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

D-RAIL

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LCC analysis and recommendation (economic focus)

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Executive Summary

Work Package 7 of the D-Rail project provides an overall assessment in terms of a technical and economic evaluation of inspection and monitoring systems related to derailment. The base is reliability, availability, maintainability and safety (RAMS) and lifecycle cost (LCC) analyses.

The present deliverable D7.3 focuses on the economic assessment of the proposed inspection and monitoring systems by application of cost-benefit analyses and LCC analyses. Established methods for LCC are adapted to the D-Rail scope and requirements. A full cost breakdown was developed based on actual operational experience and data from infrastructure managers. Based on the business cases for monitoring in D5.2 – notably the number of sites and placement strategies – costs for Europe could be derived.

The safety assessment as performed in D7.2 of WP7 and based on data collected from WP2, WP3, WP4 and WP5, forms a component of this economic analysis, but additional benefits are also incorporated in the economic assessment. The effect of increase in freight traffic volume by 1.5% annually up to 2050, estimated in WP2, has been taking into account in the economic analyses. The effectiveness of each of the proposed systems in reducing frequency of freight derailments, and the associated reduction in risk, has already been estimated in D-Rail report D2.3. Given that, safety benefits based on derailment cost reduction were analysed through risk assessment in D7.2.

More specifically, WP7 performed cost-benefit analyses and LCC analyses to assess the economic value of the proposed inspection and monitoring systems. As these analyses have been made using the data and assumptions derived in WP2 and WP5, the indicated findings of these analyses shall be considered on the given input data and assumptions. Safety forms a part of the overall economic assessment, but the present deliverable attempts to quantify further benefits, especially in the area of maintenance optimization. Through LCC analyses the reduction in derailments in relation to number of monitoring system is determined. This fact is reflected in the evaluation of the business cases developed by WP5 by indicating the additional monitoring systems necessary to achieve 20% LCC reduction set out for D-Rail. Even though a causal link between the required number of additional monitoring systems and their life cycle costs (LCC) is not absolutely definitive. Also the combination of measures targeting different type of derailment causes is discussed based on intervention reports.

Based on the outcome of cost - benefit analyses Axle Load checkpoints (ALC) and Track geometry measurement systems (TGMS) are beneficial. Axle load checkpoints have a remarkably good ratio between costs and benefits. Track geometry measurement systems show an even better efficiency ratio in the cost-benefit analysis. The outcome of cost-benefit analyses considering hot axle box detection (HABD) is that the costs in both scenarios are very high in relation to the benefits and thus unfavourable, due to the evident reasons such as: the placement strategy is a density-based approach; the safety benefits are rather low, which can be explained by the already widespread use of HABD in many countries and the low maintenance benefits.

Contrary to this, HABD brings financial benefits in the LCC analysis. The LCC analyses demonstrate that the 20% LCC reduction can be achieved with fewer of additional monitoring systems concerning HABD than assumed by the WP5 business cases. That is to say that ca. 330 additional HABD devices (instead of 790 assumed in the business cases of

WP5) are necessary to achieve 20% LCC reduction. The same goes for ALC, as ca. 210 additional ALC installations are necessary to reduce the LCC by 20%. The difference between the WP5 and WP7 results is explained by the fact that WP5 has initially estimated the number and location of additional monitoring systems as a starting point but to be assessed by LCC analysis afterwards.

However, focusing more on ALC would lead to more financial benefits. So the installation of additional ALC generates more benefit than installing additional HABD, as there are already many HABD in use.

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

It is well known that TGMS has the highest potential maintenance cost optimization (assumed 15 Mio € by performing Condition-Based Maintenance as indicated in section 3.6.2 and in 3.7.3). So TGMS becomes very interesting from a maintenance perspective in terms of better usage of measurement data for prediction of trend analysis and performance of the right intervention. In addition, the transition from corrective maintenance to enhanced condition-based and predictive maintenance would be enhanced.

The LCC analysis reveals the enormous potential maintenance cost optimization based on the efficiency gains of using monitoring data to perform Condition-Based Maintenance instead of Time- or Interval-Based Maintenance. It is noteworthy that the quantitative results agree with operational experience in the U.S., where maintenance plays a very prominent part in the business cases for monitoring systems.

When considering the placement of installation sites, many aspects influencing the life cycle costs of inspection and monitoring systems have to be taken into account. However, the efficient deployment of the installations by risk-based decision at appropriate locations creates an added value considering important aspects (legal, financial, safety (SMS, CSM-RA), requirements of the concerned infrastructure manager, traffic volume, specific boundary conditions etc. To increase the number of installations does not lead to a LCC benefit automatically.

Three different aspects of migration are considered: technical migration of equipment, migration towards an integrated approach facilitating data exchange, and the shift from manual surveillance towards automated equipment that is due to today's inhomogeneity of the risk landscapes (traffic densities, speeds, topography, climate, etc.)

While these economic potentials are immediately available for infrastructure, the identification problems remain a hurdle for vehicles, although RFID-based schemes are in discussion for quite some time. Since these discussions lie on the interface between infrastructure managers bearing the costs and railway undertakings/entities in charge of maintenance deriving the benefits, an active role of supranational bodies would help develop these potentials within a short timeframe for the railway system and society as a whole.

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Glossary

ALARP .... (Risk) As Low As Reasonably Practicable

ALC........... Axle Load Checkpoint

CBM .... Condition Based Maintenance

CBS........... Cost Breakdown Structure

CH .... Swiss currency

CSI............ Common Safety Indicator

CSM RA ..... Common Safety Methods for Risk Assessment

CST .... Common Safety Target

DNV.......... Det Norske Veritas

ECM .... Entity in Charge of Maintenance

ERA .... European Rail Agency

GB .... Great Britain

HOA .... Hot Axle Box

HABD .... Hot Axle Box and Hot Wheel Detection

HRMS........ Harmonization – Running Behaviour and Noise on Measurement Sites

ICT............ Information Communication Technology

IM .... Infrastructure Manager

LCC........... Life Cycle Cost

MGT.......... Million Gross Tonne

MRR .... Monetized Risk Reduction

MTBF .... Mean Time Between Failure

MTTR .... Mean Time To Restore

NPV.......... Net Present Value

NRV.......... National Reference Value

NSA .... National Safety Authority

ÖBB........... Austrian Federal Railways (Österreichische Bundesbahnen)

PBS........... Product Breakdown Structure

RAMS .... Reliability, Availability, Maintainability and Safety

RFID .... Radio Frequency Identification

RSD .... Directive on Safety of Community Railways 2004/49/EC

RSSB.......... Rail Safety and Standards Board

RU .... Railway Undertaking

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

SIL .... Safety Integrity Level

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

SOA .... Struck Brake Detector
SRM .... Safety Risk Management
TGMS .... Track Geometry Measurement System
VO .... Vehicle Owner
WIM .... Wheel Impact Monitoring
WILD .... Wheel Impact Load Detector
WP .... Work package
WTMS .... Wayside Track Monitoring System

1 Introduction

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

This deliverable focuses on the economic aspect of WP7 addressing the effects on LCC. The technical part with the effects on RAMS is covered by D7.2. However, work package 7 provides the basis to consider the impact on reliability, availability and safety of the railway track system as well as economic effects related to derailment.

This work package includes four deliverables. Deliverable D7.1 gives 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. Deliverable D7.2 RAMS analysis and recommendations has the technical focus of the overall assessment. The present deliverable is the third deliverable of WP7 and aims to assess the impact of derailments and to evaluate the cost efficient mitigation measures in order to achieve the cost reduction of 10-20% within Europe set out as one of the D-Rail targets. Last but not least D7.4 summarizes the recommendations and findings of WP7 assessments.

The first part of this deliverable presents the conceptual framework on RAMS and LCC analysis but with a focus on LCC issues - detailed description of the framework is in D7.2 - including the key input data, the relevant cost data for LCC analysis and the defined boundary conditions. It should be noted that the application of the developed conceptual framework of RAMS and LCC analysis is applicable for all types of monitoring systems (like WTMS, vehicle based systems), but not limited to the used case studies of ALC, HABD and TGMS.

More specifically, the approach regarding LCC analysis with developed LCC models containing the elements of LCC such as the Product Breakdown Structure (PBS), Cost Product Breakdown Structure (CBS), the three dimensional cost matrix of LCC and the calculation methods (using discounted cash flow or present value method) are presented in section 3.

Based on the business cases of WP5 the economic impact of current and estimated increased freight traffic is analysed in section 3.2 and 3.3 of this deliverable.

Section 3.4 of this report outlines three different aspects of migration, owing to a very inhomogeneous situation in Europe. Existing monitoring systems will not be removed before end of life time and the integrated approach should be realised in the next step to gain the benefit of network connectivity and “central” intelligence. In addition, the migration from manual surveillance towards automated equipment will especially be driven by traffic volume and speed.

But derailment also has socio-economic effects. As described in section 3.5 the negative effects of derailments can be classified in the following:

- Direct consequences (injuries and damages)
- Indirect consequences (collision with another train after derailment, track unavailability etc.), which are not directly to derailments
- Long term effects (loss of public confidence in railway safety…) can be seen as “soft factors”

Normally costs of direct and indirect consequences can be calculated quite sufficiently, but no meaningful quantification for long term effects could be found. Usually single derailments don’t have any stable impact on freight volumes, however any loss of a single percent in modal split caused by long term effects will top any others.

The last section of this deliverable describes the non-safety related benefits of the proposed monitoring systems. It is shown that a risk-based maintenance strategy using maintenance data for trend analysis will lead to additional benefits and underlay the values of inspection and monitoring systems.

2 LCC- and RAMS management and related boundaries

2.1 Common understanding of LCC and RAMS

Since D-Rail focuses on a reduction of derailments and derailment related questions, targeted at feasible and cost-efficient solutions regarding inspection and monitoring systems for prevention of derailments resulting in an a enhancement in safety levels, it is clear that the monitoring concepts should be based on an economic assessment coupled with the technical appraisal in terms of RAMS.

A major requirement when carrying out LCC and RAMS 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 consideration is taken to LCC and RAMS 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 collection of key input data taking into account the background, detailed explanation of key parameters and goal setting for RAMS and LCC analysis.

The total costs of a product results from the combination of investment, operation, maintenance costs and costs for non-availability which is determined by the technical performance of a product. However, the technical performance of a system influences the LCC, and consequently RAMS and has a direct impact on the follow-up costs over the life time of a product. To identify the follow-up cost, RAMS analyses together with Life Cycle Costing are necessary. A better technical performance is often connected to higher investment costs, but it reduces operational costs. The trade-off can be estimated by RAMS and LCC analyses.

Life Cycle Costing (LCC) is the collection, systematical analysis and goal oriented reporting of all product related costs from the first phase to the end of its life span.

LCC is an appropriate method to identify cost drivers and to gather the costs of a system, module or component over its whole lifetime including development, investment maintenance and recycling costs. Different views and evaluations allow the comparison of different systems and deliver necessary information for technical and economic decision.

In the field of railways, LCC methods are starting to be employed and will provide a definite advantage to the IMs in helping to calculate costs for the implementation of innovative technologies.

The most important decision criteria concerning LCC analyses are:

- Net present value (NPV:) the NPV of a sequence of cash flows takes into account the cash flows and the chosen discount rate; it is the most accurate procedure for decision support.
- Discount rate: future cash flows have to be discounted to the starting point of the study period; within a LCC analysis all payments – also future payments – will be referred to a reference date using the discount rate.
- Annuity: the annuity refers to a fixed payment over a specified period of time.

Basically the application of RAMS engineering coupled with LCC management for a railway system is vital to being able to deal with failures proactively and to reduce the consequences of failure, to an acceptable level. The implementation of RAMS and LCC management is a complex task and requires proper understanding of the underling concepts, key parameters etc., including interaction between these, to arrive at an effective decision.

The standard IEC 300-3-3 as a guideline for application of reliability management emphasizes in section 3 that LCC analysis is an integral part of reliability management, if the approach of achieving the optimum in terms of product properties and costs is aimed for.

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

In the course of the development of the framework for RAMS and LCC analysis in D-Rail all the relevant RAMS and LCC issues and key parameters have been defined and explained. The RAMS and LCC template for data collection related to the inspection and monitoring systems shall serve as an integral part of the developed framework for RAMS and LCC analysis to provide a common understanding of the RAMS and LCC in regard of derailment. In addition the proposed RAMS approach complies with the related standards relevant for RAMS analysis. It can be stated that an agreement on the same and consistent definitions and methodology has been established in order to have a common ground on the approach regarding LCC and RAMS.

The approach with the framework and the boundary conditions for LCC and RAMS analysis are described in the following section.

It should be noted that the focus of this report is on LCC rather than on RAMS. The technical assessment is part of D7.2 RAMS analysis.

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

The main objective of the D-Rail project is to obtain a future reduction in freight derailments through an increased understanding of derailment causes, and improved methods of predicting derailment critical conditions through measurement of appropriate system parameters. The reduction of derailments by 8-12% (referred to 500 derailments) and a cost reduction of 10-20% within Europe respectively are defined as D-Rail goals.

The task 7.4 in WP7 intends to perform the economic analysis of the existing situation and the local and global monitoring concepts including the tasks:

- Development of LCC-models, incl. documentation of LCC models, boundary conditions, input and output parameters
- Economic impact and additional benefits of monitoring systems
- Comparison of different cases (monitoring and reduced derailment costs)
- Economic effect of use of monitoring systems in maintenance process
- a final report

Particular emphasis should be given to the definition of the boundary conditions in order to have a common understanding of these. In the context of carrying out LCC and RAMS analysis the definition of boundary conditions is two-fold: one are the preconditions such as the necessary framework, available methodologies, knowledge, models, software, data input etc. for LCC and RAMS management and the second definition relates to the technical system or sub-system or component aim 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 section 2.3.1 of D7.2 extensively. It is important to have a common understanding of the boundary conditions both for RAMS and LCC analysis and for the technical system.

The aim of this deliverable is to perform an economic evaluation (LCC analysis as far as input data are available) based on the developed framework of “RAMS and LCC analysis”. In the context of D-Rail the conceptual framework of RAMS and LCC analysis aims to assist in 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 these. The development of a framework for traceable and reliable RAMS and LCC analysis ensures that the whole process and decisions has a cohesive goal. It should be pointed out that the framework is developed as a generic approach 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 intended analysis. For that reason 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 application of the developed conceptual framework of RAMS and LCC analysis is applicable for all type of monitoring systems (like WTMS, vehicle based systems), but not limited to the used case studies of ALC, HABD and TGMS.

The framework and the approach of carrying out RAMS and LCC analysis including the required key input data are presented in deliverable D7.2 (chapter 2.2) in a very detailed form. Therefore in this deliverable only the LCC relevant issues are highlighted.

The significant steps of a LCC assessment are described subsequently (but should not be regarded as exclusive):

- definition of (LCC) tasks
- creation of the basic LCC elements
- data collection and data processing
- evaluation of LCC values (e. g. NPV, Annuity)
- formulate a recommendation as a basis for decision
- ensure knowledge cycle through feedback loop

These steps are shown in the figure below as indicative of the scope to perform an effective LCC analysis, but should not be regarded as exclusive.

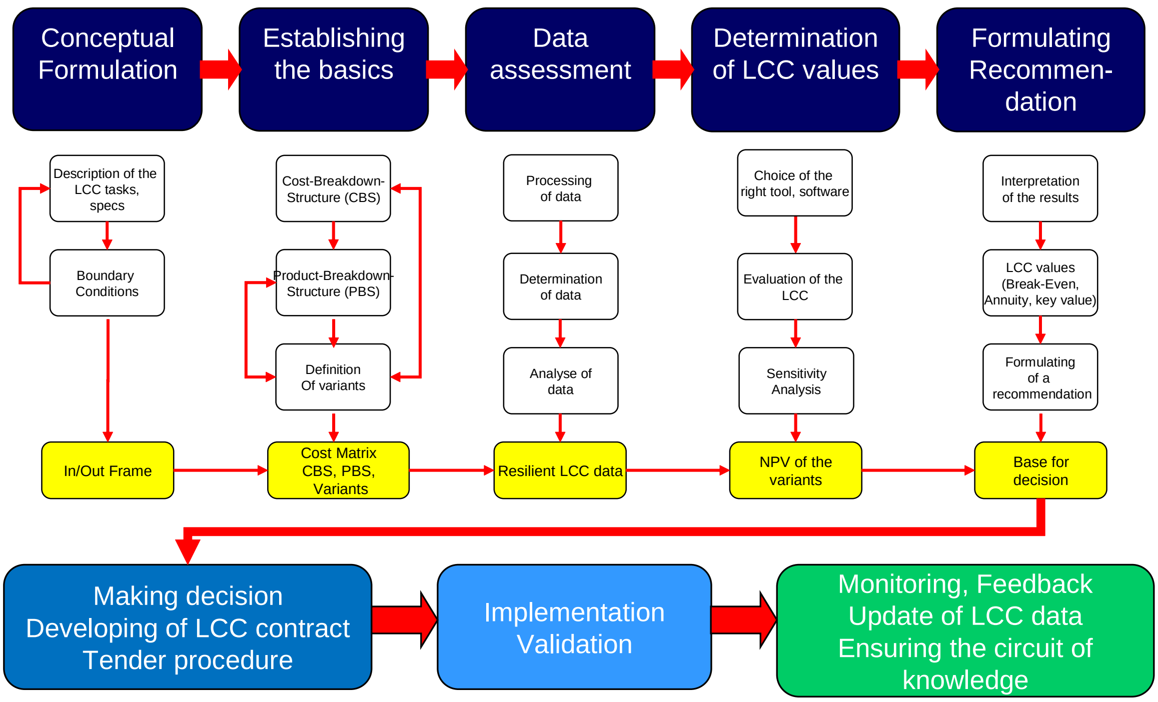

Figure 1: Schematic description of a LCC procedure

The evaluation of the procedure will be proved by the defined case studies. Among the top derailment causes, hot axle box and axle journal rupture failure, wheel failure, spring and suspension failure and skew loading were selected by WP7 partners to be focused on for further RAMS analysis of the associated protections 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 one of the most popular types of wayside-monitoring equipment which are presently in use, and that targets the top derailment causes. The hot axle box and axle journal rupture failure can be covered by the protection system of Hot Box and Hot Wheel Detection Systems (HABD), while the wheel failure, spring and suspension failure and skew loading are covered by dynamic Axle Load Checkpoints (ALC).

By establishing the basics for LCC analysis it's necessary to define the relevant LCC parameters, boundary conditions and the required input data. In addition the case study has to be determined in order to collect all the required and relevant LCC 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 aimed for:

- Establishing a 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 failures
- Time between failures (MTBF) for the selected inspection and monitoring system
- LCC relevant parameters

Subsequently the developed RAMS and LCC template is presented, but only referring to the LCC relevant parts, as the framework incl. RAMS related parts described in detail in D7.2.

Table 1: Explanation of the relevant LCC parameters

Parameter	Description
Quality of data	*Please indicate the quality of data like verified or estimated*
	Please take care of high quality of data
	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*

Regarding LCC input data for inspection and monitoring systems these include:

- Life time
- Investment, Re-Investment
- Disposal cost
- Inspection cost
- Operation cost
- Maintenance cost

- Quality of LCC data (estimated, verified, by experts)

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

No	System / module / technology	Quality of LCC data	Life time [a]	Investment cost [€]	Re-investment cost [€]	Disposal cost [€]
		verified / estimated	LT	IC	RC	DC
1	Hot box detectors	Verified (SBB)	15	CHF 280,000	CHF 180,000	
2	Track Geometry Measurement System	estimated	10	from 500 000€ to 1 400 000€ according to the application field		
3	Dynamic axle load checkpoint	verified (DB)	10	110.000,00 €	73.000,00 €	1.000,00 €

Figure 2: Indicated LCC parameters (part 1)

Maintenance activity description	Maintenance interval [a]	Maintenance cost [€] Preventive / Corrective		Inspection activity description	Inspection interval [a]	Inspection costs [€]	Operation Cost [€/a] Energy / Labour	
MA	MI	MCP	MCC	ISA	ISI	ISC	OCE	OCL
	1	CHF 2.000	CHF 7.000				n.a.	n.a.
calibration of system replacement cameras or laser if failure	0,5	around 4% per year of the project price		Visual checking	0,1			
calibration, fault diagnosis, maintenenance	1		13.000 € per year & per system	system check, remote diagnosis, monitoring	1	4.500 € per year & per system	1.300 € per year & per system	

Figure 3: Indicated LCC parameters (part 2)

For the partners within D-Rail the framework seems rather clear in structure and understandable since it is important that all variables are defined.

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.

Particular emphasis shall be given to the collection of RAMS & LCC relevant data for inspection and monitoring systems within D-Rail. It is preconditioned that the collection of the needed data for RAMS and LCC is done by the WP's and provided for WP7. Clearly WP7 relies on the provision of the required data, to complete the LCC and RAMS analysis.

Given that the (technical) boundary conditions under which the technology/system is 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 respectively. More details are given on page 18 and in section 2.3.1 of D7.1.

The combination of investment, maintenance costs and costs for non-availability, determined by technical performance, result in the total costs of a product, which provide the base for decision making. Therefore not only the technical parameter but also the follow-up costs over the life time of a system or component like maintenance costs should be taken into consideration.

Figure 4 presents an overview of the main processes and decisions within the proposed RAMS framework of the D-Rail project, and shows the interactions between different concepts. Technical performance of a system influences the LCC and therefore the RAM results are supposed to feed into the LCC calculation in order to assess the impact of the technical performance of a system (RAM data) on the total costs. The LCC analysis can only be set up after the RAM analysis as can be seen from the diagram shown below.

Within the frame of D-rail project WP7 D7.2, the framework for LCC and RAMS analysis follows the process shown in the Figure 4 and Figure 8.

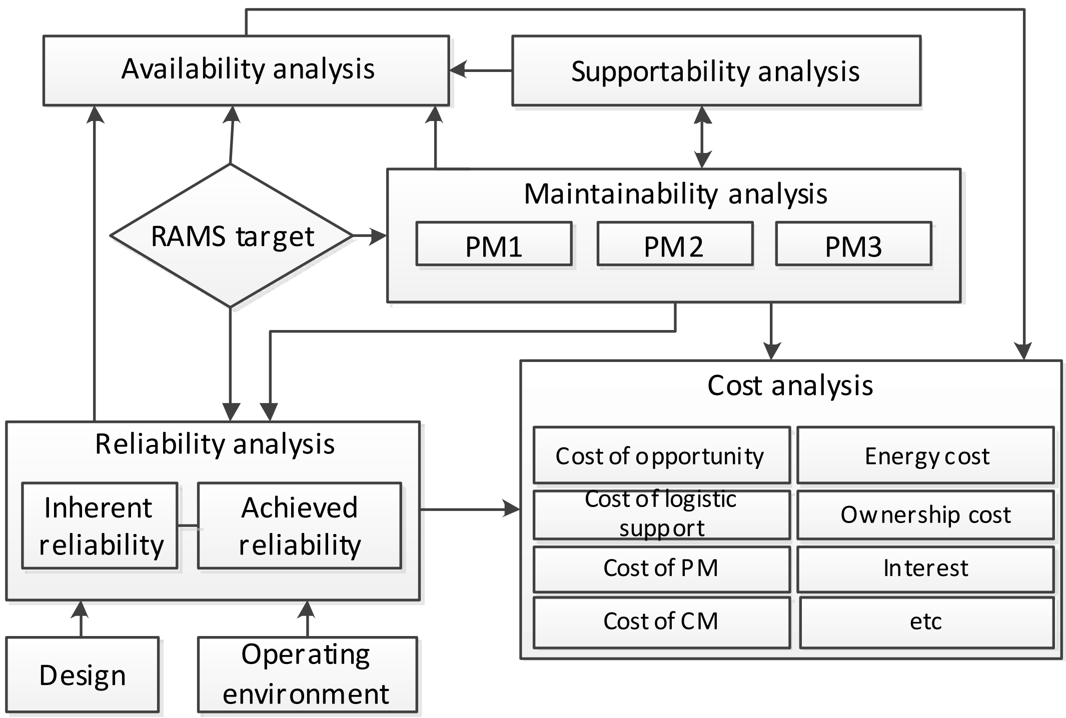

Figure 4: RAMS data analysis and LCC analysis framework

Detailed descriptions of each process and the above procedure is presented in the deliverable D7.2.

Once the needed key input data have been collected for 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.

The presented standardised templates (used in DB) aims to document:

- scope, objectives, time schedule and responsibilities of the analysis
- relevant boundary conditions to be taken into account
- economic parameters, include the relevant cost items (LCC)
- technical parameters (RAMS) as presented in detail in D7.2

For instance, the subsequent standardized template (Figure 5) can be used for the documentation of relevant economic parameters (LCC): the economic parameters, which are relevant for the analysis in relation to technical performance and related to costs, should be defined by using a cost matrix like shown below (to be considered as a proposal in context of D-Rail):

Cost matrix – top level

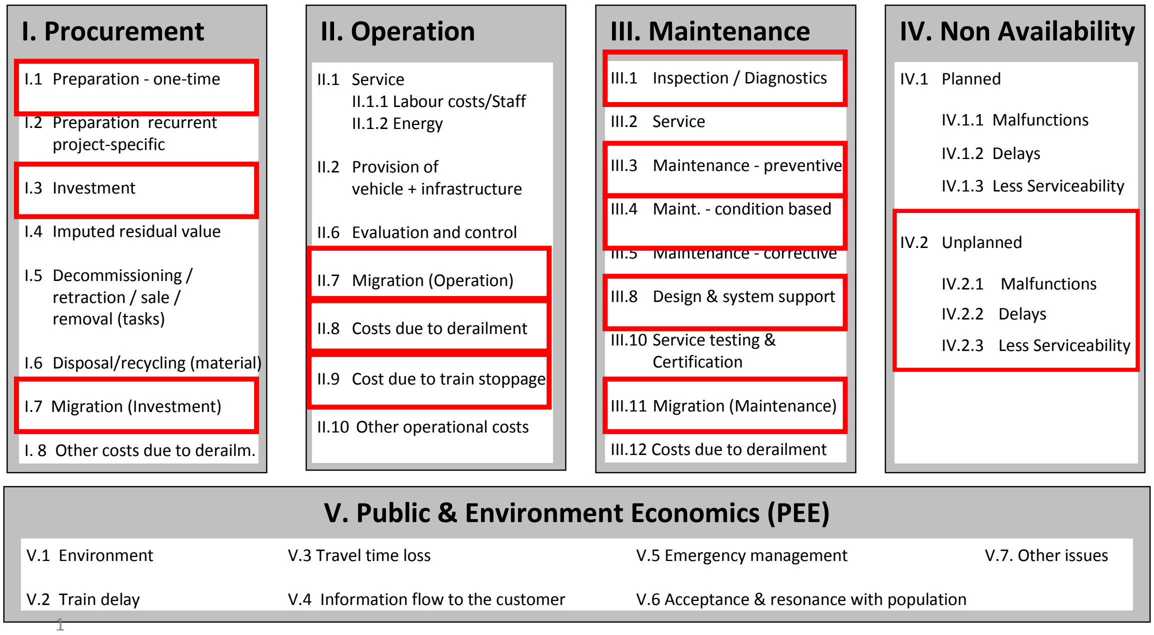

Figure 5: Documentation of relevant cost block related to derailment (high level)

For the documentation of the relevant cost items: the economic parameters, which are relevant for the LCC analysis, should include details about the type of costs, cycle of payments, the source and quality as it can be seen in Figure 6.This is to be considered as a proposal in the context of D-Rail:

Cost block	Data structure	Reference	Scenario A	Scenario B
Derailment	Euro Cycle Source Quality			
Investment	Euro Cycle Source Quality			
Re-Investment	Euro Cycle Source Quality			
Operation	Euro Cycle Source Quality			
Maintenance	Euro Cycle Source Quality			

Figure 6: Documentation of relevant economic parameter

In section 3.6.3 the above presented template is filled out for the three proposed monitoring systems.

It is essential to clarify what is within or outside of the LCC calculation, i. e. the range and the base of the boundary conditions to be analysed within LCC and RAMS analysis should be defined. Besides the availability and quality of needed data, the clear and accurate boundary conditions that are well defined and documented improve the RAMS and LCC analysis. This can be visualized for example with the appropriate diagram (see Figure 7) in terms of the identification of those cost elements that will be part of the LCC calculation and, as a result, will require a detailed clarification and possibly a breakdown.

A migration approach is described in section 3.4, 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. The costs for the implementation of the additional monitoring systems are not included in the LCC analyses, since verified cost data are not available. The impact of the issues in terms of the risk landscape of the IM (own risk assessment, risk management for the concerned boundary conditions and requirements) as well as the effect of higher increase of traffic volume (more than 1.5% per year) as well as the decrease of derailments by 10-20% by 2050 (as taken into account in WP2, D2.3, chapter 3.1) are not considered in the LCC analyses.

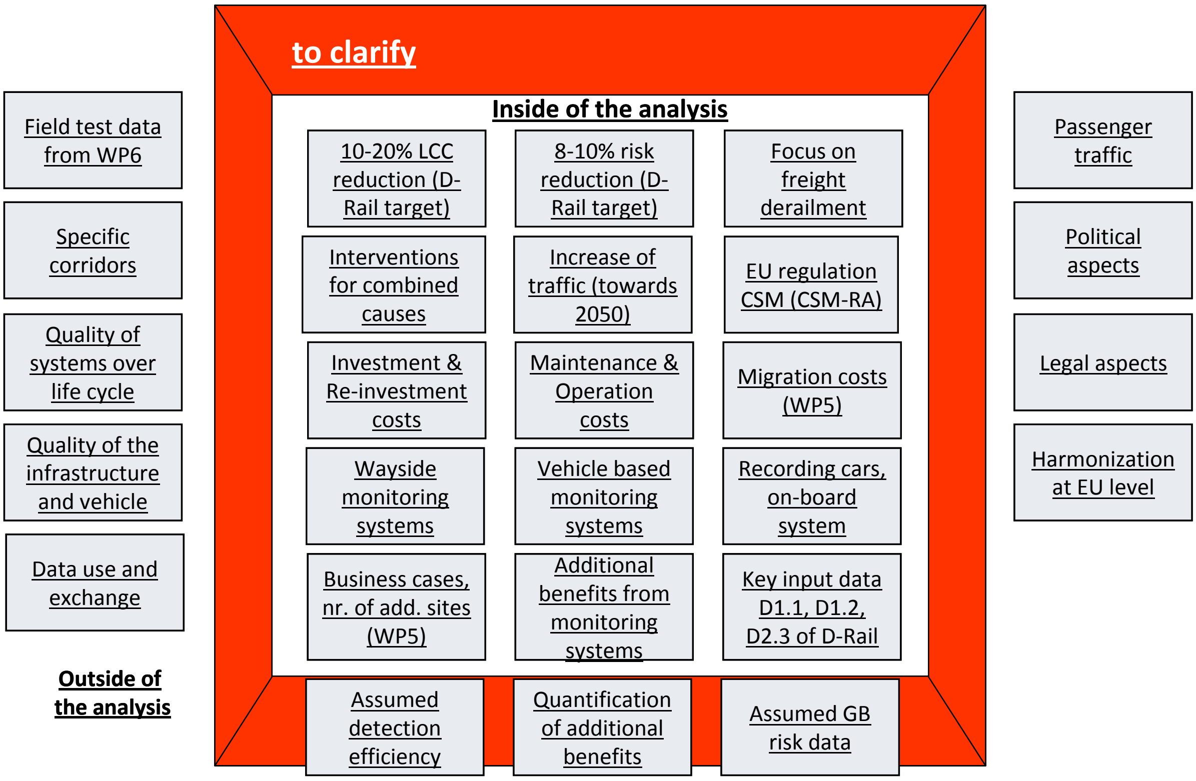

Figure 7: In/Out frame for the documentation of the boundary conditions

In section 3.6.3 this template is filled out for the three proposed monitoring systems given the available data and assumptions. This has bee done in close cooperation with WP5 taking into account the defined business cases.

In fact, the boundary conditions differ from country to country: meteorology, topography, traffic composition, track utilization are all factors in this respect. This leads in practice to different intervention thresholds per country. Consequently the individual national situation, requirement of each IM (to do his own risk assessment e. g. using CSM-RA), national financing of investments and other aspects (see 3.6.3) have to be taken into account to ensure risk-related decision-making.

As can be seen the elements of the framework are developed for use in RAMS and LCC analysis. In addition it can be stated that the implicated parties in WP7 have the necessary skills and competence in terms of delivering a systematic approach with well-known and widely used methodologies and processes, appropriate models for risk analysis, RAMS and LCC analyses, and the appropriate software. This is proved by the already performed risk assessment and RAMS analysis.

In conclusion, to make an LCC calculation there is a need for:

- definition of relevant boundary conditions
- make clear what is within the calculation and what is included in the Product Breakdown Structure (PBS)
- a Cost Breakdown Structure (CBS)

- a cost model definition
- documentation of input and output parameters

More details to the above listed points are presented in the following sections.

2.3 Definition of key input data for LCC analysis

The expected results from WP7 need relevant input data. The following cost parameters are required to perform LCC analysis for identification of the most cost efficient solution that most reduce the LCC cost.

- Period under consideration (basically the service life time of the concerned systems)
- Discount rate, interest rate
- Relevant cost items such as
    - Installation costs (Investment and Re-Investment)
    - Cost of inspection activities
    - Cost of repair activities
    - Disposal cost
    - Operational costs
    - Costs of monitoring
    - Cost due to derailments (direct and indirect costs
    - Cost of track process (lost production)
    - Migration costs
    - Socio-economic effects due to derailments
- Constraints and limitations regarding e. g. the key input data from other WP's in D-Rail
- Documentation of input and output LCC parameters

The issue of key input data, data quality and associated constraints regarding LCC (and RAMS) analysis is not referred to since this issue is already covered in D7.2.

2.3.1 Boundary conditions to be taken into account in LCC and RAMS analyses

The identification and definition of the related boundary conditions that will affect the RAM(S) parameters (e. g. the reliability of system or component) and the LCC are vital. The environmental conditions in which the equipment is to operate (e. g. temperature, humidity, dust, maintenance facilities, maintenance and operation training of personnel etc.) often have significant impact on product reliability characteristics and thereby on the maintenance and operation. The connection between technical performance and total cost (LCC) of the system/subsystem/component is presented in the following figure.

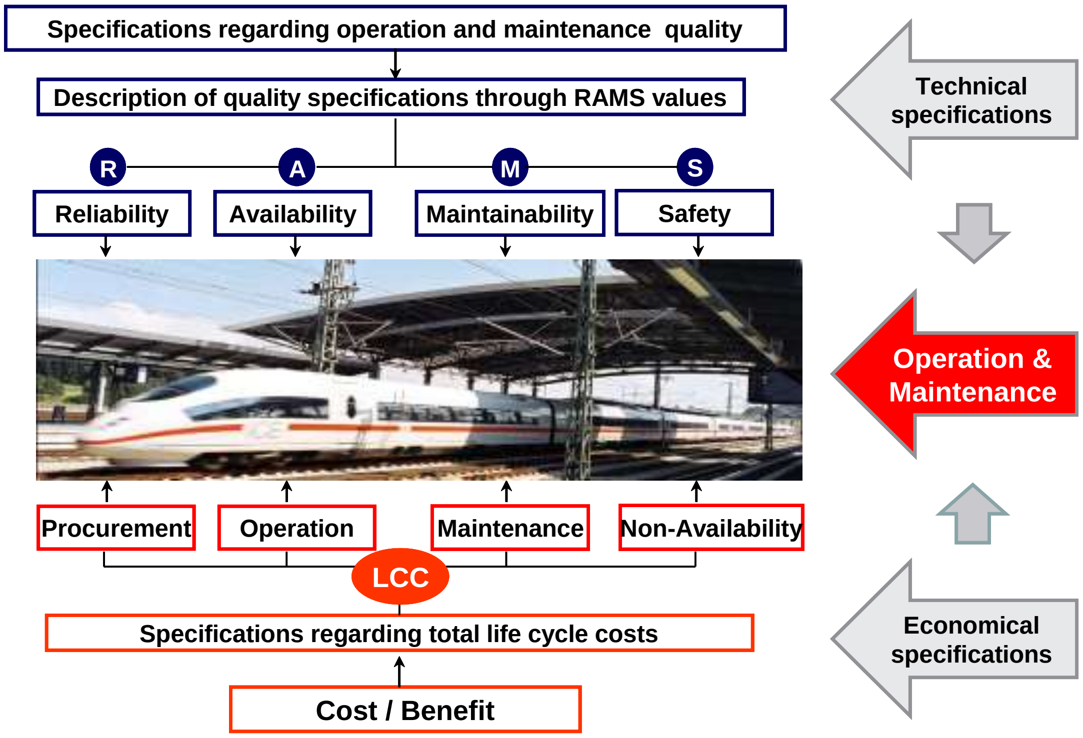

Figure 8: Connection between LCC & RAMS

More details on boundary conditions for RAMS and LCC analysis can bee inferred from D7.2, chapter 2.3.1.

Technical performance of a system influences the LCC. Together with LCC analysis the most important key drivers and necessary improvements can be identified.

The most important part of a RAMS and LCC calculation is the processing and determination of the relevant RAMS and LCC data. Since the approach and the needed data and used assumptions in terms of boundary conditions, top derailment causes, proposed monitoring systems, data quality, are already described in D7.2 report of WP7 (chapter 2.3. to 2.3.5), it is not repeated in this present deliverable.

2.3.2 Relevant cost data for LCC

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 boundary conditions. This is presented in the next section.

In the following the output of WP1 (D1.1 and D1.2) regarding derailment costs are summarized, since this serves as an input for the economic evaluation performed in WP7.

A number of observations for analysing derailment costs made from the analysis of derailment impact in WP1 are:

- Number of annual derailments 500, of which 7% (35 derailments) involve dangerous goods.

- There are, on average, 2 fatalities per year and 3 serious injuries per year, at costs of 1.5M€ per fatality and 0.2M€ per serious injury, consequently the human cost is 3.6M€ per year. This is equivalent to a human cost of 7.200 € per derailment.
- Environmental clean-up costs are small except in the 7% of derailments involving dangerous goods. If the minimum cost per dangerous goods derailment (250.000 €) is assumed here, this is equivalent to 17.500 € per derailment.

Based on this, human and environmental costs an average of approximately 25.000 € per derailment should be added, regardless of the type of derailment. As this this is an average value, and could be in reality be, for example, six severe derailments per year, each incurring costs of 2M€ (rather than 500 derailments per year, each incurring the cost of 25.000 € per derailment).

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

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

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

For calculating the total impact in cases where only direct costs are known, the direct cost should be multiplied by a factor – ERA's cost benefit analysis model gives a factor of 2.5. Data for the USA indicate this factor to be 1.8 - 2. The analysis of the data provided by the infrastructure managers in the D-RAIL project suggests that this factor may be much lower, (only 1.33) but it is likely to vary considerably between countries.

Based on the above findings the average costs of derailments were calculated as follows:

- if we take an average of all derailments, the average cost per derailment is 802.361 €. However, this is significantly skewed by maximum values in the dataset.
- if we look only at derailments in the range 100.000 € - 2.000.000 €, i.e., excluding 'low-cost' derailments and extreme events, the average cost per derailment is 608.353 €.

Regarding delay costs: delay minute' (the European recommendation of 6.000 € per hour). Basically it is difficult to estimate disruption cost (delay minutes) and ranges from only 15% of the direct cost in one data set, to 150% based on ERA's cost benefit analysis model. According to deliverable D1.2 a reasonable practice would be to assume that the indirect costs, if unknown, are equal to the direct costs. 'An average value of 192.000 € is suggested by deliverable D1.2 to be taken for disruption cost. This is in addition to the direct cost of 600.000 €.

The key question is which costs should be used in the analysis. According to D1.2 Report on Derailment Economic Impact Assessment the following are the typical cost components which should be considered in the impact evaluation:

a) Direct infrastructure cost
b) Direct rolling stock and asset costs

c) Human cost in terms of fatalities and injuries
d) Disruption to other services, i.e. passenger & freight (specially delay minutes)
e) Legal and litigation costs
f) Third party damage i.e. property or business
g) Attendance of emergency services
h) Environmental costs: post-accident clean-up operation; public dangers (hazardous cargo)
i) Loss of cargo and freight customers.

Note that this study does not include the cost decreased or lost production, which is a part of a wider societal cost.

To this end, the 2012 ERA estimate is that the number of line derailments in the EU25 is 500, of which roughly half are serious enough to be reported. As discussed above, the large deviation is due to reporting procedures.

An attempt to provide a more detailed cost analysis is presented in deliverable D1.2 Report on derailment economic impact assessment. In general an economic evaluation of derailment costs is very cumbersome for several reasons: not all derailments are reported, economic figures are confidential in many countries *etc*. Further, estimations of disruption costs (delays *etc.*) vary by an order of a magnitude between different analyses. Finally, average costs may be very misleading since the scatter in costs of individual derailments may vary by several orders of magnitudes.

With these reservations, the average cost of a severe derailment is estimated in D1.2 as 600 k€. Human costs (fatalities and serious injuries) and environmental cost are, on average, estimated to an additional to 24.7 k€ per derailment. Note that the latter costs are in reality related to a few number of derailments.

An attempt is made in D1.2 to categorize the cost. As mentioned above, the categorisation of accidents is cumbersome in itself. When categorizing costs, the case is even more complicated by the fact that most European databases do not provide a cost breakdown. With these limitations, the analysis in D1.2 indicates that rolling stock is the assigned cause for about 38% of derailments, which corresponds to over 50% of total derailment costs.

The following sections regarding LCC analysis cover the question of reducing derailment costs and the cost for monitoring systems. The balance between the increase of investment, maintenance and operating costs will be compared to saved costs due to fewer derailments.

To address all advantages and benefits of monitoring systems, the analyses have not only to include the direct cost for the carriers and the infrastructure managers, but also the indirect costs (e. g. socio economic effects).

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

Table 2: Short list cost benefit analysis per cause and intervention set of accidents (D2.3, Table 2.1)

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%

More details on the table above are given in D7.2

The values in the table are not influenced by any risk based models, like CSM-RA. Contrary to this the upcoming cost-benefit analyses and LCC analyses take this into account as already done in the risk assessment of D7.2.

The following conclusions can be derived from the table above:

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

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

The main challenge in collecting relevant input data is to find high quality data. This not only relates to getting data from systems but also to being aware that both the number of sites and the quality of measuring (measuring accuracy, see also section 3.6.3 LCC analyses) affect the monitoring whole life costs. However, the measuring accuracy of inspections and monitoring systems influence the effect on avoidance of derailments and linked costs.

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

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

3 LCC analysis

Work package 7 will provide a basis to consider the impact on reliability, availability and safety of the railway track system as well as the economic effects.

Task 7.4 in WP7 is intended to perform economic analysis of the existing situation and the local and global monitoring concepts.

In the following, the approach reg. LCC analysis shall mainly cover the development of LCC-models, economic impact of existing concepts and monitoring systems and economic effect of using monitoring systems in the maintenance process.

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 of D7.2. For the application of the RAMS theory hot axle box and hot wheel detection system are selected since most of the RAMS and LCC related data are available for these systems. In addition to the RAMS analysis, risk analysis and risk assessment has been applied for Axle load checkpoints and Track geometry measurement system.

Particular emphasis shall be given to the fact that the aim of WP7 was not to focus on Wayside Train Monitoring System (WTMS) and HABD respectively, but owing to the fact that Hot axle box and hot wheel detectors, and Axle load checkpoints are the systems with the most the experience and good and sufficient RAMS and LCC data are available to perform RAMS analysis, these will be used as a basis for the LCC analysis.

In addition the results of D2.3 match very well with the experience of the involved IM's in this project, since hot axle box and hot wheel detectors (HABD) and Axle load checkpoints (ALC) were identified with the highest benefit to cost ratio considering the cumulative benefits.

3.1 Development of LCC models

To summarize, the necessary steps for LCC analysis consist of the definition of the scope, creating the basic LCC elements, processing of data, evaluation of LCC values and formulating a recommendation as a basis for decision.

3.1.1 Methodology

The life cycle cost analysis calculates the cost of a system or product over its entire life span. The method is one of the most recommended for investment projects, assessment of different solutions over the whole life cycle and comparison of various strategy options. The classic LCC phases are:

- Concept and definition,
- Design and development,
- Production,
- Installation,
- Operation and maintenance, and
- Disposal

The standard IEC 300-3-3 as the guideline for application of reliability management points out in section 3 that the LCC analysis is an integral part of reliability management, if the approach of achieving the optimum in terms of product properties and costs is aimed at.

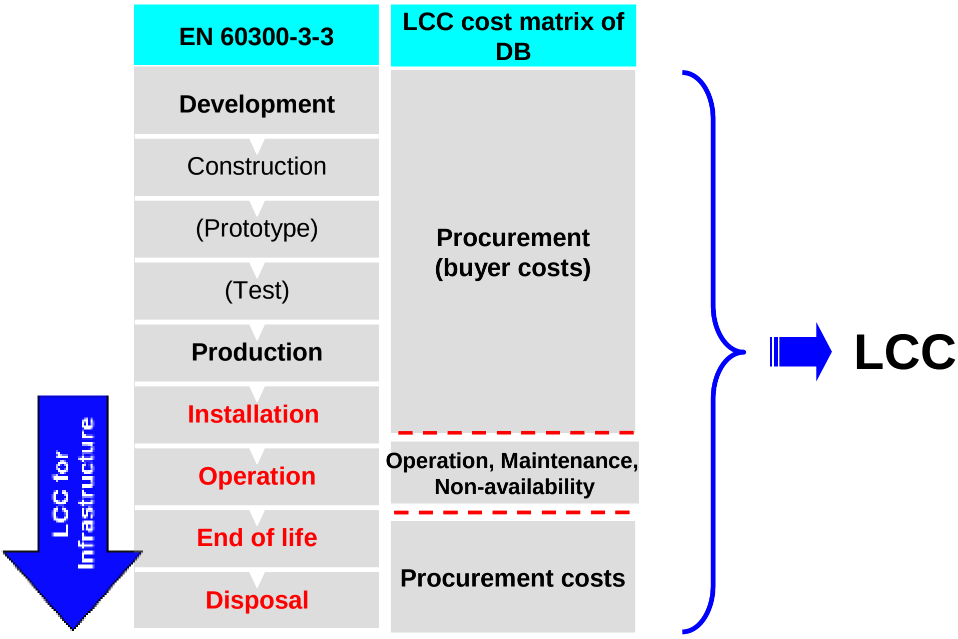

Figure 9: Life cycle phases according to EN 60300-3-3

The total life cycle cost of a system/product/component consists of the costs of the LCC phases:

$$\mathbf{LCC = Cost_{C} + Cost_{D} + Cost_{P} + Cost_{I} + Cost_{O\&M} + Cost_{Dis}}$$

C=Concept

D=Design & Development

P=Production

I=Installation

O&M=Operation and Maintenance

Dis=Disposal

3.1.2 Elements

Life cycle cost analysis (LCCA) is a structured method to assess all costs incurred within a given system along the technical life cycle considered for this system. Major phases of the system life cycle must be included in the analysis (i.e. concept and definition, design and development, manufacturing, installation, operation and maintenance, and disposal phases). As can be derived from Figure 10, the LCC models consist of a 3 dimensional matrix that includes:

- a breakdown of the product to lower indenture levels (product break down structure - PBS),
- a cost categorisation of applicable resources such as labour, materials, equipment, etc. (cost break down structure - CBS) and
- a time axis or life cycle phases where each work or activity performed is allocated to each cost element (see Figure 2)

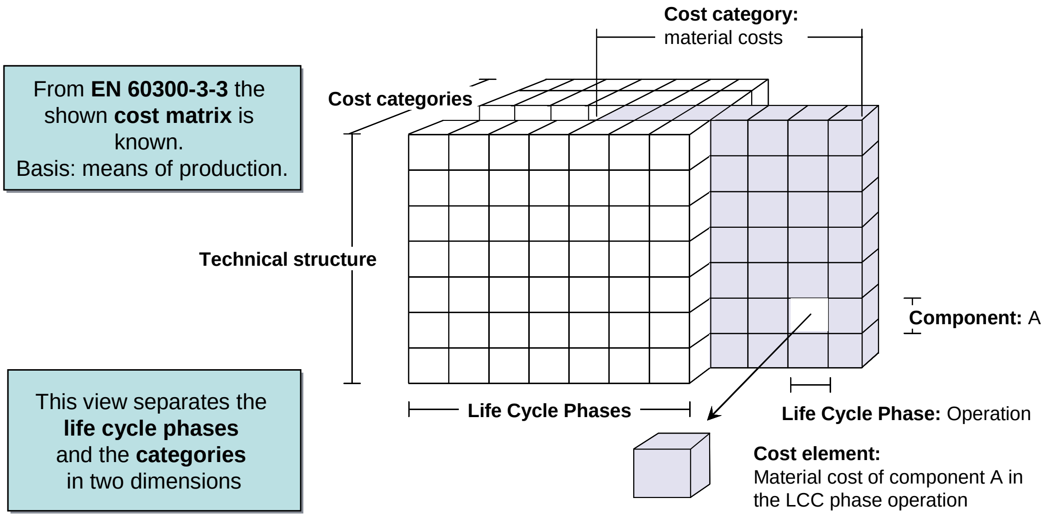

Figure 10: Three-dimensional cost matrix of LCC (cost element concept)

Cost Breakdown Structure (CBS)

Given the top derailment causes and related derailment costs as an outcome of WP1 and the effects on derailment reduction assessed by WP2 (see section 2.3.2), sufficient cost data are available to identify the cost blocks related to derailment and to model the cost matrix. In addition, the relevant cost figures have been used, as estimated and collected from involved D-Rail partners through the RAMS and LCC template (see section 2.2 of the present deliverable as well as 2.2 of D7.2).

This standardised cost matrix for LCC is used as the basis for assessment and describes all costs. The main focus is thus on the unification of the used terms. This definition allows the comparison of each cost blocks between different calculations independent of the analyst. Also an important point is the standardized form of the useful explanations of the LCC, taking into account the data and uncertainties. The life cycle costing is carried out on the basis of the defined cost matrix with predefined cost items see Figure 11 below (as an example):

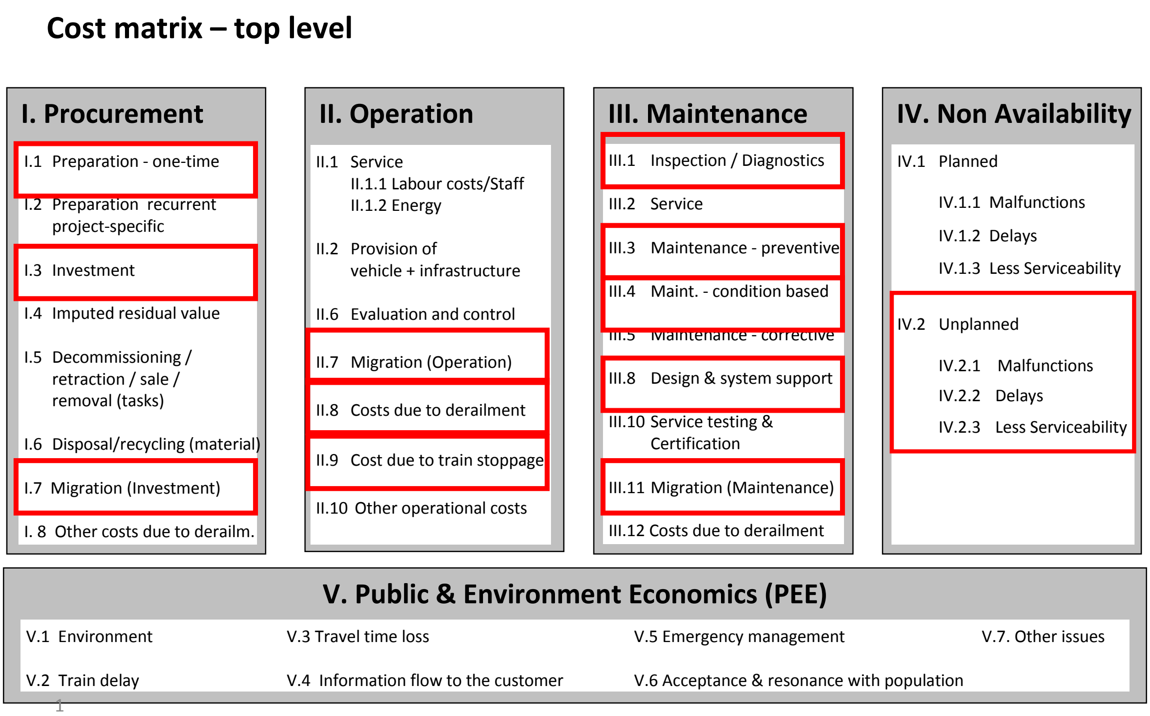

Figure 11: Cost matrix – top level

The task is to define the relevant cost blocks, which are relevant for the LCC analysis by using a cost matrix approach. The global approach is to use the mean value for the top level items and split up of values for investment, maintenance etc. (as shown in the Figure below).

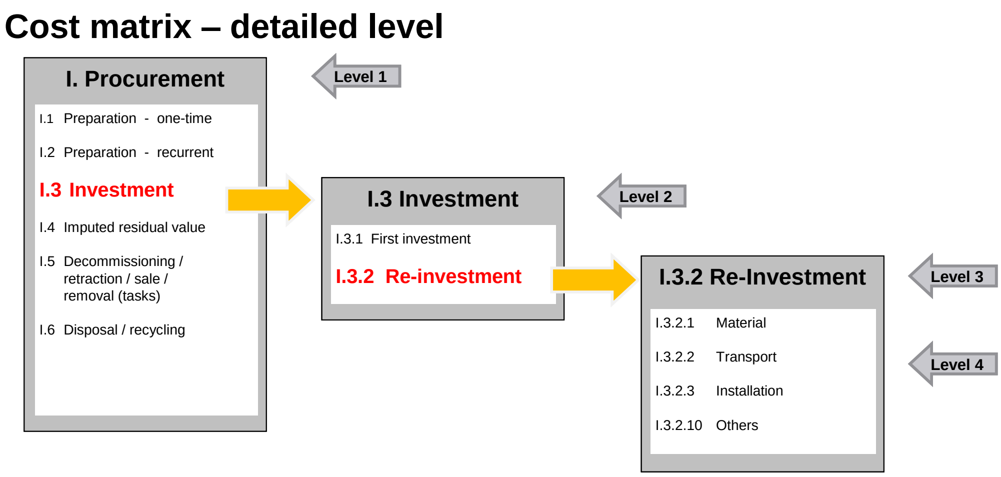

Figure 12: Cost matrix - split up of values

As a result the economic view on cost items at different levels as shown below (exemplary for superstructure of the track):

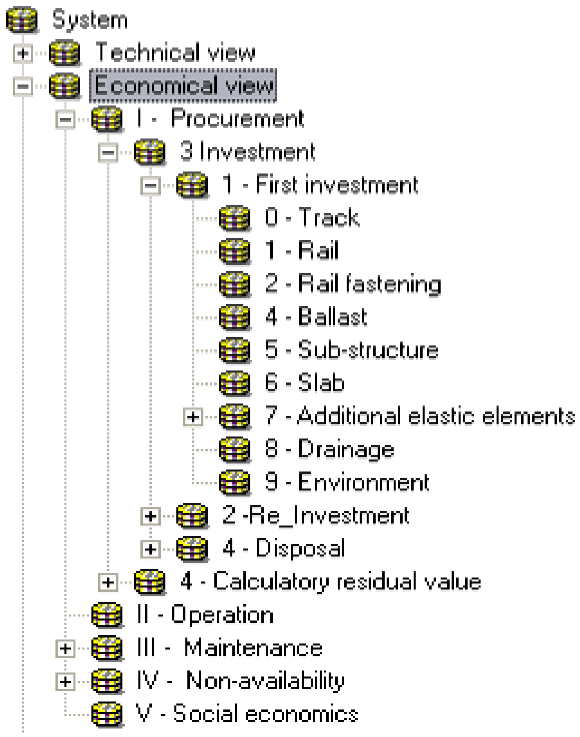

Figure 13: Economic view with results structured by cost items

Product Breakdown Structure (PBS):

Based on the breakdown of WTMS components and associated environment presented by the figure below, the PBS of WTMS can be built up.

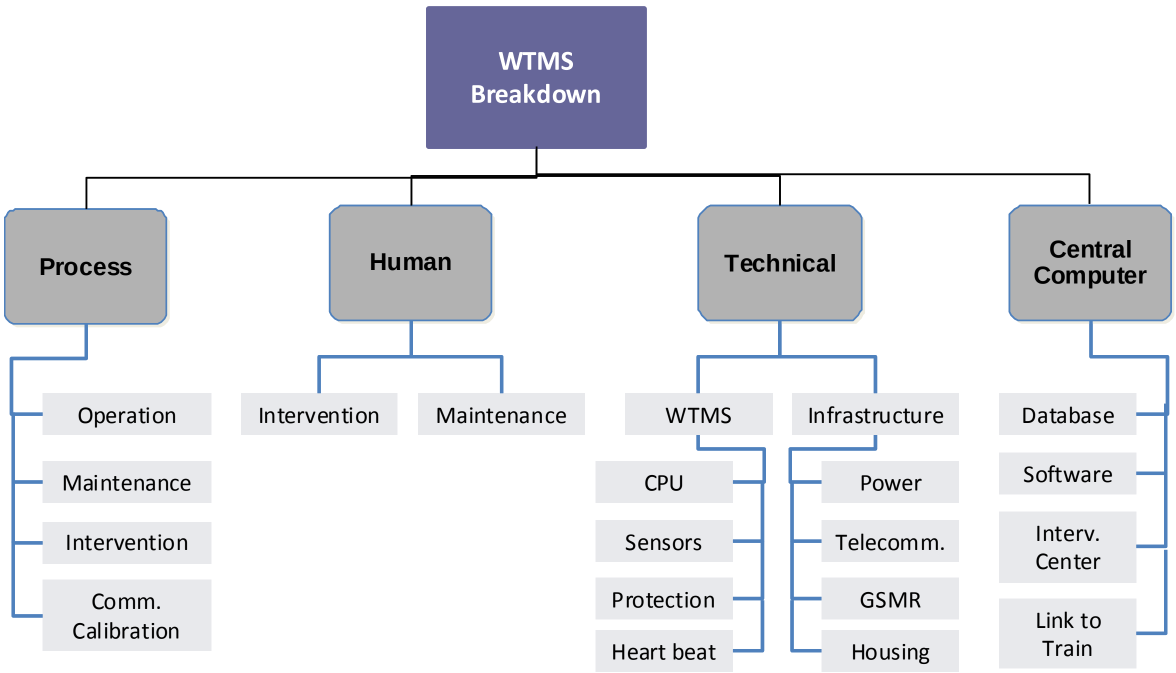

Figure 14: Components breakdown reg. WTMS

The Hot Box Detection System (used in Austria by ÖBB Infrastruktur Betrieb AG) consists of the following elements:

- Track-side equipment (scanners)
- Evaluation and control unit
- Data transmission equipment
- Visual display unit

The track-side equipment includes:

- Control and evaluation electronics accommodated within a cabinet
- Rail fastened measurement equipment with infrared sensors to record axle box and wheel temperatures, and also axle counters.

As a result the technical view contains the view on system, sub systems and components or modules, which are necessary for modular LCC models. An example is presented below.

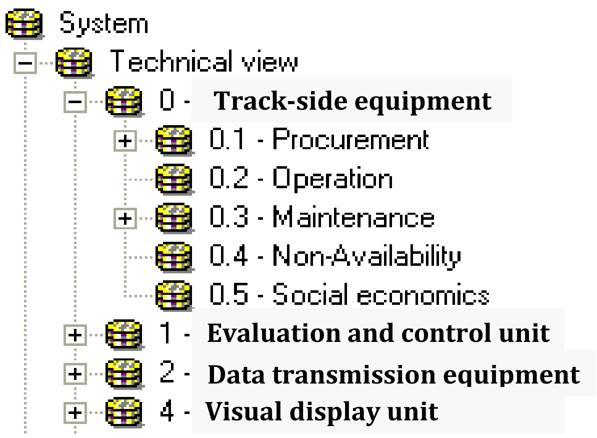

Figure 15: Technical view with results structured by components

The LCC model ensures a link between technology and economy.

Discounted cash flow or present value method

Costs and cost drivers have to be identified. Therefore the cash flow is very important for planning or controlling and for checking the financial budget. Future cash flows have to be discounted to the starting point of the study period, the time before (time to market) could be escalated to compare different alternatives.

The discounted cash flow is obtained by multiplying these factors with the annual costs for each year and the result of these accumulated costs is the New Present Value (NPV) for each of the alternatives. Within a LCC analysis all payments – also future payments – will be referred to a reference date using the discount rate i. The exponent means the respective year, in which the costs are incurred (see Figure 16).

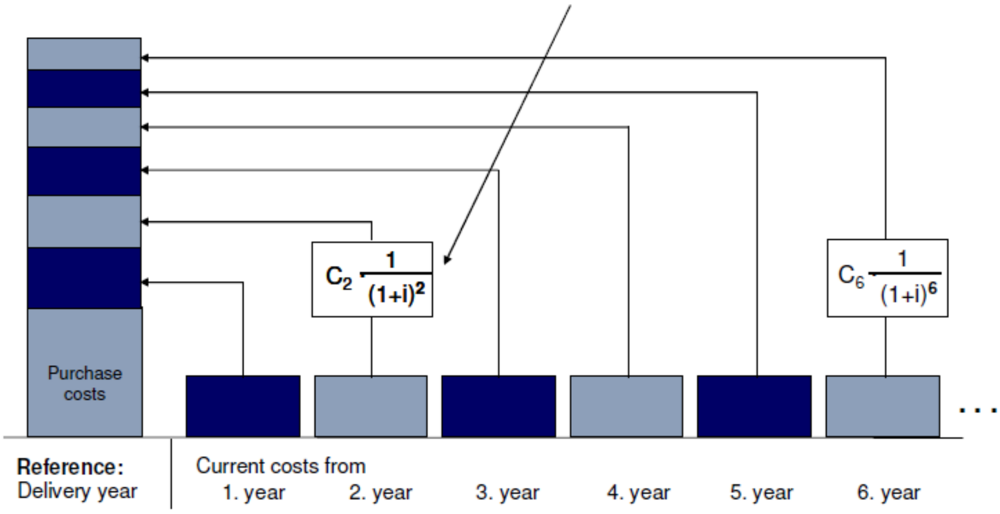

Figure 16: Annual costs

One sadvantage of the LCC as a complete financial assessment is that, if both the alternative and the reference have equal dimension time and costs, then the cost blocks could be neglected. If all the annual costs should be used for budget planning, this simplification is not allowed. In the case of comparing two alternatives with larger differences in the first investment the selected discount rate is the most important parameter for the LCC evaluation result. Only in the case of a major reduction of maintenance cost in the first year will the higher investments be balanced.

Discount rate and time horizon

Within a LCC analysis all payments – also future payments – will be referred to a reference date using the discount rate. In order to use a common discount rate and agreed study period for the LCC calculation, an evaluation was needed. Economic boundary conditions are key factors on the results provided through LCC analysis. It's inevitable to discuss and to agree on the selection of appropriate discount rate and time horizon to be valid for a given country.

Since the discount rate is not fixed in the D-Rail project, a 4% discount factor commonly used in project appraisal is used for the upcoming LCC analyses.

Based on the technical and economic view, the LCC analysis within WP7 of D-Rail project follows the process as shown in Figure 4 and Figure 8.

3.2 Description of monitoring cases and concepts

D1.2 provided a classification of derailment causes and their associated costs. D4.2 defined possible monitoring actions that would address these derailment causes. After short listing within the aims of the D-RAIL project three classes of interventions remain for LCC evaluation: hot axle box and hot wheel detection, axle load checkpoints and track geometry measurement systems.

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

- Hot axle box and hot wheel detection systems are already in wide-spread use. The general approach in all countries is the same, namely a density-based approach, i.e. one installation every x kilometres. The amount of kilometres is defined per country, based on the individual risk assessment. Based on the risk assessment in WP7.2, the benefit from additional systems is limited, however it should be emphasized that some countries have virtually complete coverage and others almost none. In the latter countries, significant benefit can be derived from HABD as it is a mature technology with low entrance hurdles.
- Axle load checkpoints are extensively used in some countries, but have not yet achieved the same overall penetration as HABD. Since they cover several derailment causes, their potential is high. For ALC, a risk-based approach makes more sense than a density-based approach. As such, sites will be chosen at border stations, shunting yards, and major ports as well as to protect expensive infrastructure elements such as tunnels. This leads to an irregular distribution across countries, and it is no surprise that the highest current use is found in countries with many border crossings, shunting yards and tunnels, combined with higher operating speeds
- Track geometry measurement systems are mobile systems installed on track recording cars. They detect several types of derailment causes and were shown in D7.2 to be an efficient safety measure. These systems are in wide use in Western Europe, but a significant benefit can be derived in countries that do not make use of this technology.

The safety benefits based on derailment cost reduction (monetized risk reduction) were analysed in D7.2. Safety forms a part of the overall economic assessment, but the present deliverable will attempt to quantify further benefits, especially in the area of maintenance optimization. All cost figures from LCC and safety benefits were taken from D7.2 based on the scenarios developed in D5.1 & D5.2. Additional numbers for further cost and benefit categories were developed in close cooperation with WP5 as they were not provided from other work packages.

The business cases and related scenarios developed in WP5 are presented in the following Table. The LCC analyses will assess the scenarios based on the defined business cases described below in order to evaluate the additional number of monitoring systems concerning the three proposed systems to achieve the 20% LCC reduction as set out in D-Rail. Thus the reduction in derailments in relation to number of monitoring system will be determined through LCC analyses. The assumed additional number regarding the monitoring systems will be used in the cost-benefit analyses and LCC analyses in the sections 3.6.2 and 3.6.3 respectively.

Table 3: Investigated scenarios based on the business cases of WP5

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

In the course of the development and assessment of business cases WP5 has developed a concept for the estimation of the number and placement of inspection and monitoring sites. This concept proposes a categorization to cover all upcoming systems and to answer the question of positioning in the network of an IM by considering the existing experiences of IM with WTMS. And the categorization will in principle also apply to on-board systems monitoring the infrastructure.

Therefore measurement values in a sense of parameter types - connected to WTMS and/ or OMD are categorized, when and how quick they might change during a train journey, are well described in the concept (see details in D5.2, section 6.6.1). In the following tables the results of the concept with the relevant figures for the economic analyses (both cost-benefit analyses and the LCC analyses) are presented.

Table 4: Scenarios for hot box detection (HABD)

HABD	**Target and assumptions**	**Result: Number of devices and risk/cost reduction**
Maximum scenario	100% risk reduction, aiming at linear and exponential cases on all tracks. This would require a target density of 65 km, but isolated cases of exponential events remain possible.	3’600 devices for ~100% risk reduction
Optimum scenario	aiming only at linear cases on all tracks, assuming a distance of not less than 150 km between inspection sites, 65 km for	1’790 devices for ~91% risk reduction and ~97% cost reduction. This scenario is in line with

	main freight lines, and a lower value for high-speed tracks (out of scope).	established practice or target values in countries such as Germany, Switzerland, France and Austria.
Minimum scenario	Aiming only at linear cases on main freight lines, assuming a distance of no less than 150 km between inspection sites.	160 devices for a 9% risk reduction, although a much higher proportion of the costs would be covered.

Table 5: Scenarios for Axle Load Checkpoints (ALC)

ALC	**Target and assumptions**	**Result: Number of devices and risk/cost reduction**
Maximum scenario	Any scenario aiming for the dynamic effects will result in very high numbers without eliminating residual risk completely	
Optimum scenario	ALCs positioned at shunting yards and ports (1 double system per yard) and border crossings and in front of 1/3 of critical infrastructure elements.	500 devices. This should catch all cases of skew loading and wheel defects and reduce the damage of load shifting due to the protection of critical infrastructure elements by ~35%,
Minimum scenario	ALCs positioned at shunting yards and border crossings,	320 devices ~100% risk reduction for all cases of skew loading and wheel defects.

In the case of TGMS:

According to WP5 there are insufficient data in this area for a bottom-up estimation. A top-down approach would suppose that the inspection intervals are driven by present inspection requirements and that the number of measurement cars is driven by the utilization from the inspection intervals. Based on Swiss and German Figures (0.5 ultrasound car per 7.500 km (CH), 3 ultrasound cars for 61.200 km (DE)) about 22 ultrasound cars would suffice for all of Europe. Similarly, 32 geometry recording cars could cover all of Europe, but as today's measurement cars fulfil multiple roles above the pure track geometry inspections, the numbers lie in a bracket from 20-40 cars. The risk reduction can only be estimated as it is not only dependent on detection, but also on intervention. Successful intervention is dependent on several factors:

- Some measures require the right meteorological conditions (i.e. work not possible in winter)
- Some measures require significant financial outlay or are dependent on critical resources of limited availability (tamping trains, specialized construction crews, …), which triggers a delay due to planning and non-availability

- The wrong action can result from data, e.g. a low-hanging catenary might indicate a problem with the track and not the catenary.

No quantitative data could be provided from the DRAIL participants in this area.

3.3 Effect of current and estimated increase of freight traffic

The general basis for the current and estimated increase of freight traffic is listed in D7.1, based on WP 2. As a consequence of these developments the impact on wagon fleet capacity and capability are significant for the rail freight sector.

The implications of future requirements are linked with potentially higher risks and costs as these will increase with the growth of productivity of rail transport. These in turn will affect the availability of the infrastructure (e. g. capacity of infrastructure, train paths) and rolling stock (wagon fleet capacity and capability); operations (change in operation volumes e.g. possession times); safety (risks); and asset utilization of the railway system.

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

Non-linear effects can however be found in the infrastructure utilization aspects (we assume the effects on vehicles to be negligible, as the linear traffic increase will result in a linear increase in the number of vehicles and not a higher utilization of the existing vehicle fleet). Currently, there are no economic models available in this area. Operational experience from Switzerland in heavily utilized subsections of the network (those that already today show use as expected by DRAIL in 2050) suggests that the infrastructure degradation progresses faster than expected and shows new types of rail degradation that have not been previously observed (see for example derailing of Metro in Schwerzenbach, Switzerland 2013-02-16). However, it was also found that degradation of infrastructure due to freight vehicles is more or less as expected and that the unexpected effects may come from rapidly accelerating trains such as short-distance commuter trains. Since the economic impact on the IM is very heavy, more research in this area would be of high value.

Finally, we turn to the effect of traffic increase on the WTMS themselves.

The useful life of WTMS mainly depends on the weather conditions (snow, rain, ice) and possibly occurring pollution (lost freight). An increase in maintenance costs due to increased train density is not expected.

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

An LCC analysis should take into account and evaluate a system not only in terms of economic effects but also with the capability for significant improvement to future needs. Future requirements like the forecasts of increasing load in the near future have to be part of the decision making process. The effects on RAMS are discussed in D7.2, the effects on maintenance in 3.6.3.

3.4 Impact of Migration on LCC

Three different aspects of migration are to be considered:

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

3.4.1 Technical migration of equipment

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

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

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

3.4.2 Migration towards integrated approach

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

This approach requires:

- Compatible technical equipment: this is included in the LCC cost per equipment and also covers power, housing, UPS
- Network connectivity between equipment sites and central processing facilities: for many sites, network connectivity is available by fibre optic cabling. At other locations, one of the following options must be considered:
  1. Other high-bandwidth technologies (SDH over copper cable, …)
  2. Identification of alternate locations with available connectivity
  3. Mobile (GSM-R, 2G/3G/4G public, a future LTE-R technology may provide higher bandwidths)
  4. Installation of network connectivity by the IM or a telecom service provider

  Alternatives 1 & 2 are preferred and virtually cost-free at an early design stage. Alternative 3 may not provide sufficient bandwidth and cannot offer sufficient SLAs in the case of public providers. Alternative 4 is significantly more expensive, about 5€ per meter of installation.

We will assume that 20% of all sites will require Alternative 4 and 1 km of new cabling. This can be obtained e.g. by positioning close to railway stations. On average, this gives a cost of 1'000 € per WTMS site for network connectivity.

- Central processing facilities and decision-making resources (human or algorithmic): a single redundant installation costs about 600 k€. Operational expenses about 750 k€ / year (mainly manpower). A central processing facility can serve more than 500 WTMS of all types combined. It is likely that more central processing facility than strictly necessary will be constructed because every IM will have at least one facilities. We will account for this by assuming higher costs per WTMS for the central parts, i.e. 2 k€ one-time costs and 2.5 k€ yearly recurring costs per WTMS.
- Connection to railway operations to implement decisions (e.g. train stopping): a low-cost solution can be implemented with a phone call to the track operations centre at virtually no cost. This solution is in operational use as a fall-back in Switzerland. The more complex solution places a console into the track operations centre that displays intervention orders from the central processing facility. This solution allows for safety checks as the operations centre must acknowledge the order and act on it, which is controlled by the central processing facility. As all concerned sites are sites with excellent network connectivity and redundancy, the costs are limited to the pure equipment costs. These costs are not per WTMS, but per number of railway operation centres, so the effect on a single WTMS is negligible.

3.4.3 Shift from manual surveillance towards automated equipment

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

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

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

3.5 Analysis of the socio-economic effect

Social Cost and Benefit Analysis (SCBA) enables us to take socio economic effects into account which comprises (but is not limited to):

- Environment
- Train delays
- Travel time loss for the customer
- Customer information
- Emergency management
- Acceptance by customers, customer's satisfaction

The RAM(S) quality of the RAM(S) / LCC analysis is translated into money with a Social Cost Benefit Analysis. An important factor here is how the Infra Manager values the (non) delivery of certain functionalities and safety in terms of finance.

In fact, the Social Cost and Benefit Analysis is the only type of analysis that can be used to underpin choices in an integrated manner that supports the decision-making process.

The output of the Social Cost Benefit Analysis consists of a comparison of the existing situation with the new situation. It can be expressed e. g. in costs of cancelled and delayed trains caused by timetable affecting errors in infrastructure, split into effects for the rail sector (costs for busses, value of freight delay) and effects for society (value of passenger delays).

The negative effects of derailments can be classified into three different categories:

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

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

The effects from track unavailability, costs to return to normal operations and all long-term effects are typically not included at all or roughly approximated, despite their possibly large effects. The following sections will provide quantitative approximations of these effects.

- Effects from track unavailability

  There is a strong dependency of the economic effects to the track utilization and the availability of alternative routes.

  As an upper limit, an SBB analysis showed the following effects of a mainline event on one the most frequently used tracks. The actual event took place at 7:51 (heavy operating hours) and normal track operations were possible again at 12:00. The single missing track carried so much traffic that all alternatives (three tracks) could not fully compensate the traffic, due to track unavailability in the next major station and insufficient capacity of the switches-track combinations. During the four hours, 409 trains incurred delays for a total of 4'016 train delay minutes. 80 train courses were completely of partially suppressed. About 250'000 passengers were affected by the event, which resulted in 2,5 M passenger delay minutes. For delay minutes, SBB distinguishes between delays without consequence for the passenger and those that result in a missed connection. All of these costs are subsumed with a figure of 40 CHF per train delay minute. Costs from track unavailability for this single event according to SBB methodology are approximately 150'000 €, which translates to 40 k€ per hour of mainline interruption. On the lower side, on a low-traffic auxiliary line, a derailment may affect only a handful of trains, so a value of 1 k€ per hour seems reasonable. These cost figures combine all costs, i.e. including the effect on passengers.

  We suppose that the actual figures vary between countries, but no hard facts could be obtained from other countries. We note however that accident reports from Germany and UK do not show significantly different figures compared to Swiss reports for direct damages, and will thus assume the same for indirect costs.

- Costs to return to normal operations

  We will assume that repairs to vehicles and infrastructure are fully included in the direct damages. The remaining costs are thus the intervention and recovery costs. Intervention costs are typically stand-by costs, i.e. intervention organisations (infrastructure manager, public safety/security organisations) are kept in readiness at all times to be able to act in case of an event. Ignoring the public safety and security organisations, on the infrastructure side this translates to intervention management, towing and technical assistance to vehicles, and personnel for derailment. On low-density networks, this is an ad hoc service using available resources, but on high utilization networks, a professional service is required as it allows reduction of track unavailability. In some countries such as Switzerland and Austria with long tunnels, technical assistance is combined with fire fighting activities, so that rescue and fire extinguisher trains also act as technical assistance and derailment vehicles. In 2013, 7% of SBB Intervention events were due to technical assistance after derailment, i.e. 10 M€ can be assigned to derailment preparedness and recovery costs, or 26'000 € per derailment. This number can be challenged, since reducing the number of derailments will not lower the standby costs, but no better approximation of recovery costs is available to us.

Public sector costs (rescue services, fire fighters, police, justice) cannot adequately be estimated. It is very likely that no additional resources and capabilities are deployed for derailments, due to the relatively low occurrence. Where specialized capabilities are required or mandated, the infrastructure manager would be the proper instance. Some professional fire fighting brigades possess street vehicles capable to act on rails, but these seem targeted for subways and metropolitan railways outside of the D-RAIL scope. Thus it seems reasonable to exclude these costs from further consideration.

- Long term effects (as “soft factors”)

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

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

3.6 Economic impact of monitoring systems

Impact assessment suggested that cost-effective risk reduction might potentially be achieved with preventative measures, beneficial for all freight train derailments, instead of trying to mitigate a few derailments of specific dangerous goods wagons.

This section aims to evaluate the economic impact of monitoring systems by discussing the question of the reduction in derailment costs and the whole life cycle costs for the monitoring systems. To address all advantages and benefits of monitoring systems, the analyses have not only to include the direct cost for the carriers and the infrastructure managers, but also the indirect costs (e. g. socio-economic effects).

Within the economic analysis of the inspection and monitoring systems WP7 takes two approaches to demonstrate the economic benefits of the three proposed inspection and monitoring systems, which is presented in chapter 3.6.2 and 3.6.3.

The first approach presented in chapter 3.6.2 is a cost-benefit analysis with the calculation of the cumulated costs by taking into account the additional benefits on avoided costs due to derailments associated to each of the proposed inspection and monitoring system. The used data are consistent with the data used for the risk analysis based on GB and SBB risk data scaled for EU27 (see D7.2 of WP7). The second approach is the LCC analysis for the evaluation of the additional number of inspection and monitoring systems necessary to achieve the 10%-20% LCC reduction.

The cost figures regarding additional benefits result from assumptions - since it is difficult to quantify the additional benefits e. g. from maintenance cost optimization- based on SBB data, experiences from North America and on the study on Heavy Haul Transport in Sweden (see Condition-Based Maintenance for Effective and Efficient Rolling Stock Capacity Assurance). In this regard it is worth mentioning that there is an EU research project which was launched in December 2010 called ACEM-Rail (Automated and Cost Effective Maintenance for Railway) in the field of railway infrastructure maintenance organization and planning supported by the European Commission (see more in section 3.7.3).

It must be noted that the avoided costs per derailments, as taking account for the cost-benefit analysis, should only be considered if these costs are not already included in the derailment costs. For instance, the DB data on derailment costs, provided for D1.2 of WP1, are already included in the costs due to derailment and therefore don't need to be considered in the case of DB.

In contrast to this, the costs for the establishment of the required infrastructure (e. g. precise proof of measurement data and needed personal for taking decision on action, real-time data exchange and communication, connection between operation and intervention, vehicle identification by RFID, vehicle monitoring device, etc.) are not considered in these analyses.

In the second approach the Life Cycle Costs (LCC) of the three proposed inspection and monitoring systems are calculated considering the required number of additional installations to achieve the 20% LCC reduction. Similarly to the cost-benefit analysis, the LCC analyses use the same cost figures, but these are not based on GB data rather on the given specific costs per cause of derailments (taken from Table 3.4 and Table 3.5 of D2.3). Contrary to cost-benefit analysis, the LCC analysis considers only expenditures but not additional benefits.

The following sections, particularly the sections 3.6.2 and 3.6.3 demonstrate that many aspects influence the life cycle costs of inspection and monitoring systems. And not only the additional number of installations, but the efficient deployment of the installations at appropriate locations creates an added value considering aspects such as legal, financial, safety, the risk landscape (SMS, CSM-RA) of the concerned infrastructure manager, specific boundary conditions (climate effects, curves, tunnels, bridges, natural phenomenon) and many other aspects.

However, the goal should be to identify the cost-efficient solution to prevent and mitigate risk for derailment. By doing this, a right balance between the increase of investment, maintenance and operating costs compared with the saved cost due to fewer derailments should be targeted.

But first the effect of reliability and maintenance on the whole life cost of the monitoring system is evaluated by maintainability analysis. HABD is taken as a case study for this maintainability analysis because of the quality of the available (RAMS) data. This is presented in the following section.

3.6.1 Effect of reliability and maintenance on the cost

When a derailment 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 railway assets and environment and may include possible loss of human lives. Derailments can occur due to several factors caused by e. g. poor track (and vehicle) quality itself, or due to the external factors such as hot axle condition and high axle load. In order to protect against derailment due to external factors, several protective devices have been incorporated, e.g. WTMS including HABD, ALC, etc. In order to protect against derailment for instance due to a hot axle condition, high level reliability performance of HABD is vital. Unreliability of HABD's contributes negatively to the detection of hot axle condition, and increases the derailment likelihood and its associated consequence.

There are two major options to compensate for unreliability. These include 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 increases cost.

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

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

Figure 17 shows the variation of restoration cost versus restoration interval for three different HABD's with different reliability values. The important results are also tabulated in Table 6.

As seen in the figure, higher reliability of HABD (i.e. higher MTBF) will lead to higher safe-life length, when a minimum reliability level (R=99%) is required, see corresponding time in

Figure 17 for points 1, 2 and 3, and the values in Table 6. In addition, it is evident that the higher the reliability, the lower the maintenance cost that can be achieved.

It is also evident that when there are no minimum reliability requirements, higher reliability of HABD will lead to an optimum restoration time at longer intervals, and an even lower cost per unit of time, which will lead to the most cost effective LCC, see corresponding cost values in Figure 17 for points 4, 5, and 6 and the values in Table 6.

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

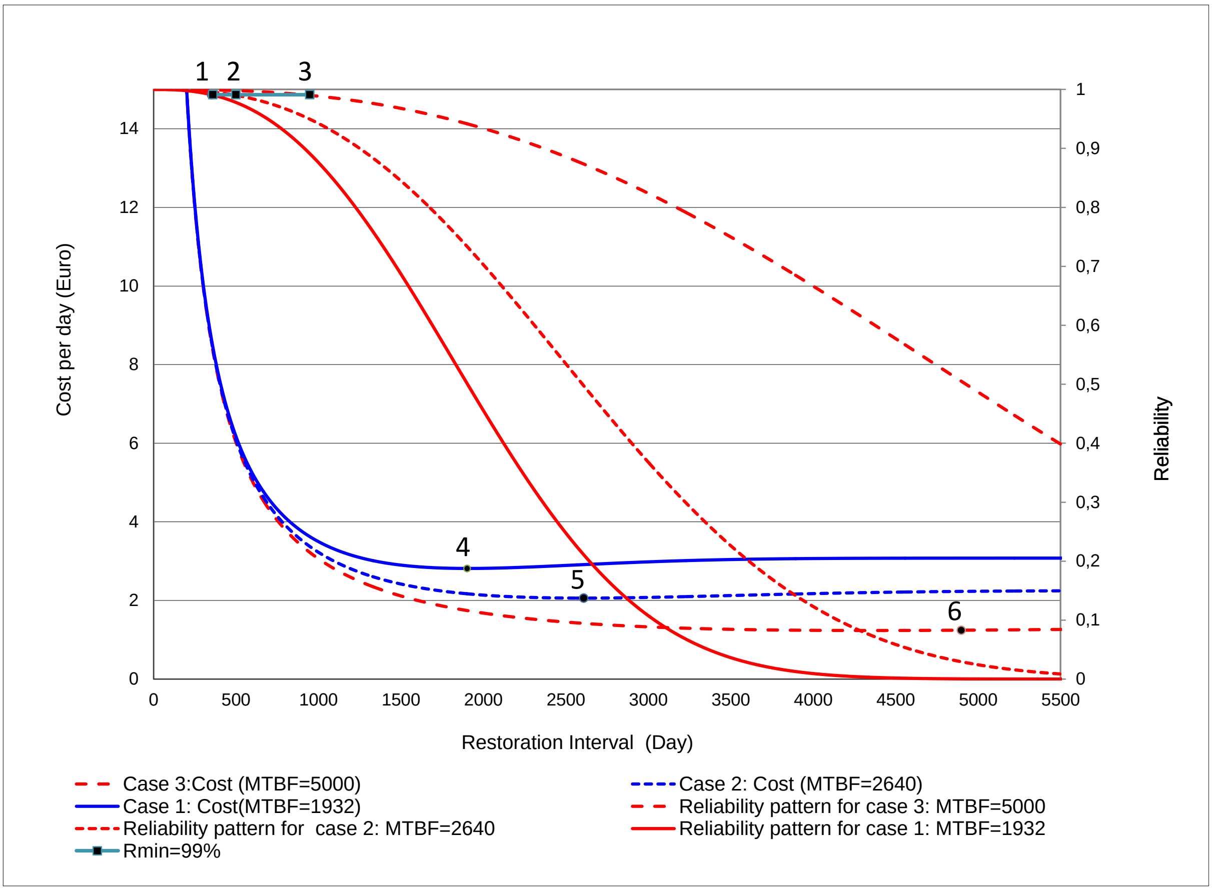

Figure 17: Variation of restoration cost versus restoration interval for HABDs

Table 6: Corresponding MTBF wit and without Reliability limit

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

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

3.6.2 Cost-benefit analysis

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

Safety forms a part of the overall economic assessment. In fact the business cases demonstrate increased value not only to safety related benefits associated with derailment reduction but also to maintenance (non-safety) related benefits, which are considered in the proposed monitoring systems. Therefore the present deliverable seeks to quantify the further benefits, particularly in terms of maintenance optimization.

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

An assumed timeline of 2020 to 2050 has been considered as the period over which the costs and benefits would be realised. The monitoring systems considered for the LCC and cost benefit analysis are Hot Axle Box and Hot Wheel Detection (HABD), Axle Load Checkpoints (ALC) and Track geometry measurement systems (TGMS). As stated previously, the reason for that is that more than half of the derailments (and a share of 75% of the costs) are addressed by these three systems and thus they have the biggest impact on derailment reduction. By taking into account of all relevant costs for the whole life cycle of the systems the LCC can be calculated. These costs refer to investment and reinvestment, operation, maintenance, disposal and migration.

Based on input from D-Rail WP5 and assumptions derived in WP2 regarding the estimated increase in freight traffic towards 2050 up to 2050 (see D7.2 section 3.2.3 risk assessment) the following two scenarios are considered:

- high scenarios: assumed "high" cost / "high" level risk reduction option according to the assumed number of additional units of WP5
- low scenarios: assumed "low" cost / "low" level risk reduction option according to the assumed number of additional units of WP5

Table 7: Summary of the assumed number of additional units (see deliverable D7.2 and D5.2 of WP5)

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

The information on the figures given in the Table 7 is based on the business cases with related scenarios defined in WP5 (see section 3.2).

It must be noted that in the cost-benefit analysis and the LCC analysis the mentioned optimum scenario (defined in WP5) corresponds to the assumed "high" cost/"high" level risk reduction option and the minimum scenario (defined in WP5) corresponds to the assumed "low" cost/"low" level risk reduction option respectively.

To evaluate the economic impact of the proposed monitoring systems, first the cost-benefit analysis is performed by taking into account the additional benefits based on avoided costs due to derailments. The avoided derailment cost per derailment are e .g. average derailment cost per type according to D2.3 and D7.2, avoided costs to return to normal operations after derailments, avoided train delay costs, and maintenance optimization due to condition-based maintenance.

In the second step LCC analysis is carried out. Both LCC and cost-benefit analyses are evaluated for the three selected systems considering the two scenarios (high and low). In the following the cost-benefit analysis is presented as an example for ALC considering the high scenario (assumed "high" cost/"high" level risk reduction) as well as the low scenario ("low" cost/"low" level risk reduction).

a) cost data for the three proposed monitoring systems (mainly based on cost data from D2.3, WP2):

Table 8: Costs for investment, reinvestment, operation, maintenance and disposal for the “status quo”

CENARIO 1: HIGH	Assumed "high" cost / "high" level risk reduction option.					
ONITORING SYSTEM		UNIT COSTS				
	(source)	Investment cost per unit D-Rail D2.3 Table 3.4	Reinvestment cost per unit D-Rail D2.3 Table 3.4	Disposal costs per unit estimated	Annual operation costs (e. g. energy, fuel consumption etc.) per unit estimated	Annual maintenance costs per unit D-Rail D2.3 Table 3.4
Hot axle box and hot wheel detection		229.600 €	147.600 €	5.000 €	4.796 €	7.380 €
Axle load checkpoints		110.000 €	73.000 €	5.000 €	3.600 €	13.000 €
Track geometry measurement systems		950.000 €	570.000 €	25.000 €	47.500 €	76.000 €

b) the total costs of the three proposed monitoring systems associated to the assumed number of additional units considering the two scenarios (based on the input from WP5 on number and location of monitoring sites, cf. 2014) are presented in the table below:

Table 9: Costs associated to the assumed number of additional installation sites for high scenario

ONITORING SYSTEM		SYSTEM ASSUMPTIONS		TOTAL COSTS				
	(source)	Assumed number of additional units (cf.2014) D-Rail WP5	Lifetime (years) D-Rail D2.3 Table 3.4	TOTAL Investment cost D-Rail D2.3 Table 3.4	TOTAL Reinvestment cost D-Rail D2.3 Table 3.4	TOTAL Disposal cost estimated	TOTAL Annual operation costs estimated	TOTAL Annual maintenance costs D-Rail D2.3 Table 3.4
Hot axle box and hot wheel detection		790	15	181.384.000 €	116.604.000 €	3.950.000 €	3.788.840 €	5.830.200 €
Axle load checkpoints		300	10	33.000.000 €	21.900.000 €	1.500.000 €	1.080.000 €	3.900.000 €
Track geometry measurement systems		20	10	19.000.000 €	11.400.000 €	500.000 €	950.000 €	1.520.000 €

Table 10: Costs associated to the assumed number of additional installation sites for low scenario

MONITORING SYSTEM		SYSTEM ASSUMPTIONS		TOTAL COSTS				
	(source)	Assumed number of additional units (cf.2014) D-Rail WP5	Lifetime (years) D-Rail D2.3 Table 3.4	TOTAL Investment cost D-Rail D2.3 Table 3.4	TOTAL Reinvestment cost D-Rail D2.3 Table 3.4	TOTAL Disposal cost estimated	TOTAL Annual operation costs estimated	TOTAL Annual maintenance costs D-Rail D2.3 Table 3.4
1	Hot axle box and hot wheel detection	160	15	36.736.000 €	23.616.000 €	800.000 €	767.360 €	1.180.800 €
2	Axle load checkpoints	120	10	13.200.000 €	8.760.000 €	600.000 €	432.000 €	1.560.000 €
3	Track geometry measurement systems	10	10	9.500.000 €	5.700.000 €	250.000 €	475.000 €	760.000 €

More information on the assumed number of additional installation sites and associated costs can be seen in section 3.6.3 and in the deliverable D5.2 of WP5.

c) calculation of the Net Present Value (NPV):

Within a LCC analysis all payments – notably the future payments – will be referred to a reference date using the discount rate. Multiple this factor with the annual costs for each year results in the discounted cash flows. Thus the NPV for each of the year’s costs (investment, reinvestment, operation, maintenance and disposal costs incurred during the whole life cycle costs) is calculated using the discount factor and summing up these cash flows. However, the result of the accumulated costs is the Net Present Value (NPV), which is presented for ALC as an example in the Table 11 and Table 12 below. As there is no specification regarding the discount rate WP7 agreed on a discount factor of 4% as this is common in project appraisal; the time period considered was 30 years up to 2050.

As a result the NPV of the considered costs (investment, re-investment, operation, maintenance and disposal) regarding ALC for the high scenario is 1.997.905 € and the cumulative NPV is 143.097.302 €. This is presented in Table 11 below.

Table 11: Net Present Value of the whole life costs regarding ALC for high scenario

Axle load checkpoints	capital costs investment, reinvestment & disposal	ongoing costs operation costs	ongoing costs maintainance costs	Net costs per year	Net Present Value 4,0%	Cumulative Net Present Value COSTS
2021	33.000.000 €	1.080.000 €	3.900.000 €	37.980.000 €	36.519.231 €	36.519.231 €
2022	0 €	1.080.000 €	3.900.000 €	4.980.000 €	4.604.290 €	41.123.521 €
2023	0 €	1.080.000 €	3.900.000 €	4.980.000 €	4.427.202 €	45.550.723 €
2024	0 €	1.080.000 €	3.900.000 €	4.980.000 €	4.256.925 €	49.807.647 €
2025	0 €	1.080.000 €	3.900.000 €	4.980.000 €	4.093.197 €	53.900.844 €
2026	0 €	1.080.000 €	3.900.000 €	4.980.000 €	3.935.766 €	57.836.611 €
2027	0 €	1.080.000 €	3.900.000 €	4.980.000 €	3.784.391 €	61.621.001 €
2028	0 €	1.080.000 €	3.900.000 €	4.980.000 €	3.638.837 €	65.259.839 €
2029	0 €	1.080.000 €	3.900.000 €	4.980.000 €	3.498.882 €	68.758.721 €
2030	21.900.000 €	1.080.000 €	3.900.000 €	26.880.000 €	18.159.165 €	86.917.886 €
2031	0 €	1.080.000 €	3.900.000 €	4.980.000 €	3.234.913 €	90.152.799 €
2032	0 €	1.080.000 €	3.900.000 €	4.980.000 €	3.110.493 €	93.263.292 €
2033	0 €	1.080.000 €	3.900.000 €	4.980.000 €	2.990.859 €	96.254.151 €
2034	0 €	1.080.000 €	3.900.000 €	4.980.000 €	2.875.826 €	99.129.977 €
2035	0 €	1.080.000 €	3.900.000 €	4.980.000 €	2.765.217 €	101.895.194 €
2036	0 €	1.080.000 €	3.900.000 €	4.980.000 €	2.658.863 €	104.554.057 €
2037	0 €	1.080.000 €	3.900.000 €	4.980.000 €	2.556.599 €	107.110.655 €
2038	0 €	1.080.000 €	3.900.000 €	4.980.000 €	2.458.268 €	109.568.923 €
2039	0 €	1.080.000 €	3.900.000 €	4.980.000 €	2.363.719 €	111.932.643 €
2040	21.900.000 €	1.080.000 €	3.900.000 €	26.880.000 €	12.267.681 €	124.200.324 €
2041	0 €	1.080.000 €	3.900.000 €	4.980.000 €	2.185.391 €	126.385.715 €
2042	0 €	1.080.000 €	3.900.000 €	4.980.000 €	2.101.338 €	128.487.053 €
2043	0 €	1.080.000 €	3.900.000 €	4.980.000 €	2.020.517 €	130.507.570 €
2044	0 €	1.080.000 €	3.900.000 €	4.980.000 €	1.942.805 €	132.450.375 €
2045	0 €	1.080.000 €	3.900.000 €	4.980.000 €	1.868.082 €	134.318.457 €
2046	0 €	1.080.000 €	3.900.000 €	4.980.000 €	1.796.232 €	136.114.689 €
2047	0 €	1.080.000 €	3.900.000 €	4.980.000 €	1.727.147 €	137.841.836 €
2048	0 €	1.080.000 €	3.900.000 €	4.980.000 €	1.660.718 €	139.502.553 €
2049	0 €	1.080.000 €	3.900.000 €	4.980.000 €	1.596.844 €	141.099.398 €
2050	1.500.000 €	1.080.000 €	3.900.000 €	6.480.000 €	1.997.905 €	143.097.302 €

Table 12: Net Present Value of the whole life costs regarding ALC for low scenario

Axle load checkpoints	capital costs investment, reinvestment & disposal	ongoing costs operation costs	ongoing costs maintainance costs	Net costs per year	Net Present Value 4,0%	Cumulative Net Present Value COSTS
2021	13.200.000 €	432.000 €	1.560.000 €	15.192.000 €	14.607.692 €	14.607.692 €
2022	0 €	432.000 €	1.560.000 €	1.992.000 €	1.841.716 €	16.449.408 €
2023	0 €	432.000 €	1.560.000 €	1.992.000 €	1.770.881 €	18.220.289 €
2024	0 €	432.000 €	1.560.000 €	1.992.000 €	1.702.770 €	19.923.059 €
2025	0 €	432.000 €	1.560.000 €	1.992.000 €	1.637.279 €	21.560.338 €
2026	0 €	432.000 €	1.560.000 €	1.992.000 €	1.574.307 €	23.134.644 €
2027	0 €	432.000 €	1.560.000 €	1.992.000 €	1.513.756 €	24.648.401 €
2028	0 €	432.000 €	1.560.000 €	1.992.000 €	1.455.535 €	26.103.935 €
2029	0 €	432.000 €	1.560.000 €	1.992.000 €	1.399.553 €	27.503.488 €
2030	8.760.000 €	432.000 €	1.560.000 €	10.752.000 €	7.263.666 €	34.767.154 €
2031	0 €	432.000 €	1.560.000 €	1.992.000 €	1.293.965 €	36.061.119 €
2032	0 €	432.000 €	1.560.000 €	1.992.000 €	1.244.197 €	37.305.317 €
2033	0 €	432.000 €	1.560.000 €	1.992.000 €	1.196.344 €	38.501.660 €
2034	0 €	432.000 €	1.560.000 €	1.992.000 €	1.150.330 €	39.651.991 €
2035	0 €	432.000 €	1.560.000 €	1.992.000 €	1.106.087 €	40.758.078 €
2036	0 €	432.000 €	1.560.000 €	1.992.000 €	1.063.545 €	41.821.623 €
2037	0 €	432.000 €	1.560.000 €	1.992.000 €	1.022.640 €	42.844.262 €
2038	0 €	432.000 €	1.560.000 €	1.992.000 €	983.307 €	43.827.569 €
2039	0 €	432.000 €	1.560.000 €	1.992.000 €	945.488 €	44.773.057 €
2040	8.760.000 €	432.000 €	1.560.000 €	10.752.000 €	4.907.072 €	49.680.130 €
2041	0 €	432.000 €	1.560.000 €	1.992.000 €	874.157 €	50.554.286 €
2042	0 €	432.000 €	1.560.000 €	1.992.000 €	840.535 €	51.394.821 €
2043	0 €	432.000 €	1.560.000 €	1.992.000 €	808.207 €	52.203.028 €
2044	0 €	432.000 €	1.560.000 €	1.992.000 €	777.122 €	52.980.150 €
2045	0 €	432.000 €	1.560.000 €	1.992.000 €	747.233 €	53.727.383 €
2046	0 €	432.000 €	1.560.000 €	1.992.000 €	718.493 €	54.445.876 €
2047	0 €	432.000 €	1.560.000 €	1.992.000 €	690.859 €	55.136.734 €
2048	0 €	432.000 €	1.560.000 €	1.992.000 €	664.287 €	55.801.021 €
2049	0 €	432.000 €	1.560.000 €	1.992.000 €	638.738 €	56.439.759 €
2050	600.000 €	432.000 €	1.560.000 €	2.592.000 €	799.162 €	57.238.921 €

As a next step the additional numbers for further benefits of the different interventions are indicated consisting of:

- Avoided costs to return to normal operations after derailments,
- Avoided train delay costs,
- Avoided derailment costs per derailment (based on average derailment cost per type according to D2.3 and D7.2) and
- Maintenance optimization assumed due to condition-based maintenance strategy (see 3.7.3).

By multiplying the additional benefits due to avoided costs as a result of derailments with the number of avoided derailments per year (from D-Rail D7.2, figures extrapolated from the GB Safety Risk Model, SRM v7.2, and scaled up to EU27 states) results in the estimated total cost reduction due to avoided derailments per year which is presented in Table 13:

- Avoided costs per derailment are composed of the intervention and recovery operation costs. We ignore public sector costs (fire fighters, medical services, police, justice) since these organisations do not have separate provisions for (rare) derailment events. Further, we limit ourselves to the costs provided by SBB for intervention (see 3.5).
- Avoided train delay costs are composed of the effect of track unavailability on subsequent trains. We focus on a mainline event and use the costs provided by SBB (see 3.5).
- Avoided derailment costs are all direct costs regarding vehicles and infrastructure. This is the identical figure as the safety benefit used in D7.2, as derived from WP 3,

and from D-Rail D7.2, figures extrapolated from the GB Safety Risk Model, SRM v7.2, and scaled up to EU27 states.

- Potential maintenance cost optimization per category is based on the efficiency gain by using WTMS and TGMS data to perform Condition-Based Maintenance (CBM) instead of Time- or Interval-Based Maintenance.
    - For axle boxes, the estimate is based on the actual number of detected hot axle boxes in Switzerland per year, subsequently scaled to Europe. With Condition-Based Maintenance (CBM) strategy it is possible to save at least 33% from the 3.000 € costs per HAB.
    - For wheels, the estimate is based on assuming a 15 minute inspection per year and 1 hour of maintenance every 5 years per wagon. By switching to CBM, a cost reduction from 33%-50% can be assumed based on investigations performed on heavy iron ore wagons [1] [2]. For this study, the lower limit of 33% was assumed.
    - For track geometry, SBB costs for tamping and grinding operations (expected to benefit heavily from CBM) were scaled to Europe after correcting for higher costs in Switzerland. The SBB cost figures are mostly public [4], except for the allocation to operations. SBB assumes that 1%-5% of these costs can be saved by changing to a full CBM strategy. This study assumes 1% cost optimisation.

Table 13: Assumed costs regarding further benefits for additional numbers of installations for high scenario

MONITORING SYSTEM		AVOIDED COSTS					
		Avoided cost per derailment (operational, preparedness, recovery after derailment, etc.)	Avoided train delay costs per derailment	Avoided derailment costs per derailment (based on average derailment cost per type)	Number of avoided derailments (from D-Rail D7.2) (per year) HIGH SCENARIO	Estimated TOTAL cost reduction due to avoided derailments (per year)	Potential maintenance cost optimisation (per year)
	(source)	SBB estimate	SBB estimate	D-Rail D2.3 Table 3.5	GB SRM v7.2 scaled for EU27		SBB estimate
1	Hot axle box and hot wheel detection	26.000 €	160.000 €	1.282.575 €	4,183	6.142.671 €	710.769 €
2	Axle load checkpoints	26.000 €	160.000 €	1.526.062 €	11,033	18.888.336 €	4.950.000 €
3	Track geometry measurement systems	26.000 €	160.000 €	436.505 €	20,484	12.751.524 €	15.000.000 €

Table 14: Assumed costs regarding further benefits for additional numbers of installations for low scenario

MONITORING SYSTEM		AVOIDED COSTS					
		Avoided cost per derailment (operational, preparedness, recovery after derailment, etc.)	Avoided train delay costs per derailment	Avoided derailment costs per derailment (based on average derailment cost per type)	Number of avoided derailments (from D-Rail D7.2) (per year) LOW SCENARIO	Estimated TOTAL cost reduction due to avoided derailments (per year)	Potential maintenance cost optimisation (per year)
	(source)	SBB estimate	SBB estimate	D-Rail D2.3 Table 3.5	GB SRM v7.2 scaled for EU27		SBB estimate
1	Hot axle box and hot wheel detection	26.000 €	160.000 €	1.282.575 €	0,414	607.517 €	710.769 €
2	Axle load checkpoints	26.000 €	160.000 €	1.526.062 €	10,132	17.346.431 €	4.950.000 €
3	Track geometry measurement systems	26.000 €	160.000 €	436.505 €	15,363	9.563.643 €	15.000.000 €

Also these additional benefits are discounted with the used discounting factor of 4% resulting in the Net Present Value concerning the additional benefits. In addition, the avoided costs of derailments contain the estimated increase of freight traffic towards 2050 by 1.53% per year (based on the assumption of WP2).

The Net Present Value of the considered costs (investment, re-investment, operation, maintenance and disposal) and of the additional benefits concerning ALC (as an example) considering high scenario is presented below.

Table 15: Net Present Value of the additional benefits regarding ALC for high scenario

Avoided cost of derailments (1.53% traffic increase)	Potential maintenance cost optimization	TOTAL yearly Net Present Value 4,0%	Cumulative Net Present Value AVOIDED COSTS
18.888.336 €	4.950.000 €	22.921.477 €	22.921.477 €
19.177.327 €	4.950.000 €	22.307.070 €	45.228.547 €
19.470.740 €	4.950.000 €	21.709.949 €	66.938.496 €
19.768.643 €	4.950.000 €	21.129.599 €	88.068.096 €
20.071.103 €	4.950.000 €	20.565.523 €	108.633.619 €
20.378.191 €	4.950.000 €	20.017.237 €	128.650.856 €
20.689.977 €	4.950.000 €	19.484.275 €	148.135.131 €
21.006.534 €	4.950.000 €	18.966.185 €	167.101.316 €
21.327.934 €	4.950.000 €	18.462.528 €	185.563.844 €
21.654.251 €	4.950.000 €	17.972.879 €	203.536.723 €
21.985.561 €	4.950.000 €	17.496.827 €	221.033.550 €
22.321.940 €	4.950.000 €	17.033.973 €	238.067.523 €
22.663.466 €	4.950.000 €	16.583.932 €	254.651.455 €
23.010.217 €	4.950.000 €	16.146.329 €	270.797.784 €
23.362.273 €	4.950.000 €	15.720.800 €	286.518.584 €
23.719.716 €	4.950.000 €	15.306.996 €	301.825.580 €
24.082.628 €	4.950.000 €	14.904.574 €	316.730.154 €
24.451.092 €	4.950.000 €	14.513.206 €	331.243.360 €
24.825.194 €	4.950.000 €	14.132.570 €	345.375.930 €
25.205.019 €	4.950.000 €	13.762.357 €	359.138.287 €
25.590.656 €	4.950.000 €	13.402.266 €	372.540.554 €
25.982.193 €	4.950.000 €	13.052.005 €	385.592.559 €
26.379.721 €	4.950.000 €	12.711.293 €	398.303.852 €
26.783.330 €	4.950.000 €	12.379.854 €	410.683.705 €
27.193.115 €	4.950.000 €	12.057.423 €	422.741.128 €
27.609.170 €	4.950.000 €	11.743.742 €	434.484.870 €
28.031.590 €	4.950.000 €	11.438.562 €	445.923.432 €
28.460.474 €	4.950.000 €	11.141.640 €	457.065.072 €
28.895.919 €	4.950.000 €	10.852.742 €	467.917.814 €
29.338.026 €	4.950.000 €	10.571.639 €	478.489.452 €

OVERALL LCC COST BENEFIT RATIO	3,34

Table 16: Net Present Value of the additional benefits regarding ALC for low scenario

Avoided cost of derailments (1.53% traffic increase)	Potential maintenance cost optimization	TOTAL yearly Net Present Value 4,0%	Cumulative Net Present Value AVOIDED COSTS
17.346.431 €	4.950.000 €	21.438.876 €	21.438.876 €
17.611.831 €	4.950.000 €	20.859.681 €	42.298.557 €
17.881.292 €	4.950.000 €	20.296.936 €	62.595.493 €
18.154.876 €	4.950.000 €	19.750.145 €	82.345.637 €
18.432.646 €	4.950.000 €	19.218.830 €	101.564.468 €
18.714.665 €	4.950.000 €	18.702.529 €	120.266.996 €
19.000.999 €	4.950.000 €	18.200.791 €	138.467.787 €
19.291.715 €	4.950.000 €	17.713.184 €	156.180.971 €
19.586.878 €	4.950.000 €	17.239.285 €	173.420.256 €
19.886.557 €	4.950.000 €	16.778.688 €	190.198.944 €
20.190.822 €	4.950.000 €	16.330.998 €	206.529.942 €
20.499.741 €	4.950.000 €	15.895.833 €	222.425.776 €
20.813.387 €	4.950.000 €	15.472.823 €	237.898.598 €
21.131.832 €	4.950.000 €	15.061.608 €	252.960.206 €
21.455.149 €	4.950.000 €	14.661.842 €	267.622.048 €
21.783.413 €	4.950.000 €	14.273.188 €	281.895.236 €
22.116.699 €	4.950.000 €	13.895.319 €	295.790.555 €
22.455.084 €	4.950.000 €	13.527.920 €	309.318.475 €
22.798.647 €	4.950.000 €	13.170.685 €	322.489.161 €
23.147.467 €	4.950.000 €	12.823.317 €	335.312.477 €
23.501.623 €	4.950.000 €	12.485.528 €	347.798.006 €
23.861.198 €	4.950.000 €	12.157.040 €	359.955.046 €
24.226.274 €	4.950.000 €	11.837.583 €	371.792.628 €
24.596.936 €	4.950.000 €	11.526.894 €	383.319.523 €
24.973.269 €	4.950.000 €	11.224.721 €	394.544.244 €
25.355.360 €	4.950.000 €	10.930.817 €	405.475.061 €
25.743.297 €	4.950.000 €	10.644.944 €	416.120.005 €
26.137.170 €	4.950.000 €	10.366.871 €	426.486.875 €
26.537.068 €	4.950.000 €	10.096.373 €	436.583.248 €
26.943.085 €	4.950.000 €	9.833.234 €	446.416.482 €

OVERALL LCC COST BENEFIT RATIO	7,80

The cost-benefit ratio for ALC is 3.34 for the high scenario and 7.8for the low scenario respectively (greater than 1.0, thus positive and can be regarded as beneficial).

The presentation of the NPV regarding HABD and TGMS is attached in the appendices of this deliverable.

The overall results of the quantitative evaluation of LCC and cost-benefit analysis referring to the three proposed measures are shown in Table below:

Table 17: NPV of the total costs and NPV of the additional benefits for the two scenarios indicated in [Mio €]. Blue columns correspond to costs (negative NPV's), green columns to benefits (positive NPV's).

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

In the following some aspects of the results are discussed:

- The methods employed are similar to those used for the risk assessment in D7.2. The cost data have mostly identical components as the same numbers and site placements as in D7.2 were used, but some costs in relation to data exchange were added. The benefit columns contain the expected safety benefits, but as discussed previously the total benefits are much wider than safety alone, so additional financial benefits were added.
- Considering hot axle box detection, the costs in both scenarios are very high in relation to the benefits and thus unfavourable, due to the following reasons
  - The placement strategy is a density-based approach, i.e. a HABD every xx km. This strategy is required due to the rapid progression of a HAB from a safe to a critically unsafe state.
  - The safety benefits are rather low, which can be explained by the already widespread use of HABD in many countries. Derailments due to hot axle box are less frequent than the occurrence of hot axle box since efficient detection and intervention are possible. It is thus likely that safety benefits are underestimated in the current risk models.
  - Other benefits, especially maintenance, are low, because the detectors target few components of the vehicle, namely the axle box, brakes and wheel temperature, of which only the axle box allows for trending analyses
- Axle load checkpoints have a remarkably good ratio between costs and benefits. The safety business case (see D7.2) is already marginally efficient on its own, but combined with maintenance effects the business case becomes comfortable, since ALCs deliver actionable data on interesting components from a maintenance perspective, namely wheels, spring and suspensions.
- Track geometry measurement systems show an even better efficiency ratio. The safety business case (see D7.2) is already marginally efficient on its own. In addition, the track is the most interesting part for maintenance optimization as it is the biggest single cost block of an infrastructure manager. Minimal improvements in this area act on a very large financial lever.
- It should be noted that the IM’s spend the resources for the deployment of monitoring systems, but the RU/VO gain the maintenance benefits. The owner of the monitoring devices (IM) provides in case of alarm the aggregated monitoring systems data free to the RU, the RU can react to the fault and save the costs for the maintenance, speed up the maintenance process etc. The relevant aggregated data may be used by the RU to improve the vehicle maintenance and to reduce the probability of a hazardous event. This effect is not calculated into the cost model, since an analysis from a safety or societal point of view clearly favours this type of financing.

3.6.3 LCC analyses

This section outlines the LCC analysis for the evaluation of the additional number of inspection and monitoring installations needed to achieve the 10-20% LCC reduction.

By identifying the required additional number of installations in order to achieve the target of 20% LCC reduction many factors have to be considered. In general, this issue is more a matter of efficient placement of the installations on the concerned network, for instance at loading sites such as ports (skew loading occurring at loading site), border-crossings, neuralgic locations for protection of the infrastructure (bridges, tunnel) of major traffic corridors and traffic flows.

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

However, when monitoring installations reach a certain number on a specific network (route) no further decrease of derailments is achievable by intensified monitoring (saturation effect). That is to say that the approach by installing e. g. more HABD would not lead to higher LCC reduction automatically, since the associated whole life costs for investment, re-investment, maintenance, operation and disposal have to be considered. But the efficient deployment of the installations sites shall follow an integrated approach based on risk-related decision process and individual national situation with related aspects such as legal, financial, safety (SMS, CSM-RA), requirements of the IM, specific boundary conditions (climate effects, curves, tunnels, bridges, natural phenomenon) and many other aspects. The goal should be to identify the cost-efficient solution to prevent and mitigate risk for derailment.

Basically, the aim of the following analysis is to get an order of magnitude in terms of the required number of additional monitoring system in order to achieve the 20% LCC reduction.

Similarly, the cost data used for risk analysis including risk model according to CSM-RA performed in WP7 are taken as input for the LCC analysis. As described in the previous sections, for the LCC analysis it is vital to define and document firstly the boundary conditions and used key input data including the sources of these data. This makes the LCC analysis traceable and clarifies what is within or outside of the calculation, which aspects and data have been considered and those that could not be taken into account due to certain reasons respectively. For this purpose the In/Out frame is used to document the relevant boundary conditions, as described in the LCC approach in section 2.2 of this deliverable. Subsequently the documentation of the relevant boundary conditions defined for the three proposed monitoring systems is presented.

All the aspects within the frame imply that they are considered in the LCC analysis, whereas the aspects outside of the frame are not taken into account due to certain reasons (e. g. lack of data). Aspects that need to be checked and clarified are placed on the edge of the frame.

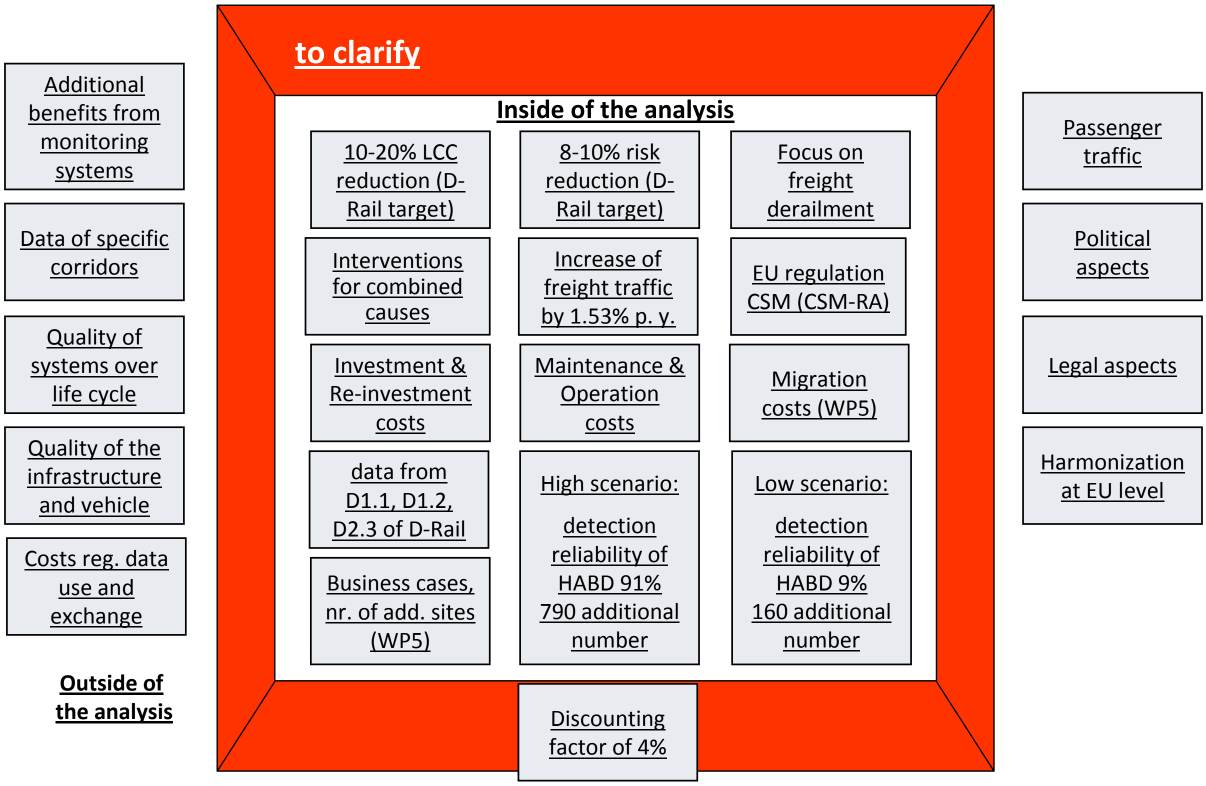

Figure 18: In/Out-frame for the definition of the boundary condition for HABD

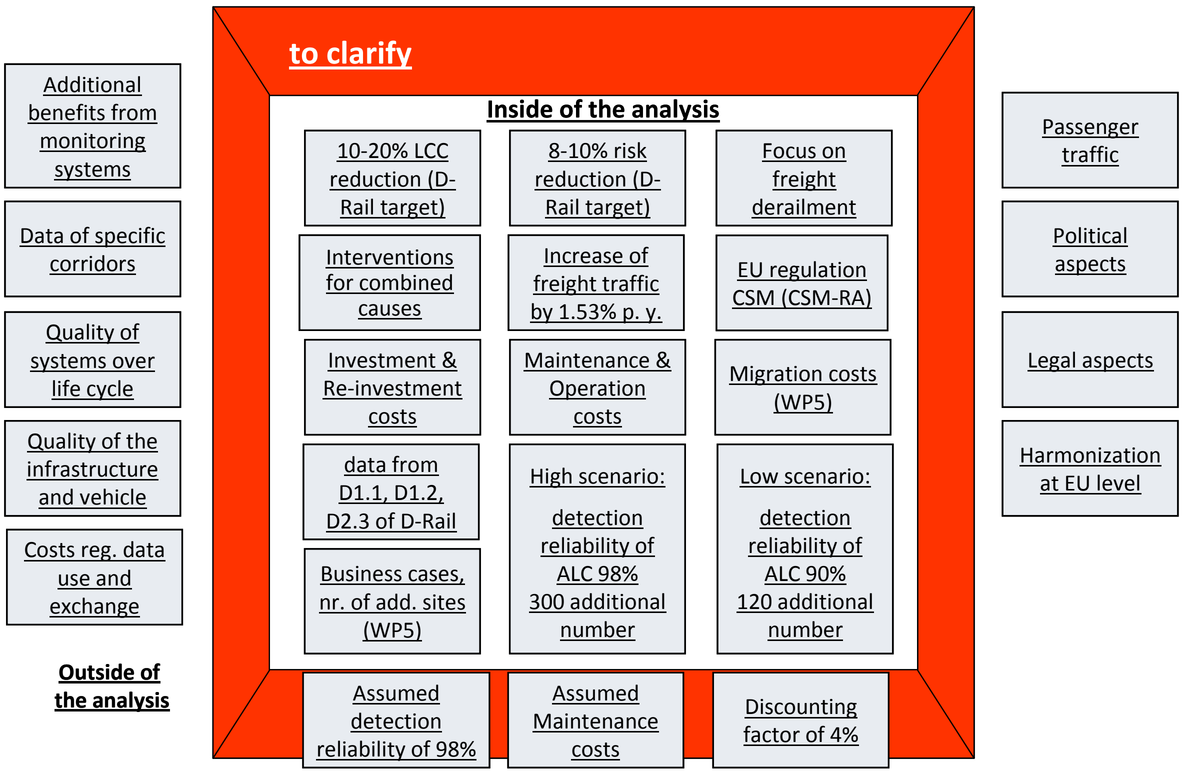

Figure 19: In/Out-frame for the definition of the boundary condition for ALC

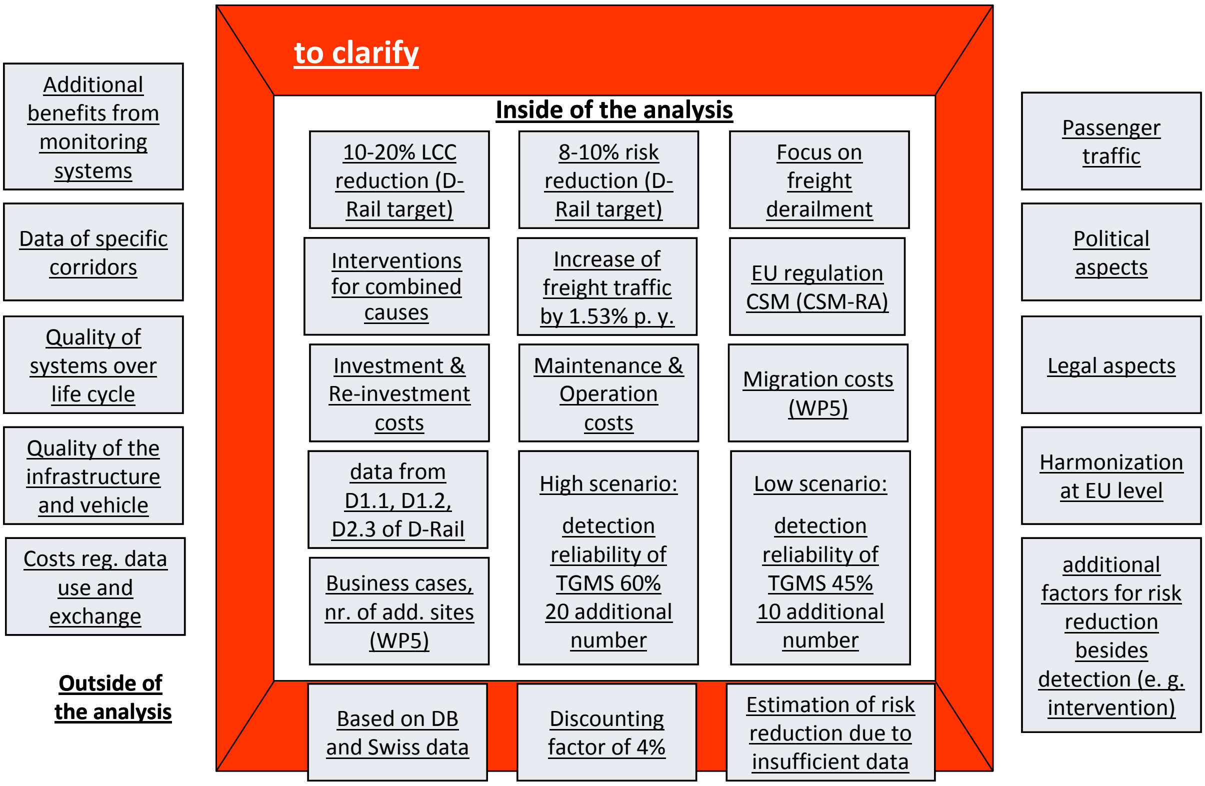

Figure 20: In/Out-frame for the definition of the boundary condition for TGMS

The data and assumptions used for this LCC analysis are summarized in the following:

- Top derailment causes are taken from D1.1 and the derailment cost from D1.2 of WP2
- Cost data regarding the three proposed systems and individual costs per derailment cause are taken from D-Rail D2.3, Table 3.4 and Table 3.5
- number of additional installation sites were developed by WP5
- values regarding the measuring accuracy of the monitoring systems are taken from WP5, D5.2, section 6.4
- Note that for the time being more appropriate data with high quality at European level are not available. Based on the provided data input only from some member states a harmonization of the used cost figures at European level is not possible. Therefore the data from D1.1, D1.2 and D2.3 as well as verified data of some member states (e. g. GB, Swiss, Germany) serve as input for the LCC analysis. Where no data was available assumptions have been done in agreement with experts and partners within WP7 and other work packages (particularly WP5) of D-Rail project.
- As there is no information regarding the precise number of existing monitoring systems deployed in the EU indicated in this project so far, WP7 refers to the assumed number concerning the number of HABD, ALC and TGMS given in the concept regarding number and sites by WP5 (D5.2).

- The costs for implementation and costs incurred in connection with the change of the quality of measurement systems during the whole life cycle (up to 2050) are not considered

As a next step of this LCC analysis the relevant technical and economic parameters need to be defined and documented. The economic parameters in terms of cost figures to be considered for the three proposed monitoring systems are presented in the following Figures.

Parameter	Status quo	High scenario	Low scenario
Number of installation sites (by WP5)	Assumed 1.000	790 additionally	160 additionally
Existing derailments as reference (cf.D1.1)	500 p. y.	60 p. y.	60 p. y.
Reduction of derailments due to detection reliability	0	55	5
Assumed detection reliability (by WP5)		91%	9%
Not avoided derailments	60	5	55
Increase of traffic volume	1.53% annually	1.53% annually	1.53% annually

Remarks and boundaries	
Discount rate	**4% (assumed as not specified in D-Rail project)**
Time horizon	**2015-2050**

Figure 21: Documentation – technical parameters for HABD high and low scenario

Parameter	Status quo	High scenario	Low scenario
Number of installation sites (by WP5)	Assumed 200	300 additionally	120 additionally
Existing derailments as reference (cf.D1.1)	500 p. y.	109 p. y. (average value of three derailment causes)	109 p. y. (average value of three derailment causes)
Reduction of derailments due to detection reliability	0	107	98
Assumed detection reliability (by WP5)		98%	91%
Not avoided derailments	109 p. y. (average value of three derailment causes)	2	11
Increase of traffic volume	1.53% annually	1.53% annually	1.53% annually

Remarks and boundaries	
Discount rate	**4% (assumed as not specified in D-Rail project)**
Time horizon	**2015-2050**

Figure 22: Documentation – technical parameters for ALC high and low scenario

Parameter	Status quo	High scenario	Low scenario
Number of installation sites (by WP5)	Assumed 10-30	20 additionally	10 additionally
Existing derailments as reference (cf.D1.1)	500 p. y.	107 p. y. (average value of four derailment causes)	107 p. y. (average value of four derailment causes)
Reduction of derailments due to detection reliability	0	64	48
Assumed detection reliability (by WP5)		60% (90%)	45%
Not avoided derailments	107 p. y. (average value of four derailment causes)	64 (97)	48
Increase of traffic volume	1.53% annually	1.53% annually	1.53% annually
Remarks and boundaries			
Discount rate	**4% (assumed as not specified in D-Rail project)**		
Time horizon	**2015-2050**		

Figure 23: Documentation – technical parameters for TGMS high and low scenario

Once the technical parameters are defined the definition and documentation of the relevant economic parameters can be done as a next step, as described in the LCC approach. This is presented below for the monitoring system HABD as an example.

Cost block	Data structure	HABD	ALC	TGMS
Derailment	Euro Cycle Source Quality	1.282.575 € costs per cause 1) D2.3, D-Rail verified	4.578.185 € costs per cause 2) D2.3, D-Rail verified	1.309.515 € costs per cause 3) D2.3, D-Rail verified
Investment	Euro Cycle Source Quality	229.600 € per unit D2.3, D-Rail verified	110.000 € per unit D2.3, D-Rail verified	950.000 € costs per cause 3) D2.2, D-Rail verified
Re-Investment	Euro Cycle Source Quality	147.600 € per unit, after 15 y. D2.3, D-Rail verified	73.000 € per unit D2.3, D-Rail verified	570.000 € per unit D2.3, D-Rail verified
Operation	Euro Cycle Source Quality	4.796 € annually D2.3, D-Rail verified	3.600 € annually D2.3, D-Rail verified	47.500 € annually D2.3, D-Rail verified
Maintenance	Euro Cycle Source Quality	7.380 € annually D2.3, D-Rail verified	13.000 € annually D2.3, D-Rail verified	76.000 € annually D2.3, D-Rail verified

1) Hot axle box and axle journal rupture
2) Wheel failure, skew loading and spring & suspension failures
3) Excessive track width, excessive track twist and track height/cant failure/rail failures

Figure 24: Documentation of the relevant economic parameters for the three monitoring systems

Cost block	Data structure	Status quo	High scenario	Low scenario
specific cost per derailment per year	Euro Cycle Source Quality	1.282.575 € costs per cause 1) D2.3, D-Rail verified	1.282.575 € costs per cause 1) D2.3, D-Rail verified	1.282.575 € costs per cause 1) D2.3, D-Rail verified
Investment	Euro Cycle Source Quality	229.600 €, per unit one time D2.3, D-Rail verified	181 Mio €, (#790) one time D2.3, WP5, D-Rail assumed	37 Mio €, (#160) one time D2.3, WP5, D-Rail assumed
Re-Investment	Euro Cycle Source Quality	147.600 € per unit every 15 y. D2.3, D-Rail verified	116 Mio € (#790) every 15 y. D2.3, WP5, D-Rail assumed	23.6 Mio €, (#160) every 15 y. D2.3, WP5, D-Rail assumed
Operation	Euro Cycle Source Quality	4.796 € annually D2.3, D-Rail verified	3.8 Mio € (#790) annually D2.3, WP5, D-Rail assumed	0.77 Mio € (#160) annually D2.3, WP5, D-Rail assumed
Maintenance	Euro Cycle Source Quality	7.380 € annually D2.3, D-Rail verified	5.83 Mio € (#790) annually D2.3, WP5, D-Rail verified	1.18 Mio € (#160) annually D2.3, WP5, D-Rail assumed
Disposal	Euro Cycle Source Quality	5.000 € every 15 y. D2.3, D-Rail verified	3.95 Mio € (#790) every 15 y. D2.3, WP5, D-Rail verified	0.8 Mio € (#160) every 15 y. D2.3, WP5, D-Rail assumed
Derailment costs (of not avoided derailments)	Euro Cycle Source Quality	76.954.500 € annually (=1.282.575 €*60)	6.412.875 € annually (=1.282.575 €*5)	70.028.595 € annually (=1.282.575 €*55)

Figure 25: Documentation of the relevant economic parameters exemplary for HABD.

The following Table gives an overview of the costs to be considered for the status quo (meaning that no additional monitoring sites are considered).

Table 18: Cost data for the three proposed monitoring systems Status quo (no additional monitoring sites)

Annual cost data	HABD	ALC	TGMS
Investment	229.600	110.000	950.000
Maintenance	7.380	13.000	76.000
Operation	4.796	3.600	47.500
RE-Investment	147.600	73.000	570.000
Disposal	5.000	5.000	25.000
derailment costs	76.954.500	58.000.436	12.955.362

Similarly to the above described procedure (see Figure 25), the cost figures can be defined and documented for the two other monitoring systems (ALC and TGMS). Instead of this presentation the two tables (Table 19 and Table 20) summarize the used costs data for the three proposed monitoring systems including ALC and TGMS. In addition, the costs due to avoided derailments as well as on the specific costs due to remaining (not avoided) derailments are indicated. This is mainly dependent on the measuring accuracy concerning each monitoring system. As described previously, the assumed values regarding the measuring accuracy and the additional number of installations for the three proposed monitoring systems based on the input from WP5 business cases.

Table 19: Assumed risk reduction and linked costs due to the measuring accuracy for the high scenario

	Monitoring System	derailment cause	Assumed % reduction in derailments due to system	Assumed number of additional units (cf.2014)	Specific costs per cause of derailment per year	Share of avoided derailments for the cause per intervention (cf 500 derailments p. y.)	Annual number of avoided derailments (cf 500 derailments p. y.)	Annual cost savings of avoided derailments based on specific cost per cause of derailment	Annual number of avoided derailments (considering the detection	Specific costs per cause of derailment (considering the detection effeciency)	Annual cost savings of avoided derailments per cause of derailment (considering the detection
			D-Rail WP5	D-Rail WP5	D-Rail D2.3 Table 3.5	D-Rail D2.3 Table 3.5	D-Rail D2.3 Table 3.5	D-Rail D2.3 Table 3.5			
1	Hot axle box and hot wheel detection	Hot axle box and axle journal rupture	91,00%	790	1.282.575 €	12%	60	76.954.500 €	55	6.412.875 €	70.028.595 €
2	Axle load checkpoints	Wheel failure	98,00%		1.879.471 €	10,3%	52	96.792.757 €			
		Skew loading	98,00%		833.144 €	5,95%	30	24.786.034 €			
		Spring & suspension failure	98,00%		1.865.570 €	5,62%	28	52.422.517 €			
	subtotals		98,00%	300	*4.578.185 €*	*21,9%*	*109*	*174.001.308 €*			
	mean value				*1.526.062 €*			*58.000.436 €*	*107*	3.052.123 €	6.215.500.705 €
3	Track geometry measurement systems	Excessive track width	60,00%		474.966 €	8,60%	43	20.423.538 €		34.501.480 €	
		Excessive track twist	60,00%		552.627 €	6,58%	33	18.181.428 €		26.397.644 €	
		Track height/cant failure	60,00%		281.922 €	3,40%	17	4.792.674 €		13.640.120 €	
		Rail failures	60,00%		587.025 €	2,87%	14	8.423.809 €		11.513.866 €	
	subtotals			20	*1.896.540 €*	*21,5%*	*107*	*51.821.449 €*		*86.053.110 €*	
	mean value				*474.135 €*			*12.955.362 €*	*64*	20.387.805 €	833.677.562 €

Table 20: Assumed risk reduction and linked costs due to the measuring accuracy for the low scenario

	Monitoring System	derailment cause	Assumed % reduction in derailments due to system	Assumed number of additional units (cf.2014)	Specific costs per cause of derailment per year	Share of avoided derailments for the cause per intervention (cf 500 derailments p. y.)	Annual number of avoided derailments (cf 500 derailments p. y.)	Annual cost savings of avoided derailments based on specific cost per cause of derailment	Annual number of avoided derailments (considering the detection	Specific costs per cause of derailment (considering the detection effeciency)	Annual cost savings of avoided derailments per cause of derailment (considering the detection
			D-Rail WP5	D-Rail WP5	D-Rail D2.3 Table 3.5	D-Rail D2.3 Table 3.5	D-Rail D2.3 Table 3.5	D-Rail D2.3 Table 3.5			
1	Hot axle box and hot wheel detection	Hot axle box and axle journal rupture	9,00%	160	1.282.575 €	12%	60	76.954.500 €	5	70.028.595 €	6.925.905 €
2	Axle load checkpoints	Wheel failure	90,00%		1.879.471 €	10,3%	52	96.792.757 €			
		Skew loading	90,00%		833.144 €	5,95%	30	24.786.034 €			
		Spring & suspension failure	90,00%		1.865.570 €	5,62%	28	52.422.517 €			
	subtotals		90,00%	120	*4.578.185 €*	*21,9%*	*109*	*174.001.308 €*			
	mean value				*1.526.062 €*			*58.000.436 €*	*98*	16.687.484 €	5.708.112.893 €
3	Track geometry measurement systems	Excessive track width	45,00%		474.966 €	8,60%	43	20.423.538 €		34.501.480 €	
		Excessive track twist	45,00%		552.627 €	6,58%	33	18.181.428 €		26.397.644 €	
		Track height/cant failure	45,00%		281.922 €	3,40%	17	4.792.674 €		13.640.120 €	
		Rail failures	45,00%		587.025 €	2,87%	14	8.423.809 €		11.513.866 €	
	subtotals			10	*1.896.540 €*	*21,5%*	*107*	*51.821.449 €*		*86.053.110 €*	
	mean value				*474.135 €*			*12.955.362 €*	*48*	27.968.038 €	625.258.171 €

Both Tables above present the effect of the reduction of derailments due to the associated monitoring system for the high scenario and can be interpreted such as: with the assumed measuring accuracy of 91% (high scenario) maximum 55 derailments be avoided with potential cost saving of 70 Mio € by HABD. By using ALC about 6 Mio € can be saved due to reduction of 107 derailments with assumed 98% measuring accuracy. The resulting cost savings of avoided derailments by using TGMS with assumed 60% measuring accuracy is about 833 Mio €. Similarly, the interpretation can be done for the low scenario.

The two Tables presented below summarize the cost figures due to the assumed risk reduction and measuring accuracy respectively for high and low scenario used as input for the LCC analysis.

Table 21: Cost data for the LCC analysis for high scenario

	HABD	ALC	TGMS	
Additional number of sites				
	790	300	20	
Annual cost data				
Investment	181.384.000	33.000.000	19.000.000	
Maintenance	5.830.200	3.900.000	1.520.000	
Operation	3.788.840	1.080.000	950.000	
RE-Investment	116.604.000	21.900.000	11.400.000	
Disposal	3.950.000	1.500.000	500.000	
derailment costs	6.412.875	3.052.123	20.387.805	

Table 22: Cost data for the LCC analysis for low scenario

Annual cost data	HABD	ALC	TGMS	
Additional number of sites				
	160	120	10	
Annual cost data				
Investment	36.736.000	13.200.000	9.500.000	
Maintenance	1.180.800	1.560.000	760.000	
Operation	767.360	432.000	475.000	
RE-Investment	23.616.000	8.760.000	5.700.000	
Disposal	800.000	600	250.000	
derailment costs	70.028.595	16.687.484	27.968.038	

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

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

The costs for the implementation of the additional monitoring systems are not included in the LCC analyses, since verified cost data are not available. The impact of the issues in terms of the risk landscape of the IM (own risk assessment, risk management for the concerned boundary conditions and requirements) as well as the effect of higher increase of traffic volume (more than 1.5% per year) as well as the decrease of derailments by 10-20% by 2050 (as taken into account in WP2, D2.3, chapter 3.1) are not considered in the LCC analyses. Contrary to the cost-benefit analysis, LCC considers only expenditures but not additional benefits (such as avoided cost per derailment e .g. operational, preparedness, recovery after derailment, avoided train delay costs per derailment, maintenance cost optimization due to condition-based maintenance strategy).

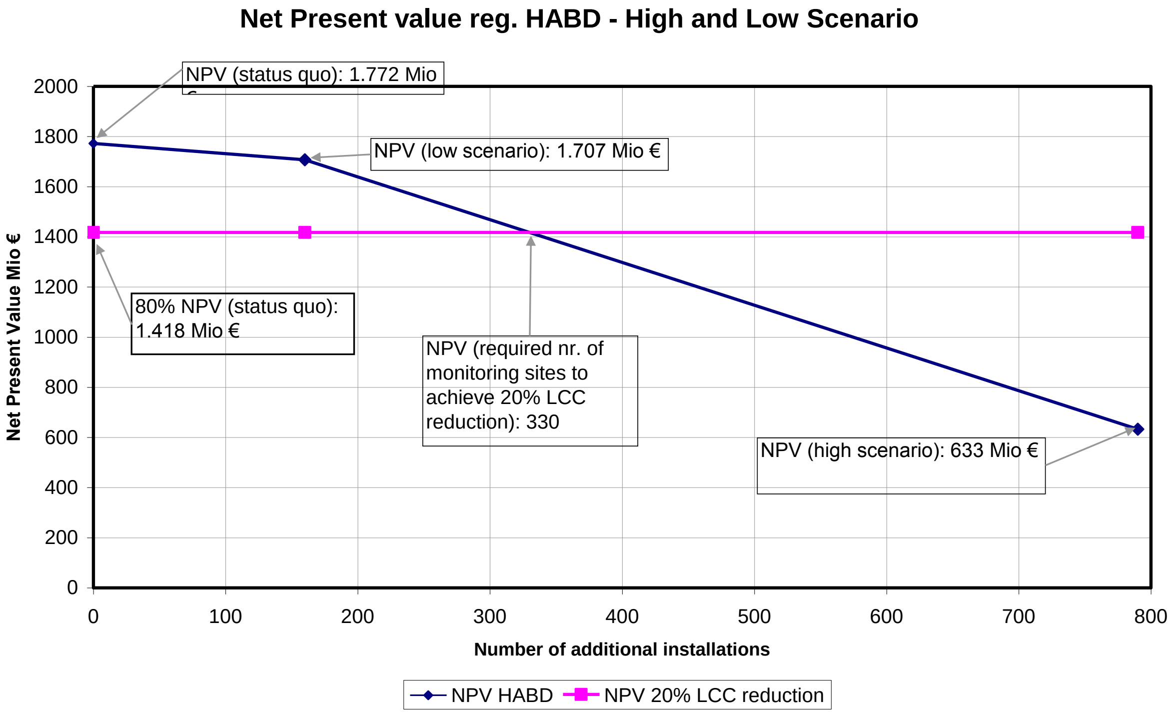

Figure 26: NPV reg. HABD with assumed measuring accuracy of 91% (high scenario) and 9% (low scenario)

The Figure 26 as an outcome from the LCC analysis shows that the objective of 20% LCC reduction can be achieved by ca. 330 additional HABD devices.

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

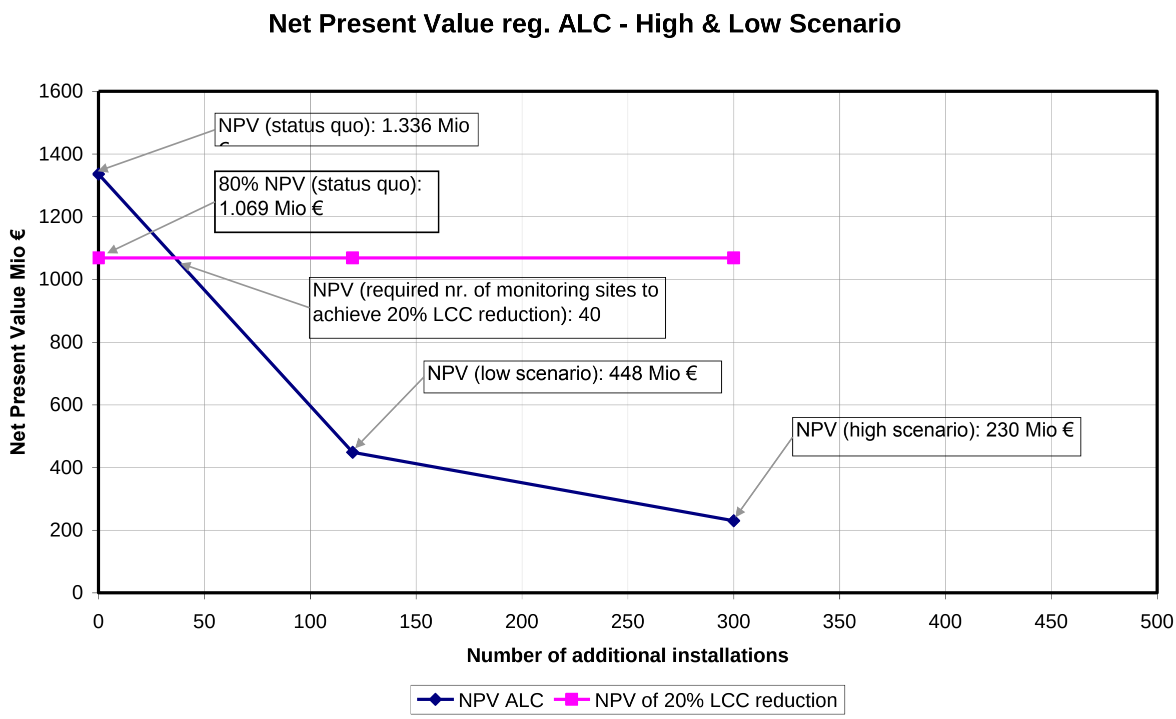

Figure 27: NPV of ALC with assumed measuring accuracy of 98% (high scenario) and 90% (low scenario)

A general remark needs to given regarding the assumed measuring accuracy of 98% for ALC. The assumed measuring accuracy of 98% regarding ALC seems to be very high and needs to be proven as this high value implies that the monitoring system measures very accurately and precisely. Consequently all trains could be considered critical in terms of derailment and could result in non-hazardous trains being stopped resulting in higher costs due to unnecessary train stoppages. Costs for false positives (operational disruption) are not included in the LCC.

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

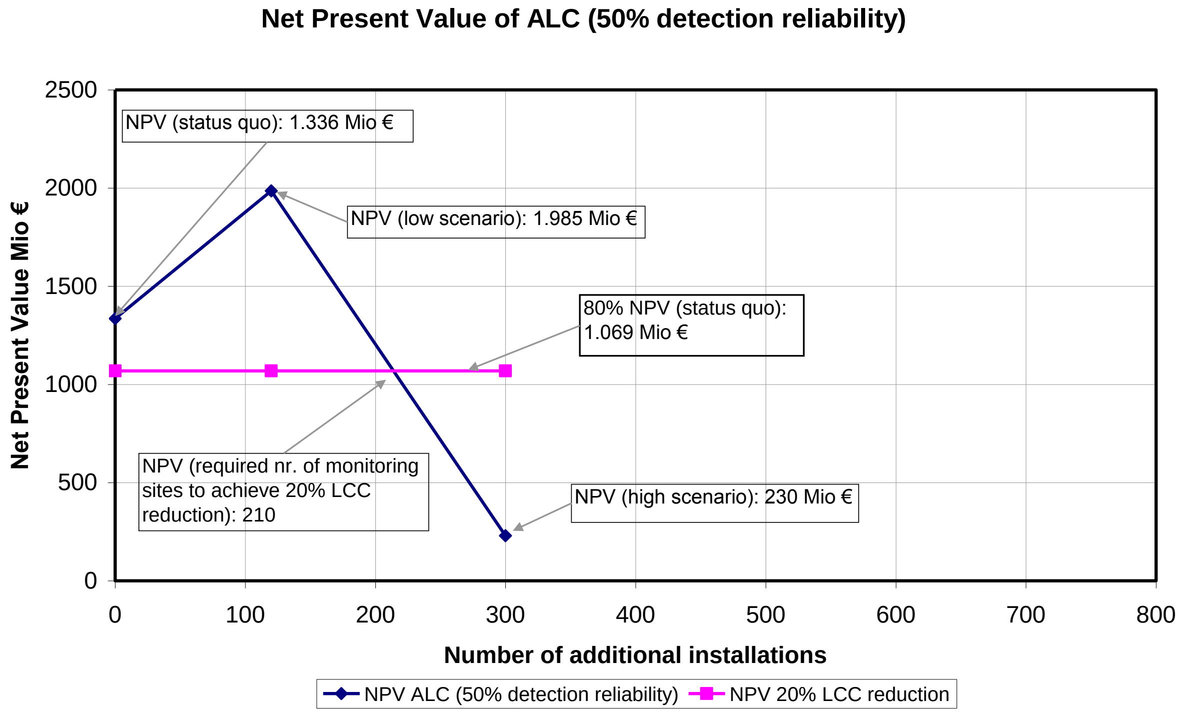

Figure 28: NPV reg. ALC with assumed measuring accuracy of 98% (high scenario) and 50% (low scenario)

Generally, due to the heterogeneity in Europe, the placement at strategic sites will result in a very unequal distribution of costs, depending on different challenges due to the different legal framework and safety management approach, but also other relevant aspects like requirements of the IM, the local boundary conditions (curve radii, track utilization, amount of infrastructure elements, occurrence of natural disasters etc.).

The outcome LCC analyses regarding TGMS shows that the LCC reduction by 20% can not be achieved, mainly due to the less measuring accuracy of 60% assumed for TGMS. But a higher measuring accuracy of 90% and associated derailment reduction ensures the benefit in terms of 20% LCC reduction.

Given that, it can be stated that a causal link between additional number of installations and LCC is not always given. To increase the number of installations does not lead to a LCC benefit automatically, whereas an increase of measuring accuracy is the more efficient approach to achieve the required benefits, as presented for TGMS see Figure 29 and Figure 30 below.

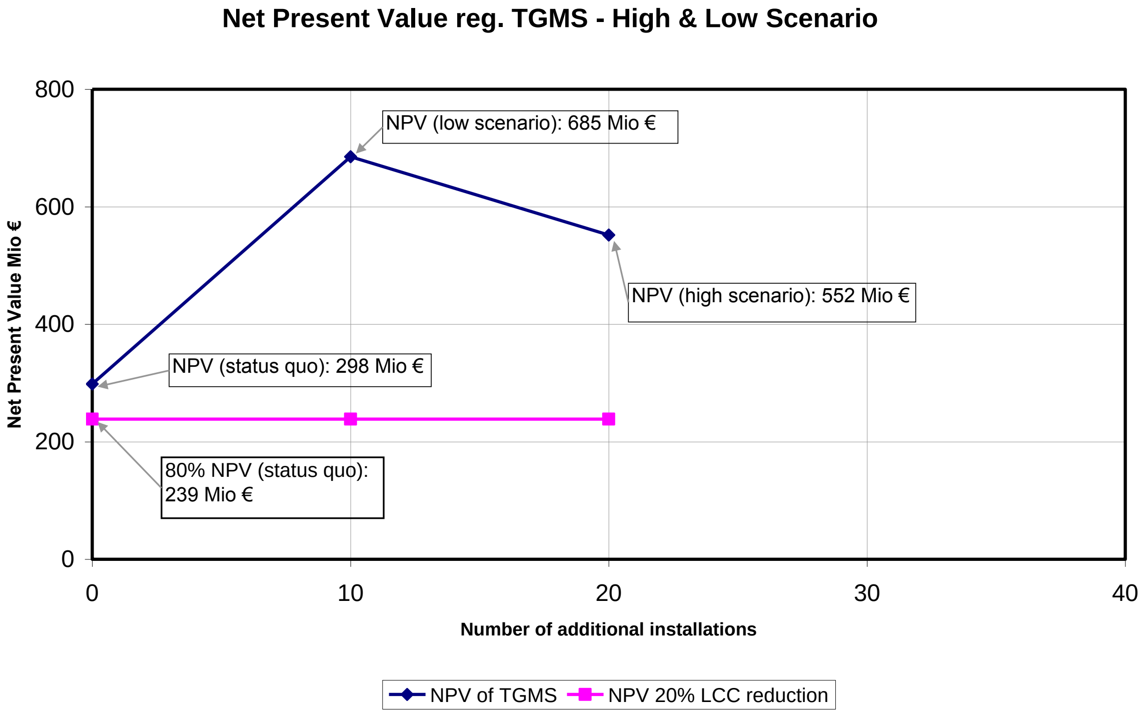

Figure 29: NPV reg. TGMS with assumed measuring accuracy of 60% (high scenario) and 45% (low scenario)

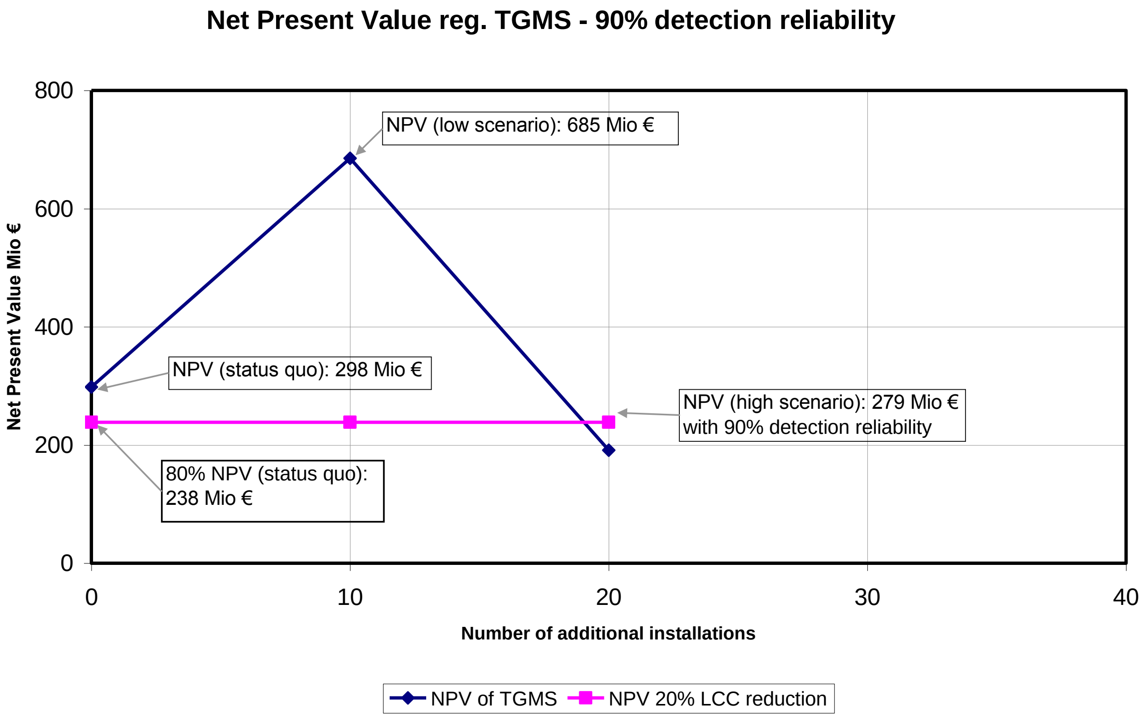

Figure 30: NPV reg. TGMS with assumed measuring accuracy of 90% (high scenario) and 45% (low scenario)

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

Table 23: Summary of the NPV's based on LCC analysis and additional installations needed for 20% LCC reduction

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

Particular emphasis shall be given to the fact, that the performed LCC analysis is based on the provided data by the WP1 (D1.1, D1.2) and WP4 (D2.2. D2.3) as indicated in the In/Out frames regarding the definition of the boundary conditions (see section 2.2 and 3.6.3).

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

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

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

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

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

However, focusing more on ALC would lead to more financial benefits. So the installation of additional ALC generates more benefit than installing additional HABD, as there are already many HABD in use. And the safety business case (see D7.2) is already marginally efficient on its own. Similarly to HABD, the density approach for ALC shall be a risk-related decision based on his (IM) own risk assessment (CSM-RA). However, firstly the placement of ALC shall be focused at specific corridors with neuralgic points (bridges, tunnels), border-crossings and loading stations. The further deployment can be done iteratively.

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

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

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

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

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

3.7 Additional benefits of monitoring systems

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

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

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

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

3.7.1 Non-safety related benefits

The benefit of using monitoring systems results from the saving of costs for reparation of infrastructure and vehicles. By using the occurrence probability of derailments, the probability of prevention due to monitoring with a certain number of systems and the average costs of a derailment, the total saving of cost can be determined.

It is straight forward that if an inspection regime is targeted effectively, derailments can be avoided, and has a direct cost savings. In general, better inspection leads to better maintenance leads to extended component life, reduced damage, reduced energy consumption, etc.

As an indication the matrix presented below summarizes the benefits based on the experiences made in North America:

Table 24: Indication of benefits by using monitoring systems (source: Harsco Rail, USA)

	Benefits						
Inspection Technology	extend rail life	extend surfacing cycles	extend sleeper life timber	extend sleeper life concrete	extend switch life	extend wheel life	extend axle/ bearing life
axle load checkpoint (Q)	5%	5%		5%	5%		
axle load checkpoint (Y ,Q, Y/Q)	same as Q	5 to 10%		same as Q	5 to 10%		
hot box detector							5 to 10%
accoustic bearing detector							
hot wheel detector							5 to 10%
vehicle profile measurement		5 to 10%					
rail profile/wear measurement	20 to 30%				20%		
wheel profile/wear measurement						20%	
sleeper inspection/track strength testing			5 to 10%				
track geometry measurement		10 to 20%					
video track inspection					5%		
ultrasonic rail testing	20 to 40%						

- Track geometry testing reduces derailments, however, utilizing track geometry data allows for more focused efforts in tamping. Effective tamping (not letting it go too long) increases ballast life, reduces energy consumption, increases sleeper/fastener and rail life (marginally), and others.
- Sleeper inspection: Breaking up clusters reduces derailments. Having comprehensive sleeper condition data allows for targeted sleeper replacement. Leaving one bad sleeper in track (surrounded by good sleepers) for an extra year or two can sometimes result in an effective increase of up to 10% in sleeper life (significant saving)
- Switch inspection. Besides identifying high risk locations, identifying proper maintenance activities (grinding, tamping, lubrication, etc.) based on this data can extend the life of switch components by up to 20% (or more).
- Rail profile measurement. Looking at wear limits and wear angles can avoid derailments. Evaluating the entire profile and defining grinding/lubrication programs allows for extensions in rail life (up to 400%)
- Same goes for wheel profile inspection

It should be noted that the above listed benefits relate to boundary conditions and approach of North America. Some aspects might not be feasible for the EU, but could serve as an indication of order of magnitude regarding potential benefits.

Generally speaking, on the one hand not all derailments could be prevented, and on the other hand the direct savings from derailments should cover the costs in terms of purchase and operation.

Thus the use of inspection and monitoring systems should not only address the issue of mitigation and prevention of derailments not just because the percentage of derailments due to freight traffic are relatively small - but also to gain benefits that will offset the investment costs of detection itself, operation and maintenance. Although in some cases cost savings in maintenance could not be quantified, but the avoidance of damage on track components and vehicles as well the use of data to predict and optimize the track can be considered as spill-off effects and benefits respectively. However, these benefits manifest in increased component life time, reduced track and equipment maintenance, reduced inspection time. Thus a risk-based maintenance strategy using profile data to define grinding or lubrication or tamping get more value from rail steel and track quality respectively. These experiences have been made in North America.

More specifically, WP3 has discussed the issue of additional benefits extensively (in chapter 6 of D3.1) in terms of cost-benefit analysis for the implementation of wayside or onboard train monitoring system as well as recording cars based on the prevented damages of infrastructure components and vehicles. The benefit of using monitoring system results in terms of costs savings regarding reparation of infrastructure and vehicles. For instance, an economic analysis of the costs and benefits associated with vertical wheel impact detectors [3] indicated that while the reduction in derailment is significant, additional benefits such as reduction in track maintenance due to elimination of impact wheels supplement these derailment benefits. Consequently these additional benefits provide a strong economic case for the implementation of wheel impact detectors.

3.7.2 HRMS project with commercial benefits

It is worth to mention here the commercial benefits for the railway system elaborated in the project "Harmonisation on running behaviour and noise measurement sites" (HRMS) such as:

Railway undertakings:

- The difference between the payload stipulated in the transport contract and the real load becomes transparent.
- Maintenance can be planned according to (predicted) wear

Rolling stock manager:

- The detection of wheel defects extends the service life of vehicle components and reduces the LCC.
- Unexpected failures which can bring a vehicle to a standstill can be avoided.
- The maintenance process can be improved by using Condition-Based maintenance instead of periodic maintenance.
- Manual inspections (measuring wheel roundness) can be replaced by automatic axle-load checkpoint measurements.
- When monitoring a special fleet of rolling stock it is possible to observe damage trends and tendencies.
- Noise emission can be used as early warning system for vehicle defects

Infrastructure managers:

- Improved wheel conditions lead to a reduction in infrastructure deterioration (e.g. damage to track and bridges).
- The track access fee can be automatically evaluated including adjustments for overloading, track-friendly and low noise vehicles.

It should be noted that the above commercial benefits are on theoretical basis and can only be achieved if RU, ECM and other stakeholders provide the prerequisite of maintaining their vehicles by IM.

In most of the countries the distinction between IM and RU as separated legal bodies by a general railway law. Both parties have their rights and responsibilities, e.g. the duty of building and maintaining their plants to ensure a safe operation. However, the IM is responsible for the building and maintenance of infrastructure and a safe operation on the infrastructure network. The RU is responsible for the maintenance of railway vehicles (ECM), vehicle safety check and control according to the legal framework in order to ensure safe operation of vehicles.

In fact the interaction between those parties (IM, RU and NSA) differs from country to country. By affecting the use of WTMS different legal agreements have to be established in the different countries.

For instance in Germany unlikely other European countries, some descriptive operational data characterising track and vehicle performance are not available for the Infrastructure part of DB. The RU gets the data from IM by the implemented system, installed by the IM only. These type of monitoring systems check wheels according to their roundness (detection system for out of round wheels) in order to provide surveillance and data for RU (if required). The data is used only to support RU for their wheel set maintenance. But it’s the responsibility of the customer (=RU) to define intervention concepts and following processes.

In other cases IM are sending data from all train passages to RU to improve possibilities to preventive maintenance e. g by using WILD.

The above listed benefits can only be achieved if the RU will establish the prerequisites for maintaining their vehicles concerning the additional information and if the IM have the needed information reg. the train composition including individual vehicle numbers, and not just being a support for collecting and providing the data by the monitoring systems. By using RFID tags for identification it’s possible to trend temperatures, axle loads etc. The detectors also provide other types of information, e. g. train speed, train length, vehicle weight, balanced or unbalanced load, number of axles and air temperature.

Applying the measurement data for maintenance allows for a better condition monitoring and control of where the wagons are on the network. Due to information from WTMS, the IM gain information about the state of vehicles. In order to protect their infrastructure from high loads or potential risks the IM’s are interested in those data. However, there is need for vehicle identification and knowledge of vehicle running performance (e. g. of locomotives) not just because of a poor vehicle condition leading to derailments, but also to come to optimized maintenance efficiency. .

3.7.3 Benefits from Condition Based Maintenance strategy

As mentioned above, data exchange between infrastructure managers and railway undertakings and entities in charge of maintenance may provide significant economic benefits.

A recent investigation on iron ore cars [1] suggest that condition-based maintenance strategies may offer LCC benefits in the range between 33% 50% over interval/time-based maintenance strategies, simply by optimizing the re-profiling and re-wheeling operations. In another study [2], it was shown that wheel wear strongly depends on outside temperature and/or attendant meteorological conditions, varying by a factor of 5 between summer and winter. This is an ideal scenario for condition-based maintenance, which could provide up to 40% of optimization in this scenario. The results are consistent with results from Switzerland concerning wheel re-profiling optimization of locomotives based on ALC data, which show about 50% benefit.

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

3.7.4 Benefits of inspection and monitoring systems for IM, RU and VO

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

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

The benefits for all stakeholders involved in the European railway freight traffic are described, resulting from the implementation of both wayside and / or on-board monitoring devices, are described in this section.

These benefits may arise from the implementation of derailment prevention measures. Hence, derailment monitoring concepts, both wayside and on-board, could be integrated and developed in such a way as to maximize potential benefits that are linked to the different monitoring concepts.

As this issue is described very detailed in D5.1 of WP5, a summarized overview is given subsequently.

General benefits for Infrastructure Managers (IM)

The monitoring systems owner - owner of the primary data from the monitoring systems:

- The owner of the monitoring devices (IM) shall provide in case of alarm the aggregated monitoring systems data free to the RU. The RU can react to the fault and save costs for the maintenance, speed up the maintenance process etc.
- The owner of the monitoring devices (IM) may provide the relevant aggregated monitoring systems data charged, according to the agreement or contract with the RU or specific subject also in standard operation. These data may include axle load, axle box temperature etc. These data may be used by the RU to improve the vehicle maintenance and to reduce the probability of a hazardous event.
- Improving security of railway transports, improving infrastructure availability
- Decreasing the infrastructure damage:

    - lowering cost of infrastructure renovation after accidents
    - lowering total train delays – better timetable performance, better customer relationships
    - less revenues from railway access fees lost due to the infrastructure damage
- Elaboration of monitoring systems statistics (how many trains are operating on the transport network or how many have passed over the monitoring systems, number of alarms from monitoring systems, etc.), suggesting trends of the selected performance indicators. The IM may improve the infrastructure to ensure better quality of service for the increasing of the freight railway traffic.
- Monitoring trends of the measured values leads to a more precise and more timely diagnosis of the vehicle faults, and consequently to lowering total train delays.

General benefits for Railway Undertakings (RU)

- Based on the monitoring data the RU may better take a decision about the quality of the used rolling stock. Based on these information the RU may improve the maintenance procedures or (in case of rented vehicles) to obtain data base for negotiations with the rolling stock providers. At the end the overall railway traffic would profit from the good state of the rolling stock (less faults, better availability, less primary and secondary delays)
- Lowering total train delays resulting from the monitoring systems implementation on the railway network – better end customer relationships
- Statistics of the aggregated monitoring systems data on operating vehicles
- Using the aggregated monitoring systems data to acquire a certificate for maintaining and repairing the railway rolling stock

General benefits for the Vehicle Owners/Keepers

- Using the aggregated monitoring systems data for statistics
- Option to monitor vehicle mileage – as additional information (vehicle position derived from the monitoring systems). By using these information a better planning of the vehicle round trips may be performed
    - the mileage is a significant parameter for calculating the vehicle rental fee – may imply increasing revenues
- Monitoring selected vehicle parameters as obtained from the monitoring systems (speed, axle load) and check against agreed parameters and against technical parameters of the vehicle
- General monitoring of the state of the fleet – an independent information source
- Monitoring the quality of the fleet
- Planning fleet availability due to the maintenance
- Planning vehicle maintenance
- Lowering costs of vehicle maintenance – earlier detection of a technical fault on vehicle
    - Using aggregated monitoring systems data to acquire a certificate for maintaining and repairing the railway rolling stock

General benefits for the national safety authority

- Utilising the primary and aggregated monitoring systems data
- Setting the monitoring methodologies for various indicator stats from the monitoring systems
- Vehicle approval process – exploiting the monitoring systems data for the technical feedback on the vehicle classes
- Exploiting the monitoring systems data for investigating the incidents
- Setting rules for preventing incidents based on the monitoring systems data
- Monitoring the quality of the RU's fleet – with an option of further inspection

Benefits for Third Parties

- railway passengers: less delays and operational disruptions
- EU citizen: Together with the successful implementation of monitoring techniques, which would lead to less derailments and more reliable, available and punctual railway operation the railway traffic may increase and the modal share of the railway may increase. As a consequence of the shift to rail the car traffic would decrease with the consequences of less air pollution, less noise pollution less street accidents and – in general - a better quality of life.

Benefits for Environment

The environment would profit from the implementation of monitoring techniques primary due to the reduced number of accidents with direct consequences for the environment (goods spilling, fuel leakage, fire, explosion etc.) and secondary due to enhanced railway modal share.

Evaluation of the benefits:

The table below gives an overview about the costs, benefits and consequences for the directly involved stakeholders (IM, RU and VO):

Table 25: Evaluation of benefits

	Measure / Benefit	Wayside Monitoring Device	Onboard Monitoring Device
Infrastructure Manager	LCC Costs	full costs	any costs for IM (the costs bear the RU or vehicle owner)
	Direct Benefit (due to reduced number of derailments and damaged infrastructure)	full profit	full profit
	Indirect benefit (reduced infrastructure wear, better exploitation)	full profit	full profit
Railway	LCC Costs	any direct costs for RU (the costs may result	full costs (if installed by RU), otherwise indirect

Undertaking		from the higher slot prices or other positions in the infrastructure pricing system)	costs in the rental fee
	Direct Benefit (due to reduced number of derailments and damaged rolling stock)	full profit	full profit
	Indirect benefit (reduced maintenance costs and time, better exploitation)	full profit	full profit
Vehicle Owner	LCC Costs	any direct costs for vehicle owner (the RU costs may influent the rental fees)	full costs (if installed by vehicle owner)
	Direct Benefit (due to reduced number of derailments and damaged rolling stock)	full profit	full profit
	Indirect benefit (reduced maintenance costs and time, better exploitation))	full profit	full profit

4 Conclusions

In WP7 has developed a systematic data-, RAMS- and LCC-framework to assess inspection and monitoring systems related to derailment based on reliability, availability, maintainability and safety (RAMS) and lifecycle cost (LCC) analysis. With this general know-how, the application of the conceptual framework of RAMS and LCC analysis can be employed for all type of monitoring systems. The assessment can be applied to any monitoring system in order to evaluate the economic benefit to the IM's and RU's. To demonstrate the functions basically the three most implemented monitoring systems have been assessed as case studies.

In D7.2 the technical view based on RAMS analysis and risk assessment is discussed, whereas the present deliverable focuses on the economic view based on LCC analyses. To establish wider understanding for the way of RAMS and LCC analysis, a conceptual framework on RAMS and LCC analysis was developed that meets the special requirements and targets of the D-Rail project. The necessary steps for LCC analyses including the appropriate definition and documentation of the technical and economic input data are shown.

In section 2.3 of the present deliverable the key input data for LCC analysis are listed and again it is shown very clearly, that the most important issue is the high quality of input data. Subsequently the relevant boundary conditions and the relevant cost data were discussed. Also the question of including some data of wider societal costs or not has to be discussed.

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

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

According to the business cases of WP5 the economic impact of current and estimated increase of freight traffic is analysed. Generally there are no economic models available, so that – considering some effects – a linear correlation of freight traffic to derailments is assumed, supposing no other parameters are changing. Such being the case linear traffic increase will lead to a linear increase of number of derailments and thus improve the business case linearly. This is to combine with the fact that freight corridors will have to be in focus of train monitoring systems relating to the goals of D-Rail.

The outcome of the cost-benefit analyses considering hot axle box detection (HABD) is that the costs in both scenarios are very high in relation to the benefits and thus unfavourable, due to the reasons outlined in section 3.6.2. In contrast to this, ALC and TGMS are beneficial by considering additional benefits. Axle load checkpoints have a remarkably good ratio between costs and benefits. Track geometry measurement systems show an even better efficiency ratio in the cost-benefit analysis. The safety business case (see D7.2) is already marginally efficient on its own, but combined with maintenance effects the business cases becomes much better. In fact, the track is the most interesting part for maintenance optimization as it is the biggest single cost block of an infrastructure manager. Minimal improvements in this area act on a very large financial lever.

However, the focus should be more on ALC as the installation of additional ALC generates more financial benefits than installing additional HABD, as there are already many HABD in use.

As an outcome of the LCC analyses HABD and ALC bring financial benefits in terms of achievement of 20% LCC reduction set out as one of the targets in D-Rail. The LCC analyses demonstrate that the 20% LCC reduction can be achieved with less number of additional installation sites concerning HABD and ALC than assumed in the business cases of WP5, given the provided input data and boundary conditions (see 3.6.3).

The LCC analyses regarding ALC show a beneficial case for both scenarios (optimum and minimum) due to the assumed high measuring accuracy of 98% and 90% respectively. The number of additional ALC installations needed to reduce the LCC by 20% is only ca. 40 (assuming 98% measuring accuracy) and ca. 210 (assuming 50% measuring accuracy) respectively. And 330 additional HABD devices are additionally necessary to achieve 20% LCC reduction.

Contrary to this outcome, the LCC reduction by 20% can not be achieved by TGMS given the additional measurement cars of 20 and a measuring accuracy of 60%, but with a measuring accuracy of 90% it is achievable. But it was shown that TGMS has the highest potential maintenance cost optimization. It may be proven that the risk reduction (and the increase of safety respectively) regarding TGMS is not only dependent on detection, but also on intervention. A better usage of collected measurement data for maintenance activities should be aimed in order to predict trend analysis and optimize the track quality. This poses the reduction of the maintenance budgets by more efficient and effective monitoring of the railway infrastructure and rolling stock and a better control, planning and balancing of maintenance and renewal activities. In addition, this would enhance the transition from corrective maintenance to enhanced condition-based and predictive maintenance.

It is necessary to bear in mind, that a causal link between the required number of additional monitoring systems and their life cycle costs (LCC) is not absolutely definitive. It's not recommendable to increase the number of installations as this approach does not lead to a LCC benefit automatically. Given that, not only the additional number of installations, but the efficient deployment of the installations at appropriate sites linked with high measuring accuracy (measurement accuracy) creates an added value. In this context a risk-based decision approach considering important aspects (legal, financial, safety (SMS, CSM-RA), guidelines, requirements of the concerned infrastructure manager, operational necessities, traffic volume, specific boundary conditions etc.) need to be considered.

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

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

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

In addition, different aspects of migration should be considered, owing to the very inhomogeneous situation in Europe. Existing monitoring systems will not be removed before end of life time and the integrated approach should be realised in the next step to gain the benefit of network connectivity and “central” intelligence. Particular emphasis shall be given to the fact, that the migration from manual surveillance towards automated equipment that will especially be driven by traffic volume and speed.

One class of benefits is derived from preventing negative effects of derailments. We quantify the direct consequences (injuries and damages) as well as indirect consequences (collision with another train after derailment, track unavailability etc.), which are not directly related to derailments. Long-term effects such as loss of public confidence in railway safety, loss of confidence with funding providers (state and local governments), loss of customer satisfaction regarding punctuality and shifting of traffic to other transport modes (road, air) are difficult to quantify. In the context of D-Rail, the effect of all these factors on the modal split is the most worrisome. Whatever the exact cause may be, shifting of rail traffic to other transport modes (road, air) will have significant negative consequences on all actors in the railway industry and society. This effect is not limited to freight: if freight trains are perceived as being dangerous, passenger transport will also suffer from it. The loss of a single percent of modal split diminishes all other direct and indirect costs incurred from derailments.

5 Recommendations

The evaluation of investments in real assets based on calculated Life-Cycle-Costs depend mainly on available data and their quality. Often some related costs from the beginning to the end of lifetime are missing, and it’s hard to achieve reliable results. Some estimations, as accurate as possible, may help but much experience is needed to keep feasibility and informative value of the calculation. Here especially the cost drivers and their magnitude have to be in focus in all phases of product life.

Life-Cycle-Cost analysis is a powerful tool to develop optimal business strategies. Applying it to investigate the possibilities of using train/track monitoring systems, some aspects shall be considered to receive optimal results.

- Optimizing monitoring system

In fact, railway operations belong to the hardest surrounding conditions for technical devices and components. High loads, huge temperature ranges, strong vibrations, water, salty air nearby the sea, aggressive dust are only a few of the challenges. Hence it is very important to attach a high value to robustness of hardware and software components so that off time can be restricted to a minimum.

In this context the system maintenance strategy should be synchronized with the requirements of the railway system as a whole in order to reduce the monitoring systems influence on track availability as much as possible and to be cost effective. In addition, condition-based maintenance strategies should be applied since it may offer LCC benefits as presented in section 3.7.3. More details on optimizing monitoring techniques can be seen in WP4 findings.

- Optimizing monitoring system application

It was shown that many aspects influence the life cycle costs of inspection and monitoring systems. One of the big working levers to realize a cost effective but efficient monitoring concept is to decide for the right number of measuring sites. This is significantly affected by the permitted probability of failure occurring, how many special infrastructure elements need to be secured, the share of train to be monitored and the segmentation of line categories on the network. Optimal planning of measurement site implementation respectively measuring car requirements is of high importance to reduce investment. This can be achieved witha density based approach and risk-related decisions considering important aspects (legal, financial, safety (SMS, CSM-RA), requirements of the concerned infrastructure manager, traffic volume, specific boundary conditions etc.Another lever is to enable (cross border) networking and data integration to enable concentrated measured data for higher-level decisions over the network to enhance safety and route availability.

In regard of migration, the different aspects of migration should be considered, owing to the very inhomogeneous situation in Europe. It has also been kept in mind that migration to a future monitoring concept is not a single step. The migration from manual surveillance towards automated equipment will especially be driven by traffic volume and speed, but consideration is required of the different surrounding conditions in order to harmonize all safety the standards. More see in WP5 findings.

- Optimizing boundary conditions

Train density and train speed are driving factors for changing to automatic train surveillance (high speed lines and pan European freight corridors). To improve operational environment improves also effectiveness of implemented monitoring systems. Therefore it can help also considering additional benefits of monitoring systems as described.

- Optimizing LCC analysis

Referring to the analysis method itself it is of high importance to assure that all relevant key input data have a high quality. It is often difficult to gain all information needed. Thus accurate estimations are needed. However, rough approximations that may cause misleading analysis results are of no use.

In order to perform a robust LCC and RAMS analysis sufficient data regarding RAMS performance of systems are needed, as these feed into LCC analysis. It is recommended to make use of ICT technology to enhance data collection and analysis process.

The effect of reliability and maintenance on the costs shows that the application of integrated RAMS and LCC modelling is needed in order to identify the most cost efficient decision. By increasing reliability, the failures and maintenance costs will be decreased and thus a higher safe life time will be obtained, whereas lower reliability means increased unscheduled repairs and increased costs. In fact these portions of cost reduction due to higher reliability of HABD (by design or application of effective maintenance) might have significant economic consequences, and needs to be considered during design and maintenance development activities.

In fact, railway design attributes and 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 design and operation phases. In the context of D-rail project, the consequences of interactions between reliability, maintainability, and supportability, and derailment scenarios need to be taken into account to achieve the RAMS and LCC targets and minimize the safety risk of derailment.

Finally, infrastructure manager (IM), railway undertakings (RU) and vehicle owners (VO) can derive important benefits from each other provided that the difficulty of exchanging data between IM and RU/ECM is solved. However, many of the discussions lie in the interface between infrastructure managers bearing the costs and railway undertakings/entities in charge of maintenance deriving the benefits. The IM must deploy a WTMS, the RU/ECM must act on the results of this monitoring to derive the safety and maintenance benefits. The largest hurdle today is the vehicle identification and correlation to the WTMS data. This problem is already solved for locomotives, which has led to an immediate demand by RU’s to obtain these data, since the economic benefits are easily realized in practice. For vehicles, the situation is currently at stand. To unblock this, an active role of supranational bodies is important. Bear in mind that maintenance optimization holds a large financial lever that can improve competiveness of railway freight compared to road transport.

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Appendices

Appendix 1: Further results from the cost-benefit analysis

Table 26: Net Present Value of the additional benefits reg. TGMS - high scenario

Track geometry measurement systems	capital costs investment, reinvestment & disposal	ongoing costs operation costs	ongoing costs maintainance costs	Net costs per year	Net Present Value 4,0%	Cumulative Net Present Value COSTS
2021	19.000.000 €	950.000 €	1.520.000 €	21.470.000 €	20.644.231 €	20.644.231 €
2022	0 €	950.000 €	1.520.000 €	2.470.000 €	2.283.654 €	22.927.885 €
2023	0 €	950.000 €	1.520.000 €	2.470.000 €	2.195.821 €	25.123.706 €
2024	0 €	950.000 €	1.520.000 €	2.470.000 €	2.111.366 €	27.235.072 €
2025	0 €	950.000 €	1.520.000 €	2.470.000 €	2.030.160 €	29.265.232 €
2026	0 €	950.000 €	1.520.000 €	2.470.000 €	1.952.077 €	31.217.309 €
2027	0 €	950.000 €	1.520.000 €	2.470.000 €	1.876.997 €	33.094.306 €
2028	0 €	950.000 €	1.520.000 €	2.470.000 €	1.804.805 €	34.899.111 €
2029	0 €	950.000 €	1.520.000 €	2.470.000 €	1.735.389 €	36.634.500 €
2030	11.400.000 €	950.000 €	1.520.000 €	13.870.000 €	9.370.075 €	46.004.575 €
2031	0 €	950.000 €	1.520.000 €	2.470.000 €	1.604.465 €	47.609.040 €
2032	0 €	950.000 €	1.520.000 €	2.470.000 €	1.542.755 €	49.151.794 €
2033	0 €	950.000 €	1.520.000 €	2.470.000 €	1.483.418 €	50.635.212 €
2034	0 €	950.000 €	1.520.000 €	2.470.000 €	1.426.363 €	52.061.576 €
2035	0 €	950.000 €	1.520.000 €	2.470.000 €	1.371.503 €	53.433.079 €
2036	0 €	950.000 €	1.520.000 €	2.470.000 €	1.318.753 €	54.751.832 €
2037	0 €	950.000 €	1.520.000 €	2.470.000 €	1.268.032 €	56.019.864 €
2038	0 €	950.000 €	1.520.000 €	2.470.000 €	1.219.261 €	57.239.126 €
2039	0 €	950.000 €	1.520.000 €	2.470.000 €	1.172.367 €	58.411.493 €
2040	11.400.000 €	950.000 €	1.520.000 €	13.870.000 €	6.330.087 €	64.741.580 €
2041	0 €	950.000 €	1.520.000 €	2.470.000 €	1.083.919 €	65.825.499 €
2042	0 €	950.000 €	1.520.000 €	2.470.000 €	1.042.230 €	66.867.728 €
2043	0 €	950.000 €	1.520.000 €	2.470.000 €	1.002.144 €	67.869.872 €
2044	0 €	950.000 €	1.520.000 €	2.470.000 €	963.600 €	68.833.472 €
2045	0 €	950.000 €	1.520.000 €	2.470.000 €	926.539 €	69.760.011 €
2046	0 €	950.000 €	1.520.000 €	2.470.000 €	890.902 €	70.650.913 €
2047	0 €	950.000 €	1.520.000 €	2.470.000 €	856.637 €	71.507.550 €
2048	0 €	950.000 €	1.520.000 €	2.470.000 €	823.689 €	72.331.240 €
2049	0 €	950.000 €	1.520.000 €	2.470.000 €	792.009 €	73.123.249 €
2050	500.000 €	950.000 €	1.520.000 €	2.970.000 €	915.706 €	74.038.955 €

Table 27: Net Present Value of the additional benefits reg. TGMS – high scenario

Avoided cost of derailments (1.53% traffic increase)	Potential maintenance cost optimization	TOTAL yearly Net Present Value 4,0%	Cumulative Net Present Value AVOIDED COSTS
12.751.524 €	15.000.000 €	26.684.158 €	26.684.158 €
12.946.622 €	15.000.000 €	25.838.223 €	52.522.381 €
13.144.705 €	15.000.000 €	25.020.541 €	77.542.921 €
13.345.819 €	15.000.000 €	24.230.125 €	101.773.047 €
13.550.010 €	15.000.000 €	23.466.028 €	125.239.074 €
13.757.326 €	15.000.000 €	22.727.332 €	147.966.406 €
13.967.813 €	15.000.000 €	22.013.157 €	169.979.563 €
14.181.520 €	15.000.000 €	21.322.651 €	191.302.214 €
14.398.498 €	15.000.000 €	20.654.994 €	211.957.209 €
14.618.795 €	15.000.000 €	20.009.396 €	231.966.605 €
14.842.462 €	15.000.000 €	19.385.094 €	251.351.699 €
15.069.552 €	15.000.000 €	18.781.353 €	270.133.052 €
15.300.116 €	15.000.000 €	18.197.464 €	288.330.517 €
15.534.208 €	15.000.000 €	17.632.744 €	305.963.261 €
15.771.881 €	15.000.000 €	17.086.533 €	323.049.794 €
16.013.191 €	15.000.000 €	16.558.196 €	339.607.990 €
16.258.193 €	15.000.000 €	16.047.120 €	355.655.110 €
16.506.943 €	15.000.000 €	15.552.713 €	371.207.823 €
16.759.499 €	15.000.000 €	15.074.406 €	386.282.229 €
17.015.920 €	15.000.000 €	14.611.648 €	400.893.877 €
17.276.263 €	15.000.000 €	14.163.909 €	415.057.785 €
17.540.590 €	15.000.000 €	13.730.677 €	428.788.463 €
17.808.961 €	15.000.000 €	13.311.459 €	442.099.922 €
18.081.438 €	15.000.000 €	12.905.779 €	455.005.701 €
18.358.084 €	15.000.000 €	12.513.178 €	467.518.879 €
18.638.963 €	15.000.000 €	12.133.212 €	479.652.091 €
18.924.139 €	15.000.000 €	11.765.453 €	491.417.544 €
19.213.678 €	15.000.000 €	11.409.491 €	502.827.035 €
19.507.647 €	15.000.000 €	11.064.926 €	513.891.961 €
19.806.115 €	15.000.000 €	10.731.375 €	524.623.336 €
OVERALL LCC COST BENEFIT RATIO			7,09

Table 28: Net Present Value reg. TGMS - low scenario

Track geometry measurement systems	capital costs investment, reinvestment & disposal	ongoing costs operation costs	ongoing costs maintainance costs	Net costs per year	Net Present Value 4,0%	Cumulative Net Present Value COSTS
2021	9.500.000 €	475.000 €	760.000 €	10.735.000 €	10.322.115 €	10.322.115 €
2022	0 €	475.000 €	760.000 €	1.235.000 €	1.141.827 €	11.463.942 €
2023	0 €	475.000 €	760.000 €	1.235.000 €	1.097.911 €	12.561.853 €
2024	0 €	475.000 €	760.000 €	1.235.000 €	1.055.683 €	13.617.536 €
2025	0 €	475.000 €	760.000 €	1.235.000 €	1.015.080 €	14.632.616 €
2026	0 €	475.000 €	760.000 €	1.235.000 €	976.038 €	15.608.654 €
2027	0 €	475.000 €	760.000 €	1.235.000 €	938.498 €	16.547.153 €
2028	0 €	475.000 €	760.000 €	1.235.000 €	902.402 €	17.449.555 €
2029	0 €	475.000 €	760.000 €	1.235.000 €	867.695 €	18.317.250 €
2030	5.700.000 €	475.000 €	760.000 €	6.935.000 €	4.685.038 €	23.002.287 €
2031	0 €	475.000 €	760.000 €	1.235.000 €	802.232 €	23.804.520 €
2032	0 €	475.000 €	760.000 €	1.235.000 €	771.377 €	24.575.897 €
2033	0 €	475.000 €	760.000 €	1.235.000 €	741.709 €	25.317.606 €
2034	0 €	475.000 €	760.000 €	1.235.000 €	713.182 €	26.030.788 €
2035	0 €	475.000 €	760.000 €	1.235.000 €	685.752 €	26.716.540 €
2036	0 €	475.000 €	760.000 €	1.235.000 €	659.377 €	27.375.916 €
2037	0 €	475.000 €	760.000 €	1.235.000 €	634.016 €	28.009.932 €
2038	0 €	475.000 €	760.000 €	1.235.000 €	609.631 €	28.619.563 €
2039	0 €	475.000 €	760.000 €	1.235.000 €	586.183 €	29.205.746 €
2040	5.700.000 €	475.000 €	760.000 €	6.935.000 €	3.165.043 €	32.370.790 €
2041	0 €	475.000 €	760.000 €	1.235.000 €	541.959 €	32.912.749 €
2042	0 €	475.000 €	760.000 €	1.235.000 €	521.115 €	33.433.864 €
2043	0 €	475.000 €	760.000 €	1.235.000 €	501.072 €	33.934.936 €
2044	0 €	475.000 €	760.000 €	1.235.000 €	481.800 €	34.416.736 €
2045	0 €	475.000 €	760.000 €	1.235.000 €	463.269 €	34.880.005 €
2046	0 €	475.000 €	760.000 €	1.235.000 €	445.451 €	35.325.457 €
2047	0 €	475.000 €	760.000 €	1.235.000 €	428.318 €	35.753.775 €
2048	0 €	475.000 €	760.000 €	1.235.000 €	411.845 €	36.165.620 €
2049	0 €	475.000 €	760.000 €	1.235.000 €	396.004 €	36.561.624 €
2050	250.000 €	475.000 €	760.000 €	1.485.000 €	457.853 €	37.019.478 €

Table 29: Net Present Value of the additional benefits reg. TGMS - low scenario

Avoided cost of derailments (1.53% traffic increase)	Potential maintenance cost optimization	TOTAL yearly Net Present Value 4,0%	Cumulative Net Present Value AVOIDED COSTS
9.563.643 €	15.000.000 €	23.618.887 €	23.618.887 €
9.709.967 €	15.000.000 €	22.845.753 €	46.464.641 €
9.858.529 €	15.000.000 €	22.099.142 €	68.563.782 €
10.009.365 €	15.000.000 €	21.378.110 €	89.941.892 €
10.162.508 €	15.000.000 €	20.681.747 €	110.623.639 €
10.317.994 €	15.000.000 €	20.009.179 €	130.632.818 €
10.475.860 €	15.000.000 €	19.359.559 €	149.992.377 €
10.636.140 €	15.000.000 €	18.732.077 €	168.724.454 €
10.798.873 €	15.000.000 €	18.125.946 €	186.850.400 €
10.964.096 €	15.000.000 €	17.540.413 €	204.390.813 €
11.131.847 €	15.000.000 €	16.974.749 €	221.365.562 €
11.302.164 €	15.000.000 €	16.428.254 €	237.793.816 €
11.475.087 €	15.000.000 €	15.900.251 €	253.694.067 €
11.650.656 €	15.000.000 €	15.390.090 €	269.084.157 €
11.828.911 €	15.000.000 €	14.897.142 €	283.981.299 €
12.009.893 €	15.000.000 €	14.420.803 €	298.402.101 €
12.193.644 €	15.000.000 €	13.960.490 €	312.362.591 €
12.380.207 €	15.000.000 €	13.515.640 €	325.878.231 €
12.569.624 €	15.000.000 €	13.085.713 €	338.963.944 €
12.761.940 €	15.000.000 €	12.670.187 €	351.634.131 €
12.957.197 €	15.000.000 €	12.268.558 €	363.902.689 €
13.155.442 €	15.000.000 €	11.880.341 €	375.783.029 €
13.356.721 €	15.000.000 €	11.505.068 €	387.288.098 €
13.561.079 €	15.000.000 €	11.142.290 €	398.430.388 €
13.768.563 €	15.000.000 €	10.791.571 €	409.221.959 €
13.979.222 €	15.000.000 €	10.452.493 €	419.674.453 €
14.193.104 €	15.000.000 €	10.124.652 €	429.799.105 €
14.410.259 €	15.000.000 €	9.807.659 €	439.606.764 €
14.630.736 €	15.000.000 €	9.501.137 €	449.107.901 €
14.854.586 €	15.000.000 €	9.204.726 €	458.312.627 €
OVERALL LCC COST BENEFIT RATIO			**12,38**

Table 30: Net Present Value reg. HABD - high scenario

Hot axle box and hot wheel detection	capital costs investment, reinvestment & disposal	ongoing costs operation costs	ongoing costs maintainance costs	Net costs per year	Net Present Value 4,0%	Cumulative Net Present Value COSTS
2021	181.384.000 €	3.788.840 €	5.830.200 €	16.836.289 €	16.188.739 €	16.188.739 €
2022	0 €	3.788.840 €	5.830.200 €	9.619.040 €	8.893.343 €	25.082.083 €
2023	0 €	3.788.840 €	5.830.200 €	9.619.040 €	8.551.292 €	33.633.374 €
2024	0 €	3.788.840 €	5.830.200 €	9.619.040 €	8.222.396 €	41.855.770 €
2025	0 €	3.788.840 €	5.830.200 €	9.619.040 €	7.906.150 €	49.761.920 €
2026	0 €	3.788.840 €	5.830.200 €	9.619.040 €	7.602.067 €	57.363.987 €
2027	0 €	3.788.840 €	5.830.200 €	9.619.040 €	7.309.680 €	64.673.666 €
2028	0 €	3.788.840 €	5.830.200 €	9.619.040 €	7.028.538 €	71.702.205 €
2029	0 €	3.788.840 €	5.830.200 €	9.619.040 €	6.758.210 €	78.460.415 €
2030	0 €	3.788.840 €	5.830.200 €	9.619.040 €	6.498.279 €	84.958.693 €
2031	0 €	3.788.840 €	5.830.200 €	9.619.040 €	6.248.345 €	91.207.038 €
2032	0 €	3.788.840 €	5.830.200 €	9.619.040 €	6.008.024 €	97.215.062 €
2033	0 €	3.788.840 €	5.830.200 €	9.619.040 €	5.776.946 €	102.992.009 €
2034	0 €	3.788.840 €	5.830.200 €	9.619.040 €	5.554.756 €	108.546.764 €
2035	116.604.000 €	3.788.840 €	5.830.200 €	126.223.040 €	70.087.174 €	178.633.938 €
2036	0 €	3.788.840 €	5.830.200 €	9.619.040 €	5.135.684 €	183.769.622 €
2037	0 €	3.788.840 €	5.830.200 €	9.619.040 €	4.938.158 €	188.707.780 €
2038	0 €	3.788.840 €	5.830.200 €	9.619.040 €	4.748.229 €	193.456.009 €
2039	0 €	3.788.840 €	5.830.200 €	9.619.040 €	4.565.604 €	198.021.613 €
2040	0 €	3.788.840 €	5.830.200 €	9.619.040 €	4.390.004 €	202.411.617 €
2041	0 €	3.788.840 €	5.830.200 €	9.619.040 €	4.221.158 €	206.632.775 €
2042	0 €	3.788.840 €	5.830.200 €	9.619.040 €	4.058.806 €	210.691.581 €
2043	0 €	3.788.840 €	5.830.200 €	9.619.040 €	3.902.698 €	214.594.279 €
2044	0 €	3.788.840 €	5.830.200 €	9.619.040 €	3.752.594 €	218.346.873 €
2045	0 €	3.788.840 €	5.830.200 €	9.619.040 €	3.608.264 €	221.955.136 €
2046	0 €	3.788.840 €	5.830.200 €	9.619.040 €	3.469.484 €	225.424.621 €
2047	0 €	3.788.840 €	5.830.200 €	9.619.040 €	3.336.042 €	228.760.663 €
2048	0 €	3.788.840 €	5.830.200 €	9.619.040 €	3.207.733 €	231.968.396 €
2049	0 €	3.788.840 €	5.830.200 €	9.619.040 €	3.084.359 €	235.052.755 €
2050	3.950.000 €	3.788.840 €	5.830.200 €	13.569.040 €	4.183.588 €	239.236.343 €

Table 31: Net Present Value of the additional benefits reg. HABD - high scenario

Avoided cost of derailments (1.53% traffic increase)	Potential maintenance cost	TOTAL yearly Net Present Value 4,0%	Cumulative Net Present Value AVOIDED COSTS
6.142.671 €	710.769 €	6.589.846 €	6.589.846 €
6.236.654 €	710.769 €	6.423.283 €	13.013.130 €
6.332.075 €	710.769 €	6.261.063 €	19.274.192 €
6.428.956 €	710.769 €	6.103.067 €	25.377.259 €
6.527.319 €	710.769 €	5.949.180 €	31.326.439 €
6.627.187 €	710.769 €	5.799.293 €	37.125.732 €
6.728.583 €	710.769 €	5.653.296 €	42.779.028 €
6.831.530 €	710.769 €	5.511.084 €	48.290.112 €
6.936.052 €	710.769 €	5.372.555 €	53.662.667 €
7.042.174 €	710.769 €	5.237.610 €	58.900.277 €
7.149.919 €	710.769 €	5.106.153 €	64.006.431 €
7.259.313 €	710.769 €	4.978.090 €	68.984.520 €
7.370.380 €	710.769 €	4.853.329 €	73.837.849 €
7.483.147 €	710.769 €	4.731.782 €	78.569.632 €
7.597.639 €	710.769 €	4.613.364 €	83.182.996 €
7.713.883 €	710.769 €	4.497.991 €	87.680.987 €
7.831.906 €	710.769 €	4.385.581 €	92.066.567 €
7.951.734 €	710.769 €	4.276.055 €	96.342.622 €
8.073.395 €	710.769 €	4.169.337 €	100.511.959 €
8.196.918 €	710.769 €	4.065.352 €	104.577.312 €
8.322.331 €	710.769 €	3.964.028 €	108.541.339 €
8.449.663 €	710.769 €	3.865.294 €	112.406.633 €
8.578.943 €	710.769 €	3.769.081 €	116.175.714 €
8.710.201 €	710.769 €	3.675.323 €	119.851.036 €
8.843.467 €	710.769 €	3.583.954 €	123.434.990 €
8.978.772 €	710.769 €	3.494.913 €	126.929.903 €
9.116.147 €	710.769 €	3.408.137 €	130.338.041 €
9.255.624 €	710.769 €	3.323.567 €	133.661.608 €
9.397.235 €	710.769 €	3.241.146 €	136.902.754 €
9.541.013 €	710.769 €	3.160.816 €	140.063.570 €
OVERALL LCC COST BENEFIT RATIO			0,59

Table 32: Net Present Value reg. HABD - low scenario

Hot axle box and hot wheel detection	capital costs investment, reinvestment & disposal	ongoing costs operation costs	ongoing costs maintainance costs	Net costs per year	Net Present Value 4,0%	Cumulative Net Present Value COSTS
2021	36.736.000 €	767.360 €	1.180.800 €	38.684.160 €	37.196.308 €	37.196.308 €
2022	0 €	767.360 €	1.180.800 €	1.948.160 €	1.801.183 €	38.997.491 €
2023	0 €	767.360 €	1.180.800 €	1.948.160 €	1.731.907 €	40.729.398 €
2024	0 €	767.360 €	1.180.800 €	1.948.160 €	1.665.295 €	42.394.694 €
2025	0 €	767.360 €	1.180.800 €	1.948.160 €	1.601.246 €	43.995.939 €
2026	0 €	767.360 €	1.180.800 €	1.948.160 €	1.539.659 €	45.535.598 €
2027	0 €	767.360 €	1.180.800 €	1.948.160 €	1.480.441 €	47.016.040 €
2028	0 €	767.360 €	1.180.800 €	1.948.160 €	1.423.501 €	48.439.541 €
2029	0 €	767.360 €	1.180.800 €	1.948.160 €	1.368.751 €	49.808.293 €
2030	0 €	767.360 €	1.180.800 €	1.948.160 €	1.316.107 €	51.124.400 €
2031	0 €	767.360 €	1.180.800 €	1.948.160 €	1.265.488 €	52.389.887 €
2032	0 €	767.360 €	1.180.800 €	1.948.160 €	1.216.815 €	53.606.702 €
2033	0 €	767.360 €	1.180.800 €	1.948.160 €	1.170.014 €	54.776.717 €
2034	0 €	767.360 €	1.180.800 €	1.948.160 €	1.125.014 €	55.901.730 €
2035	23.616.000 €	767.360 €	1.180.800 €	25.564.160 €	14.194.871 €	70.096.601 €
2036	0 €	767.360 €	1.180.800 €	1.948.160 €	1.040.139 €	71.136.740 €
2037	0 €	767.360 €	1.180.800 €	1.948.160 €	1.000.133 €	72.136.873 €
2038	0 €	767.360 €	1.180.800 €	1.948.160 €	961.667 €	73.098.539 €
2039	0 €	767.360 €	1.180.800 €	1.948.160 €	924.679 €	74.023.219 €
2040	0 €	767.360 €	1.180.800 €	1.948.160 €	889.115 €	74.912.334 €
2041	0 €	767.360 €	1.180.800 €	1.948.160 €	854.918 €	75.767.252 €
2042	0 €	767.360 €	1.180.800 €	1.948.160 €	822.037 €	76.589.288 €
2043	0 €	767.360 €	1.180.800 €	1.948.160 €	790.420 €	77.379.708 €
2044	0 €	767.360 €	1.180.800 €	1.948.160 €	760.019 €	78.139.727 €
2045	0 €	767.360 €	1.180.800 €	1.948.160 €	730.788 €	78.870.515 €
2046	0 €	767.360 €	1.180.800 €	1.948.160 €	702.680 €	79.573.195 €
2047	0 €	767.360 €	1.180.800 €	1.948.160 €	675.654 €	80.248.849 €
2048	0 €	767.360 €	1.180.800 €	1.948.160 €	649.667 €	80.898.517 €
2049	0 €	767.360 €	1.180.800 €	1.948.160 €	624.680 €	81.523.197 €
2050	800.000 €	767.360 €	1.180.800 €	2.748.160 €	847.309 €	82.370.506 €

Table 33: Net Present Value of the additional benefits reg. HABD - low scenario

Avoided cost of derailments (1.53% traffic increase)	Potential maintenance cost optimization	TOTAL yearly Net Present Value 4,0%	Cumulative Net Present Value AVOIDED COSTS
607.517 €	710.769 €	1.267.583 €	1.267.583 €
616.812 €	710.769 €	1.227.423 €	2.495.006 €
626.249 €	710.769 €	1.188.604 €	3.683.610 €
635.831 €	710.769 €	1.151.079 €	4.834.689 €
645.559 €	710.769 €	1.114.803 €	5.949.492 €
655.436 €	710.769 €	1.079.732 €	7.029.224 €
665.464 €	710.769 €	1.045.824 €	8.075.048 €
675.646 €	710.769 €	1.013.040 €	9.088.088 €
685.983 €	710.769 €	981.340 €	10.069.427 €
696.479 €	710.769 €	950.686 €	11.020.113 €
707.135 €	710.769 €	921.043 €	11.941.157 €
717.954 €	710.769 €	892.376 €	12.833.533 €
728.939 €	710.769 €	864.651 €	13.698.184 €
740.091 €	710.769 €	837.836 €	14.536.020 €
751.415 €	710.769 €	811.899 €	15.347.918 €
762.912 €	710.769 €	786.810 €	16.134.729 €
774.584 €	710.769 €	762.541 €	16.897.269 €
786.435 €	710.769 €	739.062 €	17.636.331 €
798.468 €	710.769 €	716.348 €	18.352.679 €
810.684 €	710.769 €	694.371 €	19.047.050 €
823.088 €	710.769 €	673.108 €	19.720.158 €
835.681 €	710.769 €	652.533 €	20.372.691 €
848.467 €	710.769 €	632.623 €	21.005.314 €
861.448 €	710.769 €	613.356 €	21.618.670 €
874.629 €	710.769 €	594.709 €	22.213.379 €
888.010 €	710.769 €	576.663 €	22.790.042 €
901.597 €	710.769 €	559.195 €	23.349.237 €
915.391 €	710.769 €	542.288 €	23.891.525 €
929.397 €	710.769 €	525.922 €	24.417.446 €
943.617 €	710.769 €	510.078 €	24.927.524 €
OVERALL LCC COST BENEFIT RATIO			0,30