The sustainable freight railway: Designing the freight vehicle – track system for higher delivered tonnage with improved availability at reduced cost

SUSTRAIL

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RAMS AND LCC ANALYSIS

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EXECUTIVE SUMMARY

The overall objective of WP5 is to address the business case for the freight vehicle-track system for higher delivered tonnage and give recommendations for whole-system implementation, including phasing in of novel technologies and strategies for the equitable redistribution of whole-system savings. Another objective is to demonstrate the method for performing RAMS and LCC simulations and analysis using a holistic approach. A third objective is that the innovations/option should be tested in different routes in UK, Bulgaria and Spain.

This is a challenge because the railway transport system is complex from both a technical and organisation perspective and compose of several different parties, each one with individual objectives and strategy in maintaining their assets and rolling stock. The development of the railway system has also been carried out on a national basis leading to systems hindrances such as differences in standards and different technical solution e.g. different track gauges. Another obstacle while chasing data for e.g. benchmarking or LCC-calculations is that deregulation and outsourcing has change the data from being available to being confidential and sensitive in a competitive environment.

The content of this report is to describe the results and work done in WP5 task 5.1 where RAMS and LCC analysis is to be performed on selected innovations from WP4 and WP3. There were five innovations/options from “Future Vehicle development” and ten from “Sustainable track”. Some of these are not generated by Sustrail but are highlighted as innovations/options recommended for assessment by SUSTRAIL.

The RAMS and LCC model developed in SUSTRAIL can simulate a vast number of different scenarios and can be adopted to other line sections and vehicle types. To demonstrate the capability of the model, a set of scenarios has been selected for simulation. Some scenarios have also been excluded from the simulation due to difficulties in accessing valid or accurate data.

When performing a RAMS and LCC analysis the access to data is a key issue. Problems in getting access to data can have many different reasons. E.g. failure frequencies of a vehicle could be located at different stakeholders. Wagons are repaired at different locations and wheels are constantly being shifted from a wheel pool between different wagons and owners. Data could also be located within different parts of an organisation in different formats and sometime the data does not exist due to the absence of a measurement strategy. Different stakeholders and their individual business goals can also restrict the access to information needed for a holistic railway RAMS and LCC analyses. Another reason for missing data is also due to difficulties in estimating e.g. costs and maintenance actions for new solutions which are only in the design stage. Due to difficulties in extracting some of the information mentioned above, the RAMS and LCC simulation had to be performed on a subset of the total number of innovations presented in WP3 and WP4. The innovations/solutions that were excluded from the simulation has however been discussed from a more theoretical point of view.

The RAMS and LCC model was developed to assess the innovations from an holistic approach. The holistic approach in the modelling work aims to reflect how the track and the wagons interact from a RAMS and LCC perspective. In the model maintenance actions, track is affected by a more track friendlier SUSTRAIL wagon and the economic benefits for the

Infrastructural Manager (IM) can be quantified. Effects in the opposite direction, how the track will affect the wagon, have not been implemented in the model due to lack of data.

The result of the simulation shows that the technical performance of the SUSTRAIL wagon is better than the benchmark wagon. The estimated availability of the benchmark wagon is about 95% while that of the SUSTRAIL wagon is estimated to be 99%. The main factor responsible for the lower availability of the benchmark wagon is the increased total amount of logistics and waiting time at the workshop due to a higher failure rate. In addition, the mission success rate of the SUSTRAIL and benchmark wagons is similar to the availability of their respective availability measures. From cost perspective, the initial cost of acquisition of improved wagon is about 70% higher but the reduced cost of maintenance and failure pays off in the long run. The break-even point for the SUSTRAIL wagon is quite late (around year 23) but there are promising benefits from operation and track performance viewpoints.

Furthermore, the availability performances of the benchmark track and wagon, benchmark track and improved wagon, improved track and wagon and improved track and wagon with speed increase are estimated to be 95%, 97%, 99% and 97% respectively, (as previously mentioned, how the track innovation will affect the wagon is not included). Even though the differences in the technical performance of the four cases are not pronounced, the cost implication justifies the implementation of the SUSTRAIL scenario (improved wagon and track) without speed change. More dynamic simulation is needed to validate the opined performance of the proposed improvement with speed change. It is estimated that wagon improvement with benchmark track will give at least 5% reduction in the life cycle cost over 30 years with focus on curves in the simulated route (UK1). Further improvement of the track with premium rail together with improved wagons presents about 61% reduction in the LCC. In the case of the track improvement with speed change, the estimated reduction in the LCC by 43% is based on expert assessment. It is suggested that additional dynamic simulation is required to further establish the expert judgement and these conclusions.

It is important to note that this LCC analysis has been "partial" in nature. That is, only the cost elements where significant cost changes between the base scenario and the modelled scenarios have been modelled.

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1. INTRODUCTION

1.1 Project background

The SUSTRAIL project is built up by eight work packages, WP1-WP8, where the three last work packages deals with dissemination, exploitation, project coordination and demonstration. In this section a brief description based on the description of work, for work package 1 to 5 is presented.

1.1.1 WP1 Benchmarking

WP1 provides benchmarking of the current freight 'system' to establish the existing 'zero state' for subsequent comparative and enhancement activities. The benchmarking is designed to provide information to support evaluation of the key system parameters which will ultimately influence and determine improvements towards freight sustainability and competitiveness.

1.1.2 WP2 Requirements

WP2 deals with the development of duty requirements for current and future freight traffic flows and track design requirements for reduced maintenance time and whole life cost based on optimised vehicle characteristics. WP2 deals also with prioritising the combination of technologies for a freight vehicle-track system for higher delivered tonnage. In Figure 1 the table, developed in WP2, describing the duty requirement can be seen.

Priority Level	Duty Requirements for Improvement	System
High	1. Modest increase in freight speed (e.g. 120-140kph UK; 100-120kph ES,BG)	whole
	3. Optimise axle load limits (22.5t / 25t / 17-20t)	whole
	7. (20%) reduction in energy used by rail vehicles + Vehicle Green Label	vehicle
	12. Improve bogie design to reduce lateral forces (by 50%)	vehicle
Medium	5. Reduce vertical ride force to match passenger vehicle at equivalent axle load (by suspension improvements)	vehicle
	8. (20%) reduction in unsprung mass of freight vehicle	vehicle
	2. Uniform vertical stiffness (track) - optimise between 50-100 kN/mm	track
	9. Optimise (potentially double) service life of track components	track
	10. Combine components that have a similar service life (harmonise MTBF)	track
	6. Reduced rate of tolerable defects	track
	4. More reliable insulated rail joints (life*5)	track
Low	11. Independent power supply (wagon or train based) - for braking & refrigeration	vehicle
	13. Increased loading space	vehicle

Figure 1 Table developed in WP2 describing the prioritised duty requirement for improvements

1.1.3 WP3 Railway vehicles

WP3 deals with innovations for railway vehicles which supports the duty requirements defined in WP2. WP3 has identified the key areas where recent and future developments can lead to improved running behaviour resulting in reduced impact, reduced system maintenance and lower operating costs for both vehicle and track. The latest research output and scientific developments has been used in these key areas to outline the technical requirements for a new generation of low impact freight vehicles. Where possible specific 'off the shelf' components have been selected and, if appropriate, modifications proposed. Where the new design requires completely new components prototypes have been designed and laboratory tests carried out in preparation for integration into the demonstrator vehicle in WP6.

1.1.4 WP4 Railway track

The work package facilitates the need for the railway infrastructure to accommodate more traffic whilst at the same time reducing deterioration of track and wheels through increasing the resistance of the track to the loads imposed on it by vehicles. This has been assisted in sustainable achievement of increased speed and capacity for freight traffic, thus contributing towards making rail freight more competitive. The goal of this WP is to identify performance based design principles and complementary monitoring tools that will move the lower bound of the track resistance probability curve upwards through removing the causes of track failures at discrete locations with low damage resistance.

1.1.5 WP5 Business case

Work package 5 considers the business case and implementation issues associated with the vehicle and track options developed in WP3 and WP4 respectively. The business case is based on an assessment of selected solutions developed in WP3 and WP4. The assessment will include quantifying the Life Cycle Cost (LCC) of each option and a Reliability, Availability, Maintenance and Safety (RAMS) analysis where the parameters for this analysis are informed by the Duty Requirements established in WP2 (Task 5.1) and the benchmarked track and rolling stock delivered in WP1. Also essential to the business case assessment is attempting to quantify the net benefits to freight and passenger users, given the likely improvements to freight services as a result of the options developed in WP3 and WP4. Further, any new technology is likely to have environmental impacts relative to the current situation, for example changes in noise and CO2 emissions. This will be achieved through freight demand and environmental modelling and valuation of the resulting benefits (Task 5.2).

1.1.6 WP5 Task 5.1 RAMS and LCC analysis

The content of this report describes result and work done in WP5 task 5.1 where RAMS and LCC analysis is to be performed on selected innovations from WP4 and WP3.

1.2 RAMS Theory

RAMS is a technical methodology to assess a product /system dependability in all phases of its life length to deliver a system/product that is reliable, with minimal requirements to operate and maintain, being safe without getting any negative environmental impact.

By using RAMS in an early stage of a product /system implementation, huge cost savings can be done e.g. by avoiding unnecessarily high operation and maintenance costs and also avoiding safety and health cost. It is particularly important to perform RAMS analysis and to do a maintenance impact statement in the investment phase.

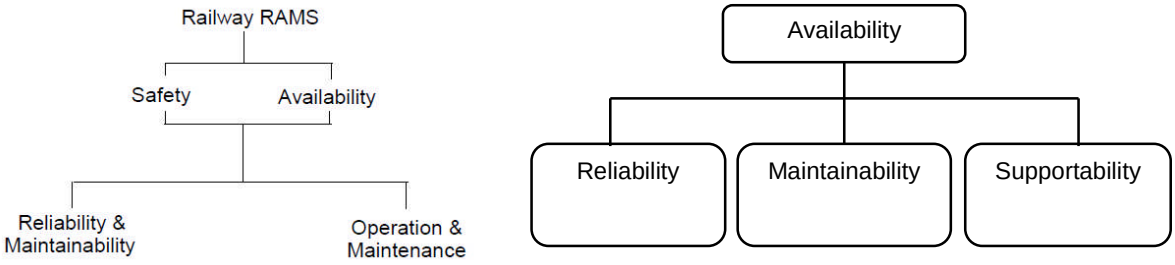


Figure 2 Left chart: Railway RAMS according to SIS-1999-SS-EN, Right chart RAMS according to EN-13306

According to SIS-1999-SS-E 50126 RAMS means Reliability, Availability, Maintainability and Safety.

Reliability is defined as the probability that an item can perform a required function under given conditions for a given time interval, measured in terms of e.g. function probability, failure rate, mean time to failure (MTTF) or mean time between failure (MTBF).

Availability is defined as the ability of a product to be in a state to perform a required function under given conditions at a given instant of time or over a given time interval assuming that the required external sources are provided.

Maintainability is defined as the probability that a given active maintenance action, for an item under given conditions of use can be carried out within a stated time interval when the maintenance is performed under stated conditions and using stated procedures and resources and is measured in terms of e.g. mean time between maintenance (MTBM), mean time to maintain (MTTM) or mean time to repair (MTTR).

Due to the fact that "Safety" is an important factor in the railway sector, the abbreviation S in railway RAMS stands for Safety instead of Supportability. Issues regarding supportability are handled together with maintainability issues. According to EN 13306 Maintenance supportability is defined as the ability of a maintenance organization to have the correct maintenance support at the necessary place to perform the required maintenance activity when required. Safety is defined as state of a technical system freedom from unacceptable risk of harm and measured as e.g. hazard rate, mean time between hazard system failures (MTBHSF) or numbers of accidents. In Figure 2 the inter relationships between elements of the railway RAMS and the industrial RAMS standard is depicted.

The railway definitions differ from the industrial RAMS standard and could lead to some confusion when comparing with the industrial way of describing RAMS. In this analysis the industrial way of describing the RAMS structure has been chosen where safety is incorporated under the collective term Dependability. This is done to highlight the impact of the maintenance organisation on the total availability. The maintenance supportability is measured by analysing the mean waiting time (MWT).

1.3 Availability analysis

One of the main purposes with a RAMS analysis is to calculate the availability of a defined required function. The availability is a measure of the combined effect of reliability, maintainability and maintenance supportability. The required function could be a combination of functions, or a total combination of functions of an item which are considered necessary to provide a given service.

The maintenance supportability is not explicitly expressed in the Railway standard [SIS-1999-SS-EN 50126] but it is included in the concept of maintenance. However to analyses the total availability or effects of non-availability the total downtime is of interest. There are three types of availabilities; inherent availability, achieved availability and operational availability. Each of the measures describes different aspect of the availability.

1.3.1 Inherent availability (A_I)

The inherent availability measures how the construction of a unit or a system will affect the availability. It considers the uptime between failures and compares it with the repair time. The inherent availability can be expressed as

$$A_I = \frac{MTBF}{MTBF + MTTR},$$

where MTBF is the mean time between failure which is equal to the up time of the system. In the inherent availability downtime due to preventive maintenance or any other intentionally generated downtime is considered as uptime. MTTR is the mean time to repair and it only considers the actual repair time for corrective maintenance.

1.3.2 Achieved availability (A_a)

The achieved availability is considering downtime due to failures and preventive maintenance. This measure includes the unit's total effect on the availability where its reliability and maintainability, including corrective and preventive maintenance properties, are considered. The achieved availability is described as

$$A_A = \frac{MTBM}{MTBM + MAMT},$$

where MTBM is the mean time between maintenance which includes the time between downtime due to failures or preventive maintenance. MAMT is the mean active maintenance time which includes both repair time and scheduled maintenance time.

1.3.3 Operational availability (A_o)

The operational availability is a measure of the total availability of the required function. This includes all aspects of the RAMS concept, Reliability, maintainability and maintenance supportability. The difference between the achieved availability is only that the mean waiting time MWT (delay due to logistic support time) is included in the MAMT, forming the mean value of the total downtime MDT. The operational availability is described as

$$A_o = \frac{MTBM}{MTBM + MAMT + MWT} = \frac{MTBM}{MTBM + MDT}$$

1.4 System reliability

If numerous components are connected in a system the total availability of the system can be calculated. If components are coupled in series the availability becomes

$$A_s = \prod_{k=1}^{n} A_k$$

Where n is the total number of components. If n components are coupled in parallel the total availability is

$$A_s = 1 - \prod_{k=1}^{n} (1 - A_k)$$

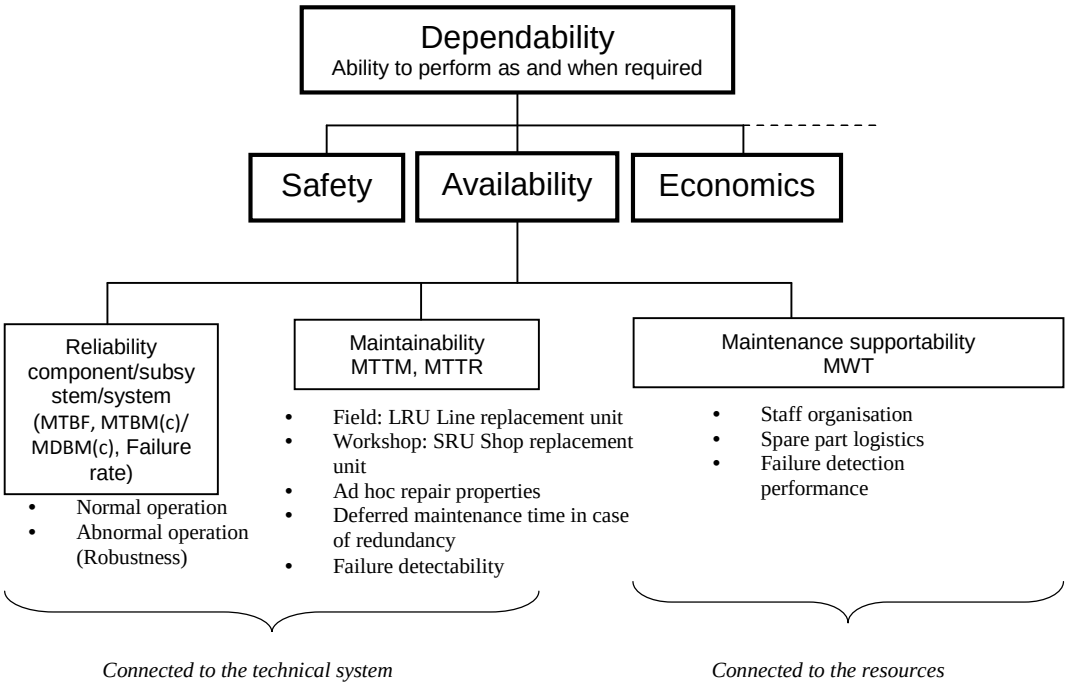


Figure 3. The figure describes the relations between dependability, safety, availability and economics according to [EN 13306].

1.5 LCC Theory

The Life cycle cost analysis (LCCA) at different levels or for different options provides basic decision support in the form of:

- strategic decisions
- decisions between different variants
- selection of appropriate solutions in terms of products and processes
- optimization of existing systems

LCCA enables this approach because it includes all costs at all relevant stages, including the technical behaviour of the product described by RAMS. An LCC calculation is based on a Product Breakdown Structure (PBS) and a Cost Breakdown Structure (CBS). PBS is used to find parts/components that will be affected by an implemented change in the structure. e.g. a rail replacement, see Figure 4, left side. The WP4 innovations have to be mapped onto a common PBS in order to perform a holistic analysis of the system. In the example: in addition to the rail fastenings and joints also hast to be replaced. In the CBS the replaced components are marked in red and they will affect the investment, installation and corrective maintenance costs. In the example, the investment cost of the rail, joints and fasteners will be added together with the installation cost and new rail will e.g. reduce the cost for corrective maintenance.

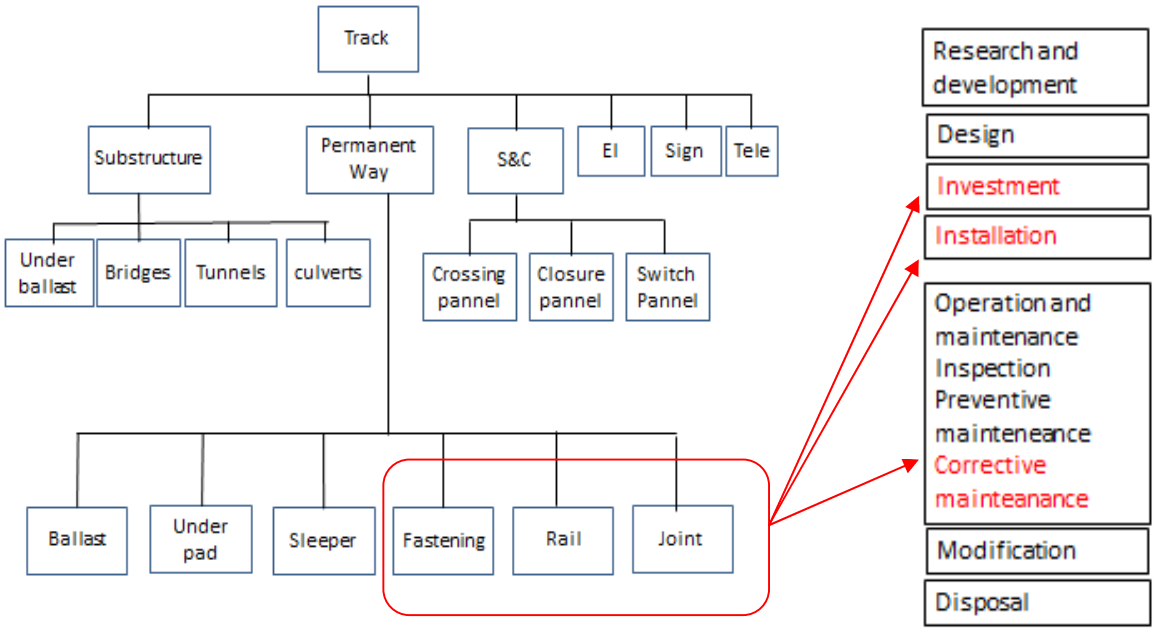


Figure 4 Example of Product Breakdown Structure (PBS) for infrastructure and Cost Breakdown Structure

What complicates the use of LCC is that the actual cost of the operation and maintenance phase is usually unknown and standard costs might have to be used. In a similar way the WP3 vehicle innovations have to be mapped onto a PBS for wagons and locos. The PBS of the infrastructure and the rolling stock will be joined to analyse the relationships between the two systems. An example off a PBS for Wagons and locos are presented in Figure 5, e.g. a new steering link will cause the wagon to run more smoothly and thereby reduce the MTBF for the wheels and axles. A known PBS and CBS will facilitate the analysis of the difference between

different options/innovations and how they will affect the RAMS parameters and LCC of the whole system/product.

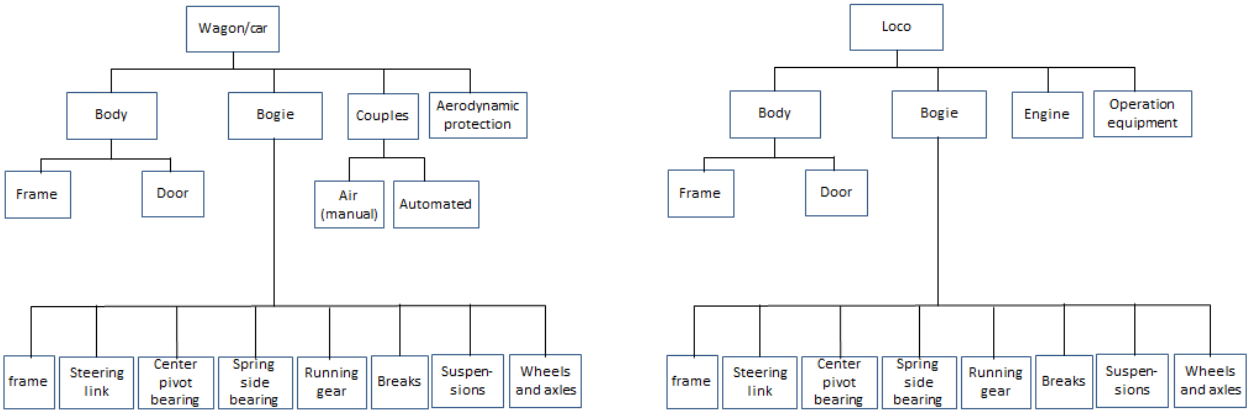


Figure 5 Example of Product Breakdown Structure (PBS) for wagons and locos.

1.6 Previous research

The concept of RAMS analysis has been evolving over decades, particularly in the field of product assurance [1] and has been interchangeably described as dependability analysis in some other fields [2]-[4]. Methods, tools and techniques for determining and assuring the RAMS or integrity of complex engineering systems were thoroughly explored in the Handbook of RAMS [1]. Railway RAMS describes the confidence with which the system can guarantee the achievement of a defined level of rail traffic in a given time, safely.

The linearity and single degree of freedom of railway infrastructure makes its RAMS analysis complex and challenging. RAMS management of railway tracks has been studied by Lyngby et. al. [5], where works on the degradation models of tracks, methods for optimizing inspection, maintenance and renewal are presented.

The application of railway RAMS analysis for effective maintenance decision support has been demonstrated by A.P. Patra [6]. Approaches and models for estimating RAMS targets based on the service quality requirements of infrastructure manager were presented

1.7 Objective

The RAMS and LCC analysis is a part of WP5 (business case) where the proposed innovations developed within the SUSTRAIL project (WP3 (Vehicle) and WP4 (track)) will be assessed from a RAMS and LCC perspective. The overall objective of WP5 is to address the business case for the freight vehicle-track system for higher delivered tonnage and give recommendations for whole-system implementation, including phasing in of novel technologies and strategies for the equitable redistribution of whole-system savings. Another objective of the WP5.1 is to demonstrate the method for performing RAMS and LCC simulations and analysis using a holistic approach.

1.7.1 Input to task 5.1

The input to task 5.1 is related to the RAMS and LCC parameters and includes information related to:

- Failure frequencies

- Maintenance times
- Logistic delays
- Maintenance activities
- Maintenance strategies
- Product structure
- Cost elements
- Service life
- Etc.

Much of the information mentioned above is often hard and difficult to extract, e.g. for an item, different information could be located within the different parts of an organisation or within the organisation of different stakeholders. Their individual business goals could restrict the access to information needed for the RAMS and LCC analyses. Due to difficulties in extracting some of the information mentioned above, the RAMS and LCC simulation had to be performed on a subset of the total number of innovations presented in WP3 and WP4. Each Innovation will however be discussed from a more theoretical level.

1.7.2 Output from task 5.1

The result of the RAMS and LCC analysis described in terms of availability and cost with and without the proposed innovations for different speeds. The cost and the availability will be fed into task 5.2 where the cost benefit analysis (CBA) is done.

1.7.3 Holistic approach

In this project a holistic approach will be used when performing the RAMS and LCC analysis. In the railway industry there are many stakeholders with different agendas and goals. The vehicle owner and the infrastructure manager might develop separate RAMS and LCC models for their assets. However, the railway is a system where vehicles and infrastructure interacts e.g. if the vehicle owner reduces its maintenance costs for wheels, the infrastructure manager might get increased costs of rail replacements and vice versa. The railway system must therefore be considered as a system, not only from a technical point of view but also from an economical and maintenance point of view.

To analyse the effect that the SUSTRAIL wagon will have on the track, the wagon will be treated like a track innovation. The effect of the track innovations on the wagon has not been studied in this work due to lack of input data. The SUSTRAIL wagon is assumed to affect the following parameters in the track model.

- Tamping interval
- Rail grinding interval
- Frequency of rail damage occurrence
- Rail renewal interval

2. RAMS AND LCC METHOD

2.1 Railway RAMS

RAMS of a system is the qualitative and quantitative indicator of the degree that the system can be relied upon to function as specified and is both available and safe [8]. RAMS is a combination of four performance indicators: reliability, availability, maintainability and safety. It provides the means by which the performance of engineering system can be rightly assessed, analysed and improved. The concept of RAMS analysis has been evolving over decades, particularly in the field of product assurance [1] and is also described as dependability management in some other fields. Railway RAMS describes the confidence with which system can guarantee the achievement of a defined level of rail traffic in a given time, safely.

2.1.1 RAMS specification and demonstration

A dependable railway system can only be assured through adequate understanding of the interactions of RAMS elements within a system. In addition, the specification and achievement of the optimum RAMS combination for the system should be well managed. The specification of RAMS requirements is a complex process. Besides the definition and interaction of the RAMS element given in the standard EN 50126 [8], a process based on the system lifecycle and tasks within it, for managing RAMS is also presented. The systematic process for specifying requirements for RAMS and demonstrating that these requirements are achieved are defined in the standard as well. The procedure for the creation of a RAMS programme, based on certain requirements has been demonstrated to serve as guidance for practical implementation. There are several tools, techniques and approaches that can be used for RAMS analysis. However, the selection of an appropriate tool should depend on the system under consideration and on some other essential factors. In this study we have implemented a combination of some the techniques mentioned in the standard using a simulation approach. Figure 6 shows a typical flow chart that can be useful for the specification of RAMS requirement as well as the investigation of the achievement of the target for each elements.

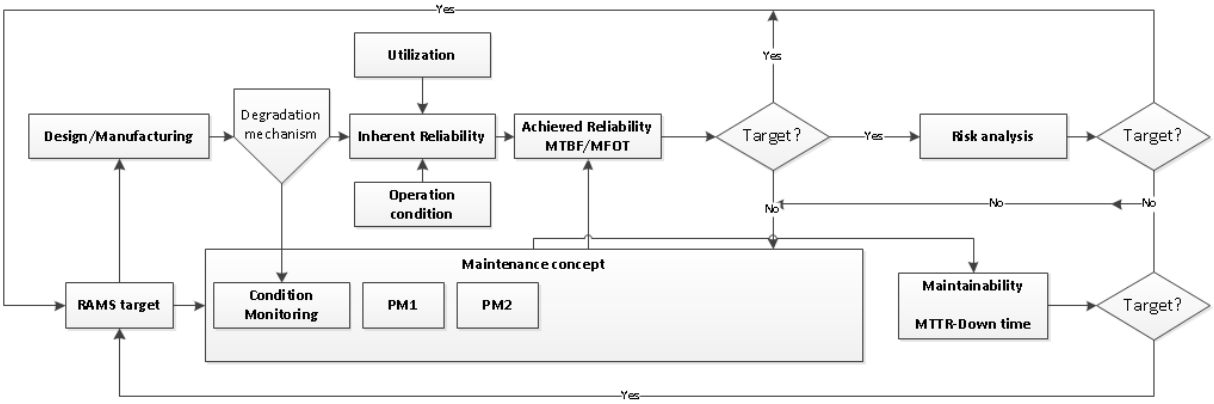


Figure 6: Specification of RAMS target considering the interaction of its elements

2.1.2 RAMS Simulation

There are different techniques or approaches that are used for RAMS simulation during the operation and maintenance phase of a system or infrastructure. These techniques can be broadly divided into

(i) white box approach where the detail of failure progression is studied and

(ii) black box approach where failure event is modelled using time or other usage parameters.

Based on the nature of the available input data, the black box approach is deployed in this study, and states of the wagon and track system are monitored using stochastic simulation of failure events. The model is developed using a simulation tool called SIMLOX which is an event driven simulation tool that enables detailed analyses of the variation of technical system performance over time given different operational and logistics support situations [7]. Based on availability of maintenance resources, maintenance strategy and the operational profile, SIMLOX makes it possible to get realistic simulations of systems operational RAM. During the simulation, the operations generate failure events, which in turn create a need for maintenance personnel, actions and other resources. The output of the simulation is technical performance indicators of the system such as availability performance and its associated measures.

The flowchart of the RAMS simulation is shown in Figure 7. The first stage is the simplification and characterization of the track section and wagon. This involves the description of the technical system breakdown structure and extraction of the some design features relevant to the RAMS study. The second stage is the model building, where models are developed to describe the stochastic failure process and logistic support plan for the system at hand. The maintenance strategy and logistics support plan for wagon and track system include preventive (PM) and corrective maintenance (CM or repair). The PM and inspection schedules are based on standard practices and expert information for both wagon and track systems. The preventive replacement of wagon components are based on the recommended interval/lifespan and are carried out when the wagon is in the workshop for inspection or CM. The failure characteristics of benchmark wagon and track systems were obtained from relevant historical records of maintenance service providers while the failure characteristics of the proposed SUSTRAIL design were based on the experts' experiences. In the model, failure events are generated as stochastic process from the estimated failure rate for each failure mode. The third major input into the model is anticipated train mission profile or traffic schedule on the line. The operation profile of the wagon and traffic on the route are specified in a simple format, such that can be accepted by the simulated tool. It should be noted that the operation profile is not explicitly defined as possible in a typical traffic simulation and management tool. In the wagon simulation, a wagon is considered to make a return trip of about 1500 km that takes about 16 h per day. On the other hand for the track RAMS simulation, daily train mission between 23 and 29, and a weekly train mission of about 200 are assumed for the selected route. The simulation proceeds as failure events are generated using the input failure characteristic and model parameter, repairs are also initiated based on the repair models. In addition the PM tasks are initiated following schedule, resources and available time. The outcomes of the model are a RAM measure including, number of failure of each sections, expected downtime in hours, expected states of the sections and the mission success based on the planned mission profiles. For instance, in the model a wagon mission is not accomplished (i) if the wagon is withdrawn from a train when it fails during operation. (ii) if a wagon is not available to start a scheduled mission.

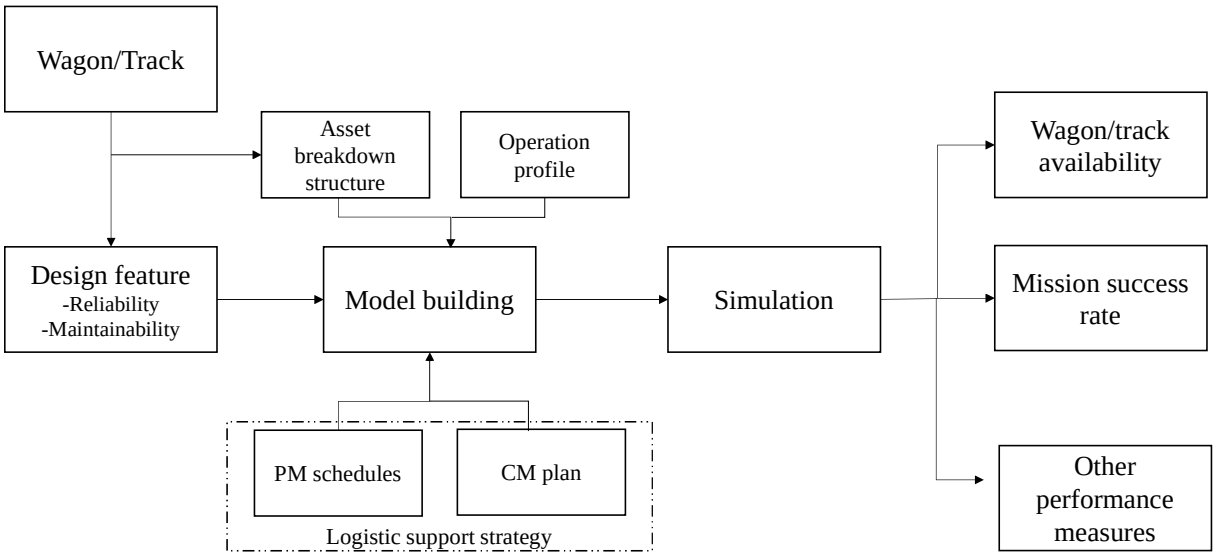


Figure 7: Description for RAMS simulation approach

2.2 Railway LCC

Life cycle costing can be described as the economic analysis process carried out to assess the total cost of acquisition, ownership (operation and maintenance) and disposal of a simple or complex system. It is either applied to the entire life cycle of a product or one life cycle phase or combinations of different phases. The basic aim of life cycle costing analysis is to provide support for decision making in any or all phases of a system's life cycle (9). An important objective in the development of LCC models is to identify costs drivers, i.e. point out those cost elements that may have a major impact on the LCC or may be of special interest for that specific application. In relation to the SUSTRAIL project, the life cycle costing analysis is carried out to support decision for some of the innovations suggested by the project towards a sustainable railway vehicle and track. In explicit terms, the method described below is aimed to support the evaluation and comparison of alternative wagons and track. The existing railway systems are referred to as benchmark wagon and track while the suggested design are called SUSTRAIL wagon and track. A third scenario is also considered for the SUSTRAIL innovations where the operating condition such as speed and load are increased.

An important aspect in LCC analysis is the estimation of the RAMS related costs which is totally stochastic in nature and dependent on so many parameters. Besides the cost of acquisition and termination, RAMS related costs may include the following: corrective maintenance cost, preventive maintenance cost, failure cost. Figure 8 highlights some parameters obtained from RAMS simulated and later translated into operation and maintenance costs.

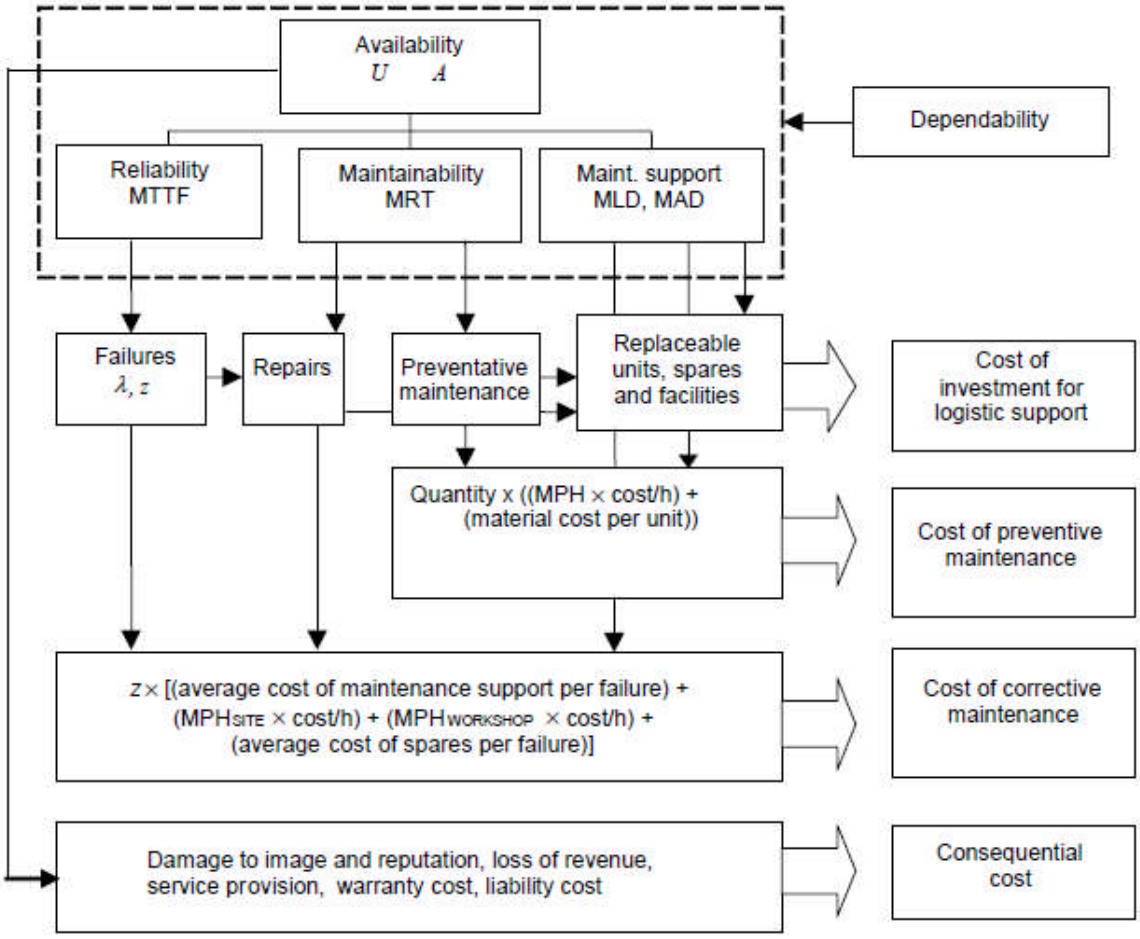


Figure 8: Connection between RAMS and LCC model for the operation and maintenance phase of the systems (9)

The LCC approach follows the outcome of the RAMS simulation. A quick description of the LCC approach is shown in Figure 9 and the cost breakdown structure is presented in Figure 10. The cost implications of the innovations suggested by the SUSTRAIL project are also considered in the life cycle cost analysis.

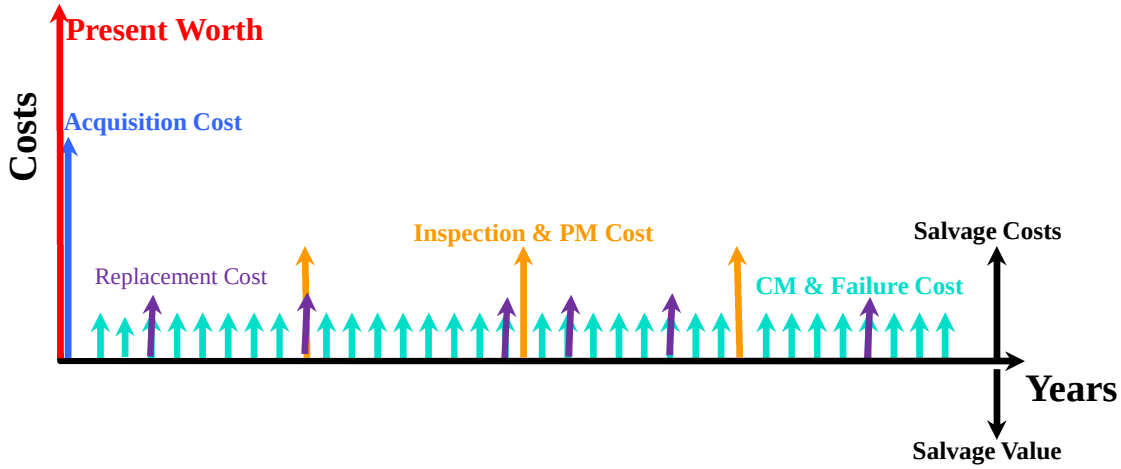


Figure 9: Demonstration of cost flow over life span

For the wagon and track LCC model, all the cost elements are categorised into four aggregates groups:

- Life Acquisition cost (Investment and Renewal for track)
- Life Operation cost
- Life Support cost (Maintenance cost for track)
- Life Termination cost

The grouping of the cost elements into the four aggregates is shown in Figure 10 and 11. In the LCC modelling for track, only significant and distinguishing costs are taken into consideration for the alternatives investigated. This implies that cost (especially those within life support cost aggregate) that are considered to remain unchanged in the alternatives are not shown in the total LCC. This therefore places the cost figure in appropriate context for readers so as to avoid misinterpretation of the results.

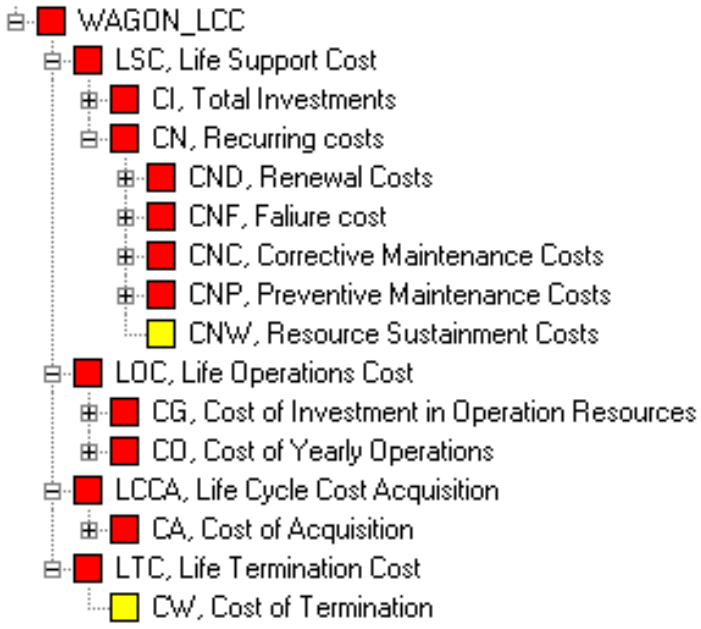


Figure 10: Cost tree and break down structure for wagon

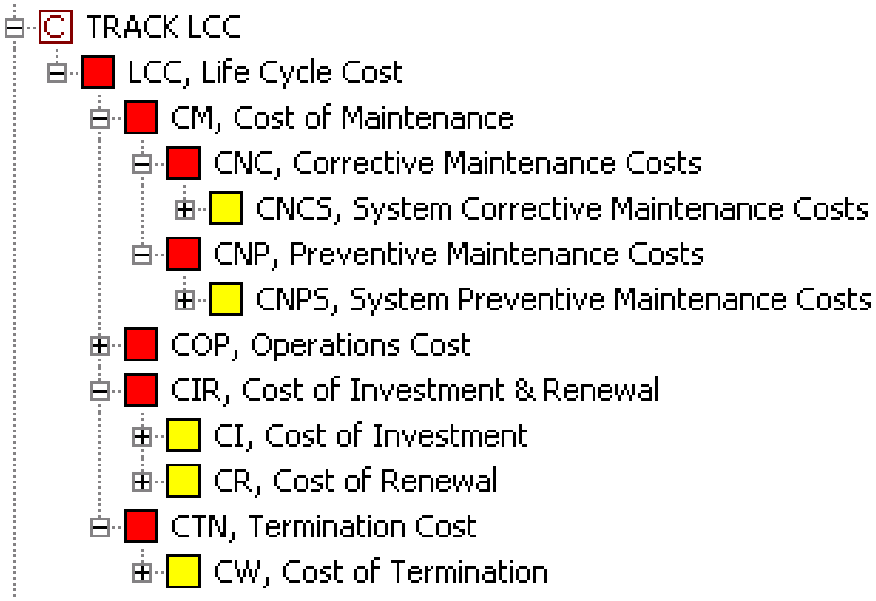


Figure 11: Cost tree and break down structure for track system

3. VEHICLE INNOVATIONS (WP3)

This section describes the innovations developed within work package 3 (WP3) In the SUSTRAIL project which are simulated in the RAMS and LCC simulation. The futuristic freight wagon has not been evaluated in this report. However the developed models can be used to simulate the futuristic wagon if data is available in the future.

Within the Sustrail project a new freight wagon has been developed. The aim of the work was to increase the dependability and performance of the rail freight system. The solutions developed within WP3 have been grouped into following the groups.

1. Hybrid locomotive
2. Freight wagon body
3. Freight wagon bogie
4. Freight wagon braking system



Figure 12 Example of the project vehicle (Ref D3.3)

3.1 Hybrid locomotive

The innovations in the hybrid locomotive group have not been included in the RAMS and LCC simulation of the freight system, this due to difficulties in gathering information regarding current system in operation and the proposed innovations. However the innovations are discussed in the following section.

Three innovations regarding the hybrid locomotive has been developed in the SUSTRAIL project. Regarding the hybrid locomotive it will cost more compared with a conventional dual-mode locomotive as it will be equipped with batteries and super capacitors.

The benefit with the hybrid locomotive is that it can operate on electrified and non-electrified railways with the advantage of having higher efficiency as it can utilize regenerative braking. This will also depend on locomotive duty cycle. According to the responsible partner (KTH) of the innovation approximately 50-60% of existing railways in Europe are electrified. Another advantage is that it can operate with a failed power line system. This is also valid for dual-mode locomotive.

3.1.1 Battery

The battery will be installed in the power train. The presence of the battery will give an opportunity to down scale the combustion engine. Thereby the efficiency of the locomotive can be kept at a high level. On these grounds, the TUB decided to use bearing generators and rechargeable batteries. With that combination the freight car is less dependent from velocity. Typical bearing generators are developed by PJM, FAG and perhaps KES. The price is about 800 Euro for one bearing generator (PJM). The drive trains with the battery installed are very common in Electric and Hybrid Electric Vehicles. The expected improvements will be lower fuel consumption and thereby increased efficiency.

3.1.2 Induction motor

The induction machine is not innovation in itself. It is chosen based on its reliability and its robustness. Compared with the Permanent Magnet synchronous machines it has lower efficiency and lower power density. However it is cheaper and more reliable. It will address the duty requirement nr 1 “Modest increase in freight speed”. Based on the cost of the material the induction machine is cheaper. There are several reasons for higher reliability. To mention some: a risk of demagnetization of the magnets in a PM machine and a risk of have a braking torque due to the short circuit in the windings.

3.1.3 Ultra capacitor

Ultra capacitor is used to support the battery. The battery size can thereby be optimized and kept smaller. The battery will take care of the energy storage problem while the ultra-capacitor will take care of the high power demand during the acceleration of the vehicle. The innovation will help to increase the efficiency of the locomotive. Charge cycles of a super capacitor is according to different sources from 100000 up to 1000 000 while for battery 1000- 10000. The batteries are more sensitive for high charging and discharging currents. Using a super cap can prolong the battery life time. However the system gets more complex.

3.2 Freight wagon body

The SUSTRAIL freight wagon consists of a hybrid flat wagon solution based on standard UIC classes R and S. The new concept uses an optimised lightweight structural frame and incorporates various features that are being employed by other types of standard flat wagons (e.g., class Os). The new configuration would increase the wagon capacity and sustainability.

The main objectives were to reduce the weight compared to traditional flat wagons design, enable the implementation of innovative multi-function features for increased capacity, and maintain the structural strength for increased loads due to SUSTRAIL duty requirements.

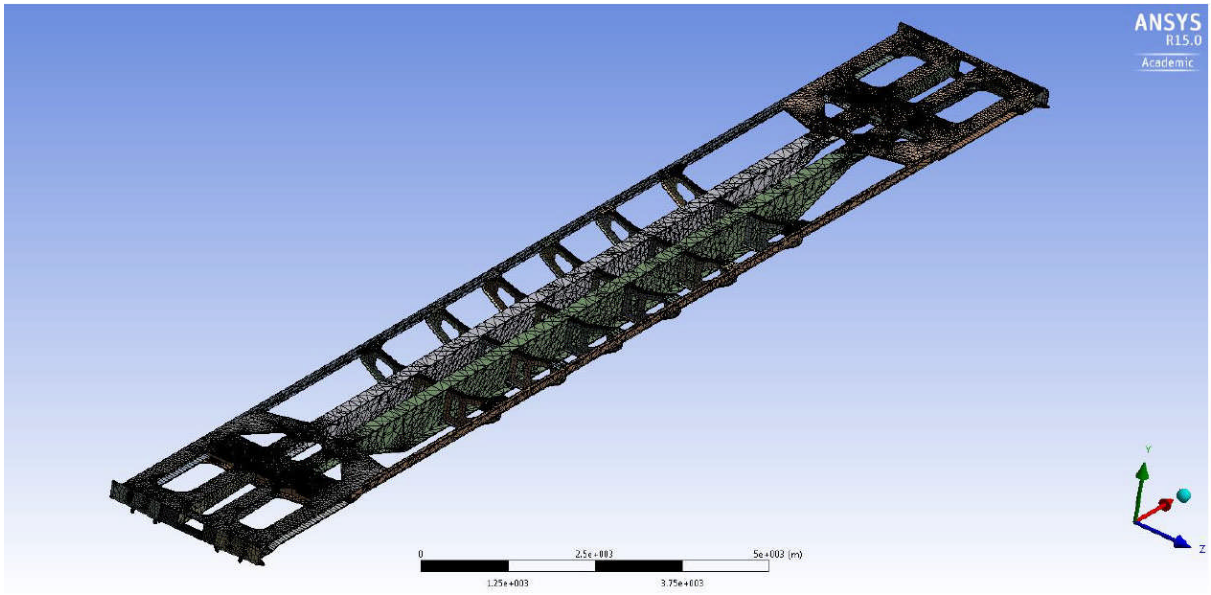


Figure 6-36: Meshed structure of the modified 65 ft wagon frame

Figure 13 Figure of modified 65 ft wagon frame developed in WP3.

In addition to the work on the wagon structure, a number of innovative features and technologies were analysed for the final wagon design. The study considered both standard components and parts to be adapted and incorporated into the new concept, as well as innovative materials and solutions for sustainability (e.g., recycled materials, noise reduction, etc.) (SUSTRAIL D3.4 OUTLINE DESIGN OF A NOVEL INNOVATIVE LIGHTWEIGHT HIGH PERFORMANCE FREIGHT WAGON BODY)

The concept design in SUSTRAIL D3.4 shows that a wagon frame mass reduction of up to 30% is possible, but not so likely for a short-medium term solution, due to manufacturing issues relating to some of the materials which were considered. This value may be considered for a 'futuristic' lightweight solution. However, for a more realistic short-medium term solution, a mass reduction of 20 - 24% may be taken into account.

Similarly, deliverable SUSTRAIL D3.5 shows that the bogie frame mass may be reduced up to 15 – 20 % but the overall bogie mass may increase due to other modifications of running gear (other suspension elements, modified wheel sets, etc.) and braking system.

The masses of the current models/designs:

- The modified bogie frame: 1031 kg;
- The wagon frame: 7634 kg;
- Standard Y25 bogie mass: ~4.7 t (with variations up to +/- 5%, for different types);
- Standard 65' flat wagon tare: ~21.5 - 24 t, including bogies and all standard components (with (+/- x%) variations due to different frame designs and variety of installed components , i.e., braking system, buffers, coupler, etc., with/without features/equipment, e.g., walls, stanchions, etc.)

Apart from the mass reduction, the most relevant aspect for the business case would be the increased 'capabilities' of the proposed flat wagon concept, equipped with different features which would enable the transport of a much larger range of commodities alongside the usual containers; this would tackle efficiently the well-known issue regarding the empty trains

running due to one-way terminals (where the containers flow is just in one direction, without any demand for the other direction).

From the conclusions in (D3.4) the following points can affect the RAMS/LCC and CBA analysis.

- The weight reduction through steel grades replacement and profiles optimisation is possible and sustainable; a mass reduction of the wagon structure up to 30% can be achieved using this design concept;
- The replacement of conventional steel with high strength steel contributes to a significant reduction of the CO2 footprint, saving thus a relevant amount within the life cycle cost due to reduced fuel consumption;
- The fabrication costs were estimated to remain at a similar level, or even to decrease with approximately 5-10% due to lower labour costs.

The weight reduction of the lightweight wagon structure is assumed to be consumed by the increased weight of the SUSTRAIL bogie mainly due to the heavier disc brakes and improved suspension.

3.3 Freight wagon bogie

A substantial part of the costs for maintaining wagons and track originate from the forces generated in the dynamic interaction between vehicle and track. The track deterioration can be divided into four different main mechanisms:

1. Track settlement
2. Component fatigue
3. Wear
4. Rolling contact fatigue

In average on the Swedish rail network it is estimated that of the cost for maintenance and renewal is 25% caused by track settlement, 35% by component fatigue and 40% by wear and RCF. The two first damage mechanisms listed above are mainly driven by the vertical track forces (often is a cubic relation found between force and deterioration). The latter two mechanisms are driven by the vehicles ability to steer (radial alignment of the wheel sets in curves). Cost for maintaining a freight wagon is to large extend given by wheels and brake blocks. For a simple wagon they can contribute up to 80% of the total cost.

The aim of developing the SUSTRAIL bogie is to accommodate the duty requirement 1, 3, 5 and 7 in WP2.

Requirements:

- (Req. 1): Increased stability
- (Req. 3): Reduced static and dynamic load on the system
- (Req. 5): Tuned primary stiffness and damping
- (Req. 7): Reduction of traction energy on curved track

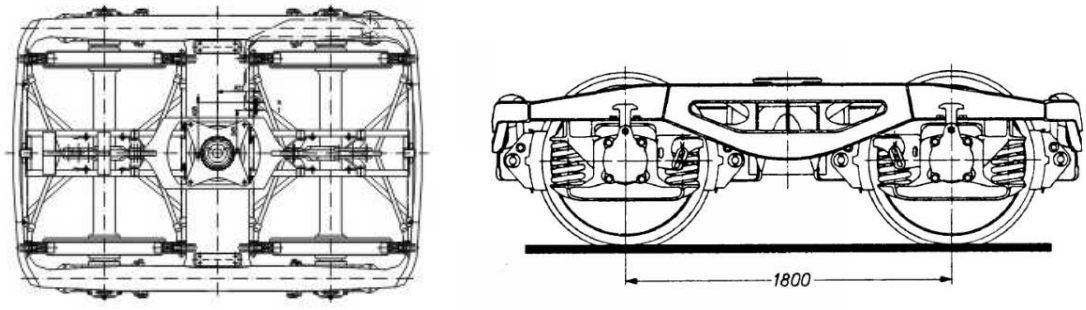


Figure 14 Y25 bogie

Bogie specification:

- Speed range of up to 120 km/h, or up to 140 km/h as an option
- Axle load 22.5t with 25t as an option.
- Wheel diameter new: 920mm, worn: 850mm
- Rotating mass xxx t
- Total weight of the bogie 4.5t (estimated

Primary suspension of a freight wagon bogie consists of coil springs linkages, and friction surfaces providing stiffness and load dependent damping for the system. Within the scope of the current innovation are the properties for these component enhanced in order to improve system performance with a limited investment.

3.4 Freight wagon braking system

An innovative braking system, as outlined in this report, can fully meet the requirements of the SUSTRAIL 'Freight Vehicle of the Future'. The specified braking system includes combined brake control and wheel slide protection systems. All relevant norms and standards are adhered to and meet the safety requirements for operation throughout Europe. (SUSTRAIL D3.3)

The proposed disk brake system will replace the current brake block system installed in the Y25 bogie.

The system applied for this project is a combined system containing brake control and wheel-slide protection functions due to the requested basic conditions see Figure 15. For a higher availability and safety both functions have been separated through separate components. Moreover, crucial functional units of the brake control have been redundantly designed for the same reason.

The architecture of the brake system for this project is thus divided into the four following sectors:

- Vehicle components such as bogie and brake equipment, air reservoirs, etc.
- Brake control, controller and pneumatic components for the activation of the brake cylinder.
- Wheel-slide protection with axle rotation speed measurement and dump valves
- Independent and reliable power supply for the control devices in the vehicles with axle generator and battery pack.

An overview of all main components designed into the new brake system is given in Figure 15. (SUSTRAIL D3.3)

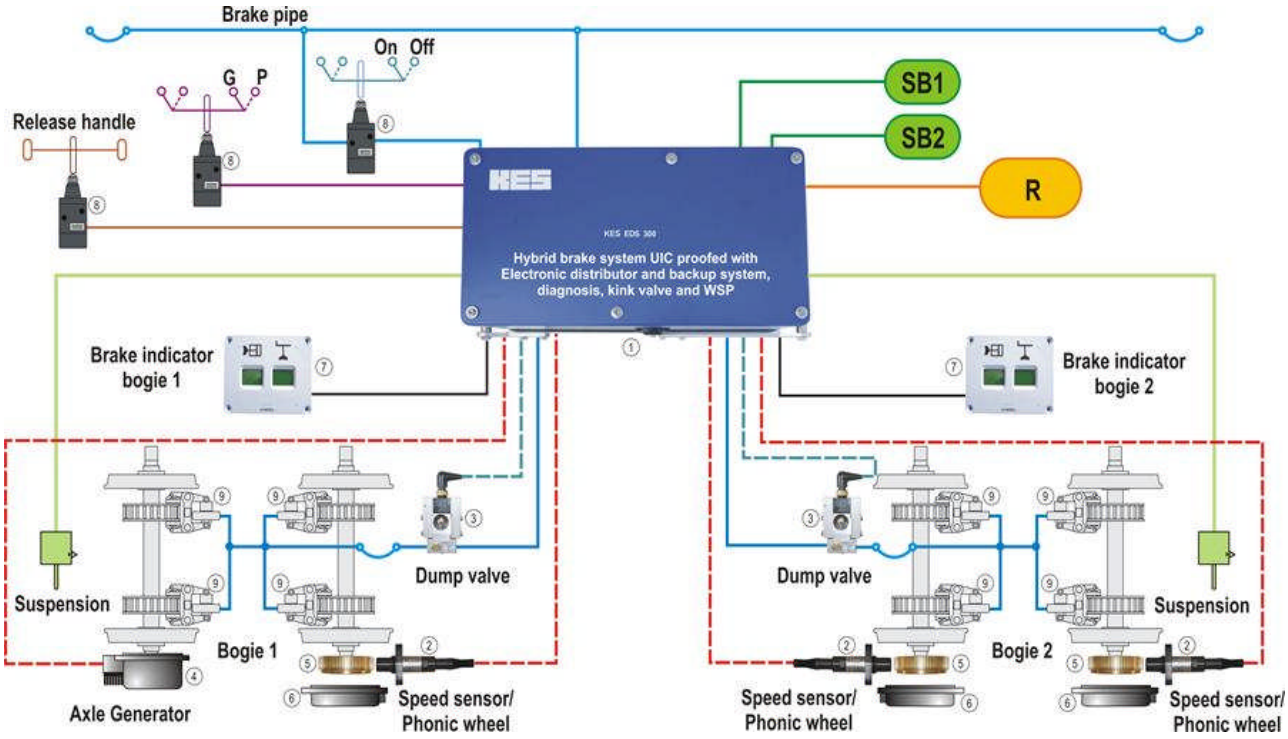


Figure 15 System overview (SUSTRAIL D3.3)

4. TRACK INNOVATIONS (WP4)

The work in WP 4 has focused on:

- Performance based design principles for resilient track – determine the factors that influence the resistance of track to the loads imposed, and how this can be improved
- Supportive ballast and substrate – support conditions vital to maintaining track geometry
- Optimised track systems and geometry - track geometry measures and intervention levels
- Switches and crossings – novel S&C component design building on the outputs from INNOTRACK
- Track-based monitoring and limits for imposed loads – includes definition of Minimum Action Rules

The work above has resulted in a number of options/innovation such as:

1. Premium Rail Steel
2. Testing and analysis of welds in Continuous Welded Rail CWR (Ultra sonic testing)
3. Impact of rail profile/ inclination on RCF
4. Multifunctional sensorized geotextile
5. Force information from Wheel Impact Detector (WID)
6. Dynamic Smart Washer
7. Transition zones to bridges
8. Under sleeper pad

4.1 Premium rail steel

Rails have traditionally been made from mild steel (up to 25% of carbon), which provides high fatigue toughness. Higher quality steels are now being produced, which has led to a significant improvement in rail fatigue performance and a considerable reduction in residual stress development. This innovation has been implemented in the RAMS and LCC model.

Virtually all rail steels in current use have a pearlitic microstructure that is based on carbon-manganese composition and this has remained essentially unchanged over the past 150 years. “Standard” rail grades used throughout Europe are typically of 220-260HB. Due to degradation mechanisms such as rolling contact fatigue (RCF) or wear, these standard grades can require replacement or remedial maintenance over short time periods.

To combat this one of the innovations chosen through the FMEA methodology is the use of “premium” rail steels. These steels offer greater hardness levels, which increase service life and reduce the need for remedial work. These benefits result in higher levels of availability and reduced cost over the life cycle. A brief explanation of the premium steels available, and the techniques used to produce them is given below. (SUSTRAIL D4.3 Optimised track systems and geometry)

4.1.1 Heat Treated Rail Steels

Conventional pearlitic steels gain their hardness from the refinement of ferrite and cementite lamellae to increase the percentage of cementite in the microstructure. However there is a limit to how refined it can be made in an as-rolled product produced via air cooling. By carefully controlled reheating and use of accelerated cooling, the structure can be further refined to increase the hardness up to 400HB, with little change in the carbon content.

Tata Steel offers a variety of heat treated grades conforming to EN standards. SFL350 delivers a minimum hardness of 350HB and the added benefit of very low residual stress. This very low stress (<50MPa) is delivered through the patented heat treat and accelerated cooling line at the Hayange plant in France. It results in excellent foot fatigue performance, an important factor in the lifetime of rails. Additionally MHH375 and MHH388 are offered which deliver world best wear resistance to combat extreme conditions found in heavy-haul routes.

4.1.2 Hypereutectoid Steels

An alternate method of gaining higher hardness and greater wear resistance is the use of hypereutectoid (HE) rail compositions with carbon levels approaching 1% as seen in Tata Steel HP335.

The development of the Tata Steel HP335 recognises that the pearlitic microstructure is a lamellae composite of pearlitic ferrite and cementite with the hardness and strength properties of the two individual lamellae being remarkably different. In three-dimensions, the orientation of the pearlite grains is random with reference to the running surface of the rail in contact with the wheel. Hence the ferrite and cementite lamellae can be randomly presented at the rail-wheel contact. Thus it is inappropriate to treat the pearlite as a single phase microstructure and assess its attributes using a macro property test such as hardness. Furthermore, although refinement of the pearlite interlamellar spacing is hugely desirable, it is equally important to strengthen the constituent phases of the pearlitic microstructure.

The composition of HP335 was based on the metallurgical objectives of:

1. Increasing the volume fraction of cementite through an increase in carbon content. This objective provided the synergistic benefit of increased hardenability to refine the cementite lath thickness and the interlamellar spacing.
2. Increasing the strength of the pearlitic ferrite through solid solution strengthening from silicon additions and precipitation strengthening through vanadium addition. Additions of both silicon and vanadium have the synergistic effect of preventing/minimising the formation of grain boundary cementite networks.
3. Precise control of nitrogen and vanadium contents to capitalise on the hardenability effect of vanadium additions and to control the magnitude of finer vanadium carbide within the pearlitic ferrite that precipitates at lower temperatures.

The above methodology has created both a finer microstructure and one with stronger individual phases. This results in a minimum hardness of 335HB without the need for heat treatment. HP335 has proven its benefits in combating RCF, wear and plastic flow, and is fully approved by Network Rail.

4.1.3 Bainitic Steels

A further methodology of obtaining superior properties in steel can be seen in the use of bainitic steel in rail. This method uses precise chemistry control to produce as as-rolled microstructure that contains high levels of bainite and retained austenite.

This microstructure produces rails of between 320-360HB that have excellent resistance to RCF. Case studies of BLF320 have shown no need for remedial grinding after 500MGT while R260 has needed

grinding every 50-100MGT. In addition the excellent resistance to RCF has led to B360 being approved for use in SNCF high speed movable points.

4.2 Testing and analysis of welds in continuous welded rail CWR

Continuous welded Rails (CWR) have been in use since the 1970s. When introduced, it was said that this was a maintenance free rail, but it was rather soon proved to be wrong. Railway rails are manufactured in 40 to 60 m lengths, these are then sent to a welding workshop were the rails are welded to form long welded rails (LWD) with flash butt welding into ~~a~~ 240 to 360 m lengths, the length can vary from country to country. The total length of flash butt welded rails is limited due to transportation restriction, special railway wagons are used to transport the rails out in the track where they can be welded into continuous track. The joining of the LWD is either performed by Thermite welding or MMA so called mould welding. Thermite welding and MMA does not deliver the same quality as flash but welds, but is often used since it has been difficulties to build mobile flash butt equipment.

Joining the LWD into CWR is affected of several boundary conditions, weather, rail temperature, personnel skill and efficiency. Small imperfection in welds can cause cracks to initiate. A defect free weld requires skilled workforce, better weld material and better welding techniques along with better welding equipment. In Sweden inspection, welding and rectification process becomes a costly affair due to snow and ice during winters. Most of the defects which do not pose immediate risk of damage to rail assets or derailment risk are deferred till the end of winter.

Welding processes and welds analysis could not be considered as pure innovations but are very relevant for rail condition and maintenance. The expected gains and investment and operation and maintenance cost of these processes has not been possible to quantify in this project.

Table 1 Expert judgement of parameters in the RAMS and LCC model that can be affected by the proposed innovation

Type	Task	Comment
PM	Geometry inspection interval	
	Curve grinding interval	Can be affected
	Line grinding interval	Can be affected
	Tamping interval	
	Stone blowing interval	
	Rail inspection interval	Can be affected
	S&C inspection interval	
	Fastener inspection interval	
	Visual inspection interval	Can be affected
	Ballast cleaning interval	
	Lubrication interval	
	Wheel grinding interval	
	Other tasks	

CM	Track failures freq/year	Can be affected
	Wheel failure freq/year	
Renewal	Rail replacement interval	Can be affected
	Sleeper replacement interval	
	Fastener replacement interval	
	Ballast renewal interval	
	Track replacement interval	

4.3 Impact of profile/inclination on RCF

Rail profile and inclination is not a real 'innovation', but the profile/inclination optimisation for various operational conditions (lines, speed, rolling stock, wheel profiles, etc.) includes innovative aspects and has been researched for many years, in many countries The expected gain of this is unknown for the lines in SUSTRAIL; however relevant studies show a significant reduction of maintenance costs when rail profile and inclination are optimised in relation with the wheel profiles, especially on freight lines The expected investment cost is also unknown for the SUSTRAIL routs as well as the operation and maintenance cost. Rail Inclination is adapted / customized to obtain a better fit between wheels and rails. The general inclination in Sweden is 1:30 while other countries in Europe often use 1:20 or 1:40.

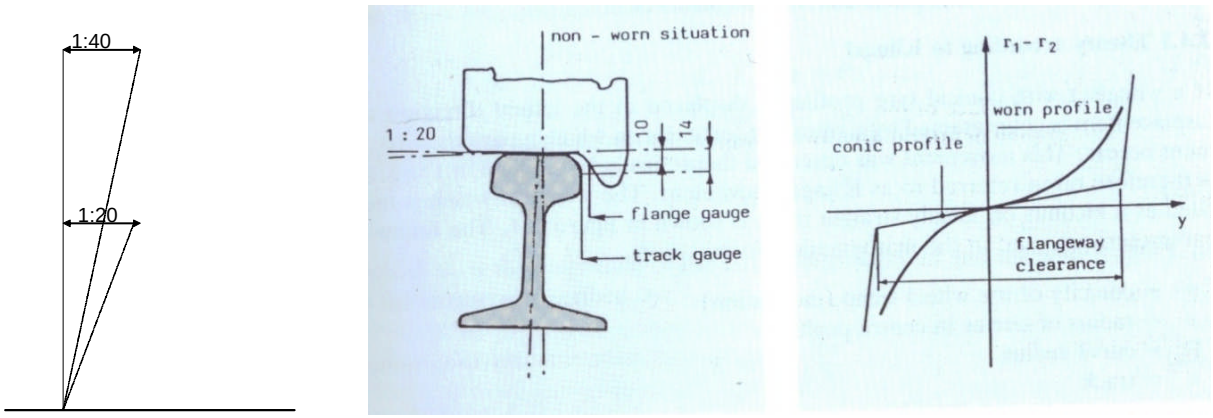


Figure 16 Rail inclination, Wheel profile / Rail Profile (Esveld, 1989)

High equivalent conicity provides an unstable driving characteristic at high speeds and tangent track (Klingel effect) but a better curving ability. Arranged rails inclination means that the rail heads tilted toward the center of the track. Inclination 1:20 means a steeper slope than the slopes 1:30 and 1:40, see Figure 16. Originally, the wheel profile has a slope of 1:20, Why the rail was also tilted. 1:20 and organized to match the UIC 54 and S1002 (wheel profile) worn profile profile.

In Figure 16 the gap between "track gauge" and "flange gauge" represents the space that the wheel can move sideways when steering in curves, a total of around 10 mm.

Since the wheels are slightly conical, the rolling radius of the left and right sides will differ when the wheelset is not rolling on the centreline. Because the wheels must have the same rotation speed as they are both fixed to the axle, the wheel pair slowly to yaw.

Yawing means that the wheelset will not roll exactly straight going forwards without steering slightly sideways. After a while the wheelset will shift the other way, and the process repeats. The process can be described as a sinusoidal motion.

Table 2 Expert judgement of parameters in the RAMS and LCC model that can be affected by the proposed innovation

Type	Task	Comment
PM	Geometry inspection interval	
	Curve grinding interval	Can be affected
	Line grinding interval	Can be affected
	Tamping interval	
	Stone blowing interval	
	Rail inspection interval	
	S&C insp. interval	
	Fastener inspection interval	Can be affected
	Visual inspection interval	
	Ballast cleaning interval	
	Lubrication interval	
	Wheel grinding interval	
	Other tasks	
CM	Track failures freq/year	Can be affected
	Wheel failure freq/year	
Renewal	Rail replacement interval	Can be affected
	Sleeper replacement interval	Can be affected
	Fastener replacement interval	
	Ballast renewal interval	
	Track replacement interval	

4.4 Multifunction sensorized geotextiles

In presence of soft subsoil it is important to quantify such effects and introduce strengthening measures. The attention is towards the use of multifunctional geotextiles, able to provide both strengthening and monitoring functions. The classical use of geotextiles in embankments on relatively soft soils is to reduce settlement and to increase the bearing capacity and slope stability.

Geotextiles are normally placed at the bottom of the embankment, about 50 cm above the original ground surface in one or more layers. In recent years a new kind of foundation, the so-called “geosynthetic-reinforced and pile-supported embankment” has been developed (and it is now in use in practice. Pile-like elements are placed in a regular pattern through the soft

soil down to a load-bearing stratum above which a reinforcement of one or more layers of geosynthetic (mostly geogrids) is placed before the embankment is filled. The stress relief in the soft soil results from an arching effect in the reinforced embankment over the pile heads and a membrane effect of the geosynthetic reinforcement.

Up to date design and construction standards require the installation of systems to monitor the stability and serviceability of geotechnical structures. New multifunctional geotextiles are nowadays introduced in geotechnical engineering practice since they provide, at the same time, both the stability and monitoring functions. The multifunctional geotextile includes protection of the railway substructure against the increased loads induced by heavier vehicles travelling at higher speed by strengthening and stabilisation of the existing structures and the monitoring of their performance with the possibility of the infrastructure owner being alerted by an alarm before structural failure occurs. Figure 17 shows an example of prototype of multifunctional geotextile developed within the Polytect research project, which has been coordinated by the writer. Such kind of reinforcing and monitoring elements will be tested in SUSTRAIL. (SUSTRAIL D4.2)

Table 3 shows expert judgement of parameters in the RMAS model that might be affected it dynamic sensorized textile would be implemented. The innovation is not included in the RAMS simulation due to lack of deployment data for the SUSTRAIL routes.



Figure 17 Multifunctional geogrid with embedded fiber optical distributed sensor (after POLYTECT) (Figure from SUSTRAIL D4.2)

Table 3 Expert judgement of parameters in the RAMS and LCC model that can be affected by the proposed innovation

Type	Task	Comment
PM	Geometry inspection interval	Can be affected
	Curve grinding interval	
	Line grinding interval	
	Tamping interval	Can be affected
	Stone blowing interval	
	Rail inspection interval	
	S&C inspection interval	Can be affected
	Fastener inspection interval	
	Visual inspection interval	Can be affected
	Ballast cleaning interval	Can be affected
	Lubrication interval	
	Wheel grinding interval	
	Other tasks	
CM	Track failures freq/year	Can be affected
	Wheel failure freq/year	
Renewal	Rail replacement interval	
	Sleeper replacement interval	
	Fastener replacement interval	
	Ballast renewal interval	Can be affected
	Track replacement interval	Can be affected. This is the most likely interval that will be affected by the implementation of the multifunctional geotextile. In a first stage critical areas could be equipped with geotextile to prevent catastrophic failures of the track embankment. In a futuristic scenario, this could be a standard component for the whole track. Due to lack of possible deployment locations along the Sustrail route the innovation is not included in the RAMS/LCC simulation.

4.5 Force information from WID systems (Sweden) & removal of bad vehicles

The JVTC Railway Research Station in Sävast measures the lateral and vertical track forces and works as a platform for studies of things such a wheel profiles, rail profiles, rail lubrication etc. Another area of research is to study and classify vehicles regarding their contribution to the overall track degradation. This is of interest when talking about differentiated track access charges. The station is owned and fully financed by the JVTC organization while Damill stands for the operative management and service and for the measurement software. The technology used in the station is also sold externally by Damill under the product name StratoForce. The latest versions of the system can, in small installations, work without any building cover as the equipment is very compact and can be placed in a cabinet on the overhead mast. Communication is handled by 3G or 4G mobile Internet so the system only needs an external power cable at installation time.

The idea with this innovation is to use the track forces as an indicator for bad vehicles operating on the track. By removing the worst individuals the accumulated load and stress imposed to the track can be reduced.

The benefits of finding and removing vehicles with high track forces are many. By doing some expert judgement followed by calculations, a list of the benefits has been created that is presented in Table 4.

Table 4 Benefits from installing and using ALC monitoring system

Strategy	Effect	Comment
Repair 5% of the axles and bogies with highest lateral forces	The mean lateral forces will drop 10% implying that also total rail and wheel wear will be 10% less	Effect calculated by using data from the JVTC monitoring station and simple friction work model
Repair 5% of the axles with highest dynamic vertical load	Very small effect as long as forces are below safety limit	Effect calculated by using data from the JVTC monitoring station
Invest in 120 more ALC stations in Europe	Reduce risk of derailment. The Benefit/Cost ration is 7,80 over 30 years	Effect according to the D-rail project D7.4
Increase the number of force monitoring stations (e.g. ALC)	By reducing the distance between stations, the downtime due to track inspection and defect vehicles (e.g. wheel flats) will be reduced. A simple model would be to assume proportional reduction in downtime	Budget price according to D-rail D7.4 is 110000 Euro per ALC station. Based on data from Sweden, a 30 km track segment might take more than 60 minutes to check after a severe wheel flat has passed. On single track lines , all traffic is blocked during that time.

4.6 Optimized maintenance scheduling using geometry monitoring

The optimisation maintenance schedule will be based on track irregularities and traffic load. Data from measurement stations will also be used. An existing model will be used to fit settlement equation with the experimental results. The optimised model will simulate how the track deterioration evolves with time, and it will be possible to evaluate the trend to see if there is any advantage by changing the tamping calendar to a different pattern. The main gain of this predictive technique is an improved tamping strategy and tamping schedule.

This task is not finished and thus, no simulation in the track RAMS/LCC model can be performed and hence the benefit could be judged at the time of the deliverable of the assessment report D5.1. Table 5 shows an expert judgement of parameters in the RAMS and LCC model the can be affected by the proposed innovation.

Table 5 Expert judgement of parameters in the RAMS and LCC model that can be affected by the proposed innovation

Type	Task	Comment
PM	Geometry inspection interval	Can be affected
	Curve grinding interval	
	Line grinding interval	
	Tamping interval	Can be affected
	Stone blowing interval	Can be affected
	Rail inspection interval	
	S&c insp interval	
	Fastener inspection interval	
	Visual inspection interval	
	Ballast cleaning interval	Can be affected
	Lubrication interval	
	Wheel grinding interval	
	Other tasks	
CM	Track failures freq/year	Can be affected
	Wheel failure freq/year	
Renewal	Rail replacement interval	
	Sleeper replacment interval	
	Fastener replacement interval	
	Ballast renewal interval	Can be affected
	Track replacement interval	Can be affected

4.7 Dynamic smart washer

In the rail industry the assembly and maintenance of critical threaded fasteners is widely acknowledged to be a necessary yet an expensive, time consuming activity and subject to human error. The failure implications of such fasteners can be lead to catastrophic incidents, as can the failure of the present manual systems which aim to ensure their integrity. Two of the worst accidents in the UK (Potters Bar and Grayrigg) yielded 8 fatalities and 106 serious injuries. They are thought to have been caused by missing/fractured nuts and bolts. There are ~26,000 sets of points in the UK rail network, each of which has ~30 high criticality fasteners associated with it. Similarly, critical threaded fasteners are used in overhead lines and bridges. The ongoing costs of fastener monitoring and maintenance are significant, and the potential costs of fastener failure (financial and human terms) are extreme. The proposed solution, a Smart Washer (SW) will address 3 key priority areas for the rail sector: Reduce costs of installing, maintaining & managing infrastructure; Operational safety, reliability & efficiency; Network management & control.

The global rail control market in 2015 will be worth an estimated £11.5bn, of which Western Europe accounts for £4.4bn. Smart Washer system will contain a static-force sensing smart sensor, with RFID tag and 100m wireless range and can be produced for <£10. The technology could be used in hundreds - thousands of critical fasteners, thus decreasing railway maintenance costs.

The static smart washer operates in the range 0-10Hz and 0-180kN and is used in a wide variety of operational environments to achieve significantly improved maintenance capabilities. The smart washer is designed to work well in wet and dry conditions during summer and winter time. The innovation has the potential to provide an audit trail from which the tightness of fasteners can be assessed/trended so the smart monitoring of critical fastenings will generate a huge benefit in terms of operational safety and will significantly reduce the cost of rail infrastructure maintenance when the freight speed is increased. Smart washer technology will also be capable of monitoring fastener integrity, transferring the data to ensure remote monitoring and enabling the transition from time based planned preventive maintenance to a condition-based approach with integrated audit and quality assurance features.

In order to integrate the smart washer into the RAMS model of the track specific information regarding the deployment of the washers must be established. The number of smart washers and possible locations along the SUSTRAIL routes where they could be implemented has not been identified in the project. Hence the effect on track availability could not be simulated as well as the cost implications due to lack of purchase, implementation, operation, maintenance and disposal costs.

4.8 Transition zones to bridges

Investigations in transition zones between the line and a bridge has been performed in SUSTRAIL WP4 and reported in D4.2. The problem with transitions zones is the different stiffness between conventional embankments and the bridge resulting in larger dynamic track forces in the transition zones. In order to reduce this this effect, a transition plate has been studied which gradually increases the stiffness from the softer embankment to the stiffer bridge.

Some experiences of tracks on bridges and transitions zones can be summarized as follows:

- Tracks on bridges can give extra strength to steel bridges
- Transition plates used on a steel truss bridge were not effective
- Under-sleeper pads seems to be a better solution

Transition plates used on a steel truss bridge at Sikån in northern Sweden were not effective the bumps after installation were as big as before. A reduction of the dynamic forces was not detected in this study and therefore no further RAMS and LCC assessment was done for this innovation.

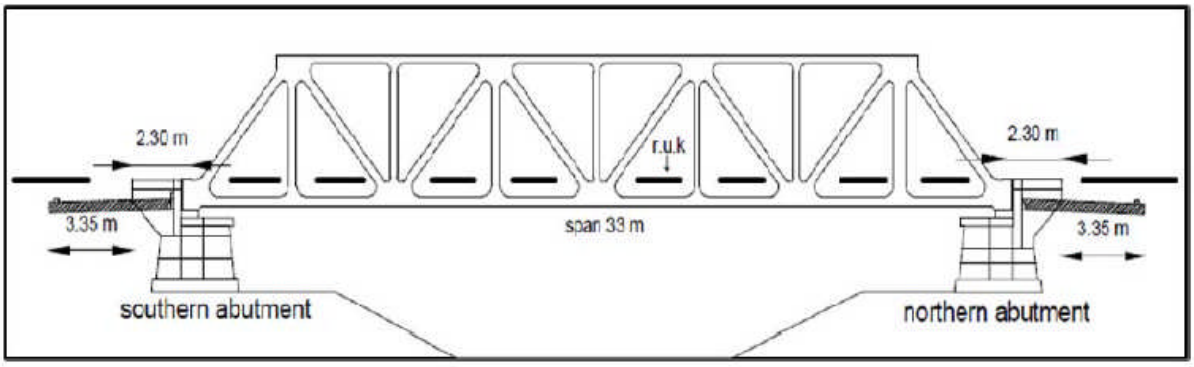


Figure 18 Transition slabs

4.9 Under sleeper pads

Under sleeper pads (USP) is a 10 mm thick rubber mat that are embedded beneath the concrete sleepers. USP provides better attachment surface and increase the track elasticity. The UIC project “Under Sleeper Pads” which ran between 2005 and 2007, conducted a number of laboratory tests, theoretical calculations and practical measurements track. The positive effects of USP were found to be:

- Improvement of the original track geometry quality and reduced degradation rate, ie. reduced need for tamping.
- Reduction of structure-borne noise and vibration
- Reduction of rail corrugation in narrow curves
- Reduction of maintenance actions
- Increased ballast and sleepers life length

UPS uses is to equalize locally inhomogeneous conditions, eg in leveling zones between different building types (UIC60 against BV50), at bridge abutments and at level crossings. In

order to improve the quality of track geometry, some railways have already introduced the USP as a standard solution for the special case of applications in their networks. The implementation of under sleeper pads in the RAMS/LCC model has not been performed due to lack of information of relevant data. However in Table 6 an expert judgement can be seen describing which parameter in the model that the under sleeper pads could affect.

Table 6 Expert judgement of parameters in the RAMS and LCC model that can be affected by the proposed innovation

Type	Task	Comment
PM	Geometry inspection interval	Can be affected
	Curve grinding interval	Can be affected
	Line grinding interval	Can be affected
	Tamping interval	Can be affected
	Stone blowing interval	Can be affected
	Rail inspection interval	Can be affected
	S&C insp interval	Can be affected
	Fastener inspection interval	
	Visual inspection interval	
	Ballast cleaning interval	Can be affected
	Lubrication interval	
	Wheel grinding interval	
	Other tasks	
CM	Track failures freq/year	Can be affected
	Wheel failure freq/year	
Renewal	Rail replacement interval	Can be affected
	Sleeper replacement interval	Can be affected
	Fastener replacement interval	
	Ballast renewal interval	Can be affected
	Track replacement interval	Can be affected

5. CASE AND SYSTEM DESCRIPTION

5.1 Route description

The implementation of premium rail depends on a number of criteria related to the technical characteristics of the route. The use is dependent on the traffic characteristic on the route as well, as it is used differently for freight and passenger lines. The passenger line application uses it to counter high bogie stiffness at high speeds and so tends to be used in the 700m to 2500m radius curves. For freight it tends to be lower speed tighter curves in the range of 0 to 1200m radius. Within SUSTRAIL it is considered more appropriate to consider the use of proposed premium rail only for freight application on one of the routes documented in SUSTRAIL D1.2. The route is assumed to be of low speeds, which means that high stiffness express services are not offered on the routes. Using the percentage of route curvature and overall distance described in SUSTRAIL D1.2, the potential implementation sections are curves with radius less than 1200m. The description of the routes is given below. To demonstrate the modelling procedure, the first route, UK1 – Felixstowe to Nuneaton, has been selected and implemented in the model. A list of the different Sustrail routes can be seen below.

- UK1 – Felixstowe to Nuneaton

  0-1200m radius curves are approximately 7.1% of the total 256.6km route or 18.21km. This track is doubled.

- UK2 – Southampton to Nuneaton

  0-1200m radius curves are approximately 5.6% of the total 211.2km route or 11.82km. This track is doubled.

- Spain – Valencia to Sagunto-Cargas

  0-1200m radius curves are approximately 27.3% of the total 29km route or 7.91km. This track is doubled.

- Spain – Sagunto-Cargas to Vila Real

  0-1200m radius curves are approximately 31% of the total 33km route or 10.23km. This track is doubled.

- Spain – Vila Real to Tarragona

  0-1200m radius curves are approximately 7.8% of the total 209.8km route or 7.79km. 152.8km of this track is doubled and 57km is single track.

- The Bulgaria route Dimitrovgrad (Serbia) – Kapikule (Turkey) line runs through Bulgaria from west to east. The traffic mix on this line is freight and passenger; freight traffic has a typical line speed of 75 km/h, except for the section between Parvomaj and Jabalkovo where freight can travel at up to 120 km/h; the speed for passenger traffic on this line ranges from 65-130 km/h.

5.2 Simulation cases description

Table 7 shows the different case that were implemented in the model and simulated. Case 1 represents the current situation for the track wagon and operating condition (speed). Case 2 represents a situation where an improvement has been introduced to wagon and track operated at the same speed as in case1. Finally the third case represents a situation with an improved wagon on an improved track at a higher speed.

Table 7 Simulation cases

Case 1 (Benchmark)	Case 2 (SUSTRAIL1)	Case 3 (SUSTRAIL2)
Current track (UK1) Current vehicle Current speed(120 km/h)	Improved track (UK1) Improved vehicle Current speed (120 km/h)	Improved track (UK1) Improved vehicle Improved speed (140 km/h)

5.3 Operational profile

To demonstrate the RAMS simulation the following operational profile has been used on the UK1 route. Different number of train sets is being sent on a mission each day of the week. Table 8 lists the number of train missions for each day. The direction of the mission is optional but for normal freight operation on a single track there would be 12 missions in each direction, resulting in 24 missions. Figure 19 illustrate the mission profile for one week. The black vertical lines in the upper graph show departure time for each of the mission. The amplitude (y–value) of the line represents the number of mission for each point in time. The lower graph illustrates the daily missions.

Table 8 Train missions per day.

Day	Train missions
Monday	26
Tuesday	27
Wednesday	29
Thursday	24
Friday	27
Saturday	25
Sunday	23

In the wagon simulation, a wagon is considered to make a daily return trip of about 1500 km that takes around 16 h. A representative mission profile for a wagon over a week is shown in Figure 20. The weekly amount of mission is shown together with the total weekly mission time.

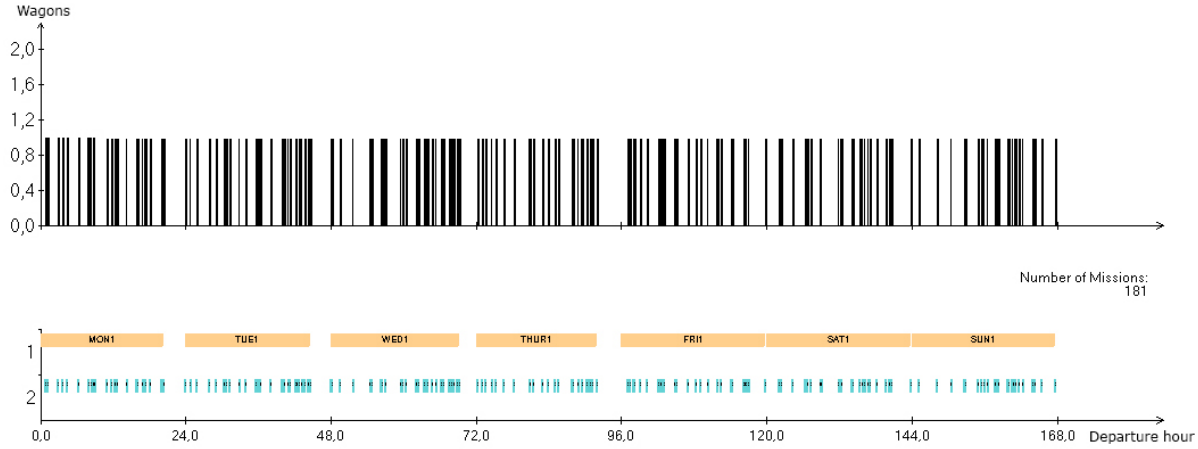


Figure 19 Mission profiles on the route for one week. The black vertical lines in the upper figure show departure time for each of the mission. The amplitude (y–value) of the line represents the number of mission for each point in time. The lower figure illustrates the daily missions.

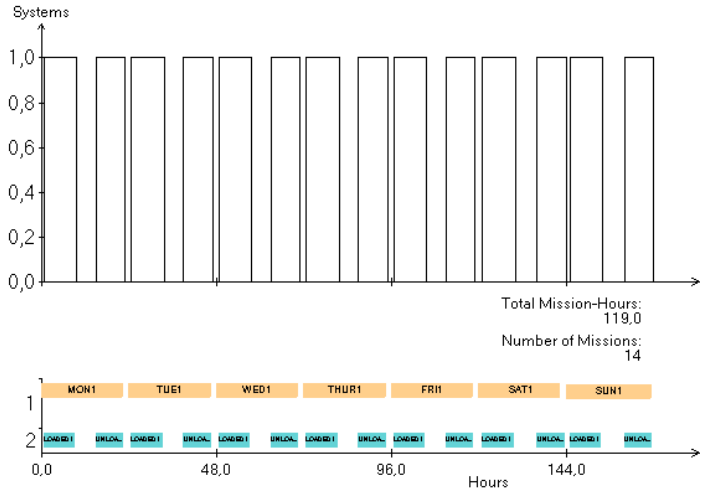


Figure 20: Mission profile for a week operation of the wagon.

5.4 Wagon break down structure

For effective simulation of technical performance of a system in terms of its reliability, availability and logistic support performances, it is essential to break the system down into possible hierarchical levels from the topmost level to the maintainable component level. This breakdown into subsystem, module, assembly and component will help in the apportionment and verification of the RAMS requirement. It will also facilitate the improvement or modification of the system. For the benchmark and SUSTRAIL wagons, the simplified breakdown of the system is given in Figure 21.

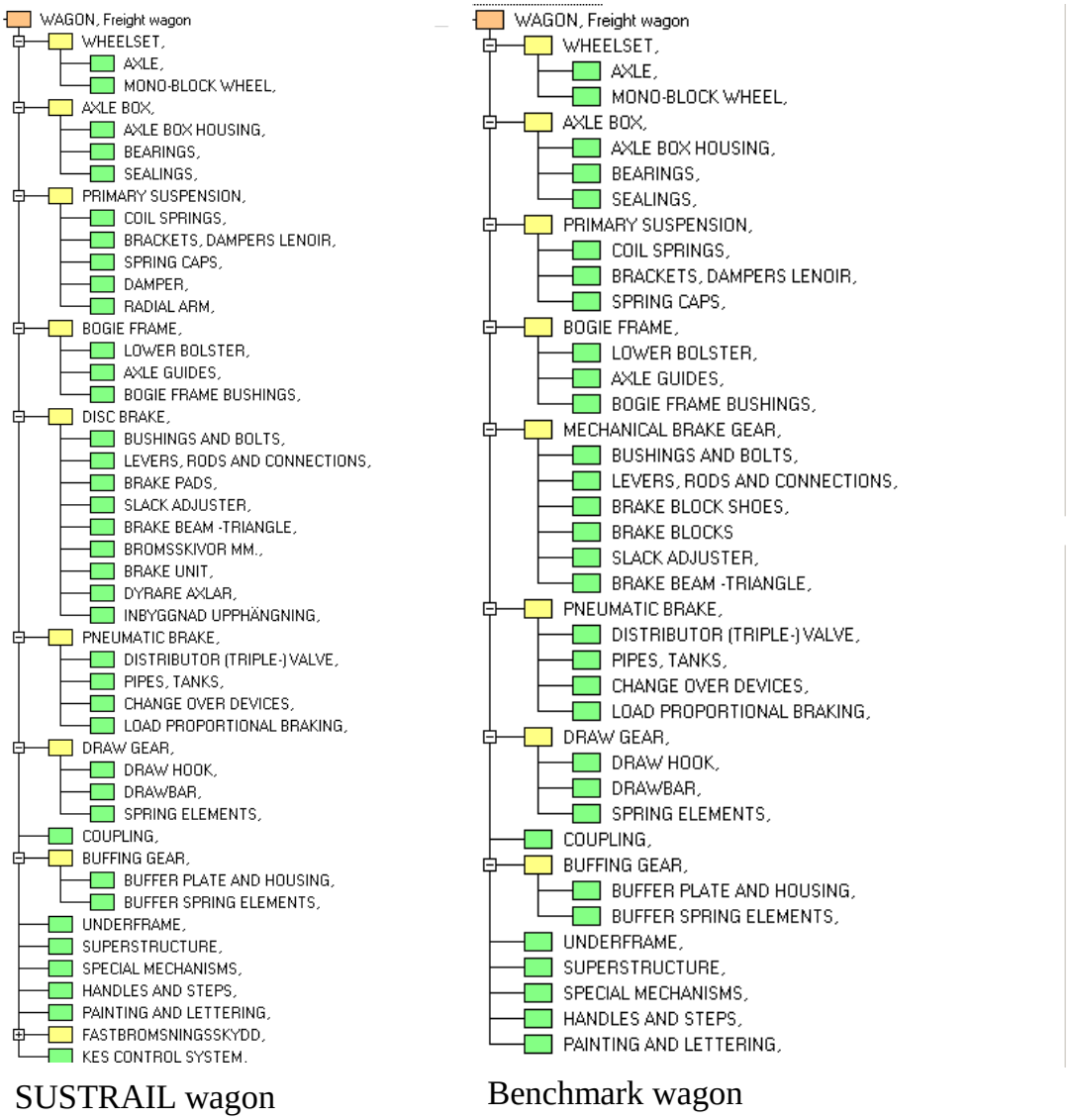


Figure 21: Breakdown structure of SUSTRAIL and benchmark wagons

5.5 Infrastructure breakdown structure

In order to avoid unnecessary complexity and complication in the modelling process, only distinguishing characteristics, components, and events are taken into consideration in the infrastructure breakdown and analysis. The route has been simplified to highlight the enhanced performance and additional cost of the route owing to the implementation of the track innovations suggested in SUSTRAIL. The descriptions of the possible performance improvement of the different track innovations have been given in the previous chapter though without adequate analysis to quantify them. Due to availability of data, expert views and some other technical reasons, only analysis on premium rail implementation is provided in this section. The simplified breakdown of the track on the UK1 route is presented in Figure 22. It is basically focussing on the impact area of the premium rail.

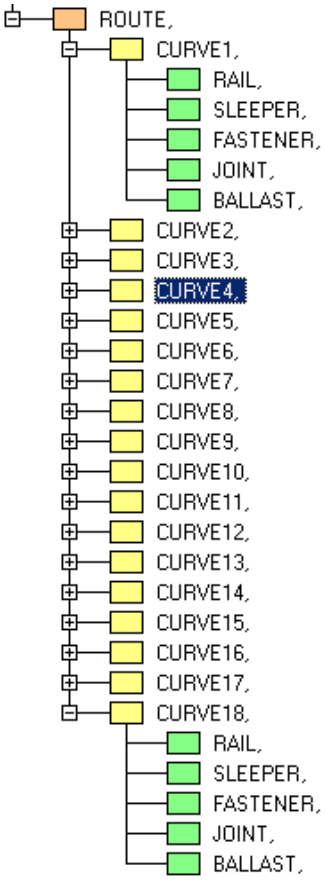


Figure 22: Simplified breakdown structure of the infrastructure for the RAMS and LCC analysis

5.6 Cost breakdown structure

The figures representing the cost breakdown structure of the LCC for the wagon and track systems have been given in chapter 2 (see Figure 10 and Figure 11). However the basic cost elements are:

- Cost of renewal: This cost is estimated based on manufacturer's recommended life length for each maintainable component. For example a component with a life length of 6 will be renewed 4 times in 30 years with the exclusion of the fifth renewal that takes place in the last year in the time horizon. The cost of renewal of a component is thus cost for each renewal multiply by the number of renewal occasions.
- Cost Failure: The cost of unavailability of the system when it is needed for mission. This is particularly used for wagon LCC. This is estimated by estimating the total hours of unaccomplished mission multiplied by a downtime cost per hour.
- Cost of preventive maintenance: The cost of all preventive maintenance tasks for wagon and track system is based on the time required to carry out the tasks. For example the time for the different wagon inspection categories are based on historical records from a maintenance service providers. This works are exclusively differentiated from renewal works.
- Cost of corrective maintenance: This is estimated from the mean time to restore a failed system or item. It is assumed that all corrective works are repair actions, so cost of item replacement during corrective maintenance are not envisaged.
- Cost of acquisition: This is calculated from estimated cost of systems and items based on manufacturers' suggestion and past researches.
- Cost of Termination: This is adapted to take care of the value of the different items at the end of the calculation owing to their varying life span. This is more or less a benefit since cost of disposal is not considered in the analysis. A parametric expression was developed to estimate the remaining value of each item at the end of the calculation year (30 years). This is then used to develop a cost function for end of life value.

6. SIMULATIONS

6.1.1 RAMS

Data availability and quality are the principal barriers against accurate RAMS and LCC analysis. In order to overcome this challenge, available data were combined with expert views for the simulation of the technical performance of both wagon and track system. Even though the values obtained in this study are not absolute, they are sufficient enough to evaluate the performances of the alternatives under investigation and also support decision towards sustainable railways with improved availability and low LCC. Examples of the data used in the simulation are presented in Table 9 and Table 10.

Table 9: Expert opinion used for wagon performance simulation

Events	Benchmark wagon	SUSTRAIL wagon
Number of annual brake failure	6	1
Number of annual wheel failure	2	0.2
Small Inspection interval [Years]	3	3
Average Inspection interval [Years]	6	6
Large inspection interval [Years]	12	12
Component replacement interval [Years]	Based on recommended life length for each component	

Table 10: Expert opinion used for track performance simulation

Events	Benchmark	SUSTRAIL 1	SUSTRAIL 2
Annual rail damage events (due to wheel impact)	26	5	13
Rail renewal interval [Years]	4	16	9
Grinding Interval [Years]	0.5	1	1
Tamping Interval [Years]	4	6	3.5
Inspection Interval [Years]	0.25	0.25	0.25

6.1.2 LCC

Some of the cost parameters used in the LCC calculations are highlighted in table below. It should be noted that these costs parameters are close to reality in Sweden, they may differ from one infrastructure to another and also between different countries.

Cost parameter	**Wagon simulation**	**Track simulation**
Interest rate	3%	3%
Life length [years]	30	30
Cost of wagon subsystem and components	Based on past researches and literature	
Cost of labour per hour	217 €	217 €
Downtime cost per hour	5.4 €	
Grinding cost per pass and Km		1380 €
Tamping cost per Km		5400 €
Cost of rails	Based on similar researches	
Note	The cost relates to 2014	

7. RAMS SIMULATIONS

There are many aspects of infrastructure performance that can be monitored and analysed from the simulation model. The output includes relevant performance measures such as: expected failure frequency, expected downtime and expected states of each section as well as the expected success outcome of the planned traffic schedule. The indicators discussed in this section are the RAM characteristics relevant to SUSTRAIL objective.

7.1 RAMS simulation for wagon

Firstly, the performances of the two wagons in terms of the expected states are presented in Figure 23, considering the planned mission profile, preventive maintenance plans and failure correction strategy. Four major states are adopted in this report with the fourth state having few other sub-states. The time fraction when the wagons are scheduled for operation and are actually available is referred to as “wagon on mission”. The time fraction when the wagons are available but there is no scheduled mission is referred to as “wagon ready”. The time fraction when the wagons are scheduled for operation and are available but mission could not be carried out due to external factors is referred to as “mission assigned to wagon”. The time fraction when the wagons are unavailable is referred to as “wagon unavailable”. The fourth state is further broken down to give explanation of the cause of unavailability. The wagon is considered to be in an unavailable state due to active repair, PM actions waiting for items or resources and logistic reasons. Figure 23 shows that benchmark wagon has overall availability performance of 0.95 (67% on mission, 28% ready for mission and 5% under maintenance support). On the other hand SUSTRAIL wagon has availability performance of 0.99 (70% on mission, 29% ready for mission 1% under maintenance support). The lack of performance or unavailability characteristics of the two wagons over the simulation period of 30 years are shown in Figure 24. The average annual unavailability of the benchmark wagon is about 0.5 while it is close to 0.1 for the SUSTRAIL wagon.

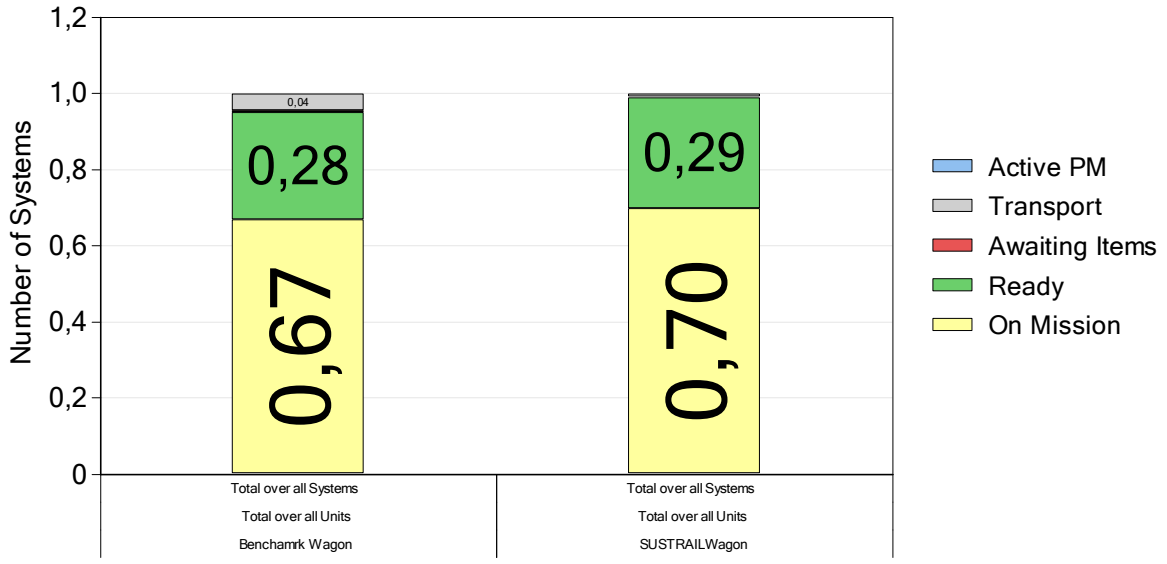


Figure 23: Expected states of the system over the simulation period

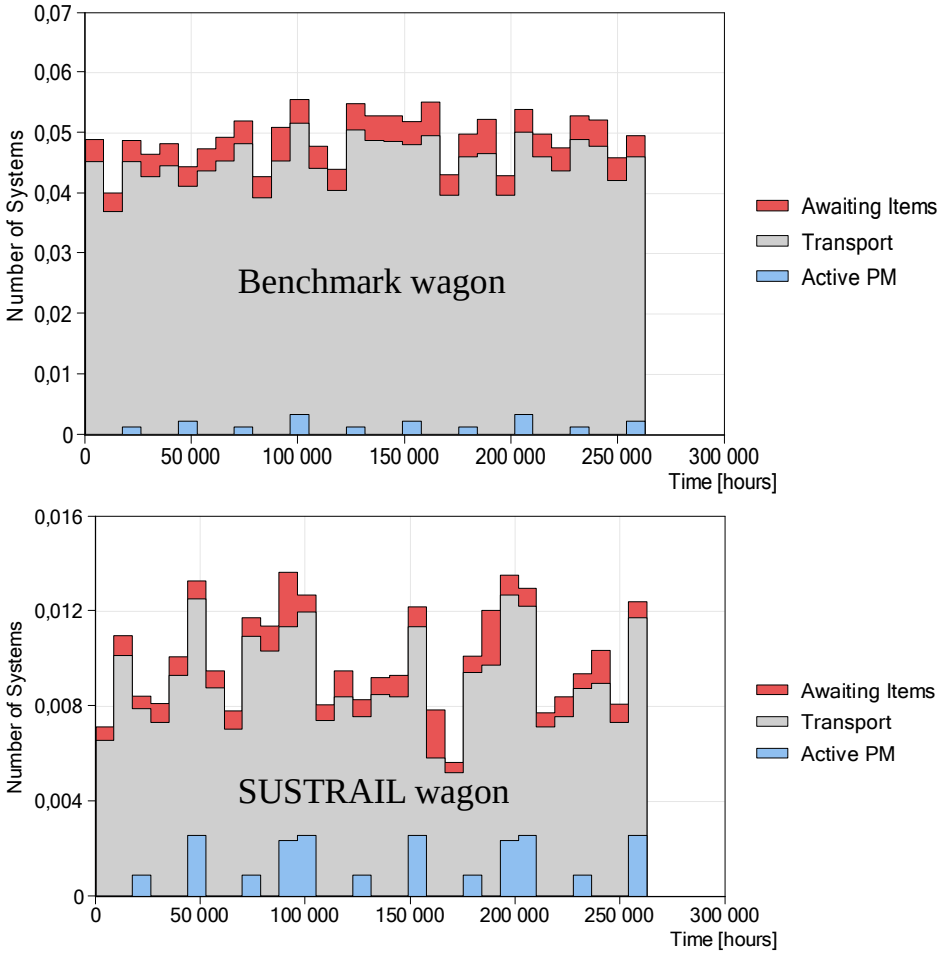


Figure 24: Unavailability measure of benchmark and SUSTRAIL wagons

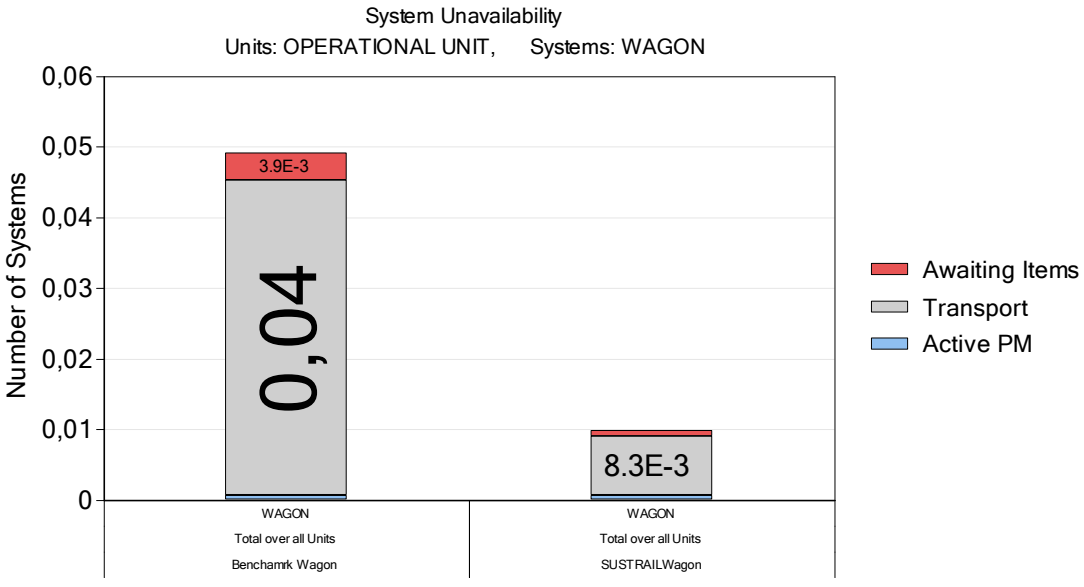


Figure 25: Average unavailability of benchmark and SUSTRAIL wagons (where E-3 = 0.001)

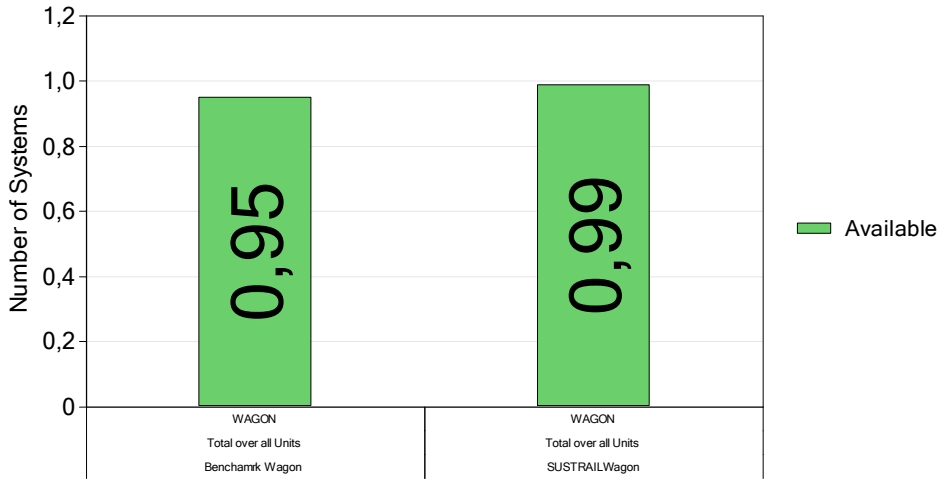


Figure 26: Average availability of the two wagons

An important aspect of the technical performance of a system is the measure of its ability to accomplish the planned and requested missions. The mission requested of the wagons over the simulation period is as described in section 5.3. The total mission hour requested of the two wagons is a function of the operation profile they are subjected to. Owing to the availability performance estimated, the proportion of mission hour that is expected to be accomplished is 94.66 for the benchmark wagon and 98.89 for the SUSTRAIL wagon. The mission success rate is coincidentally similar to availability performance in this case, this is not always the case.

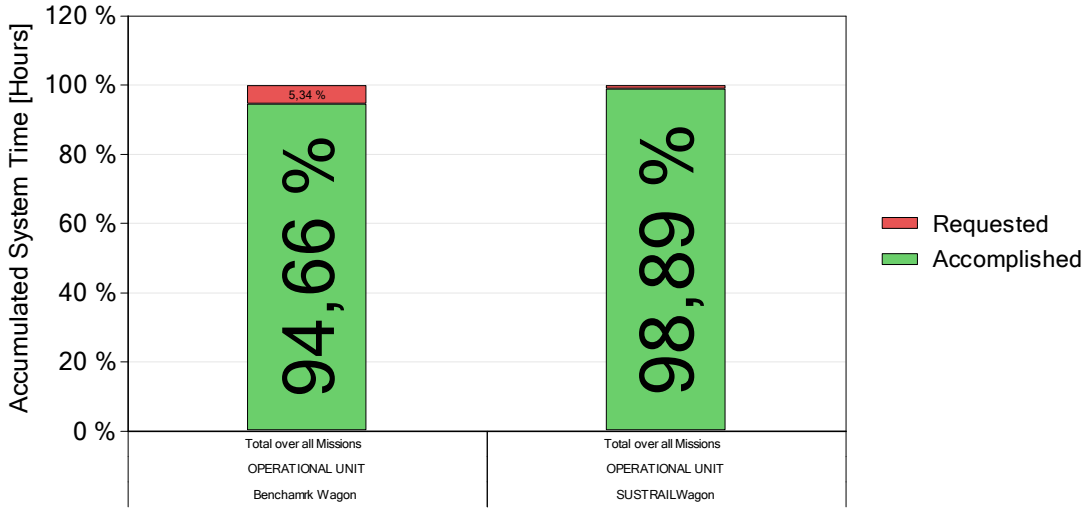


Figure 27: Mission success rate of the two wagons for the operation profile described earlier

7.2 RAMS simulation for tracks (UK route 1)

As mentioned earlier, only the performance of the curves on the selected route is generalised as route performance since only the improvement due to premium rail implementation is studied. The estimated unavailability and availability of the cases described earlier are presented in Figure 28 and Figure 29. Figure 30 gives the estimated success rate of train missions operated on the route with the different cases. There is an improvement in the availability performance of the route due to the implementation of premium rail at curves, an increase in availability from 95% (benchmark) to 97% (SUSTRAIL0) with only the wagon

improvements. Further with track improvement, availability performance up to 99% (SUSTRAIL1) is possible with this installation of premium rail at selected curves. Even though the differences in the technical performance of the three cases are not pronounced, the cost implication of the four cases justifies the implementation of the SUSTRAIL innovation without speed change. In addition, events such as temporary slow order due to rail conditions are not accounted for in the estimated availability performance from the model. If such instances of reduced track capacity are to be considered, then the availability of the benchmark case will adversely reduce.

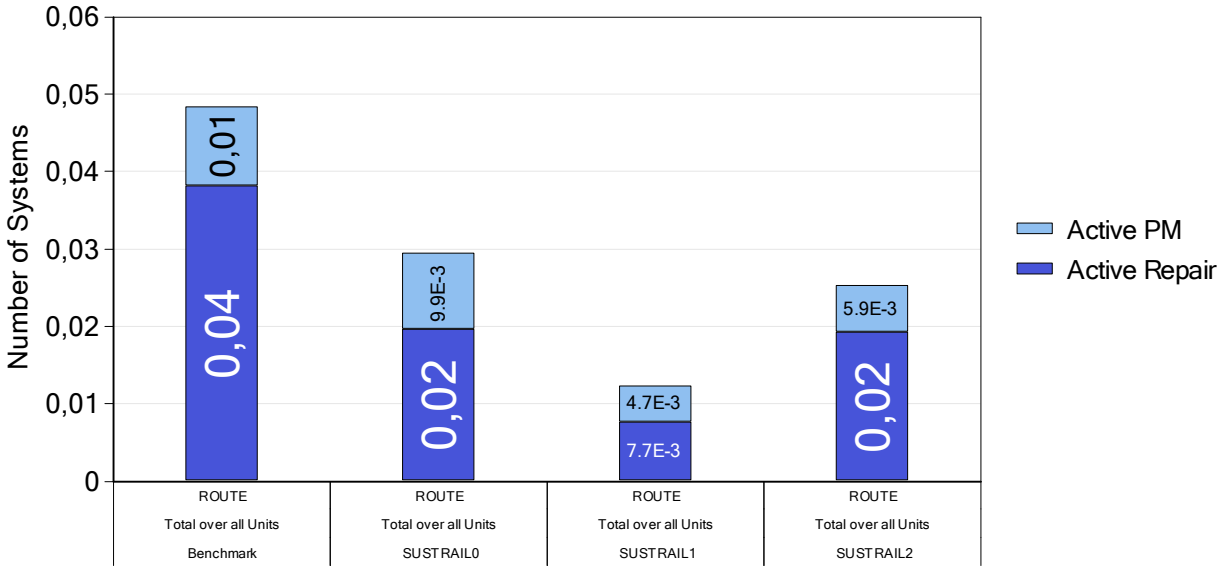


Figure 28: Estimated unavailability of the simulated route with the 3 cases described earlier (E-3 =0.001)

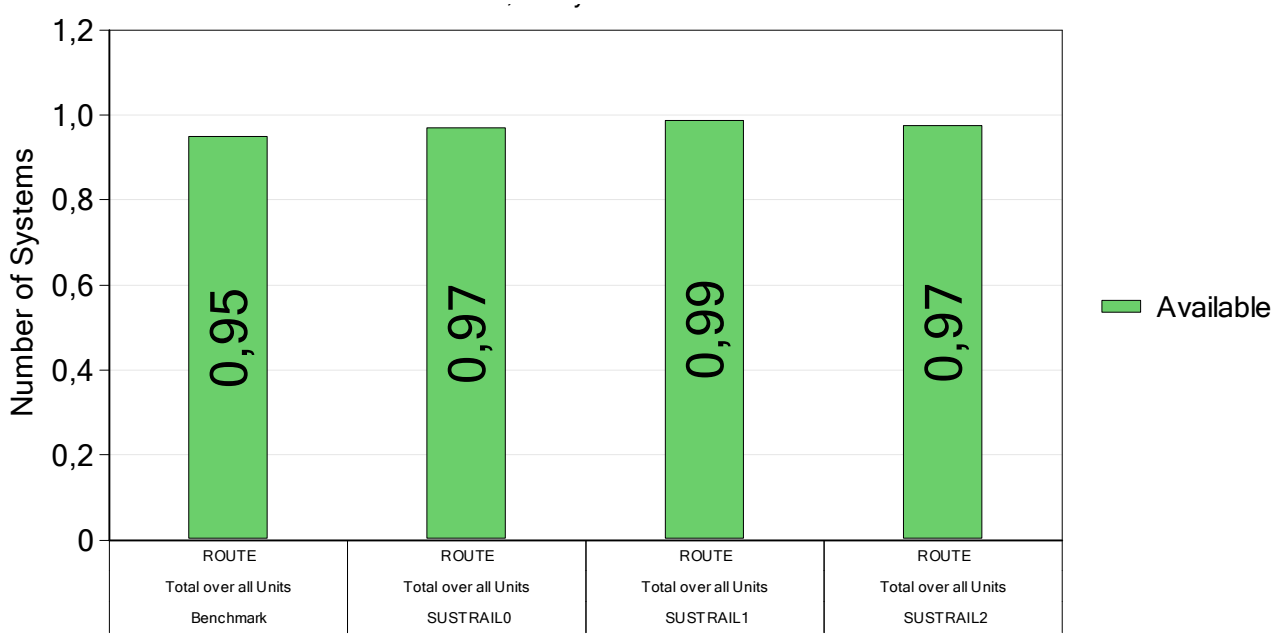


Figure 29: Estimated availability of the simulated route with the 3 cases described earlier

From the perspective of quality of service, it is expected that the increased availability of track will support additional 1.59%, 2.28% and 3.61% improvement in the achievable mission success for the SUSTRAIL0, 1, 2 respectively. This could be translated into economic benefits from the viewpoint of rolling stock operators and freight buyers.

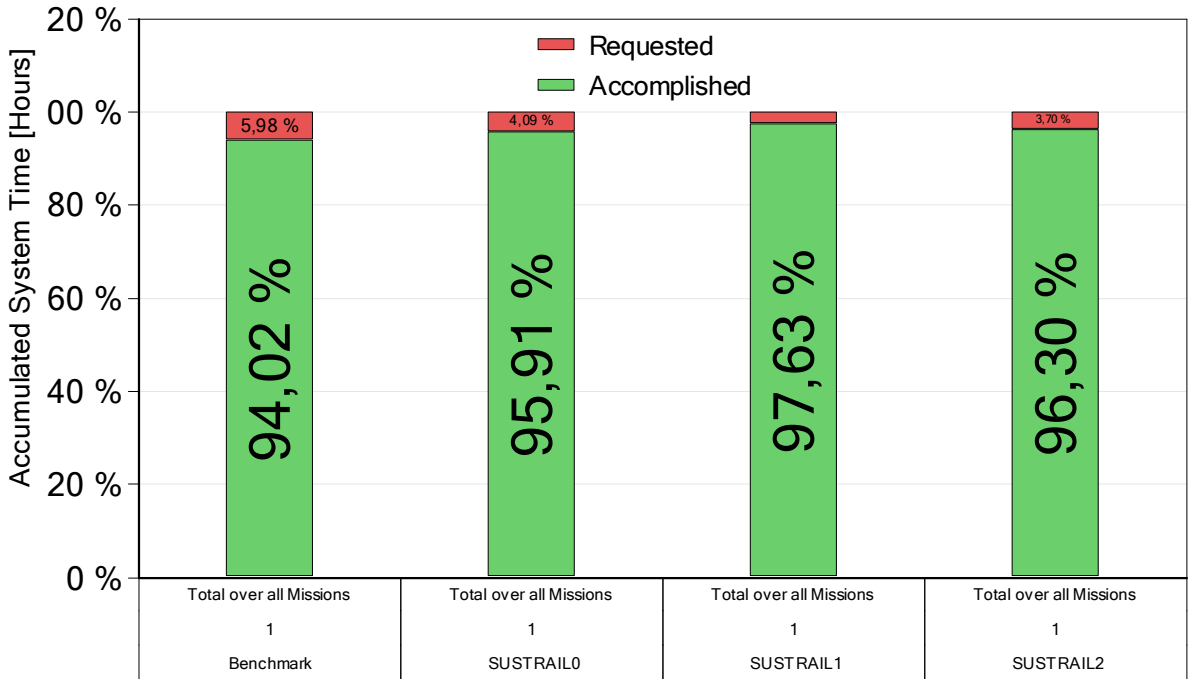


Figure 30: Mission success rate of the three cases with the operation profile described earlier

8. LCC ANALYSIS

8.1 LCC for wagon

In this calculation almost all the cost aspects from cradle to grave have been considered. For the two alternatives, the following cost elements have been taken into consideration: cost of acquisition, cost of renewal, cost of unavailability, cost of corrective & preventive maintenance, and cost of termination. However, fuel costs and track access charges have been excluded in this calculation for the reason that they are expected to be estimated in separate reports under cost benefit analysis and track access charge respectively.

The result of the LCC calculation is presented in different perspective to show the

- Total LCC of the benchmark and SUSTRAL wagons
- Cash flow over the period considered in the study (30 years)
- Contribution of different cost elements to the total LCC
- Cost drivers
- Break-even point for SUSTRAIL wagon

The total LCC for the benchmark wagon over a time horizon of 30 years is 307,186.75 €. On the other hand the expected LCC for the SUSTRAIL wagon with improvements in the primary suspension, wheelset, body, braking system and condition monitoring system is 281,992.54 €. Even though the initial acquisition cost of the SUSTRAIL is estimated to be about 70% higher than the benchmark wagon, the LCC of the SUSTRAIL wagon is on the long run lower by circa 8%. The breakdown of the LCC for the two wagons is presented in Figure 31. The drastic reduction in the corrective maintenance cost and slight reduction in other cost elements compensate for the high initial cost of acquisition of the SUSTRAIL wagon. Mass production could further reduce Sustrail wagon purchase price in the future.

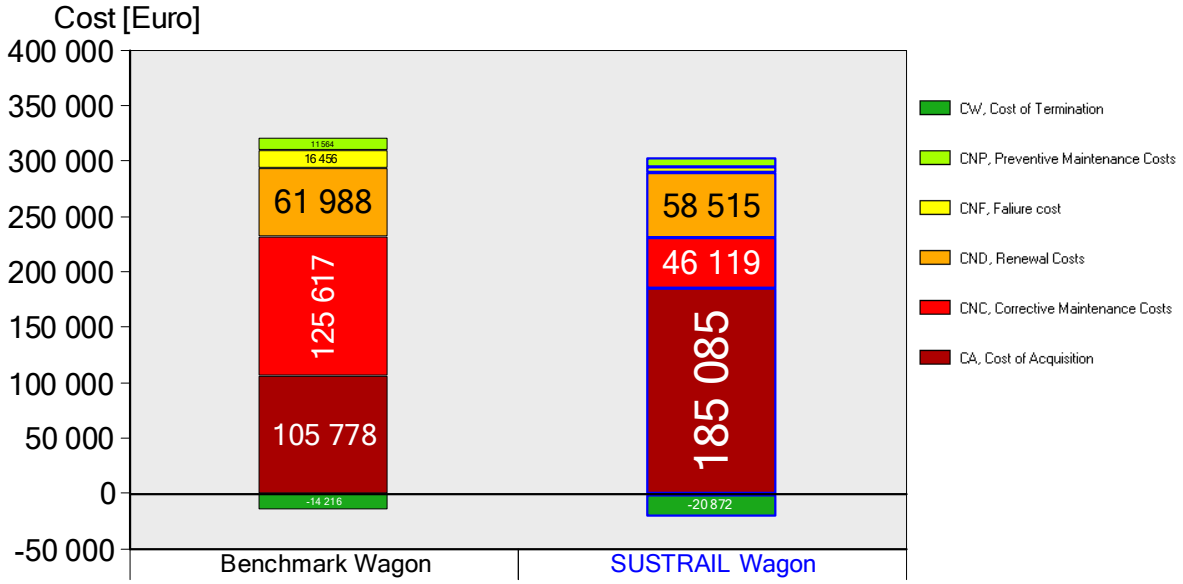


Figure 31: LCC for the two wagons

As mentioned earlier two important cost elements (cost of fuel and track access charges) are not included in these calculation. These cost elements are definitely to the advantage of the SUSTRAIL wagon. The addition of these cost elements will make SUSTRAIL wagon more promising and attractive for potential freight operators. Other benefits that would boost the deployment of SUSTRAIL wagon such as traffic flexibility are reported in the report on cost benefit analysis.

The sum of the 6 cost categories for both alternatives are shown in Figure 32. These figures show the annual flow of the different cost items over the calculation period. Basically preventive, corrective and renewal costs are the cost items that spread over the calculation period. The significant difference in the two alternatives is the high initial cost of acquisition for the SUSTRAIL wagon and high recurring cost for the benchmark wagon.

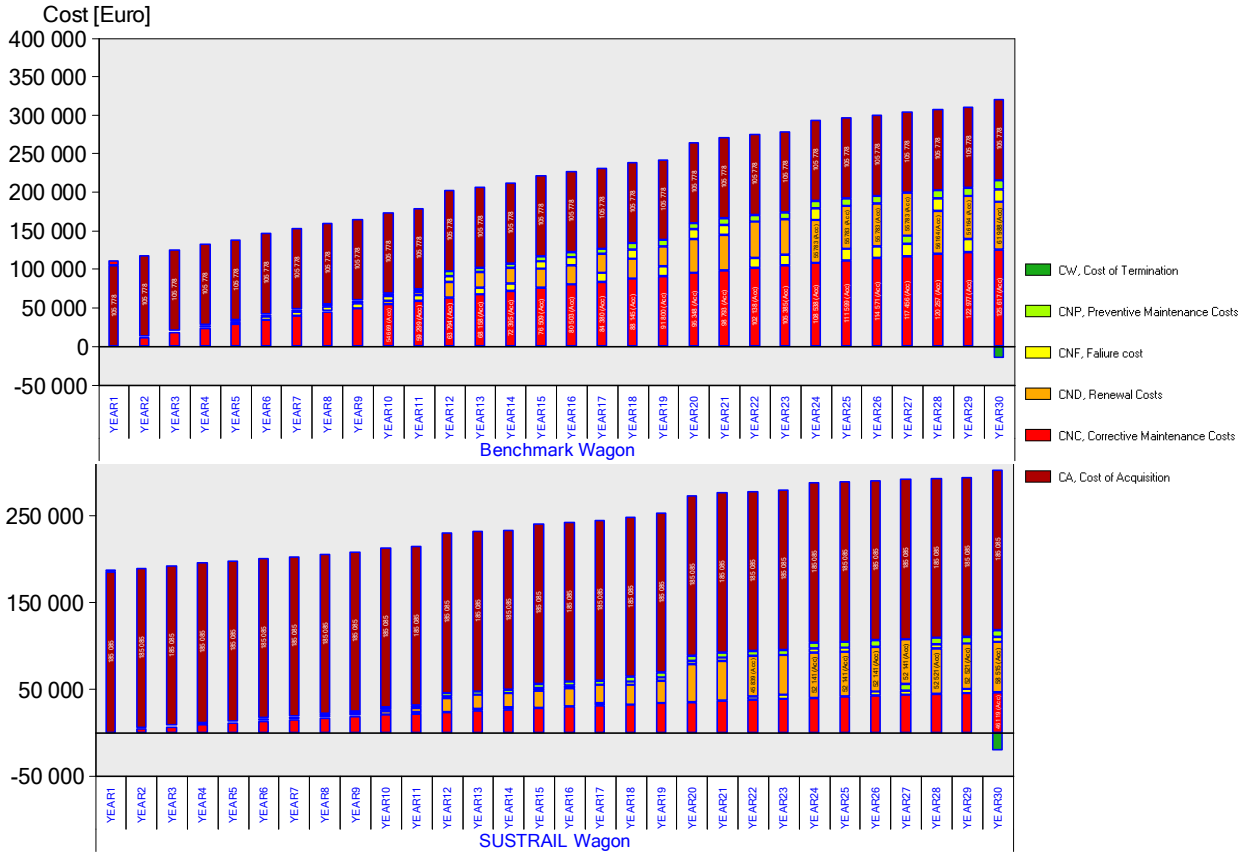


Figure 32: Cost flow of different cost aggregates for benchmark and SUSTRAIL wagons.

The preventive maintenance and renewal costs are periodic in nature for both cases while the failure cost and corrective maintenance cost are more regular on annual time scale (with a small resolution of time, the last two cost items are actually random in their occurrence).

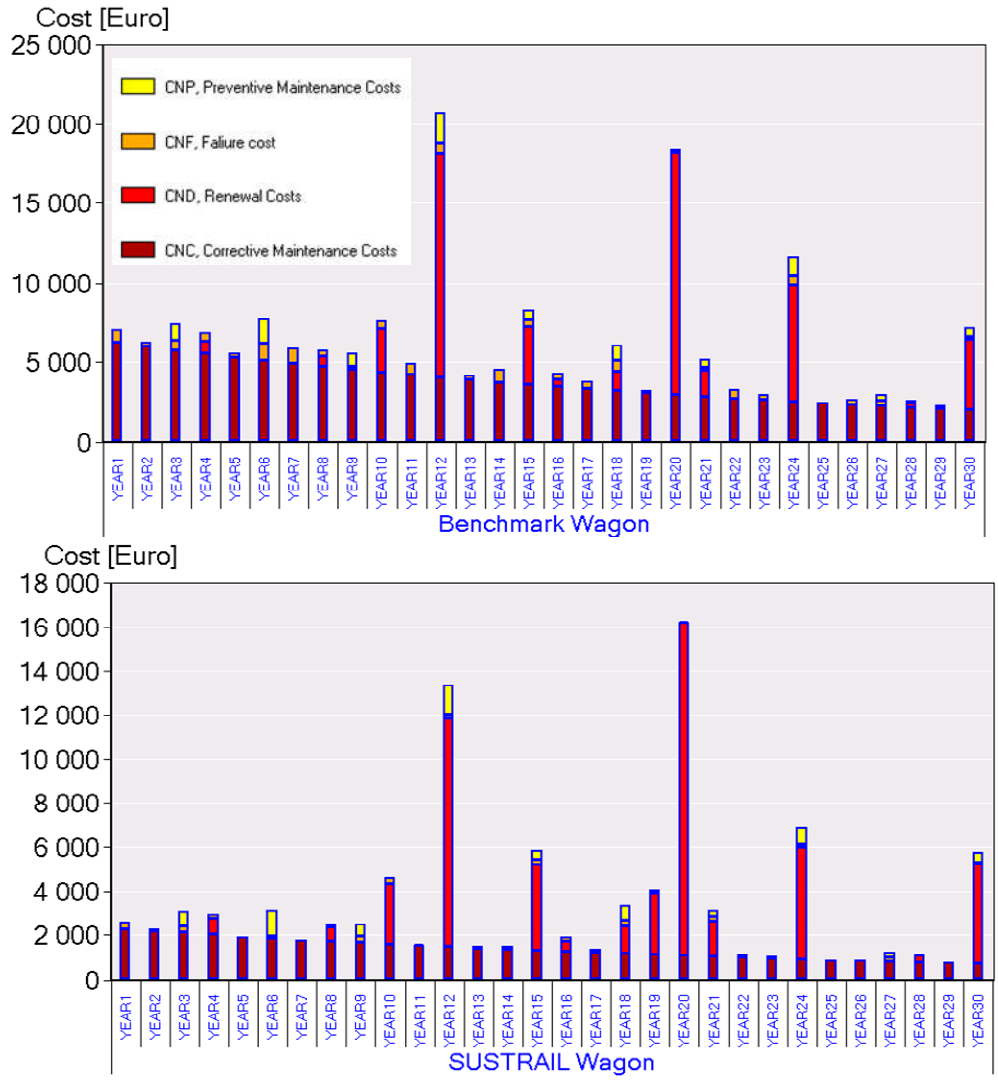


Figure 33: Maintenance, renewal and failure costs for benchmark and SUSTRAIL wagons

Final note on wagon LCC is the identification of cost drivers. Based on the data collected and interview carried out in the course of this study, the cost driving items in benchmark wagon are brakeblocks, monoblock wheel, Lenoir dampers, spring cap, couplings and bearings. The cost driving items for the SUSTRAIL wagon are disc and pad, Lenoir dampers, monoblock wheel, couplings, spring cap, and bearings.

An interesting aspect is to show the breakeven point considering only the cost elements used in this study. The cost of ownership of the benchmark wagon is estimated to become more expensive than SUSTRAIL wagon starting from the 23rd year as can be seen in Figure 34. However, this is dependent on the interest rate. A change in the interest rate from 3% to 4% makes a shift in this break-even point from year 23 to 25 as shown in Figure 34 and Figure 35. If all the costs and benefits are put together in the same model, the break-even point will even be much earlier than shown in Figure 34 and .

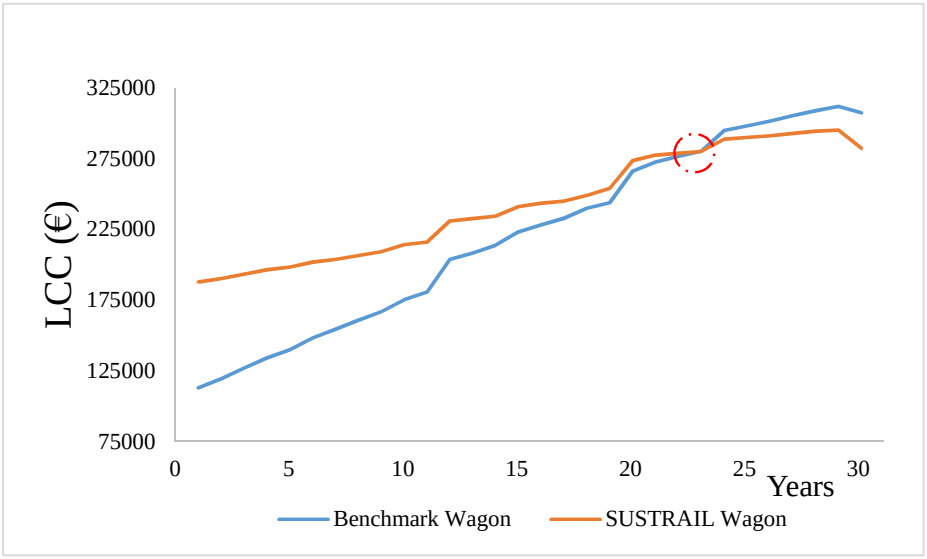


Figure 34: Comparison of benchmark and SUSTRAIL wagons to show break-even point with 3%

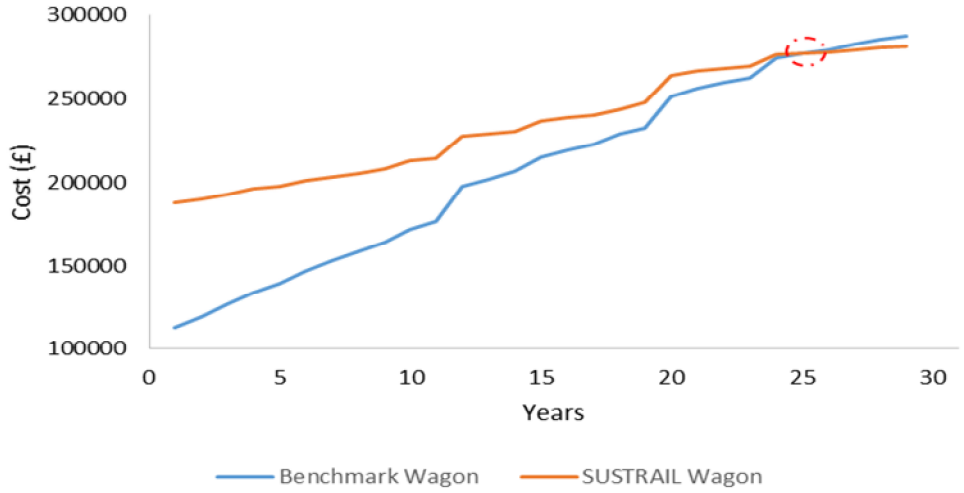


Figure 35: Influence of interest rate on the break-even point (change in interest rate from 3% to 4% led to change in break-even point from 23 to 25 years).

8.2 LCC for UK1 route

The LCC calculation for the track is limited only to distinguishing and significant cost element. It should be noted that the LCC is also calculated in such a way that the focus and objective of SUSTRAIL will be highlighted. Economic implications of safety and extreme failure events with low likelihood such as derailments are not considered in these calculations. However track damage cost as likely to be caused by wheel impact and wagon dynamics are included in the model as part of corrective maintenance cost. This simplified LCC is hereafter referred to as LCC.

The result of the track LCC calculation is presented in different perspective to show the

- Total LCC for route for three scenarios under investigation
- Cash flow over the period considered in the study (30 years) with the different cost elements
- Contribution of different cost aggregate and cost atom to the total LCC
- Cost drivers

The estimated LCC for the four cases are shown in Figure 36. This figure also shows the composition of the cost elements. The benchmark case which is considered to be the present condition of the route under study has the highest LCC. It is estimated that the introduction of SUSTRAIL wagon with less track force and vehicle dynamic related damage will reduce the LCC by at least 5%. It is assumed that majority of the railway vehicle operating on the route are SUSTRAIL wagon. Further improvement of the track with premium rails together with improved wagon presents about 61% reduction in the LCC. In the case of track improvement with speed change, the estimated reduction in the LCC is 43% based on expert assessment.

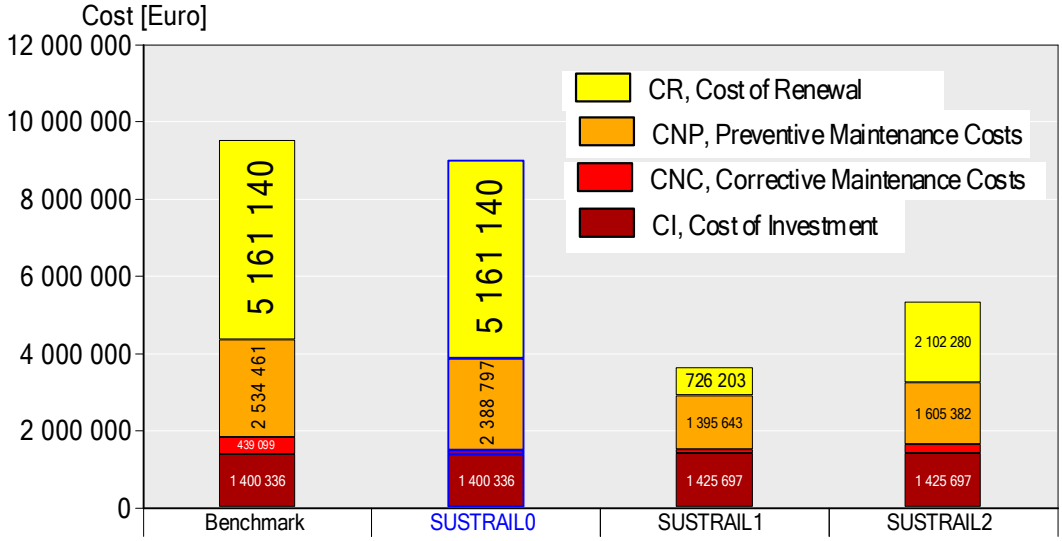


Figure 36: LCC for the three scenarios of the simulated route

The sum of the 4 cost categories for the four LCC scenarios are shown in Figure 37 to Figure 40. These figures show the annual flow of the different cost items over the calculation period. Basically preventive, corrective and renewal costs are spread over the calculation period while

the investment is the same, since it is the initial cost of installation. The significant difference in the four scenarios is the renewal cost which is based on the frequency of rail renewal at the curves. Based on information from the route (benchmark scenario), rail renewal is done at about 4 years interval. It is estimated that the similar life length would be possible with the introduction of new wagons but some maintenance intervals would be extended (e.g. tamping). Further, with the introduction of premium rails at the curves, it is predicted that the life length of the rails can be substantially increased by a factor of 3 or 4 and some maintenance intervals could be extended. If the travel speed on the improved track is increased from 120km to 140km, it has been assumed that the life length only be increased to about 9 years. There is need for the verification of this assumption using simulation approach.

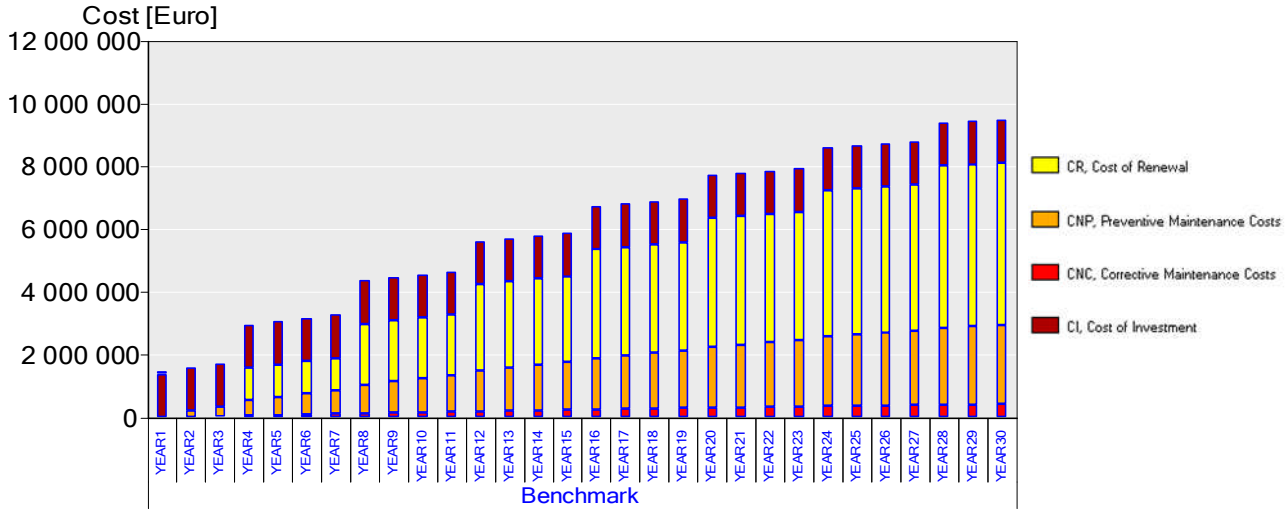


Figure 37: Cost flow for benchmark scenario on the simulated route.

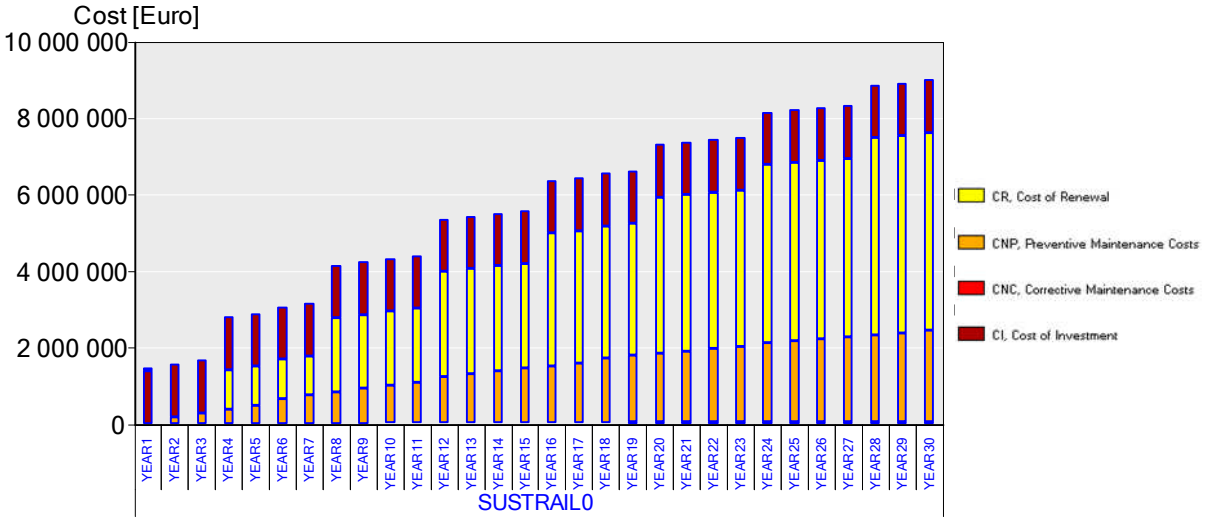


Figure 38: Cost flow for SUSTRAIL0 scenario on the simulated route

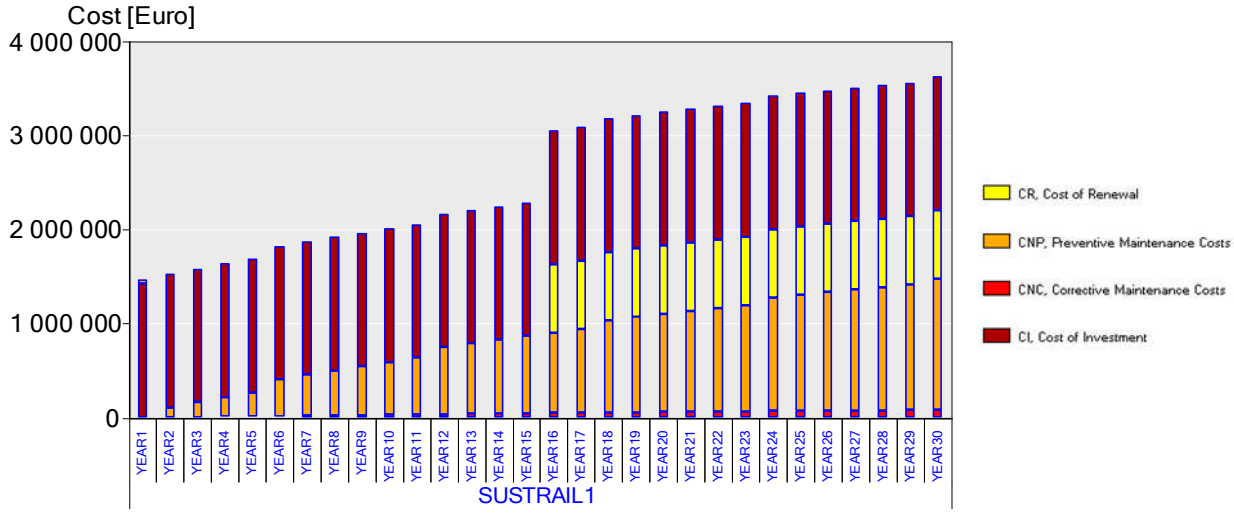


Figure 39: Cost flow for SUSTRAIL1 scenario on the simulated route

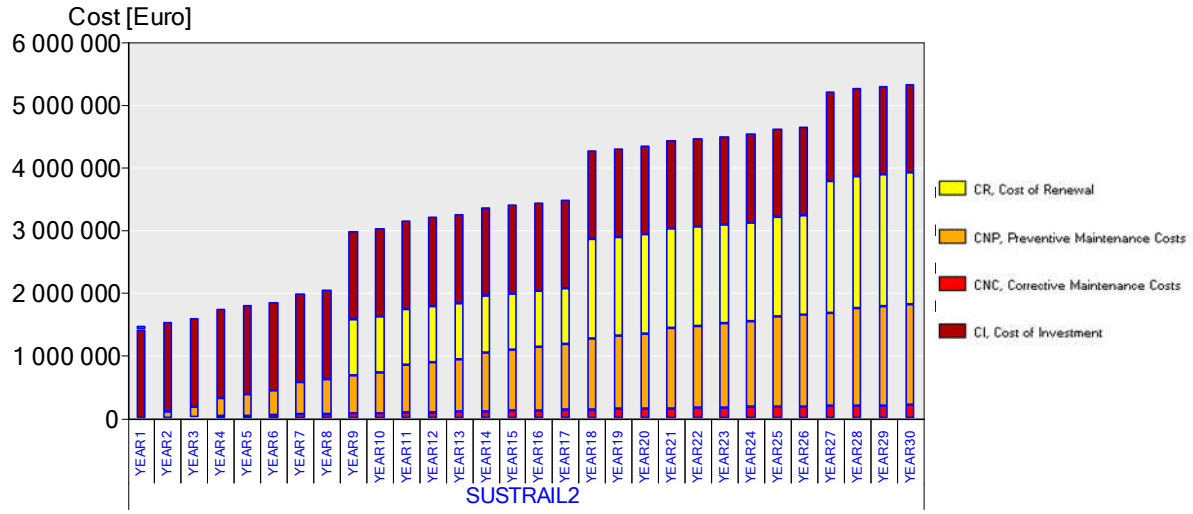


Figure 40: Cost flow for SUSTRAIL2 scenario on the simulated route

The accumulated flow of cost for 30 year calculation period is shown in Figure 41. The benefit of the installation of the high premium rail on the selected curve section is obvious in the figure. It is important to note that the large difference is as a result of the peculiar condition of the investigated route (benchmark scenario), that necessitated frequent change of rail in the curves. The difference might not be so large for other SUSTRAIL routes, if their substructure condition and track condition are better or if the routes have fewer curves.

It is important to note that this LCC analysis has been "partial" in nature. That is, only the cost elements where significant cost changes between the base scenario and the modelled scenarios have been modelled. This is particularly important with respect to the track LCC, where the elements of track cost considered are given in Figure 11and Figure 36 As such any

% change in LCC should be read referring to this restricted cost base and not total infrastructure costs. In Deliverable 5.2 and 5.6 the costs are aggregated to the case study route levels. In this case the % changes may refer to a different cost base. This explains why the % changes (and indeed absolute cost changes) may differ from this deliverable and Deliverable 5.2 and 5.6

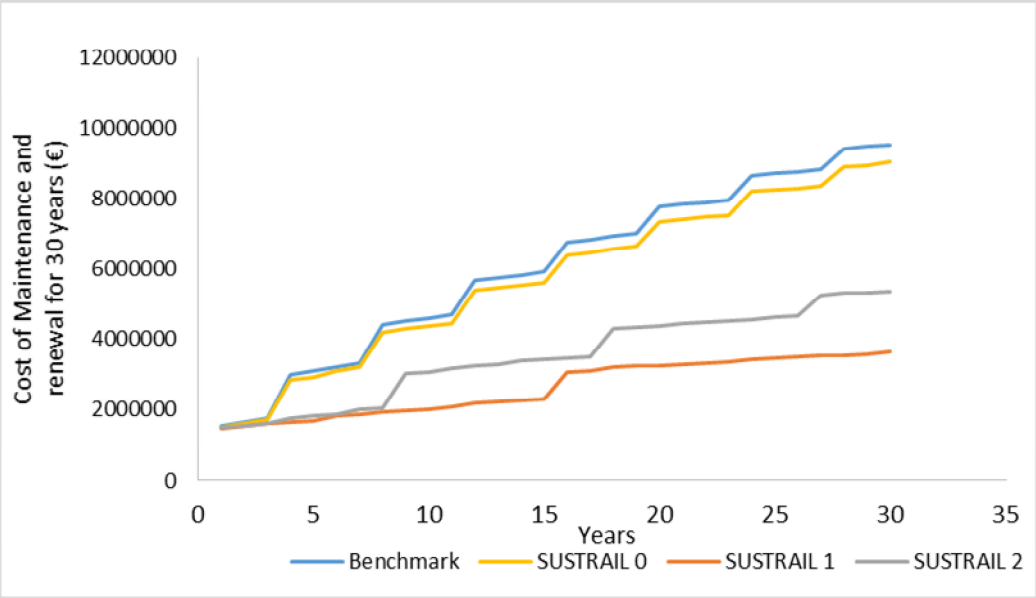


Figure 41: Comparison of the benchmark and SUSTRAIL cases

9. CONCLUSIONS

The railway transport system is complex from both a technical and organisation perspective and compose of several different parties, each one with individual objectives and strategy in maintaining their assets and rolling stock. The development of the railway system has also been carried out on a national basis leading to systems hindrances such as differences in standards and different technical solution e.g. different track gauges. Another obstacle while chasing data for e.g. benchmarking or LCC-calculations is that deregulation and outsourcing has change the data from being available to being confidential and sensitive in a competitive environment.

The content of this report is to describe result and work done in WP5 task 5.1 where RAMS and LCC analysis is to be performed on selected innovations from WP4 and WP3. These innovations should also be analysed and assessed from a holistic perspective and be tested on three different routes in UK, Bulgaria and Spain.

There were four innovations/options from WP 3 and eight from WP5, see Table 11 . Some of these are not generated by Sustrail but are highlighted as innovations/options recommended for assessment by SUSTRAIL.

Table 11 Innovations/options

WP 3 The freight train of the future	WP 4 Sustainable track
1. Hybrid locomotive 2. Freight wagon body 3. Freight wagon bogie 4. Freight wagon braking system	1. Premium Rail Steel 2. Testing and analysis of welds in CWR (Ultra sonic testing) 3. Impact of rail profile/ inclination on RCF 4. Multifunctional geotextile 5. Forced information from WID 6. Smart Washer 7. Transition zones to bridges 8. Under sleeper pad

RAMS and LCC techniques have proven helpful in bringing issues and potential solutions relating to evaluate innovations, new methods and strategies and the objective was to describe how each of the options/innovation will contribute to reaching better:

- Reliability
- Maintainability
- Maintenance supportability
- Availability
- Cost
- Holistic How it will affect the vehicles
- Capacity

The input to task 5.1 related to the RAMS and LCC parameters and needed for the assessment of the includes information related to:

- Failure frequencies
- Maintenance times
- Logistic delays
- Maintenance activities
- Maintenance strategies
- Product structure
- Cost elements
- Service life
- Etc.

Much of the information mentioned above was hard and difficult to extract, e.g. for an item, different information could be located within the different parts of an organisation or within the organisation of different stakeholders. Their individual business goals could restrict the access to information needed for the RAMS and LCC analyses. Due to difficulties in extracting some of the information mentioned above, the RAMS and LCC simulation had to be performed on a subset of the total number of innovations presented in WP3 and WP4 and the innovation has however been discussed from a more theoretical level.

The result of the simulation shows that the technical performance of the SUSTRAIL wagon is better than the benchmark wagon. The estimated availability of the benchmark wagon is about 95% while that of the SUSTRAIL wagon is estimated to be 99%. The main factor responsible for the lower availability of the benchmark wagon is the logistic and waiting time at the workshop. In addition, the mission success rate of both the SUSTRAIL and benchmark wagons is similar to the availability of their respective availability measures. From cost perspective, the initial cost of acquisition of improved wagon is about 70% higher but the reduced cost of maintenance and failure pays off in the long run. The break-even point for the SUSTRAIL wagon is quite late (around year 23) but there are promising benefits from operation and track performance viewpoints.

Furthermore, the availability performances of the benchmark track and wagon, benchmark track and improved wagon, improved track and wagon and improved track and wagon with speed increase are estimated to be 95%, 97%, 99% and 97% respectively. Even though the differences in the technical performance of the four cases are not pronounced, the cost implication justifies the implementation of the SUSTRAIL scenario (improved wagon and track) without speed change. More dynamic simulation is needed to validate the performance of the proposed improvement with speed change. It is estimated that wagon improvement with benchmark track will give at least 5% reduction in the life cycle cost over 30 years with focus on curves in the simulated route (UK1). Further improvement of the track with premium rails together with improved wagon presents about 61% reduction in the LCC. In the track improvement with speed change scenario, the estimated reduction in the LCC is 43% based on expert assessment. It is suggested that additional dynamic simulation is required to further establish the expert judgement and these conclusions.

It is important to note that this LCC analysis has been "partial" in nature. That is, only the cost elements where significant cost changes between the base scenario and the modelled scenarios have been modelled. This is particularly important with respect to the track LCC, where the elements of track cost considered are given in Figure 11 and Figure 36. As such any % change in LCC should be read referring to this restricted cost base and not total infrastructure costs. In Deliverable 5.2 and 5.6 the costs are aggregated to the case study route levels. In this case the % changes may refer to a different cost base. This explains why the % changes (and indeed absolute cost changes) may be different from this deliverable and Deliverable 5.2 and 5.6

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APPENDICES

A. RAMS AND LCC INPUT FORM

In task 5.1 a RAMS and LCC input form was developed to gather information regarding different innovations proposed during the project. This document can be seen in appendix A. The document covers aspects of the RAMS and LCC parameters and has served as a base for the information retrieval in the project. This is one of the outcomes of the research preformed in WP5.1