency of each method has been made in a next step by the project team. More detailed information on this can be seen in D4.1.

As the assessment matrix has been validated by experts by the implicated project partners the conclusions can be regarded as agreed within the D-Rail partners. For that reason the findings of the assessment matrix corresponds to the approach of WP7 and matches with the experiences of some IM's. For instance one result is that ALC seem to be beneficial for checking vehicle performance and parameters related to derailment. These systems cover wheel flats, skew loading, suspension failures, high lateral forces and large angle of attack (see more in chapter 3.4).

### **2.3.5 Quality and limitations of data**

As previously described the RAMS and LCC relevant data should have been collected by the WP's based on the developed RAMS and LCC templates and provided for WP7. The task of WP7 was to support the data collection rather than gathering the data. The interfaces and data flow between WP7 and other WP's has been communicated and addressed to ensure the provision of required RAMS and LCC relevant data. The approach of data flow from other WP's to WP7 is shown by the figure below:

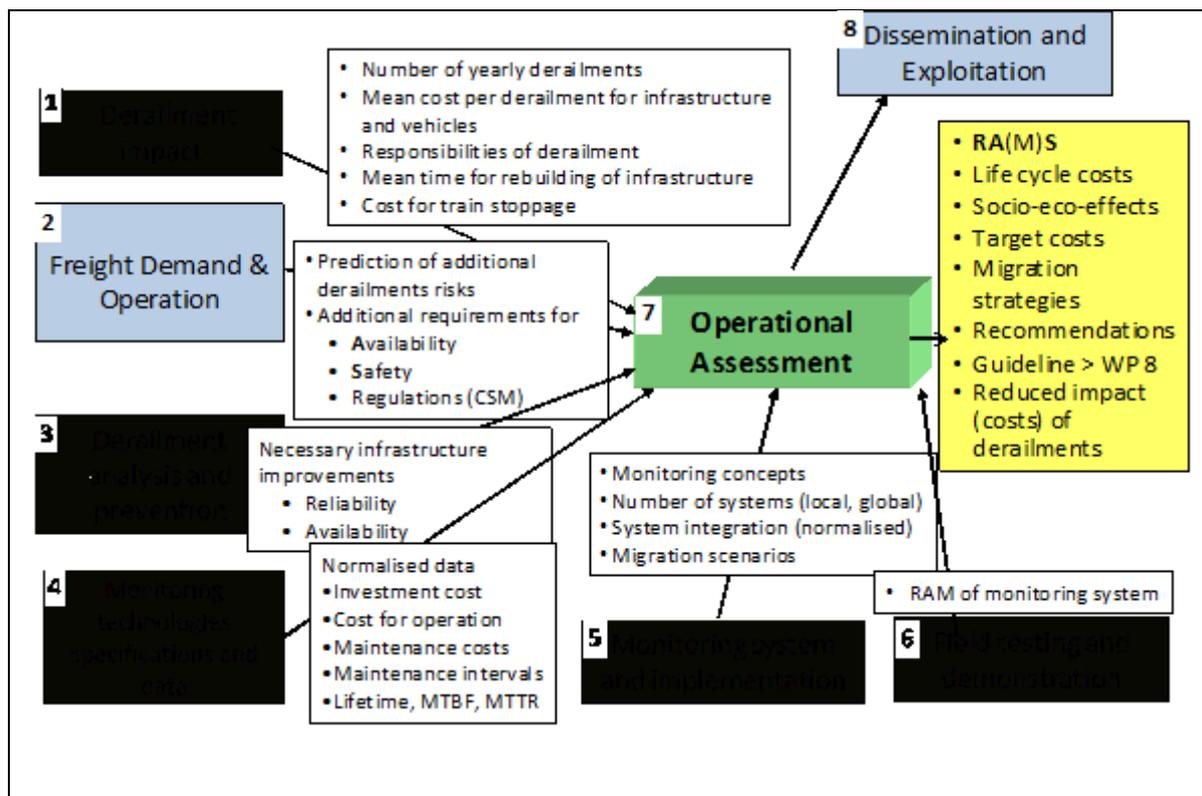


Figure 12: Project interfaces and data flow to WP7

The main challenge is not just to collect the relevant input data but also receive high quality data.

RAMS data is considered high quality only if the data set represents the operational reality with low uncertainty. The two important aspects of data quality in the RAMS analysis include data volume and homogeneity. When there is an insufficient amount of data, the intention is to use a black-box approach instead of a white-box approach. This may increase uncertainty and confidence in the results. Homogeneity refers to “The condition of being of uniform structure or composition with respect to one or more specified properties” (I. S. Organization, ISO Guide 30-1981-(E)). For the homogeneity assessment, statistical tests are conducted on the results to verify that the same properties are observed.

In terms of the quality of the provided data, the partners have been asked to define the data provided by category such as verified, estimated or given by experts (see more in section 2.2).

It should be noted that the study of WP7 concentrates on the three most promising interventions identified by WP4: Hot Box and Hot Wheel Detector systems, Axle Load Checkpoints and Track Geometry Measurement Systems. These interventions cover theoretically 55% of all derailments investigated in D-Rail. No other techniques were studied in WP7, because they lack effectiveness compared to the studied interventions. For hypothetical new interventions, no input data for RAMS, LCC and risk assessments could be provided by the relevant work packages. Consequently, general conclusions about the HABD used as case study for RAMS analyses couldn't be made. To this end more reliable RAMS data

are necessary also to evaluate the impact of monitoring systems (including ALC and TGMS) on the RAMS of the railway system.

In fact the "true" reliability of a component for the whole fleet, is generally dependent on a number of external and internal factors (S. Lydersen and M. Rausand).

- Component specific factors (design, make, finish etc.)
- Environmental factors (humidity, pressure, temperature etc.)
- Operation and maintenance factors.

Note that since axle failures was explicitly out of the scope for WP3 (due to the EURAXLES project) there was of course no data on hot axle box detectors from WP3.

Such being the case, WP7 focused on the evaluation of the systematic approach, proving that the developed framework is operational by applying the case studies, making assumptions and taking those inspections and monitoring systems where some useful RAMS and LCC data are available. Since the amount and quality of RAMS and LCC input data in relation to the HABD and ALC are available, these two systems were proposed to perform the analysis. Results from the cost benefit analysis completed in D2.3 justify this approach as well and these systems provide the biggest benefit in terms of number of avoided derailments.

It must be noted that regarding the Track geometry measurement systems just the measuring system itself is considered from an economic perspective. Due to limited RAMS data reg. the vehicle as a carrier system has been excluded for the RAMS analysis.

We assume that the train is always ready to run. The measurement trains are available for the planned measurement program even if one or two measurement equipment are defect, but the measurement will be performed under limited conditions.

Besides this, it is difficult to deal with LCC in terms of investment costs for modifying, refurbishment of vehicle components during their service lifetime. Thus the vehicle as a load-bearing system has been excluded for the RAMS analysis and only the measurement system taken into account from an economic perspective.

Additional to the problems of distinguishing vehicle and track geometry monitoring system RAMS parameters, a further complication is added in comparison to WTMS by the fact that taking the right action after detection is not a trivial task. Some intervention options such as tamping are dependent on financial budgeting, meteorology and other planning factors and cannot be taken rapidly.

To ensure a global view WP7 considered further possible technologies and measures as well as their combinations (qualitatively) and propose efficient solutions that are technically feasible and cost-efficient.

In this context WP1 identified limitations and constraints. One major obstacle in gathering data was the confidentiality of data, which means that it is not publicly available and data owners were reluctant to supply it. Besides existing differences of databases in structure, classification, reporting criteria, precise definition of causes / categories, calculating formulas different etc. made the analysis difficult and it was not easy to find broad conclusions. Besides the number and cost of derailments is generally very difficult to estimate. The reason

is that such an evaluation is based on reported incidents. However which incidents that are being reported vary between countries and also in time. The same is true for how costs are evaluated. Considering the system integration with cross-border operation and all the related issues, the harmonization process e. g. of the available data at EU level seems to be very difficult from D-Rail project perspective.

The focus of the D-Rail project on freight only is considered a constraint, i. e. that the DRAIL approach differs from established practices in European railways as it limits its scope to derailments and freight only, while all other approaches are concerned with railway safety, of which freight derailments are only a subset. This explains why already more than 1000 devices are in use today, as the need to prevent derailments on fast or high speed lines and concerning passenger trains have much higher derailment costs associated with them. One problem was to separate the risk data from cargo related events, because these are not separated from the rest like passenger traffic (in fact the events and factors of the overall traffic contribute to risk and should be the base for risk analysis).

### **2.3.6 Safety targets for RAMS and LCC analysis**

There are a number of common approaches which are relevant to setting safety targets and which have been implemented recently. The establishment of Common Safety Methods (CSM) set out harmonized approaches to risk management, the exchange of safety relevant information and the management of evidence resulting from the application of a risk management process. Common Safety Indicators (CSI's) have been established which are high level indicators of significant risks to the mainline rail network (e.g. signals passed at danger and broken rails). Common Safety Targets (CST's) define the minimum safety levels and safety performance that must at least be reached by the system as a whole in each Member State, expressed in risk acceptance criteria for individual risks to passengers, employees, level crossing users, others' and unauthorized persons on the railway. The CST are based on National Reference Values (NRV), where the NRV is a reference dimension, indicating the maximum tolerable level of risk for the railway of the concerned member state.

There are no specific targets for derailments set out. However, with regard to a safety target for D-Rail the target of a reduction in derailments by 8-12% has been considered.

Basically regarding safety the same framework conditions shall be applied for freight derailments as it is the case for the entire railway system (considering the differences in safety targets etc. in the member state etc.)

Equally, with regards to risk evaluation there is no specifically defined risk acceptance criteria. But the risk to be tolerated can be inferred from the risk reduction measures since the safety level shall not be worse than the current situation (reg. number, impact in terms of fatalities/serious injuries and costs due to derailments, already elaborated).

In general it is considered that if the measures and equipment proposed and tested under D-Rail were widely implemented, then the safety of operating freight trains on the EU rail network would be significantly improved even when taking into account foreseeable increases in rail freight.

The Safety Integrity Level of a system 0 to 4 is defined in the internationally recognised standard EN 50129 (Railway applications - Safety related electronic systems for signalling). The standard [EN 50129] defines five Safety Integrity Levels (SIL) with SIL 0 being non-safety related. The required Safety Integrity Level for a system shall be decided on the basis of the level of risks identified in hazard analysis or elsewhere. SIL shall be defined at a functional level and functional module level. Similarly, all systems, sub-systems and components shall have a Safety Integrity Level defined. The design, implementation techniques and measures shall be defined depending on the SIL of the function to be performed by each individual System, Sub-System or Component. In regard of D-Rail project techniques and measures with SIL 0 are preferred.

A general aim should be to achieve the same high safety level across Europe between now and 2050. Reference to this topic is made in section 3.3.3 Migration and in WP5 which considers the level of safety across Europe.

### 2.3.7 Additional issues to take into account

Derailments can be identified with an event code that allows the separation of shunting yards derailments and derailments on track (this is e.g. the case within DB). Most derailments of freight trains occur in shunting yards, e .g. in Germany 286 derailments during shunting trips and 37 during train runs (values of 2010). 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. That’s why WP1 did not recommend that subsequent WP studies focus on this area any further. Thus the impact of derailments in shunting yards is excluded within the analysis of WP7 and only the derailments on track (outside of the shunting yards) are considered.

Considering the issue of placing the monitoring systems on specific corridors it can be stated that the selected inspection and monitoring systems used in the member states are placed more or less on corridors with high density/speed of traffic, i. e. preferring to put in place on HSL (but in Austria ALC are also installed on freight corridors). But in fact it’s difficult to make a quantitative assessment of the systems on the specific corridors. Provided that the needed data can be quantified and made available it’s possible to do this. Besides this topic is also covered in section 3.3 in terms of risk assessment based on the business cases of WP5.

Reference is taken regarding the four technical measures assessed by the DNV study as being efficient at EU level sorted by Benefit/Cost ratio (highest B/C ratio):

Rank	Measure	Net Present Values			Benefit / Cost Ratio			Internal Rate of Return		
		10 years	20 years	40 years	10 Years	20 Years	40 Years	10 years	20 years	40 years
1	P13-WLID/WIM	379	756	1,183	3.1	<b>5.1</b>	7.4	51%	52%	52%
2	P28-Roller Cages	109	284	482	1.7	<b>2.9</b>	4.2	16%	21%	21%
3	P15 Bogie Hunting Detector	80	283	514	1.4	<b>2.2</b>	3.2	8%	14%	15%
4	P11-BAM	47	294	572	1.1	<b>1.9</b>	2.8	3%	10%	11%

Table 7: Quantitative analysis (Sorted by Benefit / Cost ratio)

It can be stated that the measures and Bogie Hunting Detector just as well covered by the Axle Load Checkpoints.

WP7 could not reproduce the positive business case for Roller Cages, which is also out of D-RAIL’s scope as it is covered by EURAXLES.

In addition the Acoustic Bearing Monitoring (BAM) equipment is not regarded as relevant for Europe today, since no European member state uses it. But possibly could be a future role of this measure or in specific context – e.g. on corridors where speed is low. However, this technique is widely implemented in the USA due to different boundary conditions and requirements (it doesn't work for powered vehicles, it needs a specific frequency profile for every type of bearing of which there are more in Europe than in the US and Australia, it doesn't work at speed above 60 km/h).

### **2.3.8 Considering of EU related projects**

Currently there are several EU Research Related Projects and many D-RAIL Partners are active in many important EU related projects. To ensure D-Rail has used this knowledge, this section gives a brief overview of EU related projects dealing with (more or less) D-Rail associated topics such as measurement, optimization of operation and maintenance, RAMS and Key Performance Indicators related to axles, increasing of capacity due to traffic prediction towards 2050 etc.

#### **HRMS (Harmonization – Running Behavior and Noise on Measurement Sites):**

The HRMS Project aims at helping to harmonize WTMS handling and defining limit values and thresholds throughout Europe. Measurement sites should be able to give exact and comparable results. These results are however valuable only if they can be linked to the right vehicle, axle or wheel and are properly transmitted and exchanged between the right actors of the system.

Today several countries are working with “Vehicle identification systems” on a national base. The aim for this is to define needs and to harmonize this on a European level.

Some European Railways use different measurement and assessment concepts in the measurements of wheel forces and corresponding quantities. Many of these systems were developed to meet local or national demands. The results from these systems are partly not comparable. The relevant existing standards do not meet all the needs of interoperability. An on-going trial in Austria and Switzerland are already exchanging data provided by measurement sites just before the border to inform the infrastructure owner of the other country in what shape the trains are before passing into the other country.

The goals are to establish an agreement on categorization (see also results of ALC-Project) of measurement sites and their results related to the standards and requirements of the various customers, for example infrastructure managers, train operators, wagon owners and others, of the data.

#### **Limit values, Assessment concept**

HRMS has developed a structured limit assessment approach that sets out from established numerical models validated in full-scale field test. Influencing parameters are analyzed and “bad case scenarios” (corresponding to very poor, but realistic, operational conditions) are defined. Limit values on measured parameters are then suggested and operational consequences may be assessed.

Unless otherwise stated 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  $20^{\circ}C$  below stress free temperature, the limit is ramped down to a limit of  $Q_{max} = 250$  kN at  $40^{\circ}C$  below the stress free temperature.

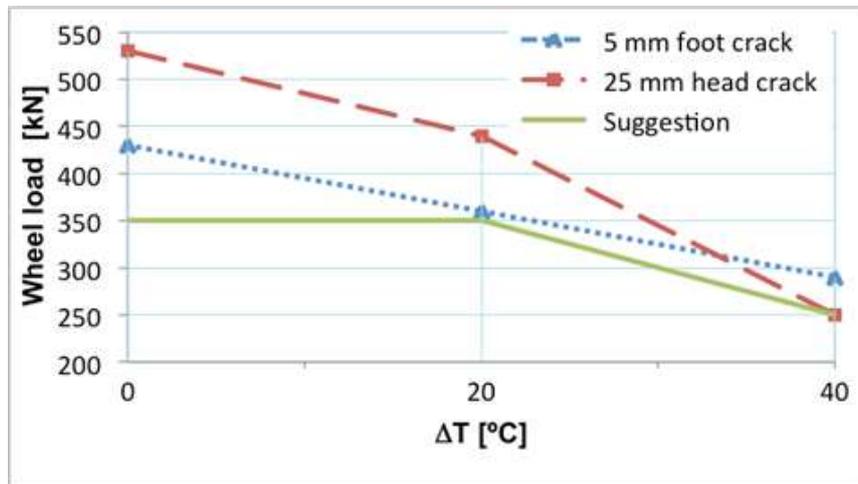


Figure 13: Proposed alarm limits for vertical peak loads, and corresponding critical loads for selected lengths of foot and head cracks. Here  $\Delta T = T_0 - T$  where  $T$  is the current and  $T_0$  the stress free temperature.

**Limit values related to skew loading to prevent flange climbing**

A limit value for skew loading is proposed as

$$I_{alo} = \frac{I_a}{k \times I_{lo} + m} \leq 1$$

Here  $I_a$  is the maximum axle load imbalance (maximum quotient between forces on left/right and right/left wheels for all axles of a wagon) and  $I_{lo}$  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  $I_d < 1.3$ , and a stop limit as  $I_d < 1.7$  where  $I_d$  is the largest quotient between forces on diagonally mounted wheels. This is to detect twisted vehicle frames for maintenance proposes.

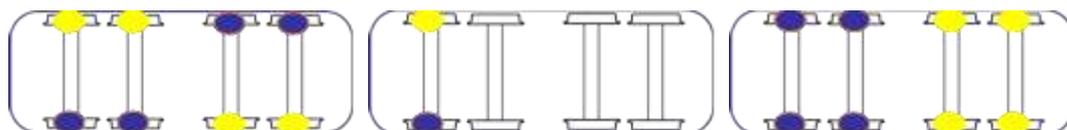


Figure 14: Illustration of force quotients, from left to right  $I_d$ ,  $I_a$ ,  $I_{lo}$ .

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.

## Overloading

Generally, trains should be loaded below the design load of the line. In particular, hard limits on the loading from trains and wagons may be imposed by the infra-manager for safety risks related to bridges, risks of landslides etc. These are local restrictions that require case-by-case evaluation and are thus not considered in HRMS.

More generally overloads impose an increased deterioration of the track. To compensate for this, a penalty per overloaded axle is proposed as

$$c = c_{\text{all}} \frac{Q}{Q_{\text{all}}} - 1 \cdot c_{\text{nom}}$$

Here  $Q$  is the load of the overloaded axle,  $Q_{\text{all}}$  is the allowed axle load, and  $c_{\text{nom}} = c_{\text{tot}} / n$  is the nominal cost of the track with  $c_{\text{tot}}$  being the total (annual) cost of the track, including (accrued) investment and reinvestment costs etc. Further  $n$  is the number of axles corresponding to  $c_{\text{tot}}$ . It is proposed that the penalty is imposed together with administrative charges (related to overload monitoring) primarily put on operators that systematically overload and thereby gain unfair competitive advantages.

## EURAXLES project

EURAXLES is a 3 year R&D project uniting 23 partners across Europe including 6 axle manufacturers, 4 railway operators/IMs, 2 system integrators, 3 technology suppliers, 5 universities, 2 rail sector associations and 1 consulting firm. EURAXLES aims to bring the risk of failure of railway axles to such a minimum level that it will no longer be considered as a significant threat to the safe operation of the European interoperable railway system; at the same time, it shall keep the cost of maintenance to a reasonable level and minimise the risk of service disruption.

The project plan includes the derivation of RAMS and Key Performance Indicators (KPI) related to axles. The D-Rail project has stated that communication will be upheld with EURAXLES and key results monitored. The communication has been established since long (several partners in D-Rail are also involved in EURAXLES). However, at the current stage, we are struggling with getting RAMS/LCC relevant information based on the results of EURAXLES since it is a project where most of the deliverables are not public.

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

This project ended in January 2014. The major goal of AUTOMAIN project is to optimize and automate maintenance and inspection where possible, and also to introduce new planning and scheduling tools and methods. AUTOMAIN project aims at reducing the possession time around 40%. To achieve this goal, AUTOMAIN project advances in railway maintenance through five main areas: new methodology by applying best practice from other industries, higher speed infrastructure inspection methods, higher speed track maintenance methods, modular infrastructure inspection methods and improvement of the automatic maintenance scheduling and planning systems, so as to reduce the disruption to scheduled traffic and to increase useful capacity.

**CAPACITY4RAIL: Increasing Capacity 4 Rail networks through enhanced infrastructure and optimised operations**

CAPACITY4RAIL will deliver research that is innovative, prepares rail for the future and takes into account results from previous research projects and programmes. The project builds on previous useable results and will deliver both technical demonstrations and system wide guidelines and recommendations that will be the basis for future research and investment, increasing the capacities of rail networks in the future and allowing for smoother operations and increased infrastructure investments with real impact. Specifically CAPACITY4RAIL will work towards the design and development of modern fully integrated railway systems for freight and passengers to meet the requirements for 2030/2050.

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

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

Further EU research related projects which are already finished, are described in D7.1 of WP7.

## **2.4 Approach for risk analysis and risk management according to CSM**

### **2.4.1 Common approach to risk management, risk assessment and risk analysis**

There are commonly accepted definitions relating to risk management, risk assessment and risk analysis, etc. Some key definitions are given below:

1. A “hazard” is a condition that could lead to an accident (EN 50126-2);
2. A “risk assessment” is the overall process comprising a risk analysis and a risk evaluation (ISO/IEC 73);
3. A “risk analysis” is the systematic use of all available information to identify hazards and to estimate the risk (ISO/IEC 73);
4. A “risk evaluation” is a procedure based on the risk analysis to determine whether an acceptable level of risk has been achieved (ISO/IEC 73);
5. The “risk acceptance criteria” are the terms of reference by which the acceptability of a specific risk is assessed; these criteria are used to determine that the level of a risk is sufficiently low that it is not necessary to take any immediate action to reduce it further.
6. “Risk Management” is the combined consideration of all of the above aspects.

Accordingly to EN 50126 a Risk analysis consists of:

- A Risk analysis is recommended to be performed at various phases of the system life cycle by the authority responsible for that phase.
- Related to EN 50126 the concept of risk is the combination of two elements:
  - the probability of occurrence of an event or combination of events leading to a hazard, or the frequency of such occurrences
  - the consequence of the hazard

A Risk analysis is recommended to be performed at various phases of the system life cycle by the authority responsible for that phase and shall be documented containing as a minimum:

- methodology of the analysis
- assumptions, limitations and justification of the methodology
- hazard identification results
- risk estimation results and their confidence levels
- results of trade-off studies
- data, their sources and confidence levels
- references

According to the Life Cycle phases of EN 50126 the risk analysis is in the V model which illustrates the relationship between the needed steps and the project phases:

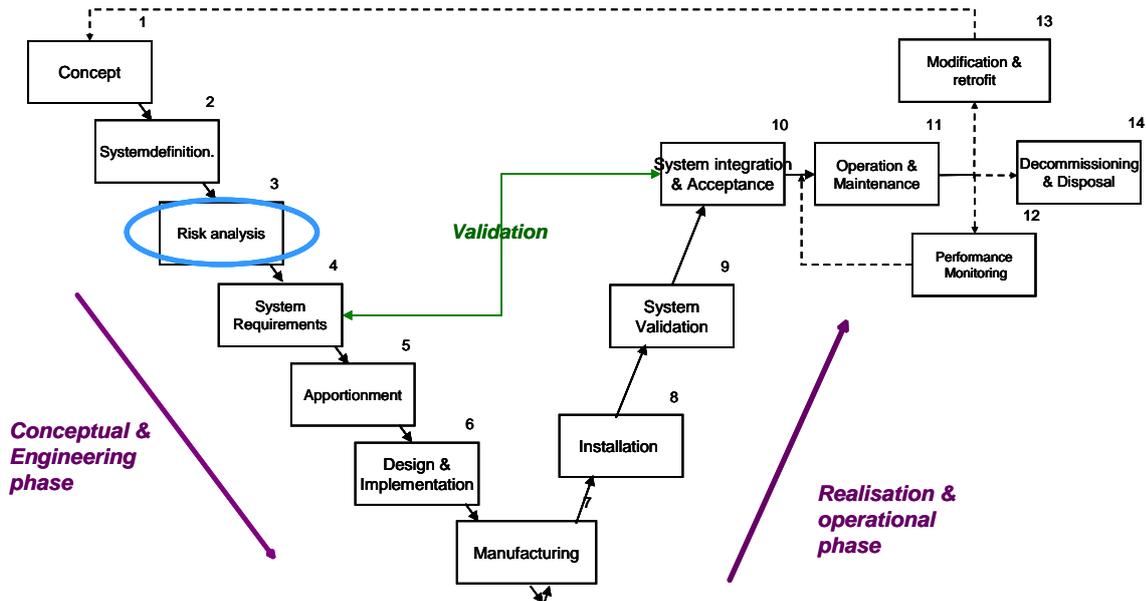


Figure 15: V-Model of EN 50126

In estimating risk, assessments need to be made in terms of extent and severity of the undesired consequence and of the probability of occurrence of this consequence. A qualitative technique is based on the experience build up in a certain field of application. Thus an assessment about the acceptability of the risk involved in the operation of a certain plant can be made based on this experience. In a quantitative risk assessment one tries to assess the risk in numerical values, the extent of the consequence, e. g. the number of casualties and the probability of occurrence.

When a quantitative risk analysis (QRA) is used to assess the risk, risk analysis sets out to answer the following three questions:

- What can go wrong?
- What is the probability that it will go wrong?
- What are the quantitative consequences?

A Hazard identification study has to be performed in order to answer the first question. The results are the identification of undesired events and the mechanism by which they occur.

In a quantitative risk assessment (QRA) the event sequences that lead to undesired consequences have to be developed. The first event in such a sequence is called the initiating event. An important part of a QRA is to calculate the probability of occurrences of each accident sequence which leads to an undesired consequence. By applying physical models the extent of the undesired consequences, e. the potential physical effects of the undesired event and the potential damage caused by the undesired consequence has to be calculated. In all three aspects of consequence analysis, the extent undesired consequence, potential physical effect and potential damage and probability plays an important role.

### Risk evaluation - Risk Tolerability Criteria

The Risk Tolerability Criteria proposed is based on a Risk Acceptance Matrix.

The risk acceptance principle has to be used by the relevant parties (System Providers) in order to demonstrate that the level of risk achieved is acceptable with regards to the risk tolerability criteria established above. Some examples are as follows.

- ALARP principle (As Low As Reasonably Practicable)
- GAMAB principle (Globalement Au Moins Aussi Bon as practised in France)  
The complete formulation of this principle is "All new guided transport systems must offer a level of risk globally at least as good as the one offered by any equivalent existing system";
- MEM principle (Minimum Endogenous Mortality as practised in Germany).

## 2.4.2 Overview of responsibilities under CSM

An important addition to the European wide regulatory regime with respect to risk management is the introduction of the Common Safety Method on Risk Evaluation and Assessment (the CSM-RA). The CSM-RA has applied since 1 July 2012 to all significant changes to the mainline railway system – ‘technical’ (engineering), operational and organisational.

The CSM-RA defines a common European risk management process. Its use is mandatory for all significant changes to the mainline railway system, and as such may be relevant to the introduction of any of the measures being taken forward for implementation due to the D-Rail project.

Just a brief overview of the risk evaluation process according to CSM-RA:

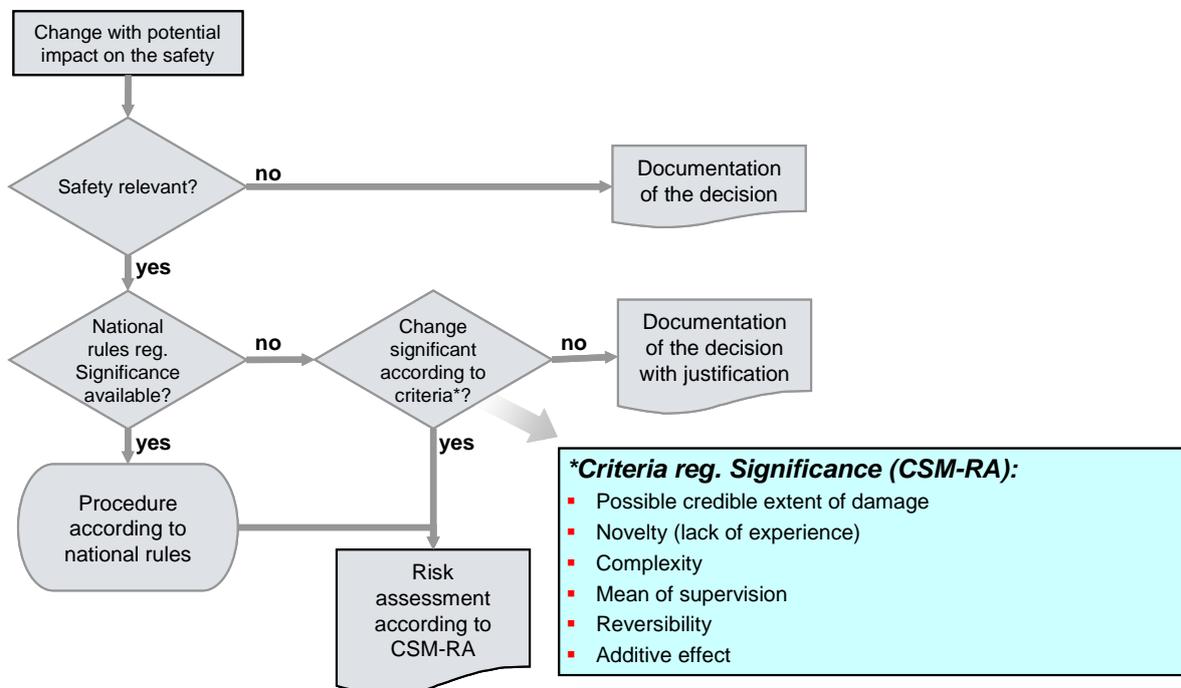


Figure 16: Overview of the risk evaluation process according to CSM-RA

The state has a responsibility to ensure the safety of the railway as a system and its duties are embedded within four Common Safety Methods. These are discharged by the National

Safety Authority and can be thought of as providing structured ways of answering two questions about railway safety.

*1. Is the railway system sufficiently safe or does the state need to intervene?*

The CSM for assessment of achievement of safety targets establishes a method that is used by the European Railway Agency to ensure that safety levels in each member state are at least maintained and that minimum levels of safety that apply across all member states are met. Depending on the results of the assessment different enforcement actions can be taken against the member state.

The CSM for supervision by national safety authorities (1077/2012) requires the National Safety Authority to monitor, promote, enforce and – where appropriate – develop the framework of safety regulation.

*2. What must the state require transport operators to do so that their railway operation can be made sufficiently safe?*

The CSM for supervision by national safety authorities also requires National Safety Authorities to ensure that transport operators have suitable Safety Management Systems in place and are monitoring their application and effectiveness.

The CSM for assessing conformity with the requirements for obtaining a railway safety authorisation and the CSM for assessing conformity with the requirements for obtaining railway safety certificates provide procedures and criteria for the National Safety Authority to apply when assessing applications from infrastructure managers and railway undertakings respectively.

### **Duties of transport operators under CSM regulation**

Transport operators' responsibilities are defined in regulations setting out Common Safety Methods (CSMs), which apply to mainline railways across Europe.

Two of the CSMs apply to transport operators. These two CSMs can be thought of as structured ways of answering the following two questions.

*1. Is my operation sufficiently safe or might I need to make a change?*

The CSM for Monitoring (1078/2012, to be applied by Railway Undertakings, Infrastructure Managers, and Entities in Charge of Maintenance) applies continually to ongoing operations. It sets out a 'repetitive and iterative' process for assessing whether or not the process and procedures in the transport operator's Safety Management System are being applied correctly and are having the intended effect. This involves:

- Defining a strategy, priorities and plan(s) for monitoring
- Collecting and analysing information
- Drawing up an action plan for when unacceptable non-compliance is identified
- Implementing the action plan when necessary and evaluating its effectiveness
- Documenting evidence from the application of the monitoring process

*2. How do I make sure the change is sufficiently safe?*

The CSM on Risk Evaluation and Assessment (CSM-RA) applies once you have decided to change something, such as introducing a new system to reduce derailments. It defines a risk assessment process that is mandatory if the change is ‘significant’ (as defined by the regulation) and applies to technical, organisational and operational change.

The process involves:

- Defining the system to be assessed
- Identifying hazards and analysing the associated risk
- Identifying the safety measures required to reduce risk to an acceptable level
- Demonstrating that the safety measures have been properly implemented

There are some specific requirements, for example around the need to produce and maintain a hazard record and for the application of the process to be independently assessed.

The CSM sets out three acceptance principles, which can be used to determine the safety measures required to make a change sufficiently safe:

- The application of codes of practice
- Comparison with similar reference systems
- Explicit risk estimation

In GB for example, when explicit risk estimation is applied, the risk acceptance criterion is to ensure safety “so far as is reasonably practicable” (SFAIRP).

### **2.4.3 What is “sufficiently safe”? Risk acceptance principles**

It is the job of the CSM proposer of a change to implement it safely. The focus should be on confirming whether or not the proposed arrangements are sufficiently safe and not on making comparisons with the previous level of risk or proving whether a hypothetical safety measure is or is not required.

The risk acceptance principles from the CSM-RA can be used, either individually or in combination, to demonstrate that the risk arising from a set of hazards has been controlled to an acceptable level.

The CSM-RA defines three risk acceptance principles:

- The application of codes of practice
- Comparison with similar reference systems
- Explicit risk estimation

The application of codes of practice potentially provides a relatively simple way of ‘closing out’ hazards, and there may already be processes in place to demonstrate compliance with them.

Comparison with a similar reference system can also be an efficient means of identifying safety measures and reaching conclusions about the acceptability of risk. As with codes of practice, this risk acceptance principle should only be used if it is applicable to the particular set of circumstances under consideration. The onus is on the proposer of the change to determine its appropriateness, and whether or not it reduces risk to an acceptable level.

The safety measures contained in suitable codes of practice and applied in suitable reference systems can be considered to represent good practice. Good practice does not stand still, but evolves over time in response to incidents, better information, and new technology or techniques. A technology or method of working that was sufficiently safe in the past may no longer manage the risk to an acceptable level.

Explicit risk estimation tends to be the most time consuming of the risk acceptance principles to apply.

#### **2.4.4 Risk Assessment in the context of the Common Safety Method for Risk Evaluation and Assessment (CSM-RA)**

The diagram of Figure 17 shows the risk management process defined in the Common Safety Method for Risk Evaluation and Assessment (CSM-RA). The process essentially consists of the following steps:

1. The proposer of a change produces a preliminary definition of the change, and the system to which it relates, and then examines this against the significance criteria in the Regulation. If a change is deemed to be significant, then a proposer is required to apply the CSM-RA, and appoint an independent assessor to assess application of the process. However, it should be noted that the CSM REA risk management process is a sound one and proposer of a change may choose to apply some or all of the process more generally within their organisation in any case.
2. The CSM process starts with the system definition. This provides the key details of the system that is being changed - its purpose, functions, interfaces and the existing safety measures that apply to it. This system definition will be kept live for the duration of the project.
3. All reasonably foreseeable hazards are identified. Their risk is classified and/or analysed.
4. Safety requirements are identified by application of one or more of the three risk acceptance principles to each hazard.
5. A hazard record for the system that is to be changed is produced and maintained. Its purpose is to track progress of the risk management process, for the project.
6. Before acceptance, the proposer needs to demonstrate that the risk assessment principles have been correctly applied and that the system complies with all specified safety requirements.
7. The assessor provides their report to the proposer. Note: the proposer remains responsible for safety and takes the decision to implement the proposed change.

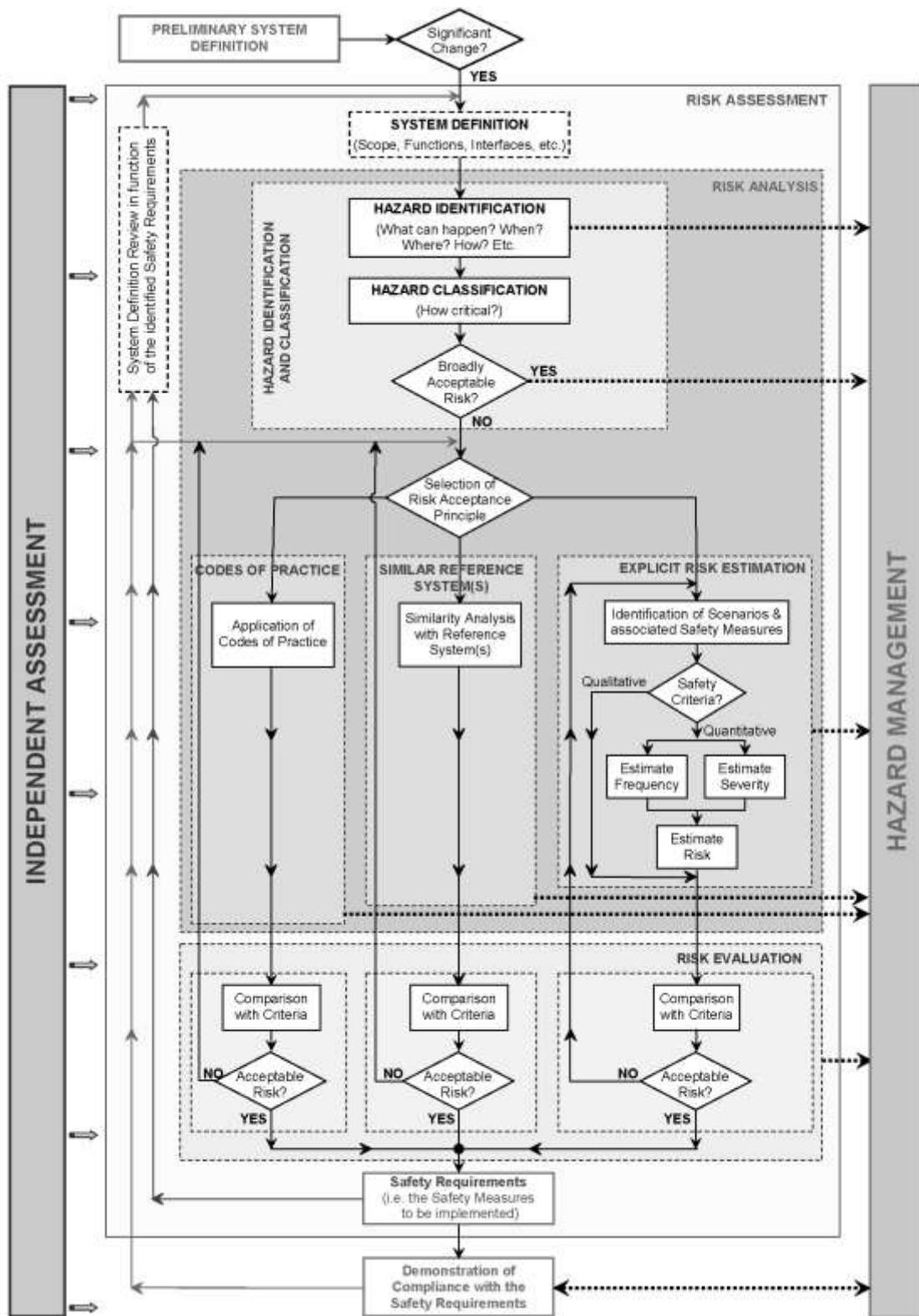


Figure 17: The risk management and independent assessment process from the CSM-RA

### 2.4.5 D-Rail in the context of CSM for Monitoring, CSM-RA and SMS

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. This has been done by analysing information and developing potential systems for future implementation. The effectiveness of these potential systems has been assessed and the output from D-Rail provides guidelines on which options might be considered by member states within their own Safety Management Systems.

In organisations with high demand on safety, a management system addressing safety is the best way to manage safety and control risks. In addition to be the best solution to manage safety, this is also a legal requirement in RSD Articles 9, 14(a) and Annex III.

According to the article 9(2) of RSD, the safety management system aims at controlling the risks related to the activities performed by the railway undertaking / railway infrastructure manager. The safety management system is a set of interrelated processes set-up by the railway undertaking / infrastructure manager to develop control measures addressing the risks related to their activities. These control measures may be:

- Operational rules for vehicles and infrastructure,
- Maintenance rules for vehicles and infrastructure,
- Prescriptions on the design of infrastructure and vehicles,
- Prescriptions on competence of staff leading to staff competences under control,
- Monitoring of the behaviour of vehicles/infrastructure in service addressing remaining risks not fully covered by preceding control measures.

More details see in the Agency Final Report on FTD - v1.0.

As part of the transport operators 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.

As part of the CSM-RA process the proposer of the change will need to select an appropriate safety criteria. D-Rail has considered a general high level target criteria of 8-12% reduction in freight derailment frequency by 2050.

It should be emphasized that the focus in WP7 is mainly on the methodology and system approach on Risk Analysis and Risk Evaluation according to CSM-RA. But the requirement reg. data exchange (Article 4 of RSD Interface management and exchange of information between the involved actors) and harmonization issues will be dealt with in WP5, 5.2.

#### **2.4.6 D-Rail approach to risk analysis**

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 CSM-RA this value might be considered the equivalent to a safety criteria for acceptability of risk. The risk assessment of these proposed systems has been carried out in parallel using GB and Swiss methods of application of 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.

So it should be paid attention that the results need to be carefully and intelligently interpreted rather than taken at face value.

### **3 RAMS Analysis**

The overall assessment (reduction of Derailment risks and costs) aims to evaluate the impact of derailments from RAMS and LCC perspective and to recommend interventions in terms of mitigation measures (in combination with prevention) that are cost-effective enough to achieve a derailment cost reduction of 10-20% in the EU.

The subsequent sections describe the RAMS approach for D-Rail purposes, the application of the proposed RAMS framework and the risk assessment considering actual and increasing freight traffic volumes and future demands towards 2050.

The range of the developed framework is proposed to be for the selected inspection and monitoring systems as described in section 2.2 and 2.3.4. For the application of the RAMS theory hot axle box and hot wheel detection system is selected since most of the RAMS related data are available for this system. But for the application of risk analysis and risk assessment Axle load checkpoint and Track geometry measurement system have additionally been considered.

Besides the results of D2.3 match very well with the experiences of the involved IM's in this project, since Hot axle box and hot wheel detectors and Axle load checkpoints were identified with the highest benefit to cost ratio considering the cumulative benefits.

Also prominence shall be given to the fact that more than half of all derailments (and at a 75% share of the costs) are addressed by three proposed monitoring systems such as Hot axle box and hot wheel detectors, Axle load checkpoints and Track geometry measurement system. Given these facts, the selected techniques are suitable good case studies of the evaluation procedure.

### 3.1 Application of the proposed RAMS framework

#### 3.1.1 RAMS analysis of the proposed Monitoring systems (WTMS)

##### 3.1.1.a.1 Reliability analysis and model selection

The data required for RAMS analysis were collected from operation and maintenance of HABDs installed at the installation sites Selzach, Dagmarsellen, and Zgraggen over a period of two years from SBB (see Table 8: Failure data of the HABDs). The data were extracted from the maintenance journals. A failure is defined in the context of this report as an event that requires an on-site intervention. In SBB definition, the term failure applies only to events that resulted in a service outage during railway operating hours.

ID	ID Text	Days between Failures							
		F1	F2	F3	F4	F5	F6	F7	F8
1	Selzach 11	72	42	2233	289	105	-	-	-
2	Dagmarsellen 3	817	876	1217	141	45	154	49	17
3	Zgraggen 251	777	290	732	346	25	133	282	71

Table 8: Failure data of the HABDs

In order to find an appropriate reliability model for the analysis of associated HABDs installed in the installation sites, the logic depicted in Figure 5-Chapter 2.2 is used. According to the logic, the two main steps for evaluating the data and selecting appropriate model, includes trend and dependency test (serial correlation test).

The trend test involves plotting the cumulative failure number against the cumulative time unit. If one obtains a curve that is approximately a straight line, then the data are free from trends. In addition, one can use Laplace or MIL-Hand book trend tests, see (Rausand and Høyland, 2004) for further study.

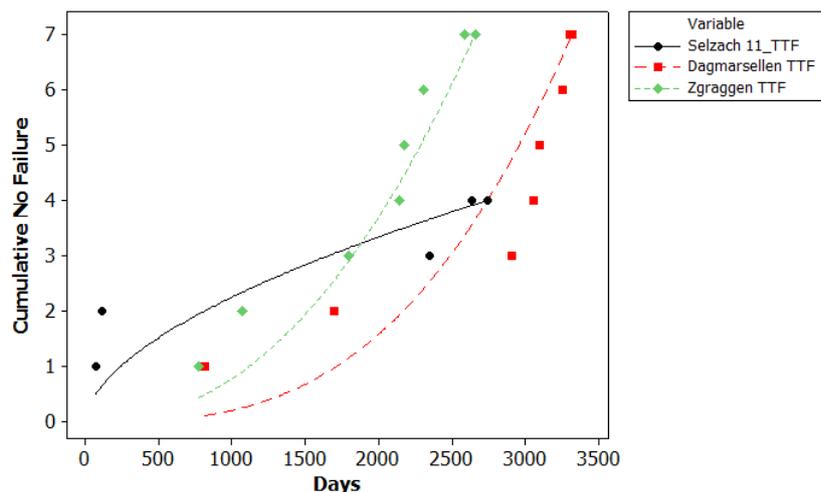


Figure 18: Cumulative number of failures versus operating days for HABDs installed Selzach, Dagmarsellen, and Zgraggen.

As can be seen from Figure 18, the plotted points for HABDs at the installation site Dagmarsellen form a convex curve which means there is negative trend between TBF of

HABDs. In other words, the time between failures in Dagmarsellen becomes shorter after each maintenance intervention. These types of units are called sad-system, in which the unit is under aging. In order to perform reliability analysis for this system, one should consider the quality of maintenance as well as residual life after each maintenance intervention. In fact making judgement with high confidence for HABD in Dagmarsellen needs more data associated with details of each intervention. A closer inspection of the maintenance journal for Dagmarsellen shows that sensor H2 was replaced multiple times because it produced false alerts. The RAMS data are thus in accordance with the subjective observation that the system has an unknown problem.

In addition, the curve associated with cumulative number of failures against day of operation for the installation site in Selzach shows a concave line which indicates that the time between failures after each maintenance intervention are becoming longer. This type of system is called happy system and means that the system is improving. Making judgement with high confidence for HABD in Selzach needs more data points.

The plotted data associated with the installation site Zgraggen also form almost a straight line with a little convexity at the bottom. A straight line among the points means that the TBF are free of trend. This type of systems is called normal system.

The results of the Laplace or MIL trend tests also are illustrated in **Error! Reference source not found.** Laplace and Military trend test are used with 95% confidence level. Following the test values in **Error! Reference source not found.**, it is obvious that according to the value for Laplace and Military trend test, for the data associated with HABD's installed in Selzach, the null hypothesis (i.e. data do not have trend) is not rejected. However, due to lack of sufficient data, making conclusion with high confidence about the trend is not possible.

According to the **Error! Reference source not found.**, for HABD in Dagmarsellen, the null hypothesis (i.e. data do not have trend) is rejected and we are confident that those data have trend. Therefore, according to the Figure 5-Chapter 2.2, Non-Homogenous Poisson Process (NHPP) is applicable to model the reliability of Dagmarsellen. NHPP model describes a sequence of random variables that are neither independently nor identically distributed. The NHPP is often used to model repairable systems that are subject to a minimal repair. Typically, the number of discrete events may increase or decrease over time due to trends in the observed data.

The associated trend test for Zgraggen (see **Error! Reference source not found.**) also shows that the null hypothesis (i.e. the data has no trend) is not rejected, and we can accept that the data has no trend. According to the Figure 5-Chapter 2.2, in order to identify the most appropriate model for HABD's in Zgraggen, dependency test is needed. The presence of dependency (serial correlation) can be examined by plotting the  $i^{\text{th}}$  TBF against the  $(i - 1)^{\text{th}}$  TBF. If the plotted points are randomly scattered without any pattern, it can be interpreted that the TBF are free from serial correlation.

The results of the serial correlation tests performed on the TBF data of Zgraggen are illustrated in Figure 19. The random distribution of the points obtained in the correlation test shows that the data are free from serial correlation.

Statistical Test ID	Laplace trend test		Military handbook test			
	Value of $U$	Rejection of null hypothesis at 5 %	Lower Bound	Value of $Z$	Upper Bound	Rejection of null hypothesis at 5 %
Selzach 11	-0.2	Not Rejected	2,17	14,03	17,53	Not-Rejected
Dagmarsellen 3	2,57	Rejected	5,62	4,76	26,11	Rejected
Zgraggen 251	1.75	Not rejected	5.62	6.23	26.11	Not rejected

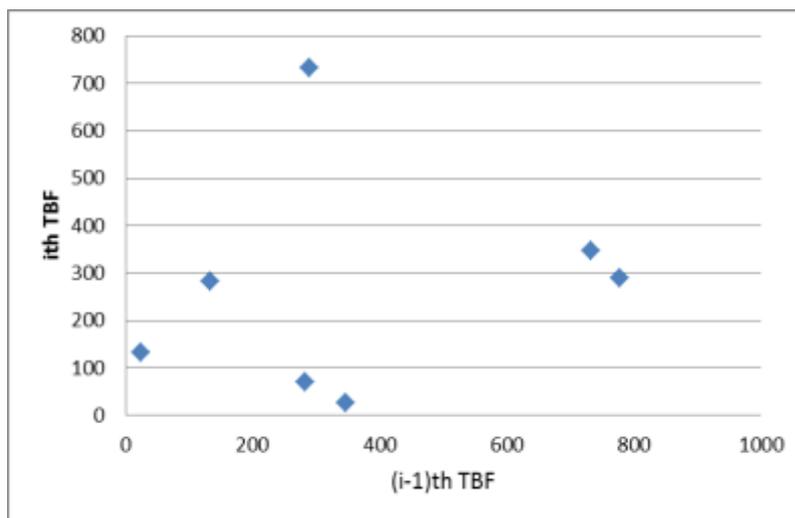


Figure 19: Serial correlation tests for HABD in Zgraggen

Therefore, the data associated with HABD in Zgraggen installation site are independent and identically distributed (iid), and consequently the renewal process is the best model for the failure analysis. A renewal process is a counting process where the inter-occurrence times are independent and identically distributed with an arbitrary life distribution. Upon failure, the component is thus replaced or restored to an as-good-as-new condition. Hence, a distribution function is fitted on the TBF data which models the failure occurrence probability during the system operation.

In order to perform further reliability analysis, we focus on the HABD in Zgraggen. Relisoft software is used to identify the best fit distribution for the HABD data set used in Zgraggen. According to the result, the Weibull-2 parameter is one of the best fit distributions with the parameter depicted in Table 9, where  $\alpha$  and  $\beta$  represents scale and shape parameters. The Weibull life distribution has long been used for most life data analysis problems.

**Distribution Parameters**

Weibull      Scale Parameter  $\eta$ : 2196,842  
                  Shape Parameter  $\beta$ : 2,578139

Table 9: Weibull distribution parameters for HABD installed in Zgraggen

Considering Weibull 2 parameter distribution, the reliability and failure probability functions at time “t” are defined as:

$$F(t) = 1 - \exp\left[-\left(\frac{t}{\eta}\right)^\beta\right] \qquad R(t) = \exp\left[-\left(\frac{t}{\eta}\right)^\beta\right]$$

Where  $R(T)$ =Reliability function,  $F(T)$ =Failure probability function,  $\eta$ = Scale Parameter and  $\beta$ =Shape Parameter. The main reason for the distribution's popularity is the versatility it provides, i.e. the Weibull distribution can take on the characteristics of other types of distributions, based on the value of the shape parameter,  $\beta$ . In order to identify the reliability limit, the minimum reliability requirement for HABD in Zgraggen should be calculated. Zgraggen HABD is positioned close to other HABD close to Flüelen, Erstfeld and Göschenen with about 15Km distance. The site in Flüelen can be considered for the purpose of this study to be a redundancy site for Zgraggen. If the reliability of 99.99% is required for detection of hot axle event within these two units, then the reliability of each HABD can be calculated as follow:

$$R_s(t) = R_Z(t) + R_F(t) - R_Z(t) \times R_F(t)$$

Where  $R_s(t)$  represents the total reliability requirement for the whole system and  $R_Z(t)$  and  $R_F(t)$  represent the reliability requirement of HABD's installed in Zgraggen and Flüelen. Considering  $R_s(t)=99.99\%$  and the units installed in both station are the same, i.e.  $R_Z(t)=R_F(t)$ , then the minimum reliability requirement for HABD installed in Zgraggen is estimated as:  $R_Z(t)=99\%$ .

### 3.1.1.a.2 Maintenance analysis

Following the discussion with the experts at SBB, restoration of HABD is found as applicable maintenance strategies:

- Scheduled discard /disposal: (or disposal): a scheduled task that entails discarding an item at or before a specified age limit regardless of its condition at the time.
- Scheduled restoration: a scheduled task that restores the capability of an item at or before a specified interval (age limit), regardless of its condition at the time, to a level that provides a tolerable probability of survival to the end of another specified interval. In this task, every mechanical part is cleaned and oiled, mirrors and sensors are cleaned, and the equipment is calibrated with an external oven (reference temperature). All tasks and calibration results are recorded and tracked.

When an applicable and effective task is selected, the frequency at which the task should be implemented must be recognized by the analyst.

In view of an operating time (day), we are interested in identifying the optimum tasks interval  $T$ , which will minimize the cost per operating day, under restoration and discard policy. Therefore, the following cost function is developed:

$$C_{Total} = \frac{(C_M) \cdot R(T) + (C_{Cr}) \cdot F_N(T)}{T \cdot R(T) + \int_0^T f^f(t) dt}$$

Where,

T=Restoration/discard interval

R(T)=Reliability function

F(T)=Failure probability function

C<sub>M</sub>=Cost of maintenance policy (restoration or discard)

C<sub>Cr</sub>=Cost of Corrective maintenance (unscheduled)

t= Local time between two maintenance

f(t)=Probability density function

The following assumptions also are considered in construction of the cost model:

1. The failures are evident by remote monitoring system for dispatchers.
2. The repair and maintenance makes the equipment as good as new except the IT equipment.
3. The behaviour of other units among HABD in SBB follows the same distribution.
4. The component is fully functional after maintenance.
5. After performing any kind of restoration (i.e. scheduled or unscheduled) the clock time becomes zero for the next restoration cycle.
6. The HABDs operate continuously and the failures of HABDs do not interrupt the planned track operation (due to the redundancy).
7. The HABD are modular system and can be removed from station very fast. Therefore, the times for these actions are negligible and do not interrupt track operation.
8. Accident costs are excluded. In SBB logic, a HABD is an additional safety measure to ensure vehicle compliancy and protect the infrastructure. It is however not a requirement to operate a track (no SIL requirements). An accident will not occur because a HABD was not working, but because a vehicle was badly maintained (no risk transfer from RU to IM due to HABD).

The following values also are considered for the cost parameters:

- Cost acquisition for 1 equipment: 250 k€, maintenance contract per year, 12k€, annualized costs 40k€ over 15 years lifetime.
- Restoration maintenance 2 man days + materials, 3000 € per restoration
- Corrective maintenance 5 man days + materials, 6000 € per intervention

Microsoft Excel™ is used to enable variation of the parameters of maintenance cost models to identify the cost per unit of time for different values of restoration and discard, T.

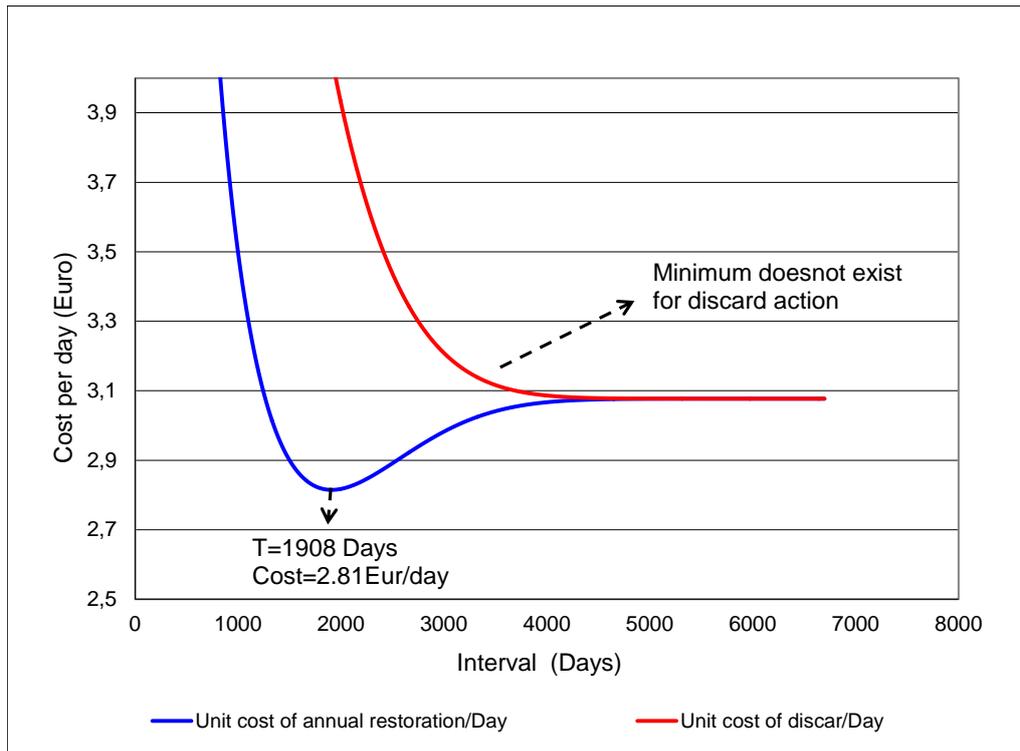


Figure 20 shows the cost per day versus intervals under the restoration and discard policies, and based on the values of reliability and cost parameters mentioned above. The following results can be concluded, from the figure:

- The cost function 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 new one. Therefore, discard is not an option for decision making.
- It is evident that under the restoration strategy, there is a specific  $T$  ( $T=1908$  Days) that results in an absolute minimum value of cost function (Cost=2.81 Euro/day).
- It is obvious that for the both restoration and discard strategies, when the maintenance interval tends to infinity, i.e. ( $T \rightarrow \infty$ ), the limit cost does not depend on the cost of restoration.

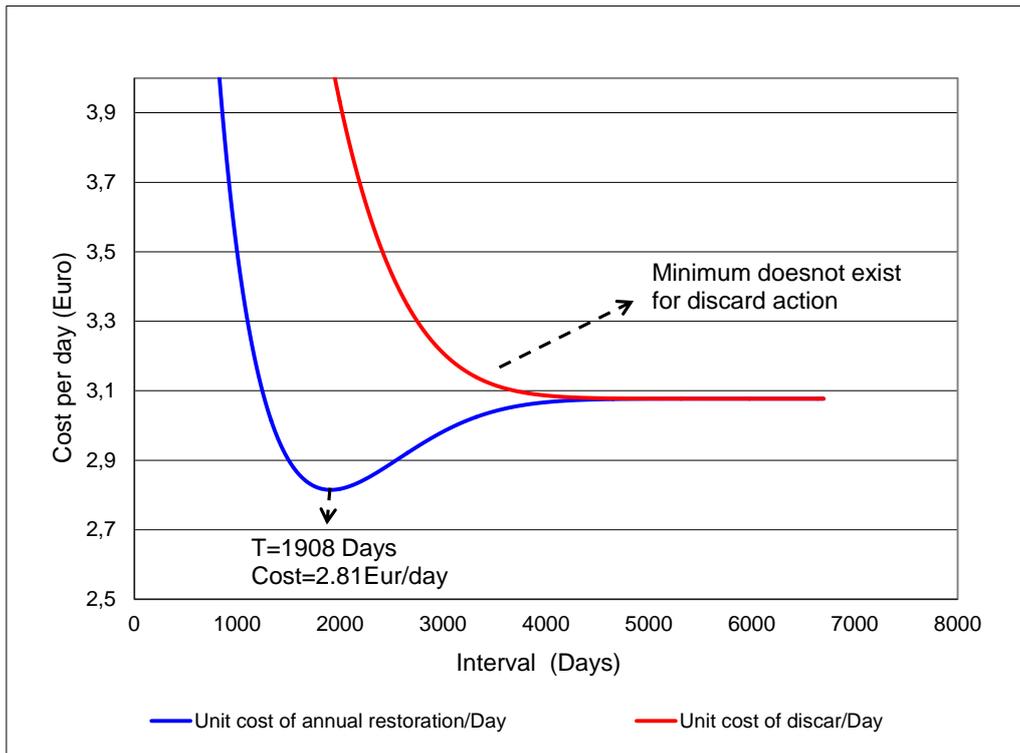


Figure 20: Cost per day versus intervals under the restoration and discard policies

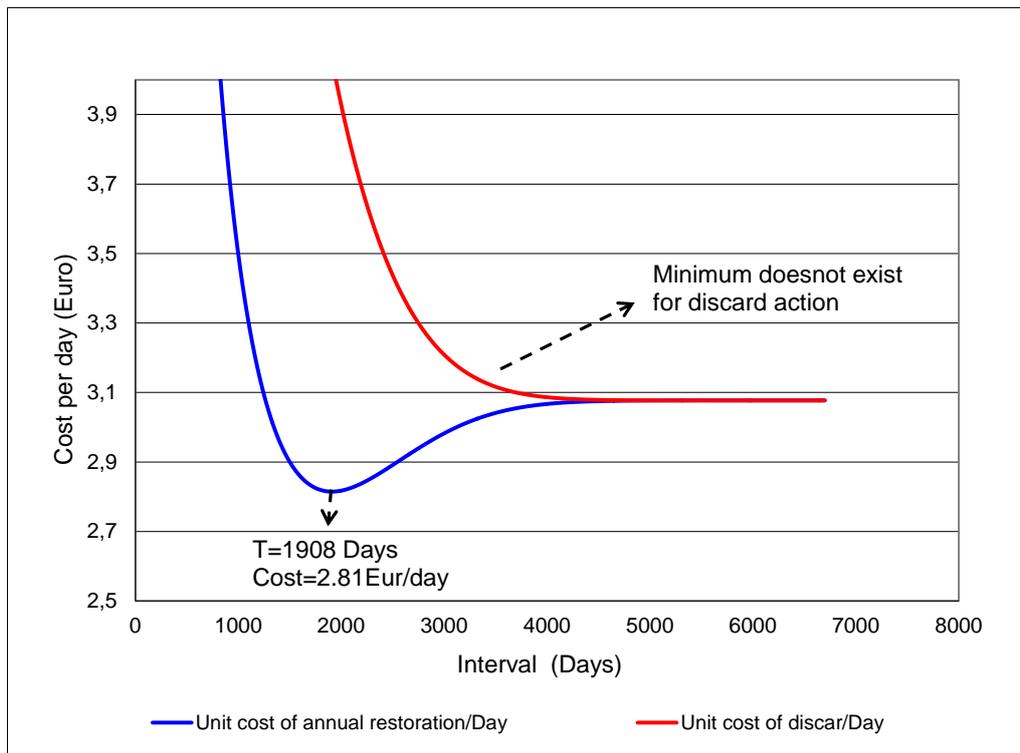


Figure 20 shows the variation of cost and reliability for different values of restoration interval  $T$ . It is obvious that the restoration interval ( $T=1908$  and  $C=2.81$  Euro/days) which was selected as optimum cost interval, exceeds the reliability limit ( $R(T=1908)=50\%$ ) and cannot be selected due to safety limits (see points 3 and 4 in **Error! Reference source not found.**).

Hence, risk analysis is needed to reveal whether the risk of failure is below the specified limit by using selected restoration intervals  $T$ . Considering  $R_{\min}$  as the minimum reliability limit for

the probability of derailment between Zgraggen and Flüelen then the optimization process needs to minimize the cost function under the supplementary constraint:

$$R_s(t) \geq R_{\min} \Rightarrow R_Z(t) + R_F(t) - R_Z(t) \times R_F(t) \geq 0.9999$$

Considering  $R_{\min}=99.99\%$  and the units installed in both station are the same, i.e.  $R_Z(t)=R_F(t)$ , then the minimum reliability requirement for HABD installed in Zgraggen is estimated as:  $R_Z(t)=99\%$ , which refers to  $T=366$  days, see figure 4. Therefore, it is obvious 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 (see points 1 and 2 in **Error! Reference source not found.**).

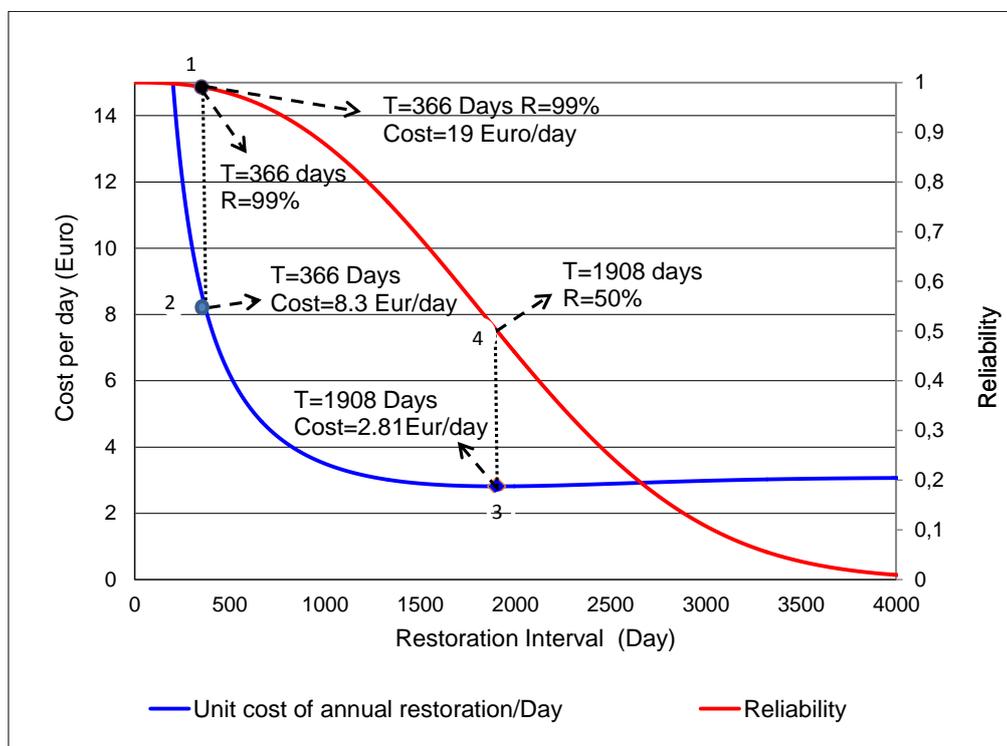


Figure 21: Variation of cost and reliability for different values of restoration interval T.

As the study shows, application of RAMS 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 their 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.

RAMS analysis also provides a scientific footing for safety and LCC management. Further analysis needs to be performed with more field data. 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, by some adjustments.

Summing up, by the integration of adequate modelling, the safety and LCC management can be considerably enhanced. Thereby, not only are the safety requirements fulfilled, but a

lower maintenance cost might also obtain 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.

## **3.2 Risk assessment for current and estimated increase of freight traffic**

### **3.2.1 Current and estimated increase of freight traffic**

WP2 analysed the actual freight traffic and attempted predictions on freight traffic for 2050. Several scenarios were looked at, which not only differ in overall growth, but also in distribution of transported goods (e.g. agriculture, petroleum...) and thus the vehicles necessary to transport it (open top wagons, covered hopper wagons,...). Some crucial parameters cannot be predicted reliably, e.g. the actual modal split, as it is influenced by political and other factors. The wide range of possible outcomes makes the degree of detail unsuited to guide the risk assessment. It seems unreasonable to deploy WTMS based on the train type distributions assumed in these scenarios. Rather, the input on WP7 must be that all likely scenarios must be addressable within the concept boundaries.

Of special note is the fact that it is very likely that the increase will occur not 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.

While it is unlikely that the increase in freight traffic will influence the choice of measures, it is a certainty 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 at least 1.5% (as predicted in WP2 of D-Rail). This shall be accounted for by calculating a case with and without increasing traffic.

### 3.2.2 Impact of future carrier demands on RAMS

In WP2 the future development of rail freight traffic was analysed and predicted until 2050 for two scenarios based on the White Paper (EC, 2011, Roadmap to a Single European Transport Area - Towards a competitive and resource efficient transport system). The freight volume on railway will increase about 1.5% p.a. because of economic development. A doubling of the freight volume is assumed and can be possible with displacements of the modal split and additional measures. The assembling of the freight volume will also change which means that the wagon stock will depend on changes too. Last but not least, the question of the amount of dangerous goods is essential for the risk management.

Focusing on these conditions the current system will reach its limits immediately and has to be optimized. To increase the capacity of lines obviously the following aspects are examined and measures are to be set.

The occupancy grade has to be increased. That means that an optimised logistic has to reduce the empty runs. In addition to, the available volume of load or the load factor has to be used more effectively. Appropriate measures make sure that the default limits are observed. That is important to keep the risk of an incident on a low level.

A higher speed of freight trains increases the attractive of an offer as well as measures for a deceleration of the whole transportation process. That can be the background for a higher capacity on specific lines, when the difference of the speed levels is lower than before.

Another subject is the raising of the axial load up to 25t. That has to be watched for a long time because the wagon stock and the rail infrastructure have to be coordinated with higher loading. High investments and the lifetime of the utilities need a long implementation of this project.

The investment needs can be optimized by a process attuned to implementation of monitoring systems. That includes the consolidation of the checkpoints and the interconnection with the IM neighbours to reduce the access control.

What is the effect of those changes on requirements of measuring points?

The expected changes of rail transport have to be considered and implemented into the concept of checkpoint installations to reduce the risks and effects of derailments.

#### 1. Increase of the freight volume

The increase of freight volume means more trains and more measurement processes in the same period of time. A shorter life time of the rails (because of higher attrition or fatigue) and the measurement device (further outage of encoders) have to be expected. The increasing of life time and robustness of the measurement device and its components should be in a particular focus and the MTTR (mean time repair) has to be reduced.

#### 2. Changes of wagon stock, change of commodity of goods, dangerous goods

Basically the derail safety is independent from the goods (except fluids due to sloshing) or the construction of the freight containing wagon bodies. The maintenance of the deck, the stiffness of the running gear construction and the influence of freight on the rail forces are important. Based on the prognoses of WP2, the absolute quantity of dangerous goods

(including petroleum products and chemicals) will more or less be the same and therefore it must be assumed that the risk of derails won't change.

### 3. Occupancy grade of the rolling stock

The higher occupancy grade of the rolling stock increases the burden for each time scale. That means, that vehicles with a maintenance cycle which is based on the mileages, don't show changes in their overall condition. Vehicles which enter the workshop after defined time scales show a lower condition when their occupancy grade has increased. That means that some preceding derailment causes may occur more often. In fact, for freight wagons the provisions for constant quality of condition are restricted to a small choice of devices (brakes, bearings). An associated maintenance-monitoring (committed for approved maintenance-companies) allows spontaneous reactions on exceeding limits of device-loads. This allows adjusting maintenance work or device designs if necessary.

### 4. Higher speed levels

Conventional freight wagons approach their limit at a speed of 120km/h. Basically rising the travelling speed is one of the possibilities to increase productivity. However this has to be balanced with a reduced maximum possible total train weight if the traction power stays constant.

### 5. Higher axial load

Higher axle loads (25t) improve productivity especially of heavy bulk commodity transport. If the main lines and the used vehicles are adjusted to 25 tonnes most of this traffic can be improved in a very efficient way. It has to be considered that changing the maximum permitted axle load to (at least) 25t is a long term investment because all railway bridges may have to be improved or rebuilt.

### 6. Optimization of the maintenance of vehicles

Based on the directive 2008/110/EC of the European Parliament and of the council of 16 December 2008 amending Directive 2004/49/EC on safety on the Community's railways (Railway Safety Directive) each vehicle, before it is placed in service or used on the network, shall have an entity in charge of maintenance (ECM) assigned to it. The standards for this ECM dictate that every possible information source should be used for the optimization of the maintenance process. From different data sources the ECM gets information about damage symptoms and causes. With that information the ECM is able to infer provisions for a better maintenance. That means that every change of the workload which has an effect on the maintenance is worked into its process. The effect is that the probability of a bad maintenance of a vehicle decreases. This is an important process to mitigate occurrences of derailing root causes on freight vehicles.

### 3.2.3 Risk assessment

The concepts and principles guiding risk assessment have been discussed in WP 7 section 2.4. Changes and development of methodology occur regularly, but it is unlikely that the outcomes of the methodologies used today and 2050 will differ radically.

It is worth to summarize briefly the essential definitions: “Risk assessment” means the overall process comprising system definition, hazard identification, a risk analysis and a risk evaluation (ISO/IEC 73). “Risk acceptance criteria” means the terms of reference by which the acceptability of a specific risk is assessed; these criteria are used to determine that the level of risk is sufficiently low that it is not considered necessary to take any immediate action to reduce it further.

The ultimate objective of risk analysis is to inform risk-related decision making: should a given system be implemented or not, and should it be preferred over another system?

To calibrate the methods, it is necessary to define targets for the expected benefits. In the context of D-Rail, these are mainly the anticipated safety improvements due to implementation of risk reduction measures such as Hot Axle Box detectors, etc. However there are no detailed targets for derailments specified. In the context of this study, we will thus consider the given goal regarding the reduction of derailments by 8-12% as a safety target to reach.

An important part of the risk-related decision making process is whether the costs associated with a measure compare favourably with the expected benefits, i.e. whether a given risk reduction is worth the required spending. The D-Rail approach differs in this area significantly from established practice in the railway enterprise by focusing exclusively on freight trains and by limiting the scope to derailments. Usually, railway enterprises seek out synergies between freight and passenger transport, and by combining measures aimed at different safety issues, e.g. derailments as well as collisions.

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 have used as a basis assumptions derived in WP2 and WP5 regarding potential implementation scenarios and estimated implementation costs for Hot Axle Box (HABD). 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 reasonable 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. An overview summary of the results of the GB risk assessment is given below:

Monitoring System	Assumed reduction in % derailments due to system	Assumed number of additional units installed (2020-2050 cf.2014)	GB ALARP Conclusion
Scenario 1: Widespread implementation with "high" level risk reduction			
Hot axle box and hot wheel detection	91%	790	Not justified to reduce risk to as low as reasonably practicable
Axle load checkpoints	98%	300	Not justified to reduce risk to as low as reasonably practicable
Track geometry measurement systems	60%	20	Not justified to reduce risk to as low as reasonably practicable
Scenario 1: Targeted/focussed implementation with lower risk reduction			
Hot axle box and hot wheel detection	9%	160	Not justified to reduce risk to as low as reasonably practicable
Axle load checkpoints	90%	120	Justified to reduce risk to as low as reasonably practicable
Track geometry measurement systems	45%	10	Justified to reduce risk to as low as reasonably practicable

Table 10: summary of the results of the GB risk assessment

It should be noted that, particularly for the track geometry measurement option, a suitable associated intervention strategy is required to actually realise any potential risk reduction.

The SBB method gives a slightly more favourable outcome, as there is a risk aversion factor of 1.135 built into the model that weighs risks affecting persons outside of the railway system (i.e. neither passengers, railway personnel nor trespassers) more heavily. This has an effect on freight derailments since some of them concern dangerous goods, which can lead to release of noxious materials, large-scale fires or similar events. The risk aversion principles are described in D7.1. The actual value is calculated based on the proportion of dangerous good-related traffic on the SBB network. A higher monetized risk value of 20 MCHF is used for the proportion of the damage that concerns victims that are neither trespassers and passengers nor employees. With the limits imposed by the D-Rail approach, the risk aversion factor is not particularly high and does not influence the results substantially. The RSSB method for GB considers passengers, workforce and members of public, but gives them

equal average weighting. High consequence/low frequency derailments such as those involving dangerous goods are integrated within the GB risk model. An overview summary of the results of the Swiss risk assessment is given below:

Measure	Annualized Cost [M€]	Monetized Risk Reduction (MRR) [M€]	MRR with risk aversion [M€]	Cost-benefit ratio	MRR with risk aversion and traffic increase (70%) [M€]	Cost benefit ratio with traffic increase (70%)
HABD: 1 system reference	0.033 [SBB]	0.017 [SBB]	0.019	1.7 (adequate)	0.033	1.0 (effective)
HABD: 3600 systems (99%)	85.8	1.28	1.45	59 (not reasonab.)	2.47	34 (not reasonab.)
HABD: 1790 systems (91%)	15	1.16	1.32	11 (not reasonab.)	2.24	6 (adequate)
HABD: 100 additional systems (9%)	3.5	0.12	0.14	25 (not reasonab.)	0.238	14.7 (not reasonab.)
ALC: 1 system reference	0.037	0.033 [SBB]	37k	1.0 (effective)	63k	0.6 (highly effective)
ALC: 500 systems (98%)	6.4	4.49	5.09	1.26 (effective)	8.66	0.74 (highly effective)
ALC: 320 systems (90%)	4.1	4.12	4.68	0.88 (highly effective)	7.95	0.51 (highly effective)

Table 11: summary of the results of the Swiss risk assessment

The outcome of both theoretical risk assessments would appear to disagree slightly with current railway practice in many EU states, where HABD's, ALC's, 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:

1. 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.

2. 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.

More information on risk analysis and risk assessment are presented in the annex.

### 3.3 Comparison of different cases & concepts of Monitoring Systems (existing situation, local & global)

#### 3.3.1 Description of Monitoring cases and concepts

Many countries in Europe use axle load checkpoints to obtain information about freight train load distribution in their network. There are a large number of systems available on the market and many more systems are built up as trial installations throughout Europe and the world. Unfortunately until now there is a lack of co-working and international experience and data exchange. Some IM put a lot of effort and money in the surveillance of the rolling stock moving on their network. Others are not yet concerned how important it is to know the real forces (these can be far above the existing thresholds) which are brought in to their track by the rolling stock.

Key letters of prefix		Measurement categories
Wheel load Q, Lateral wheel force Y, Longitudinal wheel force T, Derailment E	Q Y T E	Forces, derailment coefficient
Wheel Flats, Out-of-round wheels U	F U	Boundary conditions of the force effects
Noise, Vibration	N V	Environmental impacts
Bending, shearing, longitudinal stresses S	S	Rail stresses
Contact forces, Creep waves, Cracks	C C C	Boundary conditions of the contact effects
Buckling of rail	B	Temperatures related issues
Blocked brakes F	F	
Hot box detection	H	
Hot Disk brake detection	D	

Table 12: Key letters for the categorization of Measurement sites

Also the identification of measurement sites across borders can be done in the future by using these abbreviations. For example a measurement site, which measures Q-forces, wheel flats and noise and located in Austria, Deutsch-Wagram, would be described as:

QFU81\_001\_DW

Here QFU stands for the values the measurement site can measure, 81 is the country code, 001 is the sequential number and DW stands for Deutsch-Wagram. The measurement site identification (e.g. QFU, QYN ...), the country code (e.g. 74, 80, 81, 85 ...) and the sequential number should be standardized in future. The last digits or letters can be chosen individually by each IM to meet their needs and merge in their IT-System.

All WTMS concepts should give results referring to the international defined, harmonized measurement categories, which should be implemented for safer cross border rail traffic in the future. If transgressions of these limit values are detected, the WTMS must automatically

and immediately inform the IM to take further measurements (stopping the train, taking the vehicle out of the train ...). Furthermore the detected expedience of the defined thresholds should be linked to the specific train, specific vehicle, specific bogie, specific axle and even to the specific wheel. Here there is still a long way to go. Some exceptions are IMs in some northern countries which have already installed RFID-tags on part of their rolling stock (passengers and freight vehicles). In other countries like Austria there are intense research projects going on to allow automatic vehicle identification (AVI). Other concepts employ camera systems to meet AVI needs (Belgium). The advantage of these installations is that there are no modifications on the vehicles needed. The clear disadvantage can be graffiti or other kinds of interference for visual identification of the Europe Vehicle Number (EVN).

Generally speaking until now there are many projects and ideas for the exchange of WTMS data throughout Europe, but the implementation in neighboring infrastructures is not always as successful as it could be. One successful and very cooperative partnership is built up between SBB and ÖBB infrastructures.

To sum it up most WTMS only measure vertical wheel forces (Q) over a certain track length. From these values vehicle weight, wheel flats and polygonisations can be derived. Highly sophisticated systems are also capable of measuring horizontal forces (Y) and derive more details which allow an evaluation of possible derailment risks (Y/Q, hunting ...).

The aim of this project, the HRMS-project and related TTI-Group must be to raise the awareness of necessity for international standards and maybe even common limit values from WTMS throughout Europe.

Concepts for planned and/or installed monitoring sites vary due to different requirements coming from different needs of different infrastructure managers. Even different departments inside one infrastructure manager may cause different system strategies for different monitoring goals. And last but not least there are different development approaches of different manufacturers for the same failure to be detected.

As worked out in WP5 we find different subject areas where concepts can differ from one to each other:

- Different measurement principles
- Considering environmental conditions or not
- Different measurement geometry due to specific measuring goals

These are the main differentiations concerning the measuring process itself. But the post processing of measured raw data also enables different approaches:

- Providing the results to allow direct decisions typically used for standalone systems. If data exchange is required, the quality of measurement data evaluation has to be high, but then the data volume is quite small.
- Pre-analysed measurement data. These provided data contain more details. This leads to more data traffic, which enhance the knowledge on this.

- Measurement data and interpretation algorithm. Sending the algorithm in addition gives the data users the transparency of the recommended evaluations
- Additionally some operational data can be sent to inform the IM resp. the RU about affected wagons in case of an alarm.

Combining these possibilities of realisation we can see, that there are at least three different possible approaches of implementation:

- National driven (=business as usual)
- Bilaterally harmonized
- Full harmonized (European wide harmonization of data exchange and used standards)

The national approach has no special requirements of (international) standardisation. Every IM is free to choose a fitting strategy for his specific needs. The disadvantage is that no cooperation with other IM's is possible.

The bilaterally harmonized calls for standardisation of processes and requirements that enables every participating IM to understand exchanged data and to trust in the quality of the conclusion based on this data. One of the benefits of this approach is to spare monitoring sites on network borders – one per track is sufficient.

The full harmonized case brings additional benefits both to the single IM and to the community of IM's in the EU.

The definition of the monitoring concepts is based on the provided input from WP5 considering three scenarios such as minimum solution, standard case and full integrated solution (see also D5.2, chapter 4). The specific boundary conditions in some countries (e. g. temperature, climates, curves, mountains etc. as described in section 2.3.1) have been taken into account in the business cases of WP5. Based on the assumed number of installation for pan European network agreed with WP5 the assessment in terms of risk and costs reduction have been performed in WP7 as presented in section 3.2.3 of this deliverable. The assessment results will feed into the work of WP5 for further considerations. It should be noted that associated migration aspects are treated in section 3.3.3 of this deliverable.

### 3.3.2 Probability of derailment on the availability of the railway track system

In this chapter attempts are made to indicate the contributing factors for derailment through the development of a probability formula. It is well known that the probability of derailment has an impact on the availability of rail track, both by reduction and increase of derailments.

The railway infrastructure and the rolling stock are vital parts in the railway system and the interaction between these is managed by traffic control centres. The figure presented below shows a general breakdown of the railway system, i. e. the railway infrastructure can be divided in subsystems, (e. g. sub-structure, permanent way, switches and crossings and so on. The subsystem for instance reg. permanent way can be divided into components such as ballast, sleeper fastening, rails and joints. However, the complexity is further enhanced by the amount/density of assets. As a consequence the increased amounts of track, switches and crossings, etc., requires, among other things, more planning and control.

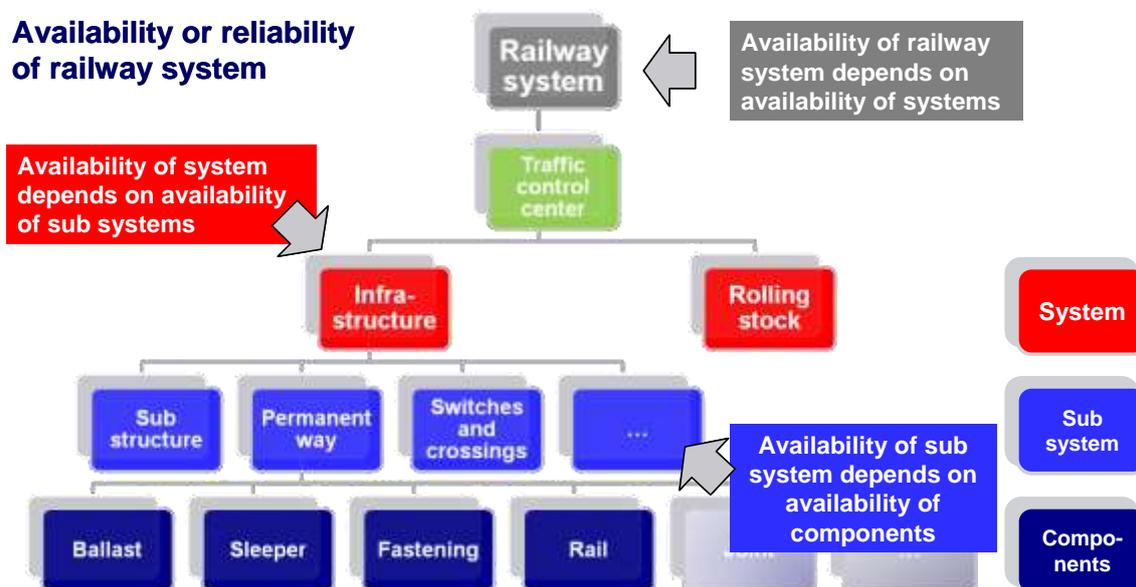


Figure 22: breakdown of the railway system

An important question is how to achieve the required availability of the system. Basically the availability depends on the technical performance of the system or component and the repair rate. Both parameters influence also the life cycle costs of the system. According to the breakdown of the railway system the system performance is determined by the performance of sub-systems and components. As RAMS describes the technical performance of a system, sub-system or component the total Availability of the system can be described and calculated respectively by the Availability of sub-systems and components. A system can be serially composed of two subsystems sub 1 and sub 2. This means that both subsystems must be available in order for the total system to work. The subsystems Sub 1 and Sub2 or the components C1 and C2 respectively with the availabilities  $A_{Sub,1}$  and  $A_{Sub,2}$  and  $A_{C,1}$  and  $A_{C,2}$  are installed in series configuration and have the combined Availabilities of:

$$A_{System} = A_{Sub,1} \cdot A_{Sub,2} \cdots \cdot A_{Sub,n}$$

$$A_{Sub,i} = A_{C,1} \cdot A_{C,2} \cdots \cdot A_{C,n}$$

However, the Availability of a system can be considered as a product of function of Availabilities of the sub-systems.

$$\text{Avail system} = F(A_1 + A_2 + \dots + A_n)$$

while Sub stands for sub-system and C for component

The better the availability of the subsystem and components is the better is the availability of the system. Consequently the higher the requirements are, the higher the technical efforts and the costs.

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 going to be monitored.

By reducing the impact of freight derailment on railway users and operation the availability of the track should be increased in order to achieve less track disruptions due to derailment and its consequences. However, the availability of the track depends on the availability and the reliability of the detection measurements. In the context of RAMS analysis for D-Rail purpose it makes to distinguish between the availability of the inspection and monitoring system itself and the availability of the entire railway system (see data collection by the RAMS and LCC template in section 2.2.1). Basically the availability is based on:

- knowledge of Reliability based on the failure rate of the system (RAM analysis)
- analyse of potential hazards (Hazard and Operability Study)
- probability of the occurrence of a failure (Fault Tree Analyse)
- analysis of the consequences on the functionality of the systems (FME(C)A)
- knowledge of the Maintainability based on the knowledge of the repair rate

The RAMS parameters influence each other and have an impact on the technical performance and LCC. Reliability (R) in the narrow sense influences the risk for humans, so the Safety (S) in the narrow sense, as well as the technical safety within the meaning of functionality, in turn, influences and changes directly the Availability (A) and requirements of Maintainability (M). It largely determines the costs incurred in the utilization process (LCC), and the maintenance costs are mainly determined by the Reliability.

The required Reliability depends on operating conditions and results from the required Availability. The required Availability depends on the technical performance and repair rate from influencing the LCC.

The repair rate influences the life time and therefore there is a connection between Maintenance and service life time (e. g. through failure rate). Thus the repair rate and maintenance costs depend on the Availability and failure rate.

Transferred this knowledge to the component breakdown regarding WTMS presented by the figure below it can be stated that the maintainability, the quality of WTMS and infrastructure would go up by increasing the detectability, reliability and quality of measuring accuracy of WTMS.

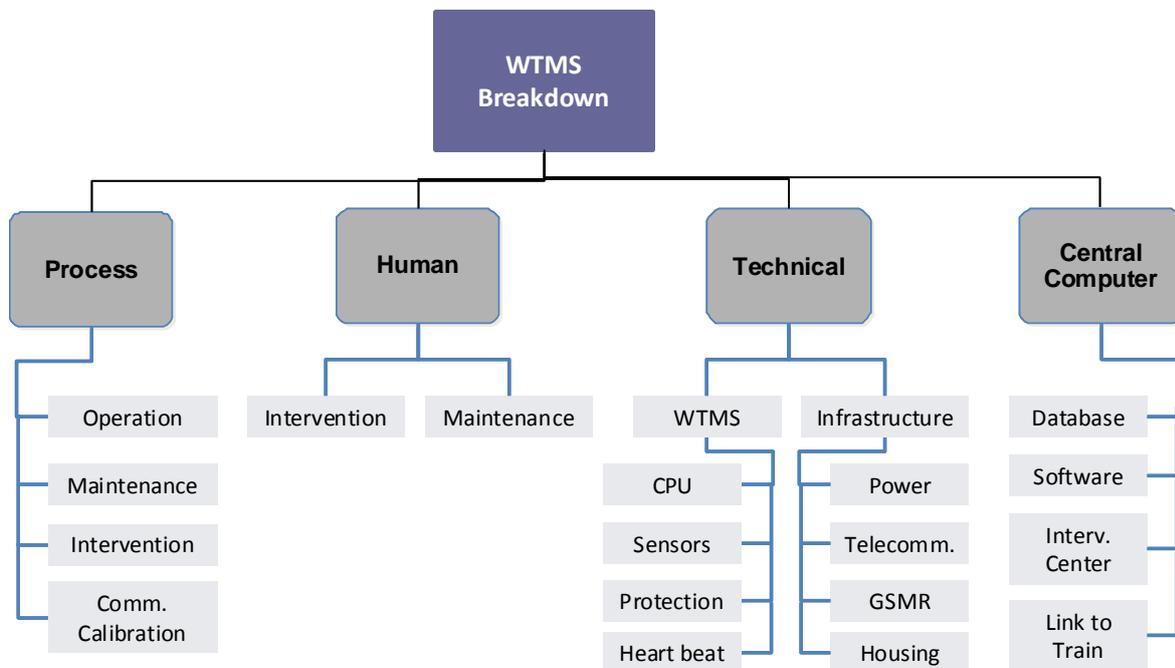


Figure 23. Component breakdown reg. WTMS

Depending on the significance which is given to the WTMS by each IM the RAMS needs to be enlightened. In either case the meantime to repair (MTTR) needs to be reduced to a minimum and the system must be repairable and maintainable without costly track closures as far as possible. Depending on the level of safety, which is expected of the WTMS the life time and robustness of the hardware and software components have to be only a very high standard.

WTMS is a protective device to detect hot axle condition and reducing the probability of derailment. As described in the below equation (see figure 25), within the scope of using WTMS, probability of derailment can be reduced by reducing the hot axle condition, or increasing the detectability of the HADB as well as improving the right decision making by the crew. In fact any of the following parameter can influence the RAMS of the system itself and the whole railway system as follows:

- $P_{HAB}$ =The likeliness of any event occurring (hot box, hot axle, blocked brake,...).
- This variable can be reduced by proper vehicle maintenance, vehicle inspections and checking for blocked brakes before the beginning of the train run (e.g. at shunting yards).



the measuring track. When it comes to choosing possible location for installing WTMS, the availability of a sufficient power supply and landline for fast internet connection needs to be kept in mind. If there is no fast internet connection available or to be build up cost efficiently, then at least the network coverage for GSM network needs to be double-checked carefully. For a high availability and long life on the system the installation of an uninterruptible power supply (UPS) is strongly recommended.

Furthermore

1. the wiring have to be reliable and redundant
2. the access roads have to be suitable for maintenance vehicles (small trucks)
3. the network availability must be provided
4. harmonized and stricter limit values for a stronger utilization of system resources
5. Network measurement sites for faster and better data analyses are responded for saving of sites near the borders

### 3.3.3 Adaption/Definition of migration scenarios

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 process both elements of software migration and data migration are coming 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 it seems necessary in order to cover the 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 figure presented below could be considered as a framework for migration whereas the migration should refer to some important issues such as:

- Technical: special boundary conditions, environment, analysis of system compatibility, comparison of old and new system, adjustment of new system...
- Professional: staff, compliance with standards and guidelines, field test, qualification and training of staff, migration of database, level of communication, functionality etc.
- Procedural: operation procedure, reporting chain, responsibilities, documentation etc.

But despite one of the expected outputs in D-Rail there is not a new system to be implemented and migration to be considered for this new system. Therefore the migration presented here is described in a generic way taking into account the existing framework conditions of the railway system (see figure 26) by addressing two relevant scenarios. One scenario is traffic with high density and/or high speed reflecting the situation to highly populated mixed traffic lines or high speed passenger traffic, whereas the second scenario is traffic with low density and/or low speed represented by secondary lines.

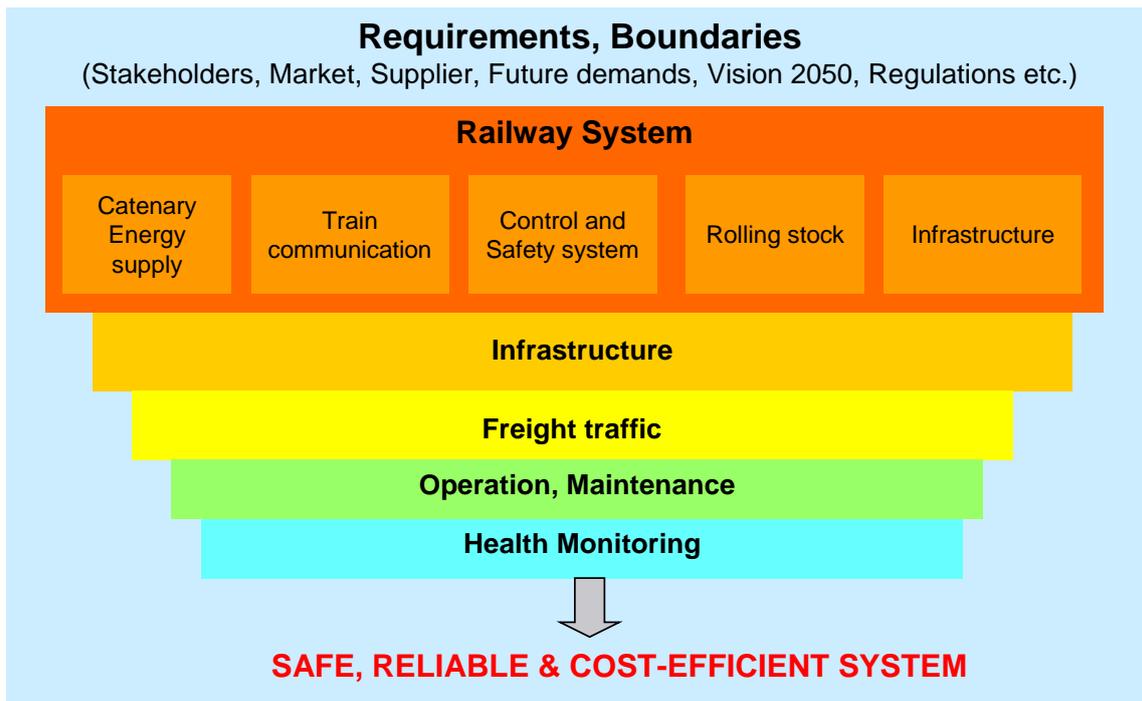


Figure 25: Framework conditions to be considered for Migration purpose in D-Rail

A migration approach is described in section 3.4 of D3.4 based on two initial scenarios are considered. One scenario is traffic with high density and/or high speed reflecting the situation to highly utilized mixed traffic lines or high speed passenger traffic, whereas the second scenario is traffic with low density and/or low speed represented by secondary lines. However, the different aspects of migration will be outlined, owing to the very inhomogeneous situation in Europe. The starting point is also different for European countries: many use technology-intense monitoring and intervention due to high traffic density, the other relies on human monitoring. It seems likely that an increase in traffic as predicted in WP2 will shift most countries to technological solutions. Thus migration issue is considered in the upcoming economic analyses.

As shown in sections 2.2 and 3.1 the results of RAMS analysis the maintenance strategy for the HADB case study at Zraggen installation site is well developed, and the existing monitoring systems being in use are performing very well, also in terms of Reliability and Safety (RAMS) performance, and an exchange of these systems is not regarded as conceivable except the required replacement after the service life time. So it's more a matter of cross-border networking and integration of the proposed systems including systematic approaches into a wider European solution to enhance the safety level (SMS) and line availability at a minimum maintenance cost. The systematic approaches need to cover different needs from different perspective, to consider the framework of existing regulations and national implementations, specific boundary conditions (meteorological and topological conditions), different national driven strategies, different rules and safety philosophies etc.

The exchange of measurement data across borders is in many countries a new field. Here new responsibilities and knowledge has to be implemented in different organisations. Otherwise the benefit – which lies among other things 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.

The related business cases developed in WP5 (s. chapter 4 of D5.2) cover the above mentioned topics and therefore a summary of the key scenarios for derailment reduction and business cases respectively is given in the following.

According to the EU regulation 2004/49/EG every actor in railway business needs to implement a SMS.

As described in regulation 1078/2012 every actor (IM, RU, ECM) has to implement a monitoring system in order to evaluate the individual chosen SMS. It has to be noted, that every actor is free in choosing the type of data collection and in the individual implementation of this monitoring system. Therefore this monitoring system is not compelling a monitoring device (like WTMS). However, derailment detectors will remain a voluntary measure at the condition that equipped vehicle fulfil the requirements for authorisation on placing into service and users have appropriate operation measures in their SMS

Nevertheless, chapter 4 of the CSM Monitoring declares that knowledge gained by one partner, and could be useful for enhancing the safety state of another partner, shall be exchanged. The benefits in risk reduction doing so will be assessed in cooperation with WP 7.

Starting from the today's situation, Figure 26 shows a traffic situation where block trains are operated across borders without any additional treatment, whereas full-load trains are decoupled at shunting yards in order to re-assemble them. Some WTMS are installed on the journey in order to survey a safe operation.

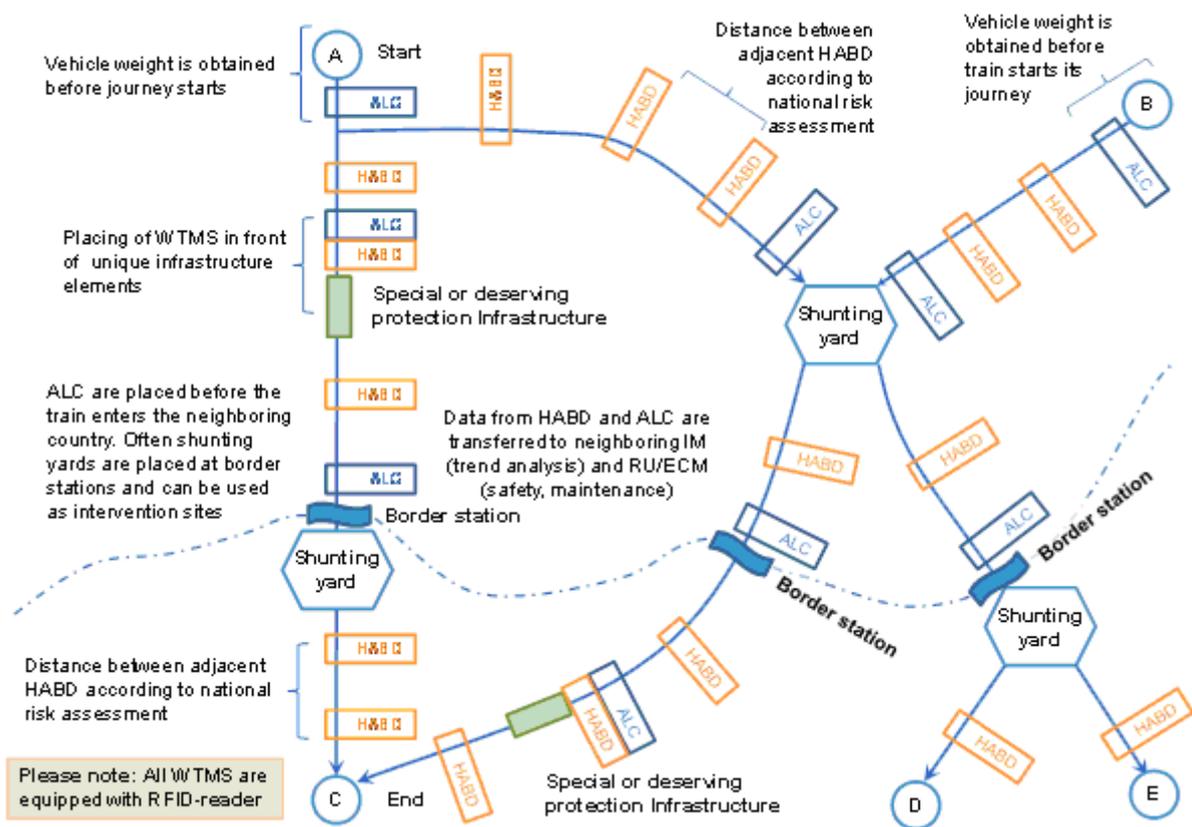


Figure 26: Placing of WTMS for block trains (left) and full-load trains (right) in 2050.  
It has to be noted that all WTMS are equipped also with RFID reader

The implementation strategy of WTMS for block trains and full-load trains in 2050 is shown in Figure 26. 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's 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's are installed before trains enter a neighbouring infrastructure, so that the facilities and staff at a border station can be used for required vehicle treatments.
- 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 would be observed if all vehicles were equipped with on-board diagnostic devices, which measure 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 of WP5.

More details on implementation scenarios including migration are presented in D7.4 of W7 as well as in D5.2 of WP5.

All involved parties established a SMS based on the characteristics of 2014. Already installed WTMS are in most of the cases not part of the CSM Monitoring in the sense of exchanging data between partners. The question, how the safety level will change, if the amount of traffic increases as predicted, is highlighted in Figure 27.

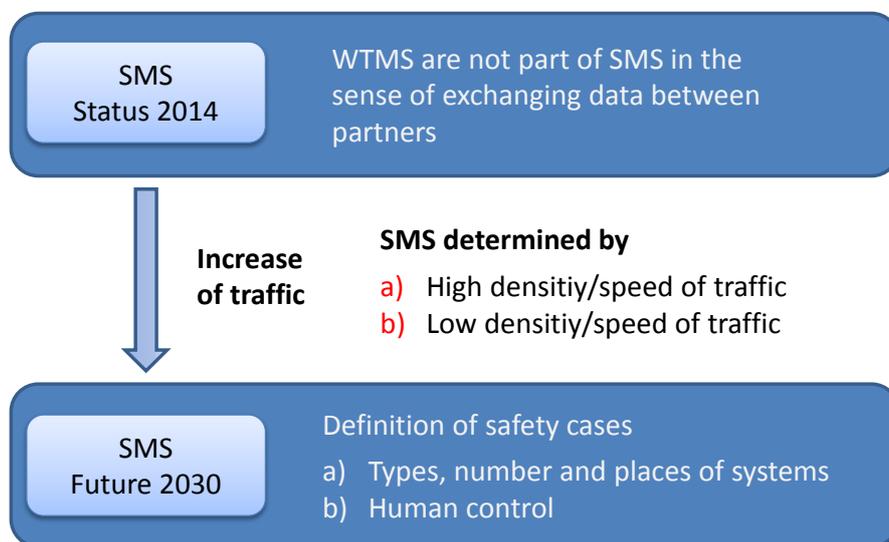


Figure 27: Status of SMS and future development in order to keep the number of incidents

Such being the case, two different traffic scenarios have to be distinguished:

1. Traffic with high density and/or high speed
2. Traffic with low density and/or low speed

The first situation reflects highly populated mixed traffic lines or high speed passenger traffic, whereas the second one is represented by secondary lines.

Based on the eight key scenarios of derailments four different use cases are identified when establishing a SMS in which an exchange of data from WTMS among different parties (IM, RU and ECM) is included, see Figure 28. First, the measurement values don't exceed certain threshold values, but indicate an early warning which may cause a higher risk of derailment in the future. The following correction – in a sense of state dependent maintenance or enhancement of (loading) processes – may ensure, that the number of detected vehicles will decrease in future. Warm axles might be detected by HABD whilst ALC are used for detecting the other three cases.

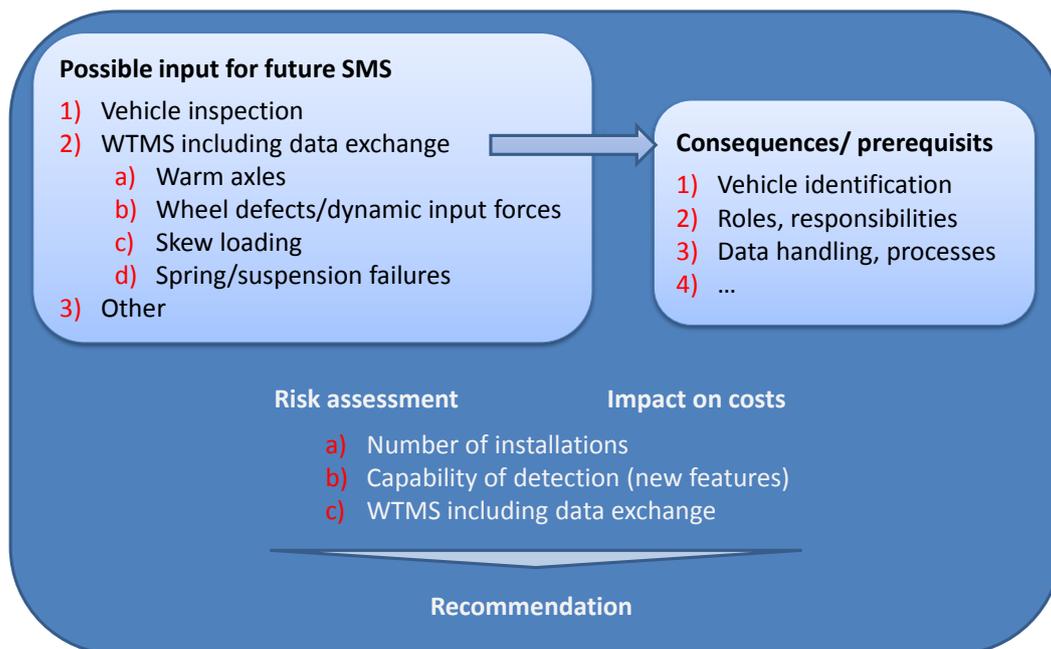


Figure 28: Possible input for future SMS including consequences when exchanging data from WTMS among parties assessing the impacts on safety and costs in order to take the best decision

When exchanging data from WTMS in order to integrate them into the SMS some consequences will follow (or are a prerequisite). A basic description given in D 5.1 of WP5, could contain the following points e.g.:

- A robust and automatic vehicle identification system is needed to connect the measurement values from WTMS to the individual vehicle components/entities.
- Establishing a database for all measurement values. This can be on a national basis, but should enable cross border data exchanges between different IM, RU and ECM.
- Connecting already existing WTMS, in order to receive measurement values at a central server. This functionality isn't changing the original functionality of the WTMS, therefore no SIL-functionalities or CENELEC-processes are necessary
- Creating national data collection centres, which act also as control centres influencing the traffic, if threshold are exceeded

The network and distribution of sites is fundamentally different for every sensor technology.

One system describes the positioning of hot axle box, hot wheel and blocked brake detection systems. The operating experience shows that a train can run a distance of at least 30km after the occurrence of losing a bearing until component failure. In consequence, sensors are placed in a density-like approach to ensure that sufficient coverage will be obtained.

The network design of other sensor systems for prevention of damage is to be regarded more complex. For example, Axle load checkpoints derive the axial load and the wagon weight from the vertical quasi-static wheel force at a measuring point. The quality of the results is not strongly influenced by the used sensor system. The vertical quasi-static wheel force is a measure for the assessment of different probable conditions. Possible backgrounds

for a transgression of permissible quasi-static wheel force/axial load or permissible quasi-static wheel force/axial differences are overload, invalid securing of the load or breakdown of a component (spring, leverage). The backgrounds are as different as the time of occurrence or the timing of secondary failures. The simple connection of a hot-box detector like “after a certain travelled distance the consequential damage is to be expected”, is not valid in this form. The following conclusions are derived from an economic point of view:

From an infrastructure perspective, covering expensive infrastructure elements is a valid target. Focusing the following areas are most important:

- High-speed-railway lines with a top speed of greater than 200km/h
- Technical control at entering into another railway system (border crossing or other IM with a high traffic density)
- Important shunting yards or rail junctions with high frequency
- Important tunnels (selected by length, top speed, train frequency)
- according to regulations of proper authority

Note to the first bullet point regarding “High-speed-railway lines with a top speed of greater than 200km/h”: One can say that this might be out of scope of D-Rail. But there are many track lines/corridors where passenger trains and freight trains travel at different speeds, e. g. in Germany or Switzerland (track speed in the Lötschberg, Gotthard and Ceneri tunnels). These are mainly freight corridors. Contrary to this situation in France the HGV network is fully decoupled from the rest including freight.

As result a high level of safety with limited investment needs is achieved. If there are joining forces with neighbour IM the expenditure of bordering measuring points can be halved by close cross-border cooperation with neighbouring IM.

For positions of fixed derail detection systems there is another approach. The first step is to find out the worth protecting points of main railway lines with a high speed greater than 160km/h and a high risk of derailment by a risk analysis. In case of derail, the train has to stop in front of the last covering signal. Further, the rail junctions of the main system and other infrastructure facilities have to be protected.

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

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

It seems safe to assume that these parameters are not readily unified across Europe, but that a risk assessment per IM is required. 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.

### **3.4 Use of monitoring systems in Maintenance procedures**

In work package WP3 it was investigated how various operational parameters influence the risk of derailment due to flange climbing, wheel failures and rail breaks. WP3 explicitly excludes the analysis of derailments due to axle brake due to the on-going parallel efforts in the EC funded project EURAXLES.

The deliverable report D3.3 summarizes main influencing parameters; tentative limit values and potential preventive measures together with recommendations for actions and a brief overview of commercial impact. Here it should be noted that it was complicated to estimate the commercial impact at that time since it relies on cost and efficiency of monitoring equipment, which was to be developed in subsequent work packages.

A summary of conclusions from WP3, their implications on RAMS and technical recommendations are given below. In each subsection “Necessary improvements” will be outlined. The extent to which these are already implemented varies between countries (and between the actions). The lists should thus be considered mainly as a basis for implementation. Needed specific actions can then be designed depending on the needs that exist Europe-wide and in the different networks.

Finally some notions on the nomenclature employed in this section: Firstly, the word “monitoring” in this chapter is considered a synonym to “inspection”: From the perspective of this section – and also WP3 in general – the necessary aspect is that data is obtained. How this is made is secondary for these parts of D-rail, but of course not in general. Secondly, the concept of “alarm limits” and “limit values” generally refer to (load) magnitudes that – to the best knowledge currently available to the project partners – provides the best balance between keeping the risk of derailment low, while at the same time preventing too excessive operational disruptions (that drive operations to the roughly 50–100 times less safe road operations). In this context they are “limit thresholds” following the definition in sections 3.4.1 to 3.4.3. However, these limits should not be exceeded in operations since this would pose unnecessarily high safety risks. Consequently they should also be considered as “intervention limits” following the definition in sections 3.4.1 to 3.4.3.

#### **3.4.1 Monitoring to prevent flange climbing derailment**

Regarding flange climb, the study featured Y25 bogies (the most common form of freight bogies in Europe) and track geometry characteristics have generally been considered to comply with regulations (e.g. EN 13848). The potential in modifying these regulations has not been explored although some indications can be obtained from the results in deliverable D3.2.

##### **Influential parameters**

The most influential vehicle and track parameters were identified. These can be clustered based on how they can be monitored as follows:

*Monitoring in workshop / at the design stage:*

- bump stop clearance
- primary suspension stiffness (transition between tare and laden states)
- frictional characteristics of the vehicle suspension

- chassis twist (measurement)

#### *Monitoring by track based systems*

- skew loading
- chassis twist (identification from force imbalance)

#### *Monitoring by vehicle based systems*

- track twist
- wheel–rail friction

### **Proposed limit values**

Limit values have been proposed in cooperation with the UIC funded HRMS project. These are:

Proposed limit value for skew loading

$$I_{\text{alo}} = \frac{I_a}{k \times I_{\text{lo}} + m} \leq 1 \quad (1)$$

Here  $I_a$  is the maximum axle load imbalance (maximum quotient between forces on left/right and right/left wheels for all axles of a wagon) and  $I_{\text{lo}}$  the longitudinal imbalance (largest of the quotient between sum of forces on front/rear or rear/front bogie of a wagon). Further  $k = -0.25$  and  $m = 2.05$ .

Proposed limit values for detection of chassis twist:

$$\begin{aligned} I_d &< 1.3 \quad \text{maintenance limit} \\ I_d &< 1.7 \quad \text{stop limit} \end{aligned} \quad (2)$$

Here  $I_d$  is the largest quotient between forces on diagonally mounted wheels (left wheels on front bogie / right wheels on rear bogie, or vice versa).

The proposed limits imply that individual measurements of (mean) wheel forces are required. Further (automatic) vehicle identification is required to ensure the correct distinction between vehicles in a train.

### **Monitoring accuracy**

The required accuracy relates to what can be considered as acceptable risks. As for track geometry, current requirements are defined in EN 13848. For workshop inspections, the required accuracy is highly dependent on vehicle construction and related to the vehicle classification.

As for wheel force measurements a reasonable accuracy (related to limit values assessed from the results presented in D3.2 and D3.3) would from a technical point of view be in the order of 10% on the imbalance measures  $I_a$ ,  $I_{\text{lo}}$  and  $I_d$ . However from a legal/operational perspective the acceptable accuracy may very well be lower: Stopping trains are costly, and these costs may be attributed to the infrastructure manager if the cause is due to too poor accuracy of the equipment. The approach to deal with this would be to contrast the cost of a higher accuracy towards the costs of additional disruptions due to a lower accuracy. Naturally this will lead to different results for different monitoring sites.

### Required reliability

Malfunctioning of track based monitoring equipment does not constitute a larger hazard than what was the case before the equipment was installed. Considering also that rail traffic is on the order of 100 times safer than road traffic, it makes sense from a global safety perspective to continue operations also when the monitoring equipment is malfunctioning, but to schedule maintenance as soon as possible.

### Probability of occurrence and suggested actions

The probability of limit load exceedance is highly dependent on operational circumstances. Estimation examples for British conditions are presented in D3.2. In general, the impact of imposed limit values should be evaluated “off-line” before any introduction in operational service.

The risk of derailment due to flange climbing is generally reduced with reduced speed. Thus, the least disruptive action would normally be to allow continued operation with decreased speed to the nearest depot where the problem can be mitigated. However this requires the effect of decreased speed to be established **beforehand** for the vehicle type in question. If this has not been done, the vehicle needs to be halted.

### Necessary improvements

To implement the suggested actions against derailment due to flange climbing, the following major actions are suggested:

- Suggested intervention threshold and introduction procedures are formalized, e.g. as a UIC Leaflet
- Verification of safe operation at (or below) proposed load imbalance limits at reduced speeds are considered in vehicle classification standards
- Vehicle parameters related to workshop/design validation are considered in vehicle classification and maintenance standards
- Wheel load detectors and related vehicle identification and data processing systems are constructed to be able to handle the proposed load imbalance limits

Please refer to D-Rail deliverable D7.1 for an exhaustive list of potential modifications (to infrastructure/ vehicle/ regulations/ maintenance *etc*) and means of influencing.

### 3.4.2 Monitoring to prevent wheel failures

Reducing the risk of derailment due to wheel fractures has been investigated in D-Rail work package 3 and presented in deliverables D3.2 and D3.3. The study concerns wheel failure due to (excessive) tread braking, (excessive) wheel-rail contact forces and due to combined damage from tread braking and wheel-rail contact. Wheels with “standard” S-shaped wheel discs have been compared to low stress wheels designed to sustain high thermal loading.

Note that the analysis presumes solid wheels without holes for brake-disc mounting or similar. For ringed and drilled wheels additional phenomena that render the conclusions below invalid may occur and should be investigated separately.

### Influential parameters

The most important parameters with respect to the risk of wheel fracture are (naturally) wheel design, thermal loading and mechanical loading. Regarding the thermal loading repetition of load cycles is a particular concern. Regarding mechanical loading combined vertical and lateral loading is a detrimental case. In addition the wheel disc surface finish (corrosion or scratches) will have a major influence.

For the risk of subsurface initiated wheel cracks, the main influential parameters are the normal load magnitude and contact patch size.

### Proposed limit values

Limits on vertical loads related to disc-breaks are in line with suggested limits related to the risk of rail breaks, see section 3.4.3.

Thermal loading due to drag braking leads to potentially detrimental consequences at brake cases corresponding to a power of 60 kW applied for 45 minutes. Thus, more aggressive braking should be restricted. This corresponds to about 550°C (rim bulk temperature at centre of rim), which can be reassessed to allow for temperature measurements at other positions on the wheel rim. Further, successive excessive brake cycles should be avoided.

Cracks, scratches, defects and corrosion in wheel discs should be identified and removed both at manufacturing and maintenance.

For the risk of subsurface induced rail cracks, suggested limit values on **re-occurring** loads is given from

$$FI_{\text{sub}} = \frac{F_z}{4\rho ab} < S_{e,dv} \quad (3)$$

where  $F_z$  is the normal force in the wheel–rail contact,  $a$  and  $b$  the semi-axes of the hertzian contact patch, and  $\sigma_{e,dv}$  can be taken as 220 MPa. Detrimental load cases mainly relate to corrugated rails or (periodic) out-of-round wheels where load frequencies up to some 1 kHz need to be accounted for. Evaluation according to equation (3) typically requires numerical simulations that may be used to identify unacceptable rail roughness/wheel out-of-roundness magnitudes, see Anders Ekberg, Elena Kabo, Jens C.O. Nielsen and Roger Lundén, Subsurface initiated rolling contact fatigue of railway wheels as generated by rail corrugation, *International Journal of Solids and Structures*, Volume 44, Issue 24, pp 7975-7987, <http://dx.doi.org/10.1016/j.ijsolstr.2007.05.022>.

An extension that allows to employ measured wheel–rail contact forces instead of numerically predicted contact forces and geometries is presented in Elena Kabo, Roger Enblom and Anders Ekberg: A simplified index for evaluating subsurface initiated rolling contact fatigue from field measurements, *Wear*, Volume 271, Issues 1–2, pp 120-124 <http://dx.doi.org/10.1016/j.wear.2010.10.045>.

With respect to monitoring, this will relate to an identification of either high-frequency loads (from vehicle and track based measurements) or (more commonly) monitoring of rail roughness and wheel out-of-roundness.

### Monitoring accuracy

Measurement of wheel or block temperatures for giving indications / warnings of tread brake malfunction for vehicles not equipped with brake blocks with a "thermal fuse function" requires an accuracy on the order of 50°C.

Cracks in the wheel disc grow rather slowly. Further, a critical crack length corresponds to a crack that is very long in the circumferential direction. Thus ocular inspections during maintenance should normally be sufficient to detect disc cracks.

Rail and wheel set gauge (and also wheel/rail profiles) need to be monitored to avoid contact close to the field side of the wheel tread. Precision of current methodologies (in the order of millimetres) should be sufficient.

Regarding detection of corrugated rail surfaces and out-of-round wheels the precision available with current technologies should be sufficient. Note that these are evolving problems, which means that measurements need to be carried out sufficiently often. Please refer to section 3.4.3 on rail breaks for needed accuracies regarding wheel/rail impact forces.

### **Required reliability**

Neither of the proposed monitoring activities will reduce safety levels to below a non-monitored state if the monitoring equipment is non-operational. Thus from a global safety perspective operations should commence even if the monitoring equipment is non-functioning. This being said, (long term) disruptions of the monitoring equipment will decrease safety levels from the monitored state, which means the monitoring equipment should be mitigated sufficiently fast.

Please refer to section 3.4.3 on rail breaks regarding wheel/rail impact forces.

### **Probability of occurrence and suggested actions**

Occurrence is highly related to local operational conditions of both vehicles and track. In addition climate (e.g. frozen brakes) may have an influence. Wheels with excessive temperatures should be arrested and the root cause mitigated. The train can then commence. If required this may (initially) be at a lower speed.

Corrugated rails and out-of-round wheels should be mitigated (typically by grinding and turning, respectively). Please refer to section 3.4.3 on rail breaks regarding wheel/rail impact forces.

### **Necessary improvements**

Please refer to section 3.4.3 on rail breaks regarding improvements in impact load detection, and to D-Rail deliverable D7.1 for an exhaustive list of potential modifications (to infrastructure/ vehicle/ regulations/ maintenance etc.) and means of influencing.

## **3.4.3 Monitoring to prevent rail breaks**

Reducing the risk of derailment due to rail breaks has been investigated in D-Rail work package 3 and presented in deliverables D3.2 and D3.3. The study concerns fracture due to a combination of high magnitude impact loads and the presence of pre-existing cracks in the rail head or rail foot.

### **Influential parameters**

The most influential parameters are the magnitude and time evolution of the contact force, track stiffness (including hanging sleepers), vehicle configuration and speed, size of cracks in rail head and foot, and rail temperature deviation from the stress free temperature of the rail.

### **Proposed limit values**

Limit values have been proposed in cooperation with the UIC funded HRMS project. These are:

- Limit values of wheel/rail (peak) contact forces: 350 kN decreased at a rail temperature 20°C below the stress free temperature down to 250 kN for a rail temperature 40 °C below the stress free temperature.
- Corresponding crack sizes that will cause fracture are in the order of 25 mm for a rail head crack and 5 mm for a rail foot crack. Cracks must be removed before they reach this critical size. Approaches and algorithms to specify inspection intervals towards this end are presented in deliverable report D3.2.
- Limit values account for the influence of hanging sleepers and not too soft ballast stiffness (presumed to be  $\geq 30$  MN/m per half sleeper). Softer ballast stiffness may require soil reinforcement or special measures to avoid additional influence e.g. from hanging sleepers, see D3.2 for details of the influence.

An “off-line” analysis should be carried out before introduction to assess and mitigate any adverse effects of the proposed limit values.

### **Monitoring accuracy**

Wheel/rail contact forces need, from a technical perspective, be measured by an accuracy of some 10 kN. However from a legal/operational perspective the acceptable accuracy may very well be lower as discussed in section 3.4.1 on derailment related to rail climbing.

Defect size measurement accuracy is in the order of one millimetre for initial, and in the order of 5 mm and 2 mm for large head and rail foot cracks, respectively.

As for track stiffness, the needed accuracy is on the order of 10 MN/m per half sleeper. More important than the absolute value is a reliable detection of stiffness variations such as hanging sleepers and transition zones.

Temperature measurement accuracies – here implying prognoses of the coldest temperature in-between two detectors at a time horizon of about a week – should be in the order of  $\pm 5^\circ\text{C}$ .

### **Required reliability**

Non-functioning monitoring does not decrease the safety as compared to a non-monitored state. A reliable detection of cracks and high impact wheels is however important since the risk of adverse consequences is very high especially if these continue to be undetected over a longer period of time (in the order of weeks/months for cracks, and hours/days for high impact wheels).

### **Probability of occurrence and suggested actions**

The probability of rail breaks is very dependent on operational and seasonal conditions, and also maintenance status.

Wagons with wheels that exceed allowed impact load magnitudes should not be allowed to continue operations in the current state. This means they either have to be arrested and mitigated, or allowed to continue in a state that decreases the impact load, e.g. at a reduced

speed. The latter requires that the reduction in impact load magnitude has been verified either beforehand (e.g. by simulations) or in connection to the continued operation.

### **Necessary improvements**

To implement the suggested actions against derailment due to rail breaks, the following major actions are suggested:

- Suggested alarm limits and introduction procedures are formalized, e.g. as a UIC Leaflet
- Prediction of crack growth is formalized, calibrated and integrated with wheel load detectors to establish inspection intervals regarding rail cracks.
- Verification of safe operation at (or below) proposed impact load limits at reduced speeds are considered in vehicle classification or through measurements at continued operation.
- Formalised procedure of temperature prognosis and pertinent establishment of alarm limits at cold climate (more than 20°C below stress free temperature) is introduced.
- Measurements of track stiffness and identification of soft sections, hanging sleepers and transition zones are formalized.

Please refer to D-Rail deliverable D7.1 for an exhaustive list of potential modifications (to infrastructure/ vehicle/ regulations/ maintenance *etc*) and means of influencing.

## 4 Additional topics

### 4.1 Combined technologies targeting different type of derailment causes

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 the benefits of interventions per cause, even though the same interventions could be used for different types of derailments. However, this section discusses the topic of the combined effect of interventions.

Some single cause derailments have a clearly identified cause, e.g. broken wheel or journal rupture due to bearing damage, etc. For combined cause derailments it is not always easy to clearly identify their causes. Many parameters could be identified, all within tolerance levels (sometimes at the limit) but it is the combination that leads to derailment. The probability for a vehicle to derail is not 0 if all the parameters are at the limit.

While most railroads and national agencies tend to report derailments as due to a single cause or to a primary and additional secondary causes, in actuality many derailments are combined-cause derailments, where the combination of several contributing factors are necessary for the derailment to occur. Thus, if one of these contributing causes was not present, the derailment would not have occurred. Thus, while sometimes reported as a secondary cause, or in many cases not included as a cause, these contributing causes are critical to the occurrence of the derailment and to its prevention.

Like previous investigations, D-RAIL focuses mainly on single cause derailments and their prevention. After a derailment occurs, the analysis might indicate that track geometry was at cause – however, the same track was used by dozens of other trains before the derailment occurred. Similarly, a train might run for hundreds of kilometres in a non-compliant condition before it derails at a given point. Operational experience suggests that there is always a combination of effects at play and the operational regulations already contain provisions that reflect this knowledge (as an example: Swiss Train Operating Regulations FDV R300.5, Art. 1.3.5).

Since no systematic examination of combined failure modes exists so far, we turned to some accident investigation reports that give indications on the existence of these combined causes:

- Final report 2013030702 of the Swiss Accident Investigation Board on the derailment of a wagon on 7.3.2013: the report concluded after extensive analyses and simulations that a combination of three negative factors was at cause: the coupling was too tight (but within limits), the vehicle was lighter (the waggon lacked internal components since it was transferred between construction plants) and some track parameters were less than ideal (but within limits) on a double slip switch.
- Investigation report 60 – 60uu2012-09/00205 of the Investigation central of the federal railway investigation board (Germany) on the derailments on 24.7.2012, 29.9.2012 and 9.10.2012: all trains derailed on switch 227 of Stuttgart Mainstation. In all cases, the longest and heaviest wagon (restaurant car) derailed despite different running positions. The employed track has one

of the tightest permitted radii on the DB network, but is within parameters. Hundreds of trains employed this route during the three months where these derailments occurred. It was found from extensive simulations that the derailed trains accelerated faster than other trains, but within allowed limits.

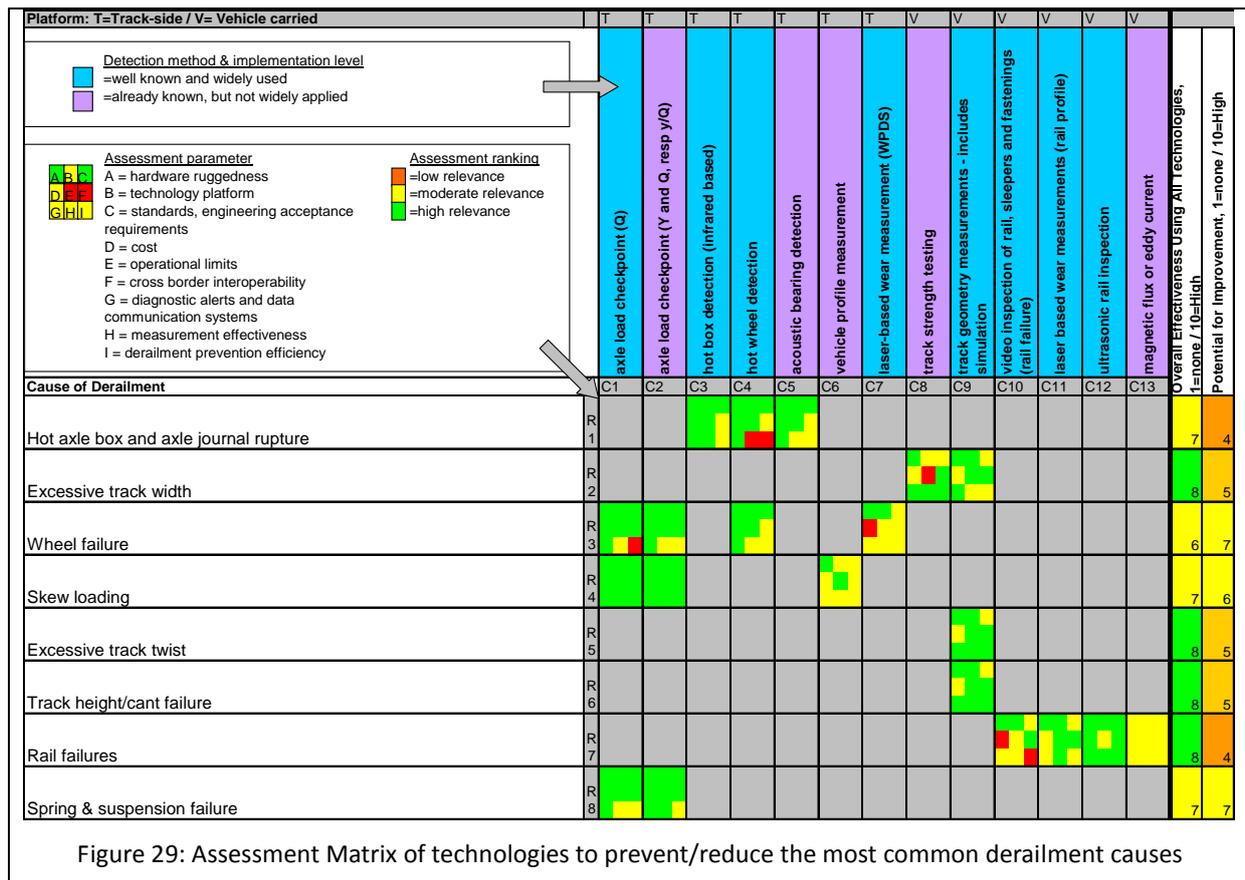
Trains and infrastructure were both within parameters, but less than perfect, and double slip switches present additional difficulties in the area of lateral acceleration and dynamic forces. It shows that today's parameters are not sufficiently strict to prevent derailments in all cases, but that approaching limits on both sides of the wheel-track interaction may lead to derailments. This is of particular concern, as IM's and RU's are nowadays separate entities that optimize their maintenance and operations independently, which precludes compensating actions on one of the sides.

The reports show that such occurrences are not theoretical in nature. However, very extensive investigations and simulations were necessary to reach this conclusion. Both cases were heavy-damage accidents (about 500 kCHF and 2 M€ respectively), so that an independent accident investigation was mandatory and a single primary cause could not readily be identified. It can be suspected that this combination would not have been examined if one of the parameters had been below tolerance, which leads to the possible conclusion that in other accidents where a single cause was identified, the train would still have derailed if the single cause had been slightly within tolerance.

Additionally based on the accident investigation reports mentioned above, some conclusions were found which cannot be structured in an overall manner, but that seem to be important enough to be documented to make sure that they are considered in this work package. These practical conclusions driven in a qualitative way are based on the assessment matrix (of WP4) by considering what is possible to be combined technically, since the assessment matrix contains relevant information reg. measurement effectiveness, derailment prevention efficiency and the potential improvement of the techniques.

The assessment matrix developed in WP3 and WP4 presents methods to prevent or reduce the most common derailment causes and risks respectively. Ranking of measurement effectiveness and derailment prevention efficiency of each method has been made in a next step which is presented in Figure 29.

When considering measurement effectiveness and derailment prevention efficiency of the proposed monitoring systems, the results of WP7 analyses corresponds to the conclusions driven by WP4 based on the assessment matrix as presented in the figure below. For instance one result is that ALC seem to be beneficial for checking vehicle performance and parameters related to derailment. These systems cover wheel flats, skew loading, suspension failures, high lateral forces and large angle of attack.



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 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 combining 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.

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 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.

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 measurement sites that are technically feasible and generate benefits for the sector.

However, some limits to further combinations are to be noted. WTMS have often specific installation requirements (space requirements, requirements on track geometry) that precluded further combining 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, so 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.

## 5 Conclusions

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 going to be monitored.

It can be stated, that for the most important derailment risks, technical solutions are readily available today for detection of abnormal situations. They provide good value for the investment, are able to tackle the most important influencing parameters with sufficient precision and are shown to be able to provide enormous benefits where derailment risks are concerned. The impact of the existing widely used monitoring systems (WTMS) on RAMS of the track system indicates good Reliability and Safety (RAMS) performance.

Section 2.4 outlines 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.

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 reasonable under the usual ALARP principle – or any other standard – for wide scale implementation. 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.

Some important conclusions can be drawn:

- 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.

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.

In section 3.6 the input from the D-Rail work package WP3 was summarized with focus on implications on RAMS. For prevention of derailment caused by flange climbing, rail breaks and wheel breaks the most influential parameters were identified. These are parameters that need to be controlled in operations.

Suggested limit values, especially on wheel forces are outlined. These have been adopted by the UIC-led HRMS project and will be suggested as a basis for a harmonized framework of limit loads. Note that these particular limit values of wheel force imbalances (relating to load imbalances, skewed frame etc.) were identified based on currently accepted track geometry limits.

Required monitoring accuracies related to limit values are then outlined. Here it can be noted that the required accuracy from a technical point of view (basically to ensure that the uncertainties from measurements are in the order of other uncertainties) may be less than what is required from a juridical perspective (i.e. if the measurements are used to motivate costly procedures, such as stopping trains).

As for the reliability of inspections it is noted that non-functioning equipment in general does not pose a larger hazard than what was the case before the equipment was installed. Since rail traffic is in the order of 100 times safer than road traffic, it then makes sense from a global safety perspective to continue operations also when the monitoring equipment is non-functioning, but to schedule maintenance as soon as possible.

The probability of limit load exceedance is then discussed and in general found to be highly dependent on operational circumstances. As for mitigating actions, stopping trains is always an option, but may be sub-optimal from a global safety and risk perspective (see above). Other mitigating options, such as decreasing speed, may be possible. The effect of such actions needs however to be assured before such actions are approved (or assured during the entire continued operation).

When considering technologies targeting different type of derailment causes, discussed in section 4, some limits to further combinations are to be noted. WTMS have often specific installation requirements (space requirements, requirements on track geometry) that precluded further combining 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, so 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.

Generally, the focus of the D-Rail project on freight only is considered as another constraint, i.e. that the DRAIL approach differs from established practices in European railways as it

limits its scope to derailments and freight only, while all other approaches are concerned with railway safety, of which freight derailments are only a subset. This explains why already more than 1000 devices are in use today, as prevention of derailments on fast or high speed lines and concerning passenger trains have much higher derailment costs associated. One problem was to separate the risk data from cargo related events, because these are not separated from the rest like passenger traffic (in fact the events and factors of the overall traffic contribute to risk and should be the base for risk analysis).

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 you get better condition monitoring and on reducing Maintenance, less Maintenance of rail tracks and equipment, decreased fuel costs, increased lifetime of rail tracks etc.

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 have direct cost savings.

## 6 Recommendations

Based on the outcome of the D7.2, it is recommended that in order to have more robust results, more data concerning failure of monitoring systems (e.g. HABD) as well as maintenance needs to be collected. 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. In addition, the proposed RAMS framework needs to be implemented in different systems and operational environments to ensure its applicability and effectiveness for a number of different scenarios.

Although the results show that the maintenance strategy for the HABD in one case study is well developed, however, RAMS property of HABD's in other installation sites are needed to be evaluated to ensure that they meet safety targets to reduce derailment at system level as well as being cost effective.

As an example, reliability analysis of some installation sites indicates an aging process meaning that their reliability performances are degrading even after a maintenance action. Therefore further analysis is recommended for other installation sites to ensure that the RAMS properties of HABD's at other installation sites fulfill the RAMS requirements of railway system as a whole. By reducing the impact of freight derailment on railway users and operation the availability of the track should be increased in order to achieve less track disruptions due to derailment and its consequences. However, the availability of the track depends on the availability and the reliability of the detection measurements, as presented in section 3.3.2. It is recommended to extend the RAMS analysis through simulation and to account for the impact of the monitoring systems on RAMS of the whole railway system. This analysis could not be done in this study due to lack of data, time and resources.

Depending on the significance which is given to the WTMS by each IM the RAMS characteristics of WTMS needs to be assigned. In either case the meantime to repair (MTTR) needs to be reduced to an optimum level.

The risk assessments outlined in section 3.2.3 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, 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.

Regarding the integration and migration of monitoring techniques into a common European solution several aspects need to be considered. The business cases should have a systematic approach taking into account different needs from different requirement perspectives, to consider the framework of existing regulations and national implementations, specific boundary conditions (meteorological and topological conditions), different nationally driven strategies, different rules and safety philosophies etc. However, the cross-border networking and integration of the proposed systems into a common European solution should have the potential to enhance safety and route availability for a minimum maintenance cost.

Generally, when setting out a wide scope of the tasks, in particular in terms of RAMS and LCC assessment, such as is the case with WP7 of D-Rail, it is essential that the provision of the relevant key input data is ensured to perform the required analyses to a high degree of quality. Likewise, time and resources should be calculated to be sufficient for the achievement of the set goals for the project.

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Elena Kabo, Roger Enblom and Anders Ekberg: A simplified index for evaluating subsurface initiated rolling contact fatigue from field measurements, Wear, Volume 271, Issues 1–2, pp 120-124

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Final report 2013030702 of the Swiss Accident Investigation Board on the derailment of a wagon on 7.3.2013

Investigation report 60 – 60uu2012-09/00205 of the Investigation central of the federal railway investigation board (Germany) on the derailments on 24.7.2012, 29.9.2012 and 9.10.2012

Dr. Allan M. Zarembski, Randolph Resor, Pradeep Patel, ASME, ZETA-TECH, Economics of Wayside Inspection Systems, 2003

# Appendices

## Appendix 1: RAMS and LCC template

Please fill out the "system sheet" first. The names of the systems / modules or technologies are linked to the LCC and RAMS sheet  
Please include new lines if necessary using "insert" button in "start menu"

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Explanation of LCC relevant data (LCC means: all product related costs from the first phase/development to the last one/disposal of a product's life cycle)	
Parameter	Description
Quality of data	Please indicate the quality of data like verified or estimated <b>Please take care of high quality of data</b> In the case of unknown data a sensitivity analysis might indicate the economic impact of the parameter(s)
System description and definition of the boundary conditions	Detailed description of the boundary conditions, what is defined within the boundary conditions and what is not like: design/configuration (type or monitoring system, combined technology?, prototype?, wider use?, quantity, nr. of sensors? etc.), location of use, alignment (curves, special track geometry), track category where the system is used (track load, high or low density track, traffic possession time for maintenance), special circumstances under which the system is used (operational, technical) etc.
Life time [year]	Mean technical life time of system in years, after the life time replacement is necessary
Investment cost [€]	Total cost for investment in a new system/modul/technology. This includes all costs for ready to use, i. e. costs referred to planning and preparation, material, transport, installation (time, construction procedure), access to the site etc.
Re-Investment cost[€]	Cost necessary for Re-installation or Renewal of system or parts of system (sub-system) after the end of the life time
Disposal cost[€]	Cost needed for disposal / recycling ...
Maintenance activity	Short description of maintenance activity
Maintenance interval [year, months]	Interval between two specific maintenance activities, different maintenance activities may have different intervals
Maintenance cost [€]	Cost for maintenance activit in case of preventive or corrective maintenance
Inspection activity	Short description of inspection activity
Inspection interval [year, months]	Interval between two specific inspection activities, different inspection activities may have different intervals
Inspection cost[€]	Cost for maintenance activit in case of preventive or corrective maintenance
Operation cost [€]	Cost per year necessary for operation, labour costs should be given in hour
Cost on operating line [€]	Cost for operating complications that arise from track closures for installation or maintenance work
Non-Availability cost [€]	Cost arised due to malfunction, train delay or less serviceability in terms of planned and unplanned maintenance activity.
Migration cost [€]	Cost for Migration considering the whole migration process management starting from installation to operation till implementation of the new system.
Design & system support cost [€]	Cost for Verification, Monitoring and Support
Service testing and Certification cost [€]	Cost for the needed work to ensure system integration and acceptance, i. e. the system can be brought safely into serviceable order in line with the design intent/requirements and contractual obligations.
Public & Environment Economics [€]	Cost related to public and environment impact
Explanation of RAMS relevant data (RAMS means: the impact of monitoring system on the Reliability, Availability, Maintainability and Safety of the railway system)	
Parameter	Description
Quality of data	Please indicate the quality of data like verified or estimated <b>Please take care of high quality of data</b>
MTBF [days]	Mean time between failure given in days. Also indicate the environmental, operational/functional strains, failure criteria and period of use of the system.
MTTR [days] or [hours]	The average time that a device will take to recover from any failure. It's the ratio of total corrective maintenance time divided by the total number of corrective maintenance.
Failure Rate [hour] or [1/t]	Failure Rate is the frequency with which an engineered system or component fails, expressed for example in failures per hour.
Technical Availability A [%]	Availability is the proportion of time a system is in a functioning condition. The Availability depends on the technical performance of the system/component and the Repair rate and both parameters influence also the Life Cycle Costs of the system. $A = \text{Uptime} / (\text{Uptime} + \text{Downtime})$ Downtime means the system does not work/ is non-operational due to maintenance or unplanned event; Uptime is the time that a system is operational and works error-free.
Safety Integrity Level (SIL)	Safety integrity level of a system (0) 1 to 4 according to the EN 50129 (Railway applications - Safety related electronic systems for signalling). The standard [EN 50129] defines five Safety Integrity Levels (SIL) with SIL 0 being non-safety related. The required Safety Integrity Level shall be decided on the basis of the level of risks identified in hazard analysis or elsewhere. SIL shall be defined at a functional level and functional module level. Similarly, all Systems, Sub-Systems and Components shall have a Safety Integrity Level defined. The design, implementation techniques and measures shall be defined depending on the SIL of the function to be performed by each individual System, Sub-System or Component.

DR-D7.2-F2-RAMS-analysis and recommendation (technical view)

General					
No	System / module / technology	Type wayside / vehicle based	Description of the technique	Direct measured values	Implementation Level
1	Hot Box Detection System	Wayside	Equipment, which measures temperature with infrared sensors.	temperature of bearing	well known and widely used
2	Hot Wheel Detection System	Wayside	Equipment, which measures temperature with infrared sensors. Configuration of DB system: Hot box and brake detection system (combination of hot box and hot wheel detection)	temperature of hot box housing and brake/wheel discs	well known and widely used
3	Track Geometry Measurement System	Vehicle based	Optical, No-contact and inertial track geometry measurement system, which is able to provide automatically the main geometric parameters of the track.	Track gauge, cross level/cant, twist, alignment, longitudinal level	well known and widely used
4	Axle Load Checkpoint (ALC)	Wayside	Track based monitoring system which measures the dynamic wheel rail forces over a distance of 6 sleeper spans. ALC (Q): track based measurement system for measuring the vertical wheel/rail force Q of each wheel or each wagon passing over the checkpoint. ALC (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.	dynamic wheel rail force ALC can reveal overloading (or unbalanced loading) of vehicles and out-of-round wheels. Checkpoints placed on curves can measure horizontal & vertical track forces.	ALC (Q): well known and widely used ALC (Y and Q, resp. Y/Q): already known, but not widely applied
5	Wheel Profile and Diameter system (WPD5)	Wayside	No-contact real-time wheel measurement system, which is able to perform in service automatic optical measurement of the wheel sets. The system acquires all major wheel parameters. System's analysis and reporting software provides wheel performance trendin	Flange height and width, Rim thickness, Flange gradient, Hollow tread, Wheel diameter, Wheel diameters differences, Back-to-back distance, Wheel selected quotes, Full wheel profile reconstruction, Wheel inclination, Equivalent concity	already known, but not widely applied
6	Rail profile measurement system (Laser based wear measurement)	Vehicle based	Optical, No-contact Laser triangulation. Provides accurate and immediate report on the profile and wear condition of the rail whilst traveling at track speeds. Can be used for grinding checking or for maintenance application. By means of the analysis soft	Full rail profile, rail wear condition (vertical, lateral and 45°), Head loss, rail incination, lamination, sidecut.	well known and widely used
7	Video Rail Inspection	Vehicle based	There are 3 types of this system: THIS, V-Cube and TSIS. Type TSIS: Particularily designed in order to detect "head check" defect type, and to provide information on defect position and dimension. Capable of finding these gage corner cracking in earliest stage, when rail grinding is still a feasible option. Type V-Cube: Vision system package can be composed of: Track Surface Inspection System (TSIS), Track Surface Measuring System (TSMG). These 2 systems can be integrated in one small, easy to mount platform, which enhances defect detection, facilitates maintenance, and reduce setup time. Type TSIS: Capable of detecting various problems along the line, from defects on the top of the rail to inconsistencies in the ballast, fasteners or sleepers. Able to classify defects into customizable classes.	THIS: Head Check Crack dimension, angle, length and frequency. V-Cube: Depends on the package (see more precise parameters in TSIS, TSMG). Classify defects according to their properties and/or their position in the rail structure. TSIS: Surface defects detection: ballst prints, wheel burns, Abrasion from sliding, crushed head, shelling, cracks on the rail surface > 1 mm. Qualitative rail corrugation, Position of detected switch hearts and intersection.	already known, but not widely applied
8	Ultrasonic Rail Inspection	Vehicle based	Vehicle based (on-board) 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. Field of application: Inspection of rail. Main comp.: Ultrasonic transducers, recording equipment, analysis software, experience operator.	The technique can give accurate data about the location, size and type/shape of the detected defects. A huge advantage of this technique is that it can detect defect inside the rail, which can not be detected visually like: internal rail flaws and cracks, split heads, head and web separation, transverse fissures	well known and widely used
9	Acoustic Bearing Detection	Wayside	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.	bearing defects and wheel impact fault	already known, but not widely applied
10	Vehicle Profile Measurement	Wayside	These track side measurement systems aim at checking the profile of the rolling stock 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.	width, height, and angle of rotation of the wagon (profile of the rolling stock)	already known, but not widely applied
11	Track Strength Testing	Vehicle based	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).	it measures the gauge widening of the track; system integrity check	already known, but not widely applied
12	Magnetic Flux / Eddy Current Rail Inspection	Vehicle based	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. Surface defects are nowadays detected by magnetic flux (eddy current) methods. Sensors are placed very close to the rail head surface and they generate a magnetic oscillating field onto the rail. Cracks on the rail surface will affect the energy loss of that field which is detected by the sensor.	track and rail defects (cracks)	well known and widely used

DR-D7.2-F2-RAMS-analysis and recommendation (technical view)

Description of the used System								
No	System / module / technology	Type wayside / vehicle based	Short description of the used system in terms of: prototype or widely used?, design/configuration, how many in use?, number of installation sites, location at network, interfaces with other systems, distinction between measuring system and the associated vehicle etc.)	Detailed description of the boundary conditions under which the technology/system is used (switch/crossing, curves, track category, special boundaries...)	Quality of measuring [high, moderate, low]	What are the boundary conditions that affect the Availability, Reliability and Maintainability of the system most? and how does it affect?	What are the boundary conditions that affect the influence the cost level of the system most? and how does it affect?	Does the system has any redundancy? If there is no redundancy, what are or could be the consequences in case of systems failure?
1	Hot Box Detection System	Wayside						
2	Hot Wheel Detection System	Wayside						
3	Track Geometry Measurement System	Vehicle based						
4	Axle Load Checkpoint (ALC)	Wayside						
5	Wheel Profile and Diameter system (WPDS)	Wayside						
6	Rail profile measurement system (Laser based wear measurement)	Vehicle based						
7	Video Rail Inspection	Vehicle based						
8	Ultrasonic Rail Inspection	Vehicle based						
9	Acoustic Bearing Detection	Wayside						
10	Vehicle Profile Measurement	Wayside						
11	Track Strength Testing	Vehicle based						
12	Magnetic Flux / Eddy Current Rail Inspection	Vehicle based						

RAMS relevant parameters									
No	System / module / technology	Quality of RAMS data	Reliability parameters			Technical Availability		Maintainability	Safety Integrity Level
		verified / estimated	MTBF [d]	Failure rate [1/t]	Reliability of detection (e. g. time for detection of failure) [%] or [d] or [hour]	Availability (system itself) [%]	Impact on Availability of the entire system	MTTR [hour]	SIL (0 to 4)
1	Hot Box Detection System	verified (SBB)							
2	Hot Wheel Detection System	verified (DB)							
3	Track Geometry Measurement System	estimated							
3a	Vehicle for the provision of Track Geometry Measurement System (RAILAB)	verified (DB)							
4	Axle Load Checkpoint (ALC)	verified (DB)							
	Axle Load Checkpoint (ALC)	verified (SBB)							
5	Wheel Profile and Diameter system (WPDS)	estimated							
6	Rail profile measurement system (Laser based wear measurement)								
6a	Vehicle for the provision of laser based wear measurement: Rail profile measuring system	verified (DB)							
7	Video Rail Inspection								
8	Ultrasonic Rail Inspection								
9	Acoustic Bearing Detection								
10	Vehicle Profile Measurement								
11	Track Strength Testing								
12	Magnetic Flux / Eddy Current Rail Inspection								

c														
No	System / module / technology	Quality of LCC data	Life time [a]	Investment cost [€]	Re-investment cost [€]	Disposal cost [€]	Maintenance activity description	Maintenance interval [a]	Maintenance cost [€]		Inspection activity description	Inspection interval [a]	Inspection costs [€]	Operation Cost [€/a] Energy / Labour
		verified / estimated							Preventive	Corrective				
1	Hot Box Detection System	verified (SBB)												n.a.
2	Hot Wheel Detection System	verified (DB)												
3	Track Geometry Measurement System	estimated												
3a	Vehicle for Track Geometry Measurement System (RAILAB)	verified (DB)												
4	Axle Load Checkpoint (ALC)	verified (DB)												
	Axle Load Checkpoint (ALC)	Verified (SBB)												n.a.
5	Wheel Profile and Diameter system (WPDS)	estimated												
6	Rail profile measurement system (Laser based wear measurement)	verified (DB)												
6a	Vehicle for laser based wear measurement: Rail profile measuring system	verified (DB)												
7	Video Rail Inspection	estimated												
8	Ultrasonic Rail Inspection	estimated												
9	Acoustic Bearing Detection	estimated												
10	Vehicle Profile Measurement													
11	Track Strength Testing													
12	Magnetic Flux / Eddy Current Rail Inspection													

## Appendix 2: Risk assessment data sheets

### Risk Assessment Scenario 1 High

SCENARIO 1: HIGH Assumed "high" cost / "high" level risk reduction option; Risk and accident costs assumed to increase at same rate as increase in traffic (1.53%).																
RISK ASSESSMENT: ESTIMATED RISK AND COSTS																
DERAILMENT CAUSES			RISK FIGURES					SYSTEM ASSUMPTIONS		COSTS						
	Monitoring System	derailment cause	EU27 Frequency (events /year)	EU27 Risk (FWI/year)	Assumed % reduction in derailments due to svstem	EU27 Reduction in frequency (events/year)	EU27 Reduction in risk (FWI/year)	Assumed number of additional units (cf.2014)	Lifetime (years)	Investment cost (€) per unit	Reinvestment cost (€) per unit	Annual maintenance costs per unit	TOTAL Investment cost (€)	TOTAL Reinvestment cost (€)	TOTAL Annual maintenance costs	Avoided Costs per cause of derailment (€)
	(source)		GB SRM v7.2 scaled for EU27	GB SRM v7.2 scaled for EU27	D-Rail WP5	GB SRM v7.2 scaled for EU27	GB SRM v7.2 scaled for EU27	D-Rail WP5	D-Rail D2.3 Table 3.4	D-Rail D2.3 Table 3.4	D-Rail D2.3 Table 3.4	D-Rail D2.3 Table 3.4	D-Rail D2.3 Table 3.4	D-Rail D2.3 Table 3.4	D-Rail D2.3 Table 3.4	D-Rail D2.3 Table 3.5
1	Hot axle box and hot wheel detection	Hot axle box and axle journal rupture	4,60	0,11	91,00%	4,1827	0,1039	790	15	229.600 €	147.600 €	7.380 €	181.384.000 €	116.604.000 €	5.830.200 €	1.282.575 €
2	Axle load checkpoints	Wheel failure	3,02	0,07	98,00%	2,9635	0,0730									1.879.471 €
		Skew loading	3,28	0,08	98,00%	3,2164	0,0809									833.144 €
		Spring & suspension failure	4,95	0,12	98,00%	4,8526	0,1216									1.865.570 €
		subtotals	11,26	0,28		11,0325	0,2755	300	10	110.000 €	73.000 €	13.000 €	33.000.000 €	21.900.000 €	3.900.000 €	4.578.185 €
3	Track geometry measurement systems	Excessive track width	15,62	0,24	60,00%	9,3706	0,1438									474.966 €
		Excessive track twist	12,71	0,21	60,00%	7,6239	0,1275									552.627 €
		Track height/cant failure	5,82	0,12	60,00%	3,4897	0,0718									281.922 €
		subtotals	34,14	0,57		20,4842	0,3431	20	10	950.000 €	570.000 €	76.000 €	19.000.000 €	11.400.000 €	1.520.000 €	1.309.515 €

**RISK ASSESSMENT INPUT VALUES**

		1 Hot axle box and hot wheel detection				2 Axle load checkpoints				3 Track geometry measurement systems			
		safety benefit	avoided cost of accidents	capital costs	ongoing costs	safety benefit	avoided cost of accidents	capital costs	ongoing costs	safety benefit	avoided cost of accidents	capital costs	ongoing costs
		FWI	cost per year	investment & reinvestment costs	maintenance costs	FWI	cost per year	investment & reinvestment costs	maintenance costs	FWI	cost per year	investment & reinvestment costs	maintenance costs
Yr 1	2021	0,1039	1.282.575 €	181.384.000 €	5.830.200 €	0,2755	4.578.185 €	33.000.000 €	3.900.000 €	0,3431	1.309.515 €	19.000.000 €	1.520.000 €
Yr 2	2022	0,1055	1.302.198 €	0 €	5.830.200 €	0,2797	4.648.231 €	0 €	3.900.000 €	0,3484	1.329.551 €	0 €	1.520.000 €
Yr 3	2023	0,1071	1.322.122 €	0 €	5.830.200 €	0,2840	4.719.349 €	0 €	3.900.000 €	0,3537	1.349.893 €	0 €	1.520.000 €
Yr 4	2024	0,1087	1.342.351 €	0 €	5.830.200 €	0,2883	4.791.555 €	0 €	3.900.000 €	0,3591	1.370.546 €	0 €	1.520.000 €
Yr 5	2025	0,1104	1.362.888 €	0 €	5.830.200 €	0,2927	4.864.866 €	0 €	3.900.000 €	0,3646	1.391.515 €	0 €	1.520.000 €
Yr 6	2026	0,1121	1.383.741 €	0 €	5.830.200 €	0,2972	4.939.298 €	0 €	3.900.000 €	0,3702	1.412.806 €	0 €	1.520.000 €
Yr 7	2027	0,1138	1.404.912 €	0 €	5.830.200 €	0,3017	5.014.870 €	0 €	3.900.000 €	0,3759	1.434.422 €	0 €	1.520.000 €
Yr 8	2028	0,1155	1.426.407 €	0 €	5.830.200 €	0,3064	5.091.597 €	0 €	3.900.000 €	0,3816	1.456.368 €	0 €	1.520.000 €
Yr 9	2029	0,1173	1.448.231 €	0 €	5.830.200 €	0,3110	5.169.499 €	0 €	3.900.000 €	0,3875	1.478.651 €	0 €	1.520.000 €
Yr 10	2030	0,1191	1.470.389 €	0 €	5.830.200 €	0,3158	5.248.592 €	21.900.000 €	3.900.000 €	0,3934	1.501.274 €	11.400.000 €	1.520.000 €
Yr 11	2031	0,1209	1.492.886 €	0 €	5.830.200 €	0,3206	5.328.895 €	0 €	3.900.000 €	0,3994	1.524.243 €	0 €	1.520.000 €
Yr 12	2032	0,1228	1.515.727 €	0 €	5.830.200 €	0,3255	5.410.428 €	0 €	3.900.000 €	0,4055	1.547.564 €	0 €	1.520.000 €
Yr 13	2033	0,1247	1.538.918 €	0 €	5.830.200 €	0,3305	5.493.207 €	0 €	3.900.000 €	0,4117	1.571.242 €	0 €	1.520.000 €
Yr 14	2034	0,1266	1.562.463 €	0 €	5.830.200 €	0,3356	5.577.253 €	0 €	3.900.000 €	0,4180	1.595.282 €	0 €	1.520.000 €
Yr 15	2035	0,1285	1.586.369 €	116.604.000 €	5.830.200 €	0,3407	5.662.585 €	0 €	3.900.000 €	0,4244	1.619.690 €	0 €	1.520.000 €
Yr 16	2036	0,1305	1.610.640 €	0 €	5.830.200 €	0,3459	5.749.223 €	0 €	3.900.000 €	0,4309	1.644.471 €	0 €	1.520.000 €
Yr 17	2037	0,1325	1.635.283 €	0 €	5.830.200 €	0,3512	5.837.186 €	0 €	3.900.000 €	0,4375	1.669.632 €	0 €	1.520.000 €
Yr 18	2038	0,1345	1.660.303 €	0 €	5.830.200 €	0,3566	5.926.495 €	0 €	3.900.000 €	0,4442	1.695.177 €	0 €	1.520.000 €
Yr 19	2039	0,1365	1.685.706 €	0 €	5.830.200 €	0,3620	6.017.170 €	0 €	3.900.000 €	0,4510	1.721.113 €	0 €	1.520.000 €
Yr 20	2040	0,1386	1.711.497 €	0 €	5.830.200 €	0,3676	6.109.233 €	21.900.000 €	3.900.000 €	0,4579	1.747.446 €	11.400.000 €	1.520.000 €
Yr 21	2041	0,1408	1.737.683 €	0 €	5.830.200 €	0,3732	6.202.704 €	0 €	3.900.000 €	0,4649	1.774.182 €	0 €	1.520.000 €
Yr 22	2042	0,1429	1.764.269 €	0 €	5.830.200 €	0,3789	6.297.605 €	0 €	3.900.000 €	0,4720	1.801.327 €	0 €	1.520.000 €
Yr 23	2043	0,1451	1.791.263 €	0 €	5.830.200 €	0,3847	6.393.959 €	0 €	3.900.000 €	0,4792	1.828.887 €	0 €	1.520.000 €
Yr 24	2044	0,1473	1.818.669 €	0 €	5.830.200 €	0,3906	6.491.786 €	0 €	3.900.000 €	0,4866	1.856.869 €	0 €	1.520.000 €
Yr 25	2045	0,1496	1.846.495 €	0 €	5.830.200 €	0,3966	6.591.111 €	0 €	3.900.000 €	0,4940	1.885.280 €	0 €	1.520.000 €
Yr 26	2046	0,1519	1.874.746 €	0 €	5.830.200 €	0,4026	6.691.955 €	0 €	3.900.000 €	0,5016	1.914.124 €	0 €	1.520.000 €
Yr 27	2047	0,1542	1.903.430 €	0 €	5.830.200 €	0,4088	6.794.342 €	0 €	3.900.000 €	0,5092	1.943.410 €	0 €	1.520.000 €
Yr 28	2048	0,1565	1.932.552 €	0 €	5.830.200 €	0,4151	6.898.295 €	0 €	3.900.000 €	0,5170	1.973.145 €	0 €	1.520.000 €
Yr 29	2049	0,1589	1.962.120 €	0 €	5.830.200 €	0,4214	7.003.839 €	0 €	3.900.000 €	0,5249	2.003.334 €	0 €	1.520.000 €
Yr 30	2050	0,1614	1.992.141 €	0 €	5.830.200 €	0,4279	7.110.998 €	0 €	3.900.000 €	0,5330	2.033.985 €	0 €	1.520.000 €
<b>TOTAL</b>		<b>3,9181</b>	<b>48.368.972 €</b>	<b>297.988.000 €</b>	<b>174.906.000 €</b>	<b>10,3883</b>	<b>172.654.311 €</b>	<b>76.800.000 €</b>	<b>117.000.000 €</b>	<b>12,9406</b>	<b>49.384.944 €</b>	<b>41.800.000 €</b>	<b>45.600.000 €</b>

**RISK ASSESSMENT RESULTS SUMMARY**

**Risk reduction over 30 year period**

1 Hot axle box and hot wheel detection	3,92	Fatalities and Weighted Injuries (FWI) avoided over 30 year period
2 Axle load checkpoints	10,39	Fatalities and Weighted Injuries (FWI) avoided over 30 year period
3 Track geometry measurement systems	12,94	Fatalities and Weighted Injuries (FWI) avoided over 30 year period
TOTAL	27,25	Fatalities and Weighted Injuries (FWI) avoided over 30 year period

**RSSB Taking Safe Decisions Tool Results - Net benefits and costs discounted over 30 year period**

	Net Benefits	Net Costs	Benefit to Cost Ratio (BCR)
1 Hot axle box and hot wheel detection	42.424.845 €	440.562.207 €	0,096
2 Axle load checkpoints	145.257.515 €	162.851.828 €	0,892
3 Track geometry measurement systems	58.672.649 €	75.234.467 €	0,780
TOTAL	246.355.009 €	678.648.502 €	

**Benefit to Cost Ratio Results**

Note BCR clearly > 1 indicates measure is considered reasonably practicable  
 BCR clearly < 1 indicates measure is not considered reasonably practicable

**ALARP BCR (based on RSSB Taking Safe Decisions - Risk Assessment Tool, assumption that risk levels are equivalent to GB average national rate)**

1 Hot axle box and hot wheel detection	0,096	< 1, therefore implementation not considered reasonably practicable
2 Axle load checkpoints	0,892	< 1, but implementation could be considered close to reasonably practicable
3 Track geometry measurement systems	0,780	< 1, therefore implementation not considered reasonably practicable

**Sensitivity Analysis**

% increase in risk required for BCR>1 therefore suggesting the measure is reasonably practicable		(compared with GB average national rate for derailment risk)
1 Hot axle box and hot wheel detection	1038%	This measure would be considered reasonably practicable where the risk is approximately 10 times the GB average national rate for derailment risk.
2 Axle load checkpoints	112%	This measure would be considered reasonably practicable where the risk is approximately only 10% higher than the GB average national rate for derailment risk.
3 Track geometry measurement systems	128%	This measure would be considered reasonably practicable where the risk is approximately 30% higher than the GB average national rate for derailment risk.

**Risk Assessment Assumptions**

**Risk scaling factors for GB network figures to EU27 network**

EU27 2010 freight km (D2.3 Table 3.3)	212.345
GB 2010 freight km	16.175
Source: <a href="#">Eurostat 2010</a>	
Scaling factor EU27/GB	13,13

**Theoretical EU equivalent to GB Value of Preventing a Fatality - VPF**

GB VPF2013 (Value of preventing a fatality)	£1.748.000
Source: <a href="#">RSSB published value</a>	
Sterling to Euro conversion	£1 = 1,27 €
17. Jul 14	
GB VPF2013 in euros	2.219.960 €

**RSSB Taking Safe Decisions Risk Assessment Tool for GB**

Hyperlink: [Taking Safe Decisions Methodology \(RSSB\)](#)

Hyperlink: [Taking Safe Decisions Risk Assessment Tool \(RSSB\)](#)

Risk Assessment Scenario 2 Low

**SCENARIO 2: LOW** Assumed "low" cost / "low" level risk reduction option; Risk and accident costs assumed to increase at same rate as increase in traffic (1.53%).

**RISK ASSESSMENT: ESTIMATED RISK AND COSTS**

DERAILMENT CAUSES			RISK FIGURES					SYSTEM ASSUMPTIONS		COSTS						
	Monitoring System  (source)	derailment cause	EU27 Frequency (events /year)	EU27 Risk (FWI/year)	Assumed % reduction in derailments due to svstem	EU27 Reduction in frequency (events /year)	EU27 Reduction in risk (FWI/year)	Assumed number of additional units (cf.2014)	Lifetime (years)	Investment cost (€) per unit	Reinvestment cost (€) per unit	Annual maintenance costs per unit	TOTAL Investment cost (€)	TOTAL Reinvestment cost (€)	TOTAL Annual maintenance costs	Avoided Costs per cause of derailment (€)
			GB SRM v7.2 scaled for EU27	GB SRM v7.2 scaled for EU27	D-Rail WP5	GB SRM v7.2 scaled for EU27	GB SRM v7.2 scaled for EU27	D-Rail WP5	D-Rail D2.3 Table 3.4	D-Rail D2.3 Table 3.4	D-Rail D2.3 Table 3.4	D-Rail D2.3 Table 3.4	D-Rail D2.3 Table 3.4	D-Rail D2.3 Table 3.4	D-Rail D2.3 Table 3.4	D-Rail D2.3 Table 3.4
1	Hot axle box and hot wheel detection	Hot axle box and axle journal rupture	4,60	0,11	9,00%	0,4137	0,0103	160	15	229.600 €	147.600 €	7.380 €	36.736.000 €	23.616.000 €	1.180.800 €	1.282.575 €
2	Axle load checkpoints	Wheel failure	3,02	0,07	90,00%	2,7216	0,0670									1.879.471 €
		Skew loading	3,28	0,08	90,00%	2,9538	0,0743									833.144 €
		Spring & suspension failure	4,95	0,12	90,00%	4,4565	0,1117									1.865.570 €
	subtotals		11,26	0,28		10,1319	0,2530	120	10	110.000 €	73.000 €	13.000 €	13.200.000 €	8.760.000 €	1.560.000 €	4.578.185 €
3	Track geometry measurement systems	Excessive track width	15,62	0,24	45,00%	7,0279	0,1079									474.966 €
		Excessive track twist	12,71	0,21	45,00%	5,7179	0,0956									552.627 €
		Track height/cant failure	5,82	0,12	45,00%	2,6173	0,0539									281.922 €
	subtotals		34,14	0,57		15,3632	0,2574	10	10	950.000 €	570.000 €	76.000 €	9.500.000 €	5.700.000 €	760.000 €	1.309.515 €

RISK ASSESSMENT INPUT VALUES													
		1 Hot axle box and hot wheel detection				2 Axle load checkpoints				3 Track geometry measurement systems			
		safety benefit	avoided cost of accidents	capital costs	ongoing costs	safety benefit	avoided cost of accidents	capital costs	ongoing costs	safety benefit	avoided cost of accidents	capital costs	ongoing costs
		FWI	cost per year	investment & reinvestment costs	maintenance costs	FWI	cost per year	investment & reinvestment costs	maintenance costs	FWI	cost per year	investment & reinvestment costs	maintenance costs
Yr 1	2021	0,0103	1.282.575 €	36.736.000 €	1.180.800 €	0,2530	4.578.185 €	13.200.000 €	1.560.000 €	0,2574	1.309.515 €	9.500.000 €	760.000 €
Yr 2	2022	0,0104	1.302.198 €	0 €	1.180.800 €	0,2568	4.648.231 €	0 €	1.560.000 €	0,2613	1.329.551 €	0 €	760.000 €
Yr 3	2023	0,0106	1.322.122 €	0 €	1.180.800 €	0,2608	4.719.349 €	0 €	1.560.000 €	0,2653	1.349.893 €	0 €	760.000 €
Yr 4	2024	0,0108	1.342.351 €	0 €	1.180.800 €	0,2648	4.791.555 €	0 €	1.560.000 €	0,2693	1.370.546 €	0 €	760.000 €
Yr 5	2025	0,0109	1.362.888 €	0 €	1.180.800 €	0,2688	4.864.866 €	0 €	1.560.000 €	0,2735	1.391.515 €	0 €	760.000 €
Yr 6	2026	0,0111	1.383.741 €	0 €	1.180.800 €	0,2729	4.939.298 €	0 €	1.560.000 €	0,2777	1.412.806 €	0 €	760.000 €
Yr 7	2027	0,0113	1.404.912 €	0 €	1.180.800 €	0,2771	5.014.870 €	0 €	1.560.000 €	0,2819	1.434.422 €	0 €	760.000 €
Yr 8	2028	0,0114	1.426.407 €	0 €	1.180.800 €	0,2813	5.091.597 €	0 €	1.560.000 €	0,2862	1.456.368 €	0 €	760.000 €
Yr 9	2029	0,0116	1.448.231 €	0 €	1.180.800 €	0,2856	5.169.499 €	0 €	1.560.000 €	0,2906	1.478.651 €	0 €	760.000 €
Yr 10	2030	0,0118	1.470.389 €	0 €	1.180.800 €	0,2900	5.248.592 €	8.760.000 €	1.560.000 €	0,2950	1.501.274 €	5.700.000 €	760.000 €
Yr 11	2031	0,0120	1.492.886 €	0 €	1.180.800 €	0,2945	5.328.895 €	0 €	1.560.000 €	0,2996	1.524.243 €	0 €	760.000 €
Yr 12	2032	0,0121	1.515.727 €	0 €	1.180.800 €	0,2990	5.410.428 €	0 €	1.560.000 €	0,3041	1.547.564 €	0 €	760.000 €
Yr 13	2033	0,0123	1.538.918 €	0 €	1.180.800 €	0,3035	5.493.207 €	0 €	1.560.000 €	0,3088	1.571.242 €	0 €	760.000 €
Yr 14	2034	0,0125	1.562.463 €	0 €	1.180.800 €	0,3082	5.577.253 €	0 €	1.560.000 €	0,3135	1.595.282 €	0 €	760.000 €
Yr 15	2035	0,0127	1.586.369 €	23.616.000 €	1.180.800 €	0,3129	5.662.585 €	0 €	1.560.000 €	0,3183	1.619.690 €	0 €	760.000 €
Yr 16	2036	0,0129	1.610.640 €	0 €	1.180.800 €	0,3177	5.749.223 €	0 €	1.560.000 €	0,3232	1.644.471 €	0 €	760.000 €
Yr 17	2037	0,0131	1.635.283 €	0 €	1.180.800 €	0,3225	5.837.186 €	0 €	1.560.000 €	0,3281	1.669.632 €	0 €	760.000 €
Yr 18	2038	0,0133	1.660.303 €	0 €	1.180.800 €	0,3275	5.926.495 €	0 €	1.560.000 €	0,3331	1.695.177 €	0 €	760.000 €
Yr 19	2039	0,0135	1.685.706 €	0 €	1.180.800 €	0,3325	6.017.170 €	0 €	1.560.000 €	0,3382	1.721.113 €	0 €	760.000 €
Yr 20	2040	0,0137	1.711.497 €	0 €	1.180.800 €	0,3376	6.109.233 €	8.760.000 €	1.560.000 €	0,3434	1.747.446 €	5.700.000 €	760.000 €
Yr 21	2041	0,0139	1.737.683 €	0 €	1.180.800 €	0,3427	6.202.704 €	0 €	1.560.000 €	0,3487	1.774.182 €	0 €	760.000 €
Yr 22	2042	0,0141	1.764.269 €	0 €	1.180.800 €	0,3480	6.297.605 €	0 €	1.560.000 €	0,3540	1.801.327 €	0 €	760.000 €
Yr 23	2043	0,0144	1.791.263 €	0 €	1.180.800 €	0,3533	6.393.959 €	0 €	1.560.000 €	0,3594	1.828.887 €	0 €	760.000 €
Yr 24	2044	0,0146	1.818.669 €	0 €	1.180.800 €	0,3587	6.491.786 €	0 €	1.560.000 €	0,3649	1.856.869 €	0 €	760.000 €
Yr 25	2045	0,0148	1.846.495 €	0 €	1.180.800 €	0,3642	6.591.111 €	0 €	1.560.000 €	0,3705	1.885.280 €	0 €	760.000 €
Yr 26	2046	0,0150	1.874.746 €	0 €	1.180.800 €	0,3698	6.691.955 €	0 €	1.560.000 €	0,3762	1.914.124 €	0 €	760.000 €
Yr 27	2047	0,0152	1.903.430 €	0 €	1.180.800 €	0,3754	6.794.342 €	0 €	1.560.000 €	0,3819	1.943.410 €	0 €	760.000 €
Yr 28	2048	0,0155	1.932.552 €	0 €	1.180.800 €	0,3812	6.898.295 €	0 €	1.560.000 €	0,3878	1.973.145 €	0 €	760.000 €
Yr 29	2049	0,0157	1.962.120 €	0 €	1.180.800 €	0,3870	7.003.839 €	0 €	1.560.000 €	0,3937	2.003.334 €	0 €	760.000 €
Yr 30	2050	0,0160	1.992.141 €	0 €	1.180.800 €	0,3929	7.110.998 €	0 €	1.560.000 €	0,3997	2.033.985 €	0 €	760.000 €
TOTAL		0,3875	48.368.972 €	60.352.000 €	35.424.000 €	9,5403	172.654.311 €	30.720.000 €	46.800.000 €	9,7055	49.384.944 €	20.900.000 €	22.800.000 €

**RISK ASSESSMENT RESULTS SUMMARY**

**Risk reduction over 30 year period**

1 Hot axle box and hot wheel detection	0,39	Fatalities and Weighted Injuries (FWI) avoided over 30 year period
2 Axle load checkpoints	9,54	Fatalities and Weighted Injuries (FWI) avoided over 30 year period
3 Track geometry measurement systems	9,71	Fatalities and Weighted Injuries (FWI) avoided over 30 year period
TOTAL	19,63	Fatalities and Weighted Injuries (FWI) avoided over 30 year period

**RSSB Taking Safe Decisions Tool Results - Net benefits and costs discounted over 30 year period**

	Net Benefits	Net Costs	Benefit to Cost Ratio (BCR)
1 Hot axle box and hot wheel detection	36.360.420 €	89.227.789 €	0,408
2 Axle load checkpoints	143.800.867 €	65.140.731 €	2,208
3 Track geometry measurement systems	53.115.629 €	37.617.233 €	1,412
TOTAL	233.276.916 €	191.985.753 €	

**Benefit to Cost Ratio Results**

Note BCR clearly > 1 indicates measure is considered reasonably practicable  
 BCR clearly < 1 indicates measure is not considered reasonably practicable

**ALARP BCR (based on RSSB Taking Safe Decisions - Risk Assessment Tool, assumption that risk levels are equivalent to GB average national rate)**

1 Hot axle box and hot wheel detection	0,408	< 1, therefore implementation not considered reasonably practicable
2 Axle load checkpoints	2,208	> 1, therefore implementation would be considered reasonably practicable
3 Track geometry measurement systems	1,412	> 1, therefore implementation would be considered reasonably practicable

**Sensitivity Analysis**

% increase in risk required for BCR>1 therefore suggesting the measure is reasonably practicable		(compared with GB average national rate for derailment risk)
1 Hot axle box and hot wheel detection	245%	This measure would be considered reasonably practicable where the risk is approximately 2.5 times the GB average national rate for derailment risk.
2 Axle load checkpoints	45%	This measure would be considered reasonably practicable even where the risk is approximately half the GB average national rate for derailment risk.
3 Track geometry measurement systems	71%	This measure would be considered reasonably practicable even where the risk is approximately three quarters the GB average national rate for derailment risk.

**Risk Assessment Assumptions**

**Risk scaling factors for GB network figures to EU27 network**

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GB 2010 freight km	16.175
Source: <a href="#">Eurostat 2010</a>	
Scaling factor EU27/GB	13,13

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### **Appendix 3: Description of the two wayside monitoring systems:**

Regarding HABD:

There are different types of Hot Box and Hot Wheel Detection used widely, which are described in Annex to D4.1. Here the type of SST Phoenix is taken just as example to describe the function and features of the system. The main components of technology consist of: Infrared detectors for measuring the surface temperature of bearing housing, of wheels and of brake discs; electronic rail contacts for activating/deactivating the system and for creating a gate signal to evaluate the collected measurement data.

In standard configuration the complete system consists of three to four scanner modules (each equipped with one infrared detector) inspecting axle bearings, wheels and brake discs. Also customer specific configurations (measuring geometries) are possible. The sensors modules are integrated into the hollow steel sleeper as modular plug-in unit. They include the complete micro-electronics that are needed for calculating the measured data. The measurement data is transferred to the Service & Communication Terminal (SCT) via high speed secure data transmission. The main part of the SCT is a IPC, which enables to carry out all service and test functions regarding the infrared sensors. The measurement data is automatically stored. Additionally, the SCT is the interface to next level network structure (e.g. IP) and can be integrated into different topologies.

Physical principle: Infrared line detector with 8 pixels in a row which acquire and interpret the thermal radiation. Hot axle box and axle journal rupture, wheel failure and brake component failure can be detected.

Bearing housing, wheel and brake discs temperature measuring devices (known as hot axle box and hot wheel detection units HABD/HWD) are installed along the line at appropriate distances and designed to monitor any overheating which could lead to train accidents. They can also detect 'cold wheels' if brakes are not applied. These devices can be installed either individually (e.g. just HABD) or together (combined HABD/HWD like in Germany and Switzerland). They are widely used in Europe.

In the schema below, you see the typical device. The central components (not shown) are completely shared. The two outer boxes are hot axle box, the single inner box is for hot wheel/stuck brakes. The components of the boxes, such as the IR sensors, are identical, only the number and placement is different. The covers can be lifted and the whole box replaced with a spare (about a minute) to get a functional system again. We will have to see how detailed the maintenance data are.

There are three steps in testing of malfunction:

1. passing of trains gives a feedback regarding warming point
2. differences between different/several systems
3. calibration with external heater in terms of Maintenance



Figure 30: Installed system Hot Box and Hot Wheel Detection – SST Phoenix

#### Reg. Axle load checkpoints (ALC):

Track based monitoring system which measures the dynamic wheel rail forces over a distance of 6 sleeper spans. ALC are distinguished as follows:

- ALC (Q): track based measurement system for measuring the vertical wheel/rail force  $Q$  of each wheel or each wagon passing over the checkpoint.
- ALC (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.

Also here there are different types of Axle load checkpoints used widely, which are described in Annex to D4.1. Here one the type of currently and widely used dynamic ALC is taken just as an example to describe the function and features of the system. The main components of technology consist of: measuring sensors between rail and sleepers equipped with strain gauges for force measurement in  $Q$ - and  $Y$ -direction

(number of sleeper typ. 12-20 sleepers); 24x shear stress sensors in the rail, strain gauge technology; processing unit for analysis of measurements.

Direct measurement of vertical forces and horizontal forces based on prefabricated strain gauge sensors. Sensors tightly fixed to sleeper and ripple plate; Use of vehicle register; Determination of wheel vertical forces, peak forces; Determination of Y-forces (hunting bogies); Assigning results to trains, wagons, axles, wheels.

Physical principle: Direct measurement of vertical and horizontal forces based on prefabricated strain gauge sensors. Wheel failure, skew loading, spring and suspension failure, failure of bogie structure are detectable by ALC.

Axle load checkpoints can reveal overloading or unbalanced loading of vehicles and wheel defects as out-of-round wheels and wheel flats, which increase the risk of rail breaks and the consequent potential for derailment. For derailment prevention, trackside inspection of vehicle forces extends to analysis of curving behaviour and running instability as well. Checkpoints placed on curves can measure the horizontal as well as vertical track forces.

There are a large number of different ALC devices in use around the world. Systems were investigated and assessed in the past and presented in many reports. ALC provide information of running behaviour of passing trains without the need for stopping trains. On track installations allow for grinding, tamping and other maintenance operations without need to dismount equipment.

Reg. Track Geometry Measurement System:

The well known and widely used technology is vehicle embedded and based on optical, No-contact and inertial track geometry measurement system, which is able to provide automatically the main geometric parameters of the track.

Direct measured values are: Track gauge, cross level/cant, twist, alignment, longitudinal level.

Excessive track width, Excessive track twist and Track height/cant failure as derailment causes can be detected by this measurement system.

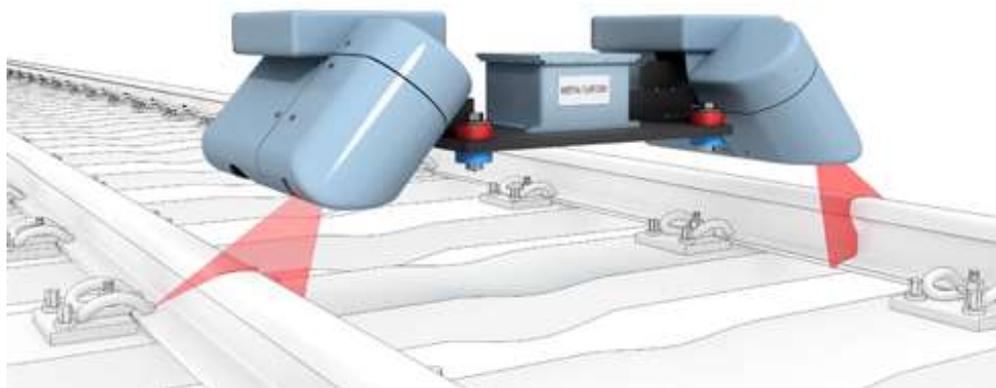


Figure 31: Type of Track Geometry Measurement System

Given the fact that the required RAMS related data are available only for Hot axle box and hot wheel detection system this system is suitable for the application of the RAMS theory. But for the application of risk analysis and risk assessment Axle load checkpoint and Track geometry measurement system have additionally been considered.