Capacity for Rail

Towards an affordable, resilient, innovative and high-capacity European Railway System for 2030/2050

Templates and tools for analysis of scenarios

Submission date: 19/06/2015

Deliverable 52.2

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement n° 605650

Collaborative project SCP3-GA-2013-60560
Increased Capacity 4 Rail networks through enhanced infrastructure and optimised operations
FP7-SST-2013-RTD-1

Lead contractor for this deliverable:

- USFD

Project coordinator

- UIC

Executive Summary

The aim of this deliverable is to produce templates which will aid the gathering of data and provide potential methodologies for the assessment of the Capacity4Rail innovations which will be assessed within work package 5.4 of this project. Presented within this deliverable are templates for LCC, RAMS and LCA analyses which have been customized for each Capacity4Rail innovation described within the description of work.

This deliverable is presented as an interim deliverable, it is expected to be updated with feedback from the other sub-projects and based on the descriptions of the scenarios developed in deliverable D5.3.2, the assessment methodology developed within D5.4.1 and as more details about the Capacity4Rail innovations are developed within WP5.1.

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Abbreviations and acronyms

Abbreviation / Acronym	Description
SP	Sub-project of the Capacity4Rail project
WP	Work package of the Capacity4Rail project
C4R	Capacity4Rail project
LCC	Life cycle cost analysis
LCA	Life cycle analysis
RAMS	Reliability, Availability, Maintainability and Safety
FMEA	Failure Mode and Effects Analysis
KPI	Key Performance Indicators
DoW	Description of Work
CO_2	Carbon Dioxide
CO_{2e}	Carbon Dioxide equivalent (global warming impact of emissions equivalent to kg/CO2)
SE Matrix	Stakeholder Effects Matrix
TRL	Technology Readiness Level
CAPEX	Capital Expenditure
OPEX	Operational Expenditure
GHG	Green house gases
NO_x	Nitrogen Oxide compounds eg NO Nitric oxide or NO_2 Nitrogen dioxide
PM10	Particulate matter (2.5-10 micrometer diameter)
PM2.5	Particulate matter (less than 2.5 micrometer diameter)
LCI	Life Cycle Inventory

1. Introduction and aims of T5.2.2

This current version of D5.2.2 is being presented as an interim deliverable to D5.2.2. The reason for this being presented as an interim deliverable is that following on from feedback from SP1-SP4 and input from D5.1.2 and D5.1.3 will allow a better understanding the activities and innovations of the other SPs and better understanding of the project scenarios from WP5.3 could impact on the content and structure of the templates may therefore require changes and updating. Also the methodology to be used in WP5.4 is not yet fixed and therefore further changes to the templates presented here may be required as the methodology develops further in task T5.4.1. Once the methodology and scenarios have been fixed and initial feedback from SP1-SP4 has been received an updated version of this deliverable will be issued.

This deliverable, D5.2.2 Assessment methodologies and templates, provides a background into the most suitable methodologies to be applied in the assessment of the innovations within Capacity4Rail sub-projects SP1-SP4 and provides a template for the input and data required from these work packages to fulfil the technology assessment which will be carried out within WP5.4 and WP5.5. These templates may be used and communicated to the other sub-projects at this early stage of the C4R project to ensure that as each technology is developed the work package participants consider the final assessment within their development and the work packages are able to plan how they will provide the necessary data.

This deliverable builds upon the outputs of deliverable D5.2.1 Identify methodologies and sources of data, and D5.1.1 Railway road map – paving the way to an affordable, resilient, automated and adaptable railway. As deliverables D5.3.1 Sites for Migration, and D5.3.2 Migration scenarios and paths develops, the assessment methodologies and the data requirements will be developed further and can be applied within WP5.4 and WP5.5.

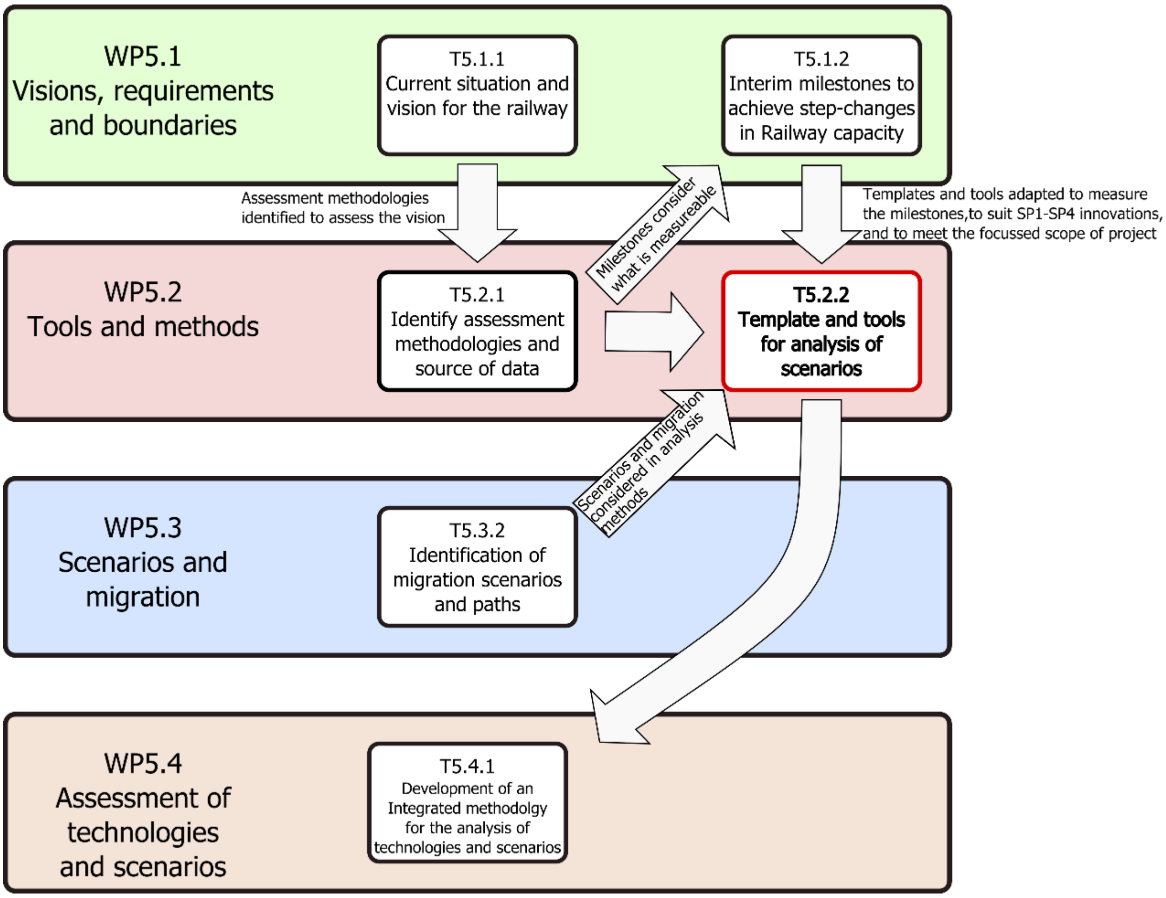


FIGURE 1– *FIT OF TASK T5.2.2 WITHIN THE CONTEXT OF OTHER SP5 TASKS AND WORK PACKAGES*

Before the templates can be created within this deliverable it is important to define the purpose of these templates and where they fit in the overall aims and objectives of SP5.

SP1, SP2, SP3 and SP4 are carrying out some forms of assessment and demonstration within their sub-project, for example within WP4 a range of sensors are being assessed on the criteria of unit cost, technology readiness, commercial viability etc. So within SP5 the assessments carried out must build upon these assessments carried out within the other sub-projects to identify how the different technologies contribute towards the overall aims of the Capacity4Rail of an affordable, adaptable, automated, resilient and high capacity railway and the progress made along the technology roadmaps developed within WP5.1 and identify the needs for further innovation.

SP5 began by creating a technology roadmap within WP5.1 and then WP5.3 will identify scenarios, key corridors and migration scenarios. WP5.2 deliverable D5.2.1 identified technology assessment methodologies from other EU rail FP6 and FP7 projects as well as methodologies from the wider industry and WP5.4 will further develop the assessment methodologies to be carried out within SP5 which could require future changes to the templates developed here in T5.2.2. Whilst WP5.5 will carry out demonstrations to complement and support those carried in SP1-4 and carry out final ranking of technology and assessment.

Potential assessment methodologies and the relationships between the different assessments being carried out within the Capacity4Rail project

Within SP5 the technologies will be assessed primarily in their application to the scenarios defined in WP5.3. This will build upon any assessment carried out within SP1-4, where the initial evaluations carried out in these sub-projects which will aid SP5 to identify the most appropriate technology for a particular scenario. These technologies may either be combined and this combination of technologies could be assessed for each scenario or technologies could be applied individually and assessed for each scenario. By evaluating a combination of technologies enables the review the cumulative impact of the different innovations from across the project and the overall impact of the Capacity4Rail project, whereas by evaluating each technology on an individual basis the direct benefits of that particular technology may be established. The result of combining the technologies might also be that not all of the technologies developed in the Capacity4Rail project are assessed in all of the scenarios, but just those scenarios where the application of the technology is most appropriate.

If a combined technology methodology is implemented the final ranking of the technologies within task T5.5.6 could include a metric of the number of Capacity4Rail scenarios in which that innovation was relevant, the more widely applicable that the innovation is, the higher priority it should be for future developments.

The scenarios can then be assessed before and after application of the appropriate technologies/innovations, this will demonstrate the potential improvement of the Capacity4Rail innovations to the particular scenarios/bottlenecks and produces a tangible and easy to understand summary of the success of the Capacity4Rail project overall.

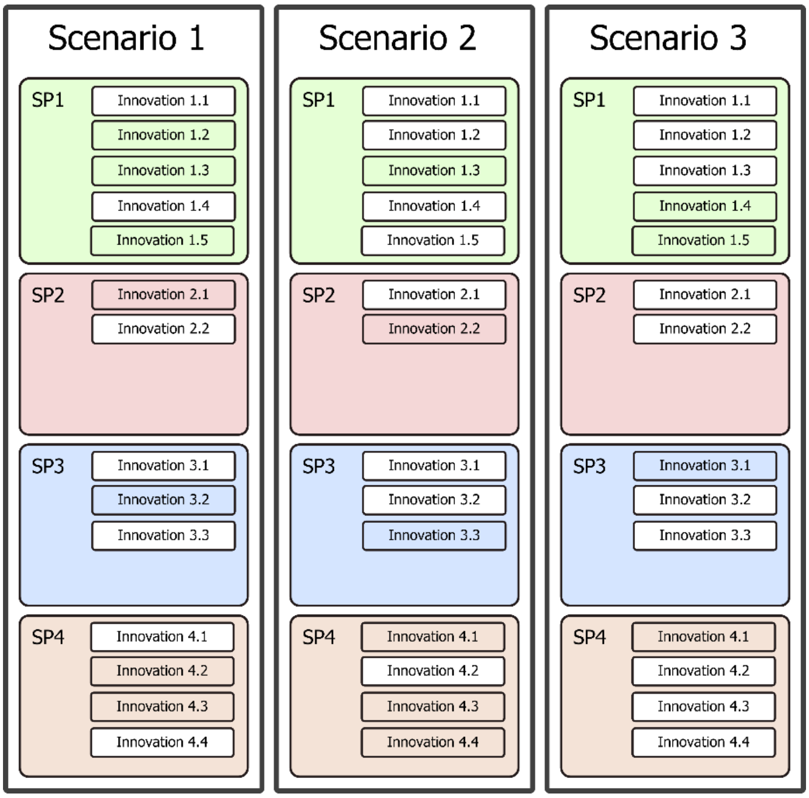


FIGURE 2– *EXAMPLE OF SELECTION OF APPROPRIATE INNOVATIONS TO EACH SCENARIO NOT ALL INNOVATIONS ARE USED IN THE ASSESSMENT OF EACH SCENARIO.*

Using a combined technology assessment methodology produces a multilayered approach to the assessment and demonstration with layer 1 carried out in SP1-SP4, these assessments and demonstrations will help to support SP5 in deciding which technologies should be applied to which scenarios and to provide data to feed into the assessment layer 2 which is being carried out within SP5. Within this second layer of assessment more detailed evaluation of the innovations can be carried out, with the assessment applied to the scenarios developed within WP5.3 and incorporating innovations from across SP1-SP4 selected as appropriate. The layer 2 assessment will use data generated within SP1-SP4 as well as data from further demonstrations carried out as part of SP5 and further data gathered from infrastructure managers, published data and past EU and national projects.

The final top layer of assessment (assessment layer 3) will demonstrate how far the innovations developed within Capacity4Rail meet the goals set out in the WP5.1 .

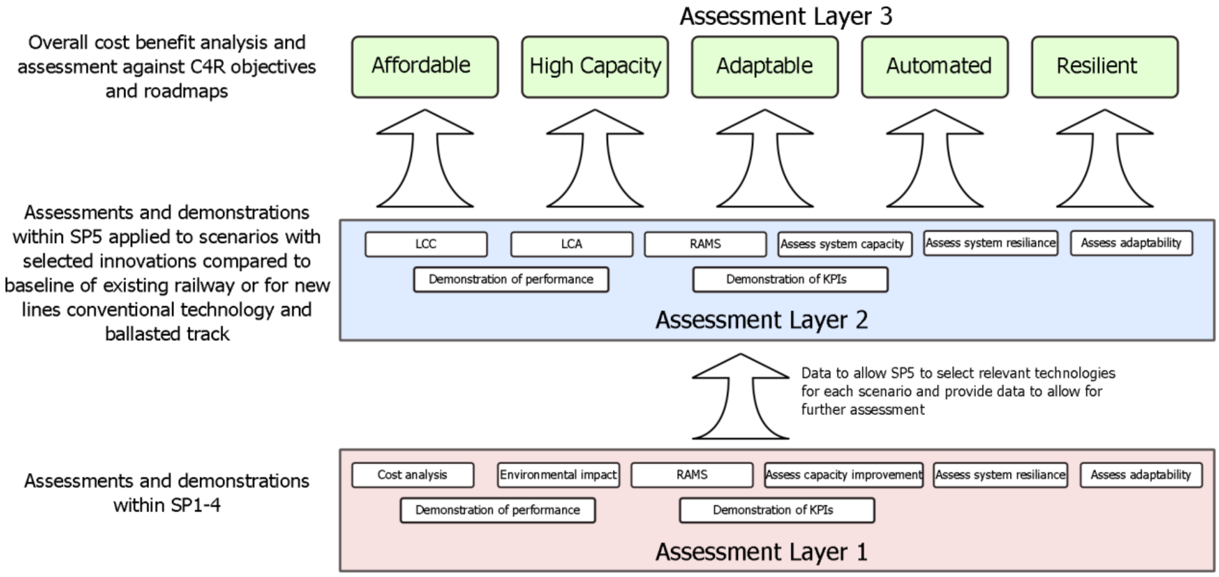


FIGURE 3– *LAYERS OF ASSESSMENT CARRIED OUT WITHIN CAPACITY4RAIL PROJECT*

This final layer 3 of assessment could be a semi-qualitative assessment, the scales used for this assessment will need to be decided within WP5.1 and WP5.5 Demonstrations, Evaluation and Assessment, but the maximum point of each of these scales will be the vision for each of High Capacity, Adaptable, Affordable, Automated and Resilient railway of the future and for the each scenario/route which is selected for assessment the situation today will be compared with the implementation of Capacity4Rail innovations demonstrating the progress made by the project towards these objectives.

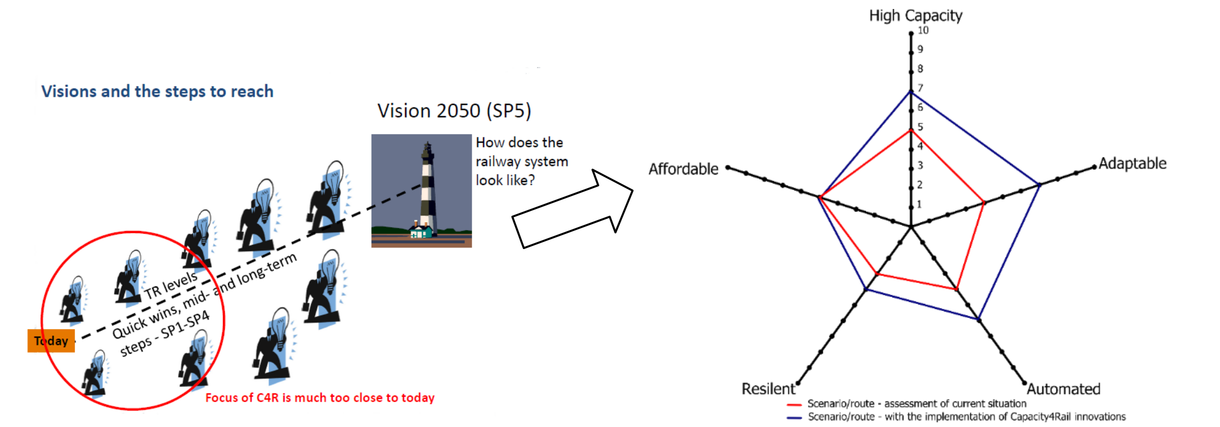


FIGURE 4– *DIAGRAM DEMONSTRATING HOW THE OVERALL ASSESSMENT OF THE CAPACITY4RAIL INNOVATIONS MAY BE REPRESENTED FOR EACH SCENARIO/ROUTE SELECTED. PROJECT*

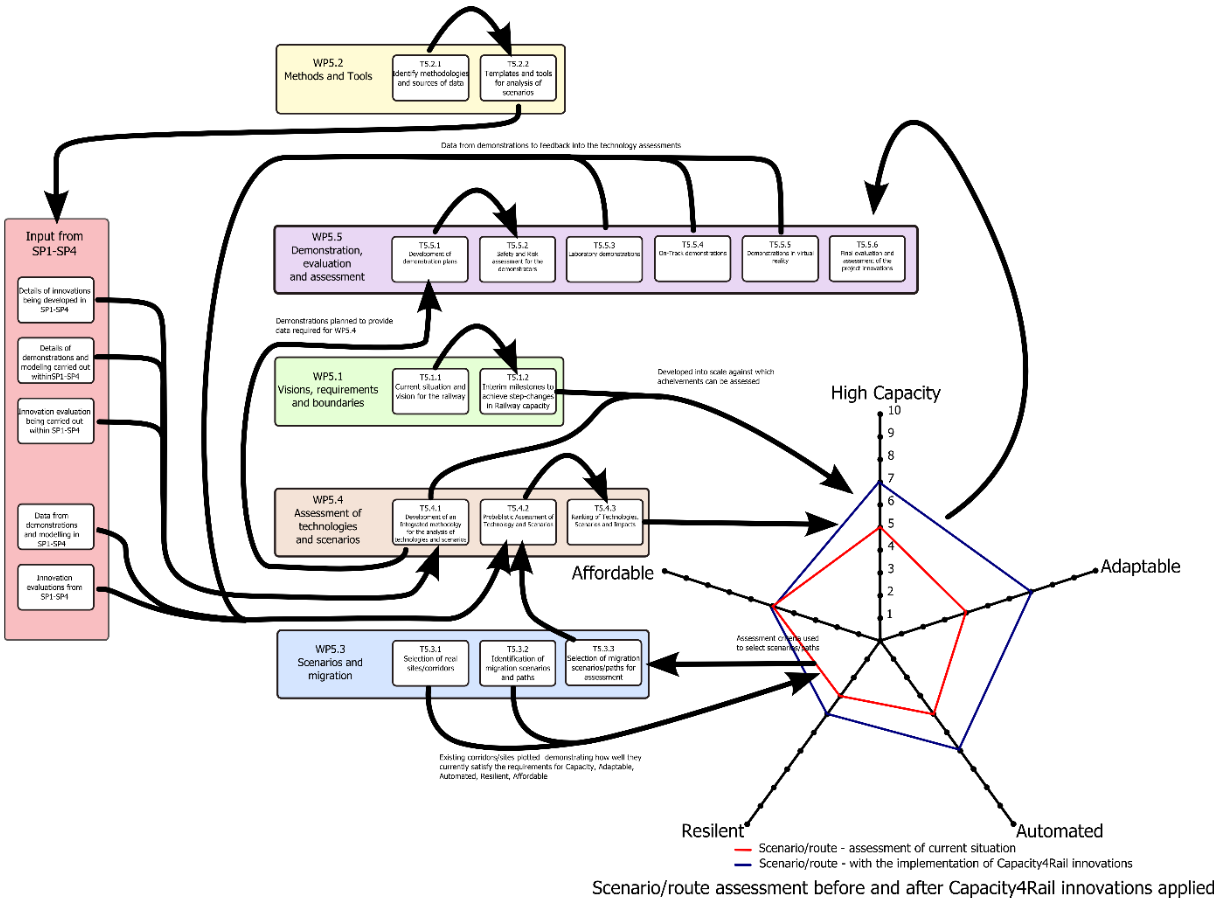


FIGURE 5– CONTEXT OF WP5.2 IN THE OVERALL ASSESSMENT SCHEME.

In the context of these overall aims for SP5 Task5.2.2 has contributed to the following objectives:

- Produce templates to identify the technological innovations being carried out within each sub-project
- Produce templates to identify assessments being carried out within SP1-4
- Produce templates to identify data and demonstrations from SP1-4 to support assessments within SP5, including the likely quality of the data
- Present templates for potential methodologies which can be selected as appropriate for assessing the impact of the innovations and contributing to the evaluation of the innovations within the scenarios.

2. Document structure

This document is structured to reflect the different aims of this deliverable, firstly identifying broadly the innovations that we expect from the different sub-projects which will require some assessment within SP5.

Section 4 describes some initial templates for developing an understanding of the assessments and data which will be generated within SP1-SP4. And then section 5 describes the assessment tools and provides templates for the assessments which can be carried out within SP5, particularly within WP5.4.

3. List of innovations in each sub project derived from the Description of work

The Capacity4Rail description of work alludes to the innovations which will be developed in each sub project, for which assessment within SP5 should be carried out. From the description of work the details of these technologies will require further definition in order to best understand how they will be assessed and therefore a questionnaire to determine the basic details of these innovations has been created (Section 4 of this document which has been fed back into WP5.1 Task 5.1.3 and the WP5.5 Task 5.5.1) to allow SP5 to plan in greater detail the assessment methodologies.

It is expected that the outcomes of Tasks 5.1.2 and Task 5.1.3 will allow this list of innovations to be updated and for the templates to be further customised based on the results of these task.

SP1

1.1 New concepts of track based on modular slab track embedding elements for power, remote condition monitoring, signalling and communications

1.2 New track designs and specifications for very high speed trains (>350km/h)

1.3 New concepts for switches and crossings design based on failure modes analysis

1.4 New designs for switches resilient to extreme weather conditions

1.5 Optimised S&C sensor strategies

SP2

2.1 Innovations in Trains/Wagons – optimised length, speed, performance, central/automatic coupler, EP/electronic braking, electrification, automation, weight

2.2 Innovations in Freight Operation – wagon shunting, intelligence for vehicles in terminals, terminal operation

SP3

3.1 Ubiquitous data architecture and automated data exchange for railway operations

3.2 Models and simulations to evaluate enhanced capacity (infrastructure and operation)

3.3 Optimal strategies to manage major disturbances

SP4

4.1 New concepts and technologies for using advanced monitoring in embankments, bridges, different track types, switches etc.

4.2 Sensor types

4.3 Energy harvesting

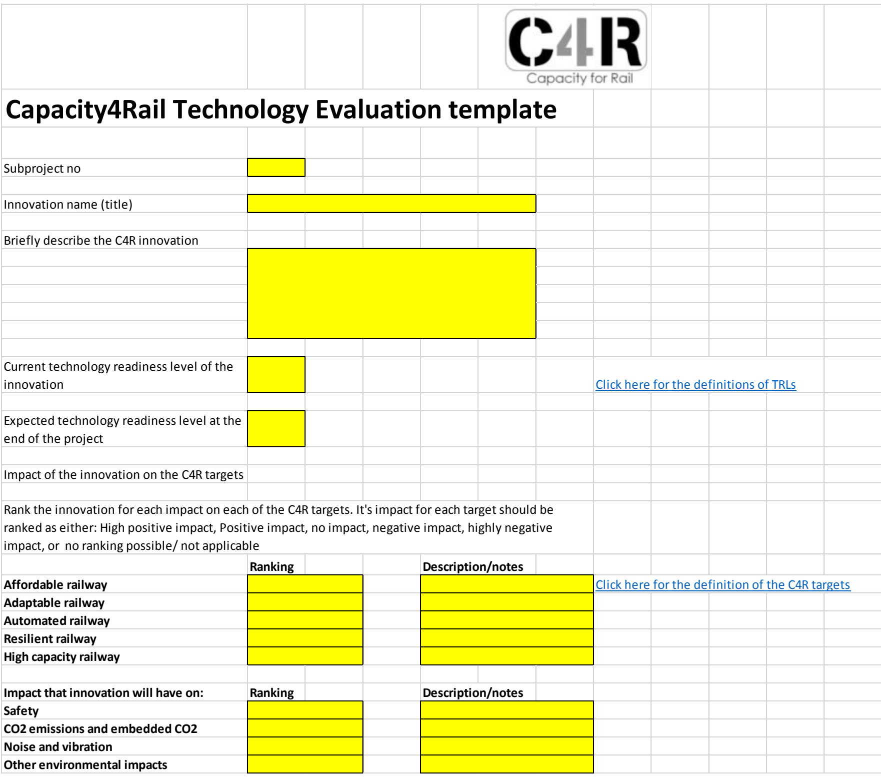
4.4 Communication and data integration technologies

4. Templates for identifying the innovations, assessments, demonstrations and data available from SP1-SP4 (Identify data that will be created in Assessment layer 1)

Aims of template for collecting initial information from SP1-4:

- Identify the technological innovations being carried out within each sub-project
- Identify assessments being carried out within SP1-4
- Identify data and demonstrations from SP1-4 to support assessments including the quality of the data

Within Task 5.2.2. initial templates for understanding the innovations being carried out within the other sub-projects have been developed, the basic data part of this questionnaire has been further modified by WP5.5 to include the requirements for demonstrations within SP5 and to understand the demonstration activities to be carried out each sub-project. This has consequently been further appended to gather data regarding the assessment which will be carried out in each SP and the data that they will generate.


C4R
Capacity for Rail

Capacity4Rail Technology Evaluation template

Subproject no

Innovation name (title)

Briefly describe the C4R innovation

Current technology readiness level of the innovation

Click here for the definitions of TRLs

Expected technology readiness level at the end of the project

Impact of the innovation on the C4R targets

Rank the innovation for each impact on each of the C4R targets. It's impact for each target should be ranked as either: High positive impact, Positive impact, no impact, negative impact, highly negative impact, or no ranking possible/ not applicable

	Ranking	Description/notes
Affordable railway		
Adaptable railway		
Automated railway		
Resilient railway		
High capacity railway		

Click here for the definition of the C4R targets

Impact that innovation will have on:	Ranking	Description/notes
Safety		
CO2 emissions and embedded CO2		
Noise and vibration		
Other environmental impacts		

Figure 6– Early template for gathering basic information developed within task 5.2.2.

Name of the organisation:
Contact Person:
Designation:
Tel. No.:
E-mail

SP5.Demonstration Activities Template

C4R Capacity for Rail

General Description

Subproject number

Work Package number

Demonstration name (title)

Leader (short name and number)

Partners and its contribution

Briefly describe how this C4R innovation is linked to the call

Is this demonstration liked to other SP? If YES, please write SP number.

Are the OUTPUTS of the demonstration neccessary for other activities? If YES, please write estimated date when it is neccessary.

Time Slot estimated

Does it appear in DoW?

Estimated overall budget — Please fill in the table in

Current technology readiness level of the innovation — Click here for the defir

Expected technology readiness level at the end of the project

Impact of the innovation on the C4R targets

Rank the innovation for each impact on each of the C4R targets. It's impact for each target should be ranked as either: High positive impact, Positive impact, no impact, negative impact, highly negative impact, or no ranking possible/ not applicable

Click here for the definition of the C4R targets	Ranking	Description/notes
Affordable railway		
Adaptable railway		
Automated railway		
Resilient railway		
High capacity railway		

Impact that innovation will have on:	Ranking	Description/notes
Safety		
CO2 emissions and embedded CO2		
Noise and vibration		
Other environmental impacts		

Briefly describe the demonstration activitie due to be carried out within the sub-project

Explain how this demonstration shows progress towards the aims of the project - eg affordable,adaptable, automated, resilient, high capacity railway. What will be the main KPIs evaluated in this demonstrator?

Explain if any special requirements are needed

If you consider any other important factors than the above mentioned, please mention below

Name of the organisation:	0
Contact Person:	0
Designation:	0
Tel. No.:	0
E-mail	0

Figure 7– *WP5.5 Demonstration template*

SP1-4.Assessments and data provision Template

General Description

C4R Capacity for Rail

Subproject number

Work Package number

Innovation name (title)

Assessments or guidelines which will be carried out within SP1-SP4 regarding each innovation.

Please describe any assessments or guidelines which will be produced within SP1-SP4 which will advise on the appropriate/optimal scenarios in

Please describe any assessments that will be carried out within SP1-SP4 or data generated to demonstra contribution o f the innovation to the following C4R objectives of affordable, adaptable, automated, res high capacity

Affordable railway

Descriptions of assessments intended to be carried out

eg LCC, RAMS analyses, cost/benefit analysis, cost savings from innovations, multifunctional analysis of innovations/ technologies, simulations demonstrating reduced need for maintenance/ longer life, FMEA.

Description of data generated within SP to support further assessments in this area and the source/quali

eg - installation cost - calculated from bills of materials and assumed logistics and labour costs
Component life - based on simulation outputs and expert opinion
Reduced fuel costs - based on simulation outputs and existing fuel consumption

Adaptable railway

Descriptions of assessments intended to be carried out

Assessments of how the innovations may aid the adaptability of the railway the adaptability of the railway to future demands or scenarios. Eg Evaluation of upgradability, resiliance to new loads and new traffic types, evaluation of modularity and reduced cost of upgrades.

Description of data generated within SP to support further assessments in this area and the source/quality of this data

eg. Time to replace components/upgrade infrastructure - expert opinion
Cost to replace components/upgrade infrastructure- expert opinion
Increased capability - such as higher loading - simulation results

Automated railway

Descriptions of assessments intended to be carried out

Any assessment of automation delivered by innovations, in construction, maintenance, operations and inspection delivered by innovation. Eg, evaluation of the reduction human labour per task.

Description of data generated within SP to support further assessments in this area and the source/quality of this data

eg. Labour costs for set tasks before and after application of innovation - data from existing data on maintance costs for particular tasks

Resilient railway

Descriptions of assessments intended to be carried out

Assessments of the recovery of the railway to incidents. Eg evaluation of improved response to an incident.

Description of data generated within SP to support further assessments in this area and the source/quality of this data

Eg - Time to system recovery from an incident - modelling / simulation results

High capacity railway

Descriptions of assessments intended to be carried out

Eg. Assessment of extra train paths generated, reduced down time due to maintenance and renewals, increased loading per vehicle, reduced headway.

Description of data generated within SP to support further assessments in this area and the source/quality of this data

eg Time to maintain - expert opinon
Additional train paths - simulations and modelling
Passengers per vehicle - simulations and modelling
Freigh axle load - simulations and modelling
Headway - simulations and modelling

Figure 8– *Further sheets added by WP5.2 to understand the assessments planned within SP1-SP4 and data that they will generate which will aid assessments within SP5*

5. Templates for assessment of innovations within SP5and boundary conditions (Assessment Layer 2)

Aims of templates for assessment of innovations within SP5

- Present templates for potential methodologies which can be selected as appropriate for assessing the impact of the innovations and contributing to the evaluation of the innovations within the scenarios.
- Provide to all SPs an indication of the information that would be required for SP5 to carry out an effective evaluation

Potential methodologies for assessment

A suggestion for the overall structure of the assessment process has been proposed within section 1 of this document, providing a high level framework. This section provides some methodologies and templates for some of level 2 assessments within that scheme. The methodologies suggested here are based on the most promising methods that were identified within Deliverable D5.2.1.

Both the UK Green Book and RailPag recommend as much as possible carrying out a purely financial cost-benefit analysis applying known costs to all costs and benefits. This is not always possible and aspects of the Capacity4Rail objectives may be difficult to apply financial measurements to. It is also been apparent from participating in SP1 workshops that supply of data and accurate use of data may be difficult to obtain and there may be a significant reliance on expert opinion and judgement, especially for translating the output of models into expected life of components or for establishing maintenance intervals when using the innovation.

The RailPag guidelines also provide a methodology for assessing the non-financial costs and benefits with the stakeholder-effects matrix, this is a useful tool to help establish the boundary conditions of the assessment as well as aiding the end user in resolving the issue of non-financial costs and benefits. The RailPag process is also flexible with the ability to encompass the different methodologies identified within D5.2.1 as appropriate. The RailPag stakeholder-effects matrix (S-E matrix) also has the potential to be adapted for the Capacity4Rail project with the development of a standard list of effects and these effects grouped and organised to represent the objectives of the project of affordable, adaptable, automated, resilient and high capacity.

The RailPag process can also incorporate all types of relevant assessment drawing in from capacity assessments, life cycle analyses, journey time analyses, assessment of the impact of systems failures etc.

Alternatively, a more qualitative method of assessment may be adopted in WP5.4 in which case the templates developed within this deliverable centred around life cycle cost analysis, life cycle analysis and RAMS will still be useful in helping to define the assessment categories in a more qualitative assessment.

Boundary conditions and baselines

The boundary conditions will be heavily dependent upon what is appropriate for the innovations developed in the Capacity4Rail project which will be identified in more detail in task 5.1.2 and task 5.1.3 and the scenarios from WP5.3 and at this stage in the project it is impossible to clearly define these. However, the use of the SE Matrix will also help to clearly identify the effects which are most significant in the assessment and therefore help to define the in/out frames for the LCC and other assessments.

The baselines against which innovations are assessed should typically be the current technology used in the particular scenario being considered or in the case where a scenario is based on a new line which is not currently built, the base line should be the best of the todays current technology or the technology which is most likely to be used if that line was built today (the “do minimum” option). The baseline should also be assessed under the same conditions as the innovations, for example, if the innovations are to consider future traffic loads of 2030, the baseline should be assessed as the current technologies under those same loads.

	Today’s traffic, loading and environmental conditions	2030 traffic, loading and environmental conditions
Baseline – eg ballasted track		
Application of Capacity4Rail innovations – eg novel slab track		

Comparable
Not comparable
Comparable

Example of RailPag customised for Capacity4Rail

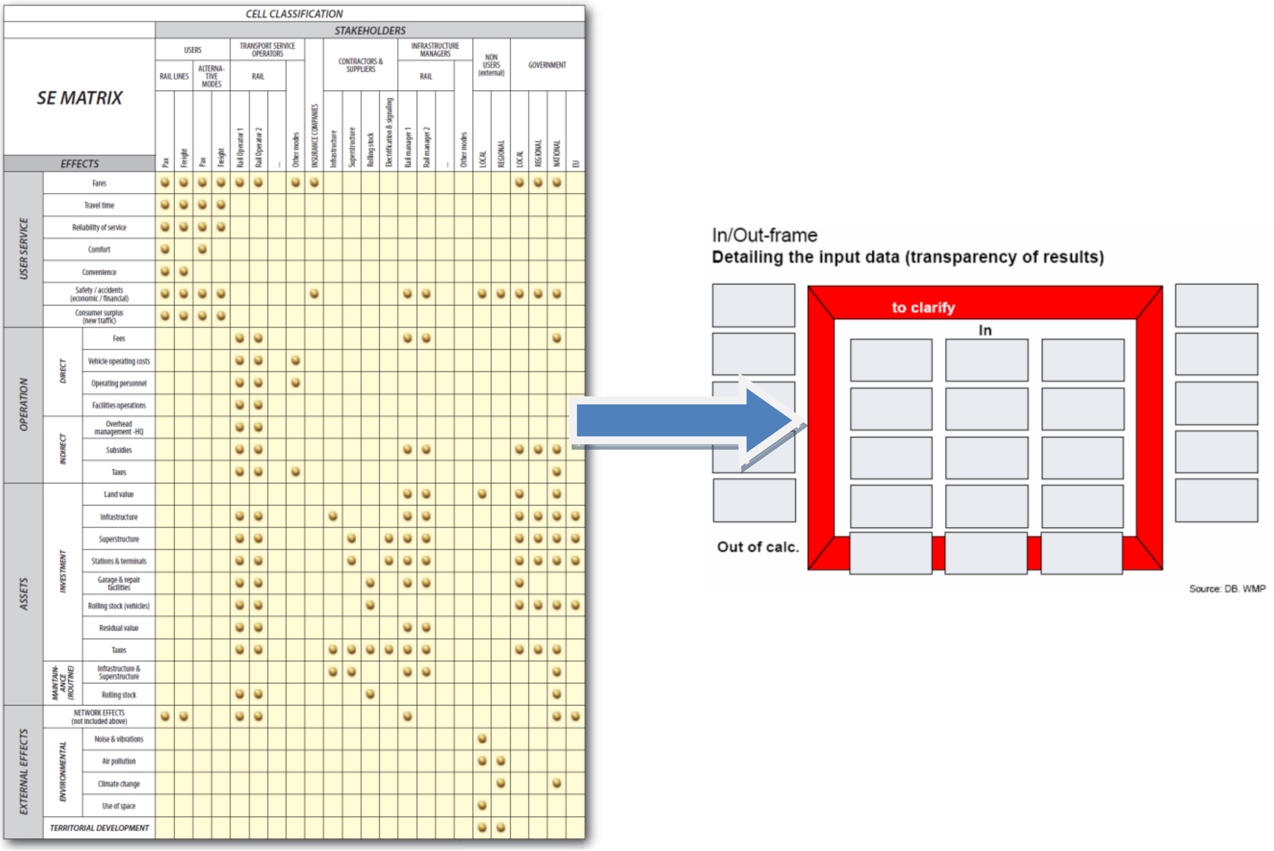
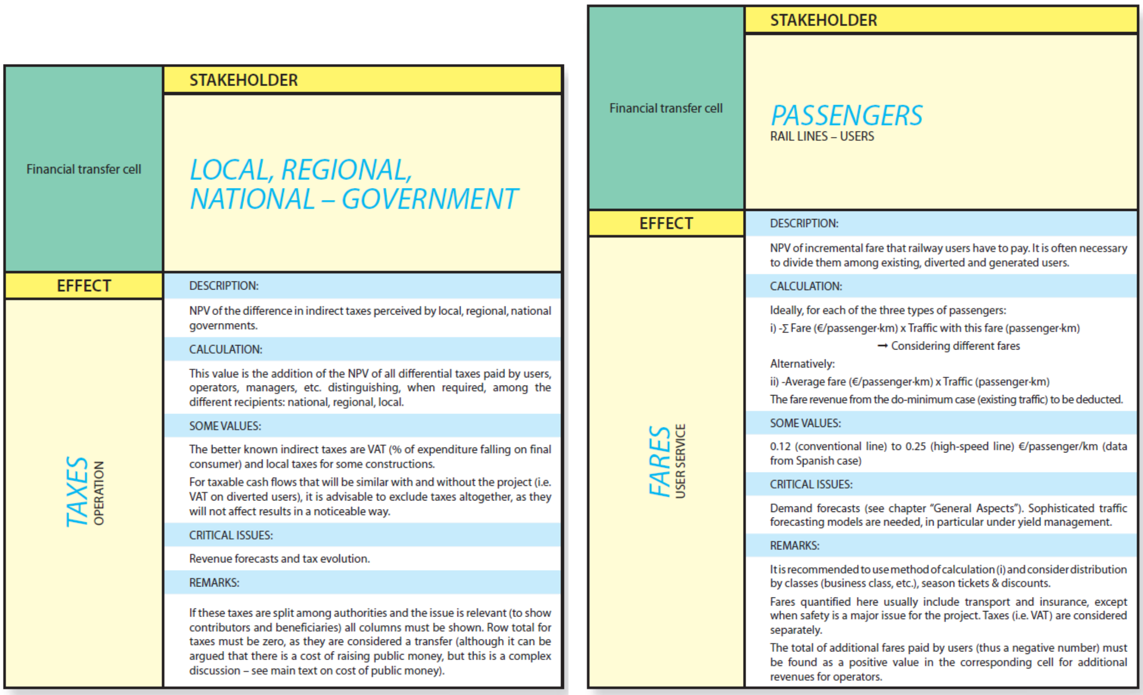


FIGURE 9– EXAMPLE STAKEHOLDER-EFFECTS MATRIX FROM RAILPAG AND DEMONSTRATING HOW IT CAN GUIDE THE COMPLETION OF THE IN/OUT FRAME OF COST ELEMENTS (FROM INNOTRACK PROJECT) FOR AN LCC ANALYSIS

The cells in the SE Matrix describe the effect on the particular stakeholder, define the relevant calculations and values relating to the costs of this effect and critical issues or further remarks about this effect on a particular stakeholder.



Financial transfer cell

STAKEHOLDER

LOCAL, REGIONAL, NATIONAL – GOVERNMENT

EFFECT

TAXES
OPERATION

DESCRIPTION:

NPV of the difference in indirect taxes perceived by local, regional, national governments.

CALCULATION:

This value is the addition of the NPV of all differential taxes paid by users, operators, managers, etc. distinguishing, when required, among the different recipients: national, regional, local.

SOME VALUES:

The better known indirect taxes are VAT (% of expenditure falling on final consumer) and local taxes for some constructions.

For taxable cash flows that will be similar with and without the project (i.e. VAT on diverted users), it is advisable to exclude taxes altogether, as they will not affect results in a noticeable way.

CRITICAL ISSUES:

Revenue forecasts and tax evolution.

REMARKS:

If these taxes are split among authorities and the issue is relevant (to show contributors and beneficiaries) all columns must be shown. Row total for taxes must be zero, as they are considered a transfer (although it can be argued that there is a cost of raising public money, but this is a complex discussion – see main text on cost of public money).

Financial transfer cell

STAKEHOLDER

PASSENGERS
RAIL LINES – USERS

EFFECT

FARES
USER SERVICE

DESCRIPTION:

NPV of incremental fare that railway users have to pay. It is often necessary to divide them among existing, diverted and generated users.

CALCULATION:

Ideally, for each of the three types of passengers:

i) -Σ Fare (€/passenger-km) x Traffic with this fare (passenger-km)

→ Considering different fares

Alternatively:

ii) -Average fare (€/passenger-km) x Traffic (passenger-km)

The fare revenue from the do-minimum case (existing traffic) to be deducted.

SOME VALUES:

0.12 (conventional line) to 0.25 (high-speed line) €/passenger/km (data from Spanish case)

CRITICAL ISSUES:

Demand forecasts (see chapter "General Aspects"). Sophisticated traffic forecasting models are needed, in particular under yield management.

REMARKS:

It is recommended to use method of calculation (i) and consider distribution by classes (business class, etc.), season tickets & discounts.

Fares quantified here usually include transport and insurance, except when safety is a major issue for the project. Taxes (i.e. VAT) are considered separately.

The total of additional fares paid by users (thus a negative number) must be found as a positive value in the corresponding cell for additional revenues for operators.

Figure 10– Examples of cell in Stakeholder-effects matrix from RailPag

Example of the effects from the S-E matrix based on and categorized according to the Capacity4Rail objectives

<table>
<tr><td rowspan="31">Affordable/financial effects</td><td rowspan="3">User Service</td><td rowspan="3"></td><td>Fares</td></tr>
<tr><td>Comfort</td></tr>
<tr><td>Convenience</td></tr>
<tr><td rowspan="8">Operation costs</td><td rowspan="4">Direct</td><td>Fees – eg Track access charges</td></tr>
<tr><td>Vehicle operating costs</td></tr>
<tr><td>Operating personnel</td></tr>
<tr><td>Facilities operations</td></tr>
<tr><td rowspan="4">Indirect</td><td>Overhead management - HQ functions</td></tr>
<tr><td>Subsidies</td></tr>
<tr><td>Taxes</td></tr>
<tr><td>Consumer surplus (new traffic)</td></tr>
<tr><td rowspan="20">Assets</td><td rowspan="8">Investment</td><td>Land value</td></tr>
<tr><td>Infrastructure</td></tr>
<tr><td>Superstructure</td></tr>
<tr><td>Stations and terminal</td></tr>
<tr><td>Garage & repair facilities</td></tr>
<tr><td>Rolling stock (vehicles)</td></tr>
<tr><td>Residual Value</td></tr>
<tr><td>Taxes</td></tr>
<tr><td rowspan="8">Maintenance (routine costs)</td><td>Infrastructure and Superstructure routine (time based) maintenance and inspection (actual costs)</td></tr>
<tr><td>Infrastructure and Superstructure condition based maintenance (actual costs)</td></tr>
<tr><td>Infrastructure and Superstructure unplanned repairs(actual costs)</td></tr>
<tr><td>Infrastructure renewal (actual costs)</td></tr>
<tr><td>Rolling stock (vehicles) routine (time based) maintenance and inspection (actual costs)</td></tr>
<tr><td>Rolling stock (vehicles) condition based maintenance (actual costs)</td></tr>
<tr><td>Rolling stock (vehicles) unplannded repairs (actual costs)</td></tr>
<tr><td>Rolling stock overhaul (actual costs)</td></tr>
<tr><td>Disposal costs</td><td></td></tr>
<tr><td rowspan="3">Environmental</td><td>Noise and vibrations</td></tr>
<tr><td>Air pollution (particulates, NOx, etc)</td></tr>
<tr><td>Carbon impact (LCA) installation, maintenance, disposal</td></tr>
</table>

Adaptable			Adaptability to increased service demands
			Interoperability across borders and railway systems
			Optimisation of rail traffic movements - flexible routing
Automated		Intelligent transport system and signalling	Automation of timetabling
			Automation and optimisation of train control systems
		Intelligent monitoring and maintenance	Automated inspection/maintenance of rolling stock (socio-economic impact of improved workforce safety and quality)
			Automated inspection/maintenance of infrastructure (socio-economic impact of improved workforce safety and quality)
Resilient			Reliability of service (unplanned failures of infrastructure or rolling stock - socio-economic impacts)
			Resilience of infrastructure to extreme climate events
			Recovery time from system perturbations
			Operability during degraded modes

High Capacity			Customer/freight travel time
			Use of space - Vehicle loading - passenger
			Use of space - Vehicle loading - freight
			Use of space - efficient layout of infrastructure
			Infrastructure and Superstructure routine (time based) maintenance and inspection (socio-economic impacts eg delays/alternative services)
			Infrastructure and Superstructure condition based maintenance (socio-economic impacts eg delays/alternative services)
			Infrastructure renewal (socio-economic impacts eg delays/alternative services)
			Rolling stock (vehicles) routine (time based) maintenance and inspection (socio-economic impacts eg delays/alternative services)
			Rolling stock (vehicles) condition based maintenance (socio-economic impacts eg delays/alternative services)

Stakeholder – Effects Cell based on Capacity4Rail objectives

	Stakeholder
	Stakeholder description:
Effect	Description:
Capacity4Rail theme:	
	Calculation:
	Values:
Effect description:	
	Critical issues:
	Remarks:

6. Tools and templates developed building upon the tools identified within D5.2.1 and applied to C4R innovations

D5.2.1 identified a number of methodologies and tools from other EU projects. This section of D5.2.2 builds upon the conclusions of D5.2.1, adds to the descriptions of methods and tools and the customization of the templates for the collecting of data for each section, for each Capacity4Rail innovation. The tools and methods have been subdivided into the objectives of the Capacity4Rail project of Affordable, Adaptable, Resilient, Automated and High Capacity, following the same structure as D5.2.1.

Affordable

Definition from D5.1.1:

An affordable railway is the mode of choice to investors (public and private) and users (passengers and freight), particularly for medium and long-distance travel. The affordable railway:

- *Is not about lowest initial cost, but the total cost of procuring, maintaining and operating the railway based on improved understanding of whole life whole system issues, such that lifetime benefits exceed lifetime costs.*
- *Optimises CAPEX and OPEX (operational expenditure) costs - which are transparent and predictable.*
- *Is energy efficient and minimises its impact on the environment.*
- *Delivers lowest Life Cycle Cost while achieving increased reliability, availability and quality of the infrastructure i. e. RAMS performances).*
- *Meets passenger and freight capacity requirements.*
- *Minimises barriers to entry and provides effective access to the rail industry.*
- *Is competitive with other modes for passengers and freight.*

For the purpose of the Capacity4Rail project 'Affordable' has been divided in the roadmap into economic aspects, environmental aspects and safety, corresponding to the targets highlighted in D5.1.1. These aspects are discussed below.

Economic Aspects

Where possible all costs and benefits, direct financial costs and social impacts, should be evaluated as financial costs and benefits as recommended in the RailPag and UK Green Book guidance. The cost allocated to non-financial measures such as environmental impact, passenger satisfaction, capacity etc, needs to be carefully considered as to what is appropriate and as far as possible should avoid double accounting for the measure and should consider the interdependency of variables. For example when considering a cost for tonnes CO_{2e} emissions it is possible to use a cost based on the Carbon Trading Scheme for example, but for most European examples material, operational and fuel prices will already include a carbon or climate change levy tax within that price and hence double accounting may occur. However, as stated in the UK Green Book, an appropriate financial figure to use will be based on market prices or the price which an end user is willing to pay, so for example if a company sets it's self a target to reduce it's CO_{2e} emissions by x number of tonnes and is allocating y m€ to achieve this target, this gives a cost for tonnes of CO_{2e} emissions which can be used on top of the material, operational and fuel prices.

With regards to the use of market prices for CO_{2e} emissions, the European Union pioneered an international carbon emissions trading in 2005. It represents the biggest international system for trading greenhouse gas emission allowances, operating in 28 countries and covering the half of EU's green house emissions. Therefore, the price of carbon emissions determined by the EU trading system could be considered as a consistent value. However, the current low prices of carbon, due mainly to the economical crisis, are expected to grow in the following years as a result of the structural reform that the EU is carrying out to address the surplus of emission allowances.

Apart from CO_2, noise is another important environmental parameter to consider in the analysis. Each time stricter regulations on noise are implemented, infrastructure managers have to allocate considerable funds to comply with noise limits. Furthermore, these limits can affect the capacity of the line, given the index to measure noise level is accumulative, thus, the higher number of freight trains, the higher the noise level. New or up-graded rolling stock must comply with Technical Specification for Interoperability (TSI) noise limits, which establish the maximum allowed stationary, pass-by and starting-up noise under a reference track. On the other hand, there are "environment" noise limits in urban areas which are fixed by each national government. Existing infrastructure and rolling stock have to cope with these limits, which require in many cases noise abatement actions. Comprehensive and reliable data is available on the effectiveness and cost of noise mitigation measures.

The life cycle cost analysis, should be carried out using methods based on those used in the INNOTRACK, MARATHON, MAINLINE, SMARTRAIL and D-Rail projects, based on a product breakdown structure and product flow diagram, with the identification of materials, products, tasks, and other indirect costs including environmental and end-user costs (eg. Train delay). These should be costed throughout the product lifecycle and then adjusted for to a NPV. The economic aspects can be reported as a Life Cycle Cost (includes just direct costs), Life Cycle Cost Benefit Analysis (includes indirect costs and benefits), CAPEX and OPEX. Therefore the LCC templates have been structured to clearly differentiate these different aspects and corresponds to targets set out in D5.4.1 where there are set targets for CAPEX and OPEX reductions.

Caution should also be applied when applying existing maintenance cost data, this should take into account the infrastructure condition and check whether the level of maintenance is sustainable, or whether it is in a cycle of track deterioration or improving overall track condition. Tools such as VTISM, TRACKEX and MAINLINE LCAT can be used to establish a sustainable level of maintenance to be used in the analysis. European standard EN 13848-5 should be used as a reference document, since it provides limit values (limit value ranges) for AL, IL, IAL size limit categories and defines the indicator of track quality to be used. Another factor that is very important in determining maintenance cost is track possession length, planning and logistics. A decrease of one hour in track possession length (from 5h30 to 4h30) implies an increase of 25% in maintenance costs. Planning and logistics should also be taken into account due to its strong effect in maintenance and renewal works (up to 60%).

The discount rate applied will be part of the overall definition of the case study used. The discount rate applied can have a very large impact on the overall result of an LCC analysis and the impact of CAPEX vs OPEX on the overall lifecycle cost; with high discount rates making low CAPEX projects with high OPEX come out of the analysis more favourably than low OPEX but higher CAPEX projects. The discount rate is heavily dependent upon particular countries and infrastructure managers.

Data from the RAMS analysis will also feed into the LCC parameters, providing data for unavailability of track and other failure modes. The financial value of the unavailability could be evaluated by several methods as described in the literature including delays for passengers which can be evaluated based on the average time lost per passenger delayed or cost for infrastructure managers due to the need of alternative bus services or compensation fees to operators.

Measures of economic impact

- Whole life cycle costs
- Whole life cycle cost benefit analysis
- Cashflow
- CAPEX
- OPEX

Sources of cost data

- Infrastructure manager’s or contractor’s cost data and maintenance records
- Supplier cost data
- Maintenance contractor cost data
- Bills of materials and supplier material costs
- Civil engineering lists of unit costs for price estimating
- Infrastructure manager maintenance frequency
- Environmental costs – see also following section on Environmental
- User costs (eg delay costs) – see also section 9.3 Resilient and 9.5 High Capacity

Potential tools

- D-LCC
- Microsoft Excel Spreadsheets with @Risk
- WinBUGS
- Palisade
- Track condition/maintenance assessment tools eg VTISM, TRACKEX, MAINLINE LCAT

Applicability to C4R innovations

The innovations within the Capacity4Rail project are diverse and although an LCC approach and calculation of CAPEX and OPEX can be applied to all scenarios, in some cases, for example in the case SP3 innovations it may not make sense to consider the capital cost of implementing a strategy to manage major disturbances and in this case any assessment on affordability should concentrate on the reduction in operating costs resulting from its implementation. Discussed below are some of the main costs to be considered for innovation, based on the description of work, and the types and sources of data which may be used within WP5.4. LCC templates have been prepared and customized for each innovation based on the sources and types of data available. However, the cost categories included in the templates may for some scenarios be redundant and can be ignored, whilst for other scenarios it may be necessary for further categories to be added. In either case the cost categories included should provide a useful cue to the end user.

The LCC templates are presented within Appendix 2 of this deliverable.

All of the LCC templates include a cost category for other indirect costs, these are likely to be based on the RAMS templates and consider the unavailability of the railway and account for passenger delays and wider impacts such as safety considerations. Using a value of life or insurance data to apply a cost on the level of safety can allow for it to be integrated into the LCC analysis. Environmental costs can be implemented in a similar manner using either a value of carbon credits or another suitable value to put a price on the carbon emissions or the embedded carbon. Costs associated to noise issues should also be considered.

SP1

1.1 New concepts of track based on modular slab track embedding elements for power, remote condition monitoring, signalling and communications

The new concepts of modular slab track are at present very low TRL innovations and even at the end of the project TRL will still be low. In this case definitive reliability and cost data may be difficult to obtain and any cost benefit analysis will rely heavily on expert judgement and some modelling outputs for the impact of the innovations on the frequency and costs of renewal and maintenance activities. The LCC analysis should be carried out using real costs where available and some material costs may be defined with high levels of confidence based on the bill of materials and standard costs for said materials. However, for new installation processes or maintenance activities expert estimates will be required with sensitivity analysis to reflect the uncertainty. Any new process will have higher costs initially, for example D1.1.1 highlights that Rheda 2000 is significantly cheaper and quicker to install compared to other slab tracks partly due to its common use and therefore tools and machinery have been developed to improve the efficiency of installation. The scenario and boundary conditions should define how this is handled and therefore the scenarios should also consider the appropriate installation cost, and whether it is assumed that the new track form should be assessed as if it is commonly installed and therefore the installation process optimised or should it be assessed as if it is a one off installation. The LCC templates for these innovations include maintenance activities for ballasted track derived from the a list of common maintenance activities within Innotrack Deliverable D6.2.4, possible maintenance activities and failure modes for the novel slab track were derived partly from the list of maintenance activities within the Innotrack deliverable, selecting those that were appropriate to the modular slab and appending this list with other activities highlighted within the Capacity4Rail SP1 workshop held in Paris in September 2014.

Baselines which may be used for comparison include ballasted track or a common type of slab track eg Rheda 2000 depending upon the scenarios defined within WP5.3. Two different LCC templates have therefore been prepared to reflect the two possible baselines.

Slab track implies an increase of noise emission and vibrations in relation to ballasted track. Common values for noise emission in ballasted track and reference slab track (e.g. Rheda) should be considered and compared with the Capacity4Rail slab track. Results from SilentFreight, SilentTrack, STAIRRS and RIVAS projects, as well as partner's knowledge, could be used to determine noise emission for baseline cases.

In addition to the cost categories identified, the templates should also be appended with additional failure modes and maintenance activities identified within an FMEA analysis and from the RAMS templates. The RAMS analysis will also help to identify the unavailability of the track due to maintenance and corrective tasks and from this a cost equivalent of the unavailability can be derived based upon the loss of track access charges or by the compensation to passengers and operators.

1.2 New track designs and specifications for very high speed trains (>350km/h)

The new track designs and specifications for very high speed trains are likely to be at higher TRL levels and as a consequence better cost data should be available, however, the structure of the template is broadly similar to that of the novel slab track designs. Although such high speed lines may need to be slab track in order to avoid the issues of ballast flight at very high speeds, technologies such as ballast gluing and the development of new type of (heavier) aggregates may make ballasted track suitable for such applications. Therefore, LCC templates have been presented for both ballasted and slab track within appendix 2. The increase in energy consumption as well as accelerated track degradation should be considered in the analysis.

1.3 New concepts for switches and crossings design based on failure modes analysis

The LCC templates for the new concepts for switches and crossings are based on the regular S&C maintenance tasks identified within the InnoTrack project. The S&C innovations are expected to impact on these existing maintenance tasks and reduce failures, however, an FMEA analysis should be carried out and this list of tasks and failure modes should be appended as necessary. The data for this LCC analysis should be obtained from a combination of existing maintenance cost data and frequency, expert opinion and also the results from simulations and models.

1.4 New designs for switches resilient to extreme weather conditions

The LCC template for the design of switches resilient to extreme conditions is similar to the template for new concepts for switches and crossings design based on failure modes analysis. However, when applying the template in the assessment the scenarios should include extreme weather conditions. New designs should be compared with existing solutions, such as switches provided with heaters, which represent an effective but a costly solution with high energy costs over the life time of the switch.

1.5 Optimised S&C sensor strategies

The optimised S&C sensor strategies LCC template, includes the costs of installation of the sensors and any additional maintenance or failures which may be required by the sensors. The LCC templates also include the other normal LCC cost categories of an S&C due to sensor strategies being expected to have an impact on the inspection regimes and routine maintenance of the S&C and potentially have an impact reducing the costs to unavailability due to a failure of an S&C by providing earlier detection and preventative maintenance being carried out with a lesser impact to services. As with all of the earlier templates not all of the cost categories provided within this LCC template will be relevant to each sensor type and if not appropriate they should be excluded from the boundaries of the LCC analysis. However, if further cost categories are identified as the LCC analysis or the RAMS is carried out these should be appended to LCC template.

SP2

2.1 Innovations in Trains/Wagons – optimised length, speed, performance, central/automatic coupler, EP/electronic braking, electrification, automation, weight

The LCC templates for innovations in trains and wagons include the capital costs of the vehicle modifications or the cost of new vehicles incorporating the innovations from SP2. The LCC template also includes capital costs for infrastructure, these infrastructure capital costs are to capture the costs of any changes required to the infrastructure to accommodate the vehicle innovations such as changes to the signalling system and track layouts to accommodate longer trains or for infrastructure electrification. As well as the maintenance activities and failure modes of the vehicles, the LCC analysis also includes the maintenance activities and failure modes of the infrastructure, these may be effected by modifications to vehicles such as changes to axial loads, braking performance, etc. Key benefits expected will be from additional track access charges due to increased capacity being available and reduced energy costs per tonne/km of freight, these are captured in the fees and energy operational cost categories respectively within the LCC template .

2.2 Innovations in Freight Operation – wagon shunting, intelligence for vehicles in terminals, terminal operation

The LCC templates for innovations in freight operation in terminals assume a baseline case of a freight terminal with no modifications and today's operating procedure. For the innovations capital expenditure costs for modifications to the terminals and vehicles are included as well as cost categories for fees (increase in revenue available from more efficient operation), energy and personnel costs.

SP3

3.1 Ubiquitous data architecture and automated data exchange for railway operations

3.2 Models and simulations to evaluate enhanced capacity (infrastructure and operation)

3.3 Optimal strategies to manage major disturbances

A single, simple LCC template has been presented for the SP3 innovations. In this template capital costs have not been included in this version of the template, as the capital cost of implementing a strategy is likely to be difficult to define. The capital expenditure required for the implementation of these strategies is likely to be data processing and storage capability which is likely to be a future requirement of any future traffic management system.

The implementation of the algorithms and data architecture developed will result in clear operational benefits and values could be attributed to these benefits such as savings in labour costs due to greater automation of traffic management and timetable planning, reduced traction energy costs and increased capacity resulting in the potential for increased revenue for infrastructure managers through track access charges. The data to support the improvements in energy efficiency and capacity increases could be derived from railway network simulators such as Hermes or BRAVE.

SP4

4.1 New concepts and technologies for using advanced monitoring in embankments, bridges, different track types, switches etc.

4.2 Sensor types

4.3 Energy harvesting

A single LCC template has been created for SP4 and this template could be used for the assessment of a single sensor type with or without the energy harvesting or for a system of sensors and energy harvesting equipment. The template includes not only the capital costs for the installation and maintenance and operational costs of the monitoring equipment, but also the operational costs of the railway infrastructure as it is expected that the sensors will result in reduced inspection and maintenance costs and increased life of assets. The data for this LCC analysis will be derived from the direct costs of the sensors and equipment and expert estimates of the costs of installation and also expert estimation of the impact of the sensors on track maintenance and life of assets.

ENVIRONMENTAL

Environmental aspects can consider:

- Carbon dioxide equivalent greenhouse gas emissions
- Ozone depleting gas emissions
- Release of other materials into the environment toxic to plants or living organisms
- Waste disposal
- Air pollution
- Noise emissions
- Vibrations

With regard to environmental impact most of the current rail strategies and the roadmap in D5.1.1 refer mainly to greenhouse emissions, the impact on greenhouse effect will be assessed within the Capacity4Rail. The methodology for assessing the impact of the greenhouse gas emissions is similar to that of life cycle costing, where a product breakdown structure and the operational stages throughout the life of a product are used to assess the bill of materials and operational energy requirements from which equivalent carbon dioxide measures can be obtained from published databases. Where possible the equivalent carbon dioxide should be converted into a cost measure and combined into the financial cost benefit analysis.

However, when looking at the carbon dioxide over the life time of a product it is important to consider external global trends and the impact that this will have on the analysis. For example across Europe the grid electricity supply is being decarbonised, with an increasing proportion of the power being supplied from renewable sources, therefore if a particular innovation aims to reduce traction energy, the impact of this innovation on greenhouse gas emissions overtime will diminish. Similar trends should also be considered for the manufacture of materials and components, where large efforts are being made to reduce the greenhouse emissions emitted in the manufacture of steel and concrete. Furthermore, the current economical crisis in Europe has caused a drop of carbon allowance price, which is expected to raise in the future as a result of EU actions (e.g. reduction of the cap). The establishment of a price band for CO_2 emission rights is also being considered, which will provide a stable value for the prognosis analysis to be undertaken in this project.

Besides GHG emissions, roadmaps in D5.1.1 also refer the importance of exhaust emissions, namely NOx and PM10, energy consumption and noise levels to achieve an affordable European rail network. Literature review showed that environmental externalities usually considered in the appraisal of railway related projects are climate change, air pollution and noise. Most of the research on environmental impacts of transport focus on the direct emissions from the vehicles operation and ignore the emissions from infrastructure construction, maintenance and operation, vehicle manufacturing and maintenance and fuel production. However the environmental performance should include the direct and indirect processes and services required to the operation of the vehicle.

Life Cycle Assessment (LCA) is a very time- and resource-consuming methodology which is usually used as a decision support tool to minimize the environmental impact. It is a standardized methodology (ISO 14040 series) which covers the life cycle of a product or a system from cradle-to-grave addressing the environmental aspects and potential environmental impacts. Although, some of its elements could be used as the basis for an environmental appraisal which will enable the assessment of the environmental impacts to consider both in the Cost-Benefit Analysis (CBA) and the semi-qualitative tool to be developed in WP5.4.

The most relevant phase of the LCA to be used in this environmental appraisal is the Life Cycle Inventory (LCI). For each SP innovation, a list of the relevant energy, material inputs and environmental releases should be created, as well as an inventory of all the construction and maintenance activities. The expected utilization of equipment during construction and maintenance phases will enable the estimation of energy consumption and emissions during such activities. Impacts on railway operation will enable the estimation of future direct and indirect emissions. Suggested cost factors derived from several studies such as HEATCO, IMPACT, INFRAS/IWW, ExternE, RailPag, etc. may be used to monetize the environmental impacts to be considered on the CBA and model sensitivity tests, as it will be explained in Deliverable 5.2.3.

The evaluation of other environmental hazards may also be assessed through use of material and substance flow analysis, providing a mass balance for the materials used on the railway, in simple terms for example copper emissions from overhead line into the environment are equal to the wear rate of the overhead line.

An inventory of waste may also be produced which relates to the waste generated in any intervention on the asset, from construction to demolition activities. According to the EU Waste Framework Directive, after the demolition of an asset, all the waste resulting from the demolition should be sent to a final destination. Construction and demolition waste (C&DW) may be classified in different ways in different countries, so as to achieve an harmonization between different users, C&DW should be classified according to European Waste Catalogue (EWC), which classifies waste materials and categorises them according to what they are and how they were produced.

Where possible all environmental measures should be converted into financial costs and assessed within the LCCA. Guidance on applying costs to environmental impacts can be found within RAILPAG and further information in EN60300-3 and in standard ISO 156865. Also if we wish to consider carbon impact as a stand alone calculation to evaluate progress against a carbon reduction target, it is possible to leave the figure as total lifetime tonnes of CO_{2e}. The same can be considered to other air pollutant emissions.

Measures of environmental impact

- Total life cycle CO_{2e} – Carbon dioxide equivalents (CO_2 = 1 CO_{2e}, CH_4 = 25 CO_{2e}, N_2O = 298 CO_{2e})
- Financial value equivalent to greenhouse emissions
- CO_{2e} /passenger km, CO_{2e} /freight tonne km
- Air pollutants – SO_2, NO_x, NMVOC, PM10
- Noise pressure levels

Sources of environmental data

Environmental databases related with the construction materials and processes:

- World steel Life Cycle Inventory
- Life Cycle Inventory of Portland Cement Concrete
- ETH-ESU libraries
- Ecoinvent
- Franklin UK
- BEES Database
- IVAM LCA Data
- IDEMAT
- US LCI Database
- European Reference Life Cycle Data (ELCD) System
- University of Bath ICE database

Other:

- Supplier embedded carbon data
- Train operators annual reports of carbon emissions
- Infrastructure managers reported carbon emissions
- Environmental Product Declarations
- United States Environmental Protection Policy

Potential tools

- Gabi LCA Software
- Sima-Pro LCA tool
- MAINLINE LCAT tool
- SmartRail LCA tool
- TEAM LCA Software
- HERMES/BRAVE traffic simulators for assessing energy consumption

Applicability to C4R innovations

For the assessment of environmental impact in the C4R project, it will mainly be the carbon impact that is assessed in terms of life cycle carbon analysis. For the most part the templates for the analysis are similar to the life cost analysis templates, with similar categories considering the carbon impact of the installation, maintenance and renewals and for each category the embedded carbon of any materials should be considered, the carbon impact of fuel used for any these activities directly or through the logistics of transporting parts and materials from their point of manufacture/storage. Environmental performances related to railway innovations may also be assessed in terms of life cycle emissions by considering three groups of activities (construction, maintenance, operation) and two main groups of innovations, infrastructure and traffic. Innovations from SP1, SP4 and SP2 (terminals) will be related to the infrastructure group, meaning that energy consumption and emissions from construction and maintenance equipment may have to be accounted in order to assess its environmental impact. The maintenance activities considered will be the same as those used in the LCC templates. Innovations from SP2 (vehicles) and SP3 will be related to the traffic group. Inventory on SP2 should include emissions associated to manufacturing and maintenance activities, as well as the vehicle's operating direct and indirect emissions (from production of energy). For the assessment of SP2 and SP3 innovations the impact of the innovations on traction energy consumed will be significant and for that purpose it may be necessary to use a simulator such as HERMES or BRAVE to evaluate how operation is effected with these optimized strategies and the impact that this will have on rolling stock braking and accelerating for particular scenarios and from these an estimate of the traction energy consumption can be made. Also in the case of the SP2 innovations, increased electrification will also have a major impact on the life cycle carbon analysis and in this case the carbon dioxide emissions can be estimated from the energy consumption of different locomotives, the CO_{2e} of the electricity consumed will be different for each country depending upon the electricity mix, this mix will also change over time and should therefore be defined when developing the boundary conditions and scenarios.

The LCA/Environmental Appraisal templates can be found in appendix 3 to this document.

SP1

1.1 New concepts of track based on modular slab track embedding elements for power, remote condition monitoring, signalling and communications

1.2 New track designs and specifications for very high speed trains (>350km/h)

1.3 New concepts for switches and crossings design based on failure modes analysis

1.4 New designs for switches resilient to extreme weather conditions

1.5 Optimised S&C sensor strategies

The life cycle analysis of the SP1 innovations will concentrate on the embedded carbon within the infrastructure and the carbon impact of building track and S&C against the carbon impact of maintenance. The SP1 analysis will need to consider the embedded carbon within the material infrastructure developed from the bills of material and using standard figures for the embedded carbon within concrete, steel, ballast etc. The carbon and air pollutants of logistics, transporting and processing materials should also be considered in both the original installation as well as within each of the maintenance and renewal tasks, for energy intensive operations the impact of fuel should also be considered such as grinding operations.

SP2

2.1 Innovations in Trains/Wagons – optimised length, speed, performance, central/automatic coupler, EP/electronic braking, electrification, automation, weight

2.2 Innovations in Freight Operation – wagon shunting, intelligence for vehicles in terminals, terminal operation

For SP2 as well as the embedded carbon in any vehicle or infrastructure modifications, the main analysis of carbon impact should come from the reduction in fuel and electrification providing the operational fuel at a reduced carbon impact compared to diesel traction. The reduction in energy consumption should be derived from the braking and acceleration patterns from train simulators or other calculations of energy consumption for diesel and electric locomotives.

SP3

3.1 Ubiquitous data architecture and automated data exchange for railway operations

3.2 Models and simulations to evaluate enhanced capacity (infrastructure and operation)

3.3 Optimal strategies to manage major disturbances

The LCA assessment for the SP3 innovations should also centre around savings in traction energy which again should be derived from the braking and acceleration patterns from train simulators used within SP3.

SP4

4.1 New concepts and technologies for using advanced monitoring in embankments, bridges, different track types, switches etc.

4.2 Sensor types

4.3 Energy harvesting

The potential carbon savings for the SP4 innovations will be around the saving from life extending infrastructure, and reducing the frequency of maintenance and inspection processes. As a consequence the templates include all maintenance operations, which can be selected for use in the LCA if appropriate to the innovations.

Safety

Assessment of the safety implications of a new technology are difficult to quantify and even more problematic to convert into financial costs for a life cycle cost benefit analysis. This is partly due to the low frequency, but high impact nature of railway accidents, which makes them statistically difficult to predict and model. Also the historical data that is held is based on existing technologies and it would be difficult to predict in absolute terms how a new technology may impact on this. Therefore, safety should be measured in terms of a semi-quantitative methodology of evaluating the probability of occurrence and the likely impact to create a risk factor. This risk factor could be evaluated against a baseline case to show a relative reduction in risk or otherwise of a new innovation. For new innovations simulations of wear and fatigue of components may also be used.

RAILPAG also recommends the use of insurance premium data to apply a financial value to safety aspects, although this may be difficult to apply to new technology. If it is possible to calculate a probability factor and impact of the event then it may also be possible to apply value of life data to calculate a cost equivalent of the safety impact.

Measures of the impact of safety

- Risk factors from risk assessment, fault tree analysis, FMEA, HAZOP
- Insurance cost
- Value of life data from the HEATCO project
- IMPACT study

Sources of safety data

- European statistics database EUROSTAT
- European safety database ERADIS
- DNV database
- European UIC safety database, includes 20 EU countries
- Non-European sources such as Russian and USA safety database
- GB Safety Management Information System (SMIS) administered by RSSB
- Safety databases from Austria, France, Germany, Sweden and Switzerland.
- European Rail Agency (the DNV study)
- past studies by UIC
- RSSB of derailments in the UK
- Information from project partners' databases and information from previous reports, studies and papers
- Insurance cost data

Applicability to C4R innovations

Safety is considered as part of the RAMS templates, with key safety considerations identified from the RSSB safety model and common failure modes, this has been developed into headline categories which may be considered in any safety risk assessment. It is expected that most innovations will have an impact on the safety risk level. Any innovation which reduces maintenance or inspection requirements or increases automation such as the innovations in SP1 and SP4 will reduce the time that track workers spend on track and hence should result in a reduction in track worker injuries and fatalities. Similarly it could be expected that changes to the coupling system or freight yard operation in SP2 should also have an impact on the safety of railway staff. Risk assessments should be used to incorporate expert judgement into the safety assessment. The innovations should also consider from FMEA analyses or fault tree analyses and modelling and simulation for the consideration of the major failures of the systems, eg, changes to the risk of derailments due to S&C or track failures and wear, failures of the substructure due extreme weather or the risk of train collisions etc.

The RAMS templates are to found in Appendix 4 of this document.

ADAPTABLE

Definition:

An adaptable railway is both flexible and extensible so that, with modest and incremental interventions, rail services can be modified to fit a range of future scenarios – including long-term service-levels and ability to integrate new technology developments. The scenarios include changes in the transport market, modal shift and external demands (such as legislation on greenhouse gas emissions). In building an adaptable railway, innovations and processes will need to be phased into existing railway systems in a sustainable way from engineering and operations viewpoints.

AND

An adaptable railway is modular and has well-defined interfaces and standards for interoperability, so that operations can respond rapidly to changes in the pattern of demand – such as providing additional trains to cater for surges in demand generated by exogenous factors (e.g. major sporting events). Improved and innovative construction techniques with less complexity (e. g. of the interfaces between railway sub-systems) and high standardization reduce costs and disruption to users.

Within the roadmaps the adaptable railway is further divided into interoperability, service demands and climate change. With outputs such as doubled rail network capacity by 2050, improved customer service, robust rail infrastructure, flexible routing of traffic and overlaps with aspects of the definition of "Resilient". There is little in the past literature regarding the assessment of "adaptability" in the railway, however, this can be measured within the economic assessment, by using sensitivity analysis to adapt key factors and account for changing circumstances. However, for many of these elements it may be necessary to devise a number of different, extreme, scenarios and to assess the innovations in these circumstances, looking at reliability, safety risk assessment in extreme conditions such as climatic change, radically increased traffic, etc.

Also interoperability in new technologies should be a given requirement, or where there are interoperability issues, it should be considered as a cost within the cost benefit analysis. For traffic management systems adaptability to changing demands or events should also be a given, or for the purpose of this project the ability of traffic management systems to be able to cope with such demands should be assessed.

High level strategic tools such as TRANS-TOOLS and TREMOVE, may be useful in generating the scenarios and understanding the impact on the wider system, and where bottlenecks may occur.

Potential tools

- TRANS-TOOLS
- TREMOVE
- Graffica HERMES/ BRAVE
- Tools for LCCA and LCA with different scenarios applied

Applicability to C4R innovations

Adaptability can be measured using the LCC templates to compare the capital costs of adapting the infrastructure to or systems to new scenarios such as increased traffic loads or more extreme weather conditions. So for example an analysis of adaptability for SP1 track innovations might be a comparison in costs to upgrade a modular slab track to higher axle loads compared to the cost to upgrade ballasted track to the same axle loading, similarly for the SP2 innovations adaptability can be measured as the relative cost of upgrading freight vehicles or freight terminals to be able to cope with different demands. For the instrumentation strategies within SP1 and SP4 a measure of adaptability may be modularity and the cost of upgrading, or a demonstration that the sensor strategy will already satisfy a wide range of scenarios without the need to be adapted in the future. Similarly adaptability applied to the SP3 innovations would be a test that the strategy for managing major disturbances is applicable to a very wide range of different future scenarios and that the strategy can be easily adapted to these.

Resilient

Definition:

A resilient railway is robust, thereby minimising the incidence of infrastructure and operational failures that affect services. Furthermore, a resilient railway is one which by design (e.g. of operations, maintenance processes, logistics, tools, equipment) is capable of recovering quickly from perturbations to normal service e.g. as a result of short-term internal events (such as the failure of rail infrastructure) or external events (such as extreme weather conditions, and vandalism).

INFRASTRUCTURE FAILURE

Normal infrastructure failures should be considered as part of the economic assessment and RAMS analysis, with RAMS parameters including reliability KPIs such as mean time between failures for corrective maintenance (MTBF), mean time between maintenance for preventative maintenance (MTBM), mean time between critical failures (MTBCF), mean time between service affecting failure (MTBSAF); availability KPIs such as passenger performance measure (PPM), train delay; and maintainability KPIs such as mean time to repair (MTTR), mean active repair time (MART), mean time to maintain (MTTM) and mean down time (MDT). This data is generally collected by infrastructure managers, available from laboratory results or simulations with a distribution of results, which together with the maintenance costs and delay costs can be applied to a Monte Carlo simulation as part of the LCCA.

Regarding delay costs, the preference is for these to reflect the market value of the cost of the delay on the customer, but failing that it should reflect the price that a customer is willing to pay to avoid such a delay and least preferable cost is based on the compensation paid out to customers in the event of a delay.

RAMS metrics

- MTBF
- MTBM
- MTBCF
- MTBSAF
- PPM
- Train delay
- MTTR
- MART
- MTTM
- MDT

Sources of RAMS data

- Infrastructure manager’s or contractor’s maintenance records
- Models and simulations
- Laboratory/test data
- Manufacturer’s data
- Generic component reliability data
- Expert estimation
- Data from tools such as VTISM and TRACKEX

Applicability to C4R innovations

The measures for resilience will come largely from the RAMS template and will be very dependent upon the scenarios, the key measures of resilience will be the reductions in the requirements for maintenance and the resilience of the structure to damage either through regular wear, or other catastrophic system failures. The other characteristics from the RAMS templates applicable to the resilience theme is the time for the system to recover back to normal, in most maintenance or corrective actions the key characteristic will be the mean time to repair or the mean time to maintain. The train simulators such as HERMES or BRAVE can be used to analyse the knock-on effects of unavailability from maintenance and repairs. For SP3 where the innovation that we want to study is the system optimization to allow for improved recovery, then the scenarios for the assessment of SP3 innovations should include response of the case study line to a particular repair or maintenance technique and demonstrate the improvement in system recovery time, measures to include the time to return to normal service or the total delay time for all traffic involved in incident.

Extreme weather

Extreme scenarios such as hurricanes, flooding and landslides should be considered within the RAMS analysis. The likelihood of failure should be assessed using a risk assessment approach and impacts s of train delay and mean time to repair should be compared between innovations and the baseline case.

Applicability to C4R innovations

Extreme weather conditions should be considered as a particular scenario for the assessment of the innovations and for some innovations the resilience to extreme weather should be considered alongside all of the maintenance and failure modes within the RAMS assessment. However, for other cases it should be considered as a standalone scenario, for example when considering the SP3 innovations, the response to a particular extreme weather scenario will form the basis of the assessment into the performance of the optimized traffic management strategy.

Automated

Definition:

An automated railway is one whose infrastructure and rolling stock are operated and maintained by machines to a degree where the intelligence, speed and scale of operations are no longer correlated with the availability, capacity or capability of human resources. That is, the railway is capable of operating efficiently and effectively without human intervention under normal and (most) degraded service conditions. Automation will cover various aspects such as:

- *Construction and maintenance*
- *Operations*
- *Communications*
- *Ticketing*
- *Inter-modal transfer of passengers and freight*

The main benefits of automation should already be considered as a safety, capacity or as a cost benefit and should therefore be considered as part of the LCCA and as part of safety risk assessment. However, there may be a case where increased automation meets a strategic long term goal beyond the current economic payback period, or as a stepping stone towards a larger goal. In this case it should be possible to define an organisation's financial commitment to this end goal in financial terms which can then be fed back into the cost benefit analysis. Otherwise a measure of automation would need to determined, which can then analysed in a multifunctional analysis with automation weighted against the other costs and benefits, with the weighting based on an expert judgement of it's worth.

Applicability to C4R innovations

Automation – assessed on the basis of the reduction in the need for labour – in the case of the assessment in the Capacity4Rail project – in some cases it may be possible to define the level of automation quantitatively as a measure in the reduction of human labour required for each task as result of the innovations, and also the potential for future automation due to modularization and infrastructure design for automated repair. However, in many cases a semi-quantitative method will be required, with a scale defined through qualitative descriptions of different levels of automation.

High-Capacity

Definition:

A high capacity railway is one which has virtually no constraints (bottlenecks) on its operation. A high capacity railway can accommodate projected passenger and freight demands spread unevenly through the day (e.g. high flows during peak hours and lower flows at other times optimally), whilst meeting customer requirements in terms of defined service levels (such as, reliability, journey time and frequency of service) in an affordable manner.

A high-capacity railway will tolerate interventions from inspection, maintenance and enhancement with minimal impact on the availability of the transport infrastructure network and enable a move towards the achievement of a 'forever open railway (24 hours/7 days a week)'.

Assessment of capacity and capacity improvements have been made in the AUTOMAIN project and the ON-TIME objective function for evaluating solutions also contains objective function elements relevant to capacity. In both of these projects they avoid assessing capacity in financial terms, but instead as a percentage improvement in possession time for AUTOMAIN and as a numerical function in ON-TIME. The UIC Leaflet 406 – Capacity also provides a measure of capacity consumption as a percentage of the overall availability of the line, node or corridor.

From these measures it is possible to create a financial cost function for capacity, for example using the reduction in possession time function from AUTOMAIN or the Capacity Consumption measure from UIC Leaflet 406, it is also possible to create a financial cost function to describe this, based on either the value of that possession time saved in terms of the track access charges for the additional train paths sold or by establishing a what the reduction in delay charges are. Similarly, for the elimination of bottle necks or creating new capacity, the value of this extra capacity could be evaluated against the cost of building new lines or the next best option. SP3 of Capacity4Rail will develop its own evaluation measures and the capacity impacts of its own innovations and therefore the evaluation work carried out within SP5 should be closely aligned to these criteria.

RAILPAG also provides guidance on the direct measurements of capacity, although it accepts that a universal definition for capacity is difficult to produce.

Key measures of capacity improvement

- Total capacity available – eg - total number of train paths per 24hr period - UIC leaflet 406 definition
- Capacity Utilisation – UIC leaflet 406 definition
- Reduction in the non-availability time or in number of maintenance, inspection and renewal activities.

Capacity tools

- Graffica HERMES/BRAVE
- TRANS-TOOLS
- TREMOVE
- UIC –Capacity definition – Leaflet 406

Applicability to C4R innovations

There are two approaches to assessing capacity – reduction in availability of track due to maintenance which can be translated into equivalent train paths. Or from system models/simulators calculate train numbers of train paths available for different scenarios with and without the C4R innovations. For SP1 and SP4 innovations the calculation of reduced unavailability of track due to maintenance, repair or inspection activities in a similar manner to how capacity improvements were calculated in the AUTOMAIN project based on the RAMS templates is probably most appropriate. For SP2 and SP3 the increase in availability from the innovations can be modelled from simulator output from HERMES or BRAVE to calculate the increase in availability of track due to compressing more capacity into the timetable and in the case of SP3 the time to return the timetable to normal operation will also be a key output. It is also possible to put financial values to the capacity increases in the numbers of train paths based on the value of these train paths in track access charges or in the case of reducing the impact of disturbances financial values of compensation or the values of passengers time may be used.

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Appendix 1 - Example of a S-E Matrix customized for Capacity4Rail

SE Matrix				Stakeholders																						
				Users				Transport service operators					Contractors and suppliers				Infrastructure managers				Non users (external)		Government			
				Rail lines		Alternative modes		Rail									Rail									
Effects				Pax	Freight	Pax	Freight	Rail Operator 1	Rail Operator 2	...	Other modes	Insurance companies	Infrastructure	Superstructure	Rolling Stock	Electrification & Signalling	Rail manager 1	Rail manager 2	...	Other modes	Local	Regional	Local	Regional	National	EU
Affordable/financial effects	User Service		Fares																							
			Comfort																							
			Convenience																							
	Operation costs	Direct	Fees eg Track access charges																							
			Vehicle operating costs																							
			Operating personnel																							
			Facilities operations																							
		Indirect	Overhead management - HQ functions																							
			Subsidies																							
			Taxes																							
			Consumer surplus (new traffic)																							
	Assets	Investment	Land value																							
			Infrastructure																							
			Superstructure																							
			Stations and terminal																							
			Garage & repair facilities																							
			Rolling stock (vehicles)																							
			Residual Value																							
			Taxes																							
		Maintenance (routine costs)	Infrastructure and Superstructure routine (time based) maintenance and inspection (actual costs)																							
			Infrastructure and Superstructure condition based maintenance (actual costs)																							
			Infrastructure and Superstructure unplanned repairs(actual costs)																							
			Infrastructure renewal (actual costs)																							
			Rolling stock (vehicles) routine (time based) maintenance and inspection (actual costs)																							
			Rolling stock (vehicles) condition based maintenance (actual costs)																							
			Rolling stock (vehicles)unplanned repairs (actual costs)																							
			Rolling stock overhaul (actual costs)																							
		Disposal costs																								
		Environmental	Noise and vibrations																							
			Air pollution (particulates, NOx, etc)																							
			Carbon impact (LCA)																							
Adaptable			Adaptability to increased service demands																							
			Interoperability across borders and railway systems																							
			Optimisation of rail traffic movements - flexible routing																							
Automated		Intelligent transport system and signalling	Automation of timetabling																							
			Automation and optimisation of train control systems																							
		Intelligent monitoring and maintenance	Automated inspection/maintenance of rolling stock (socio-economic impact of improved workforce safety and quality)																							
			Automated inspection/maintenance of infrastructure (socio-economic impact of improved workforce safety and quality)																							
Resilient			Reliability of service (unplanned failures of infrastructure or rolling stock - socio-economic impacts)																							
			Resilience of infrastructure to extreme climate events																							
			Recovery time from system perturbations																							
			Operability during degraded modes																							
High Capacity			Customer/freight travel time																							
			Use of space - Vehicle loading - passenger																							
			Use of space - Vehicle loading - freight																							
			Use of space - efficient layout of infrastructure																							
			Infrastructure and Superstructure routine (time based) maintenance and inspection (socio-economic impacts eg delays/alternative services)																							
			Infrastructure and Superstructure condition based maintenance (socio-economic impacts eg delays/alternative services)																							
			Infrastructure renewal (socio-economic impacts eg delays/alternative services)																							
			Rolling stock (vehicles) routine (time based) maintenance and inspection (socio-economic impacts eg delays/alternative services)																							
			Rolling stock (vehicles) condition based maintenance (socio-economic impacts eg delays/alternative services)																							

Appendix 2 - LCC Templates

Capacity4Rail Technology Evaluation template - LCC

Sub-project: **SP1**

Innovation: **New Concepts based on modular slab track - slab track evaluated against ballasted track**

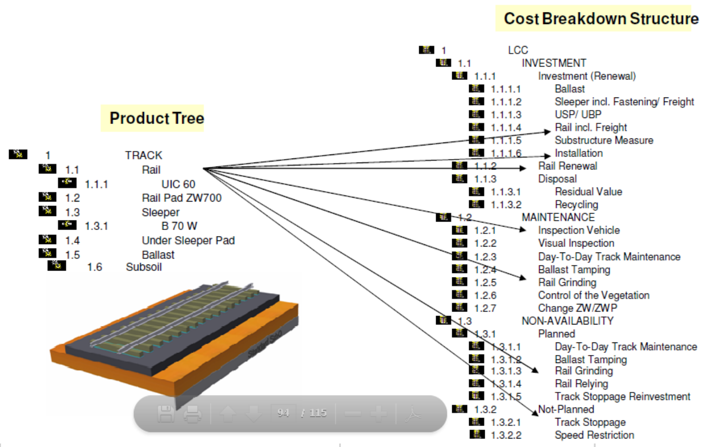
Discount rate to be used for LCC calculations [ ] %

The life cycle cost analysis will start with a product breakdown structure and will consider all of the life cycle stages from R&D through to disposal. The figure on the right shows an example product breakdown structure

R&D > Investment > Operation & Maintenance > Disposal

Life cycle phases

This sheet will mainly cover the costs from R&D, Investment (and installation), Operation and disposal. It is assumed that the majority of the maintenance data will be collected in the "RAMS data" sheet



Source: INNOTRACK - Guideline for LCC and RAMS analysis (2006)

Scenario and boundard conditions for assessment

Product breakdown structure

Baseline case - ballasted track

Component	Sub Component	Function of component/sub component
Sub-grade		

Innovation - Innovative modular slab track

Component	Sub Component	Function of component/sub component

Cost categories and Life Cycle Phases

Baseline case - ballasted track

	LCC Cost block	Cost (€) per km or Cost (€) per task	Stakeholder who benefits/pays financially	When and how frequently cost occurs in life cycle (eg every 20yrs)	Dependencies (eg relationship between cost or cost frequency upon boundary condtionitions such load (MGT), traffic type, curve etc)	Source of cost data - eg financial statements, model, expert estimate, total component and labour costs	Quality of data source and where possible accuracy of data (upper and lower limits)
CAPEX	**R&D costs**						
	Investment						
	- Project preparation						
	- Inputted Residual value						
	- Investment and installation						
	-- Ground preparation - geotechnical and civil						
	--- Site investigation						
	--- Soil substitution						
	--- Reinforcement						
	--- Subgrade layers						
	--- Drainage						
	-- Track laying - track work						
	--- Ballast						
	--- Pads						
	--- Sleepers						
	--- Fastenings						
	--- Rail						
	--- Welding						
	--- Tamping						
	- Testing and commissioning						
	-- Inspection/quality control						
	Disposal						
	- Decommission costs						
	- Removal costs						
	- Disposal costs/recycled value (rail and ballast recycling)						
	- Facilities						
	- Residual value						
OPEX	**Operation costs (non-maintenance)**						
	- Energy						
	-Personnel						
	-Training						
	- Facilities						
	- Fees						
	- Communications						
	- Facilities						
	Maintenance costs - see RAMS template						
	- Inspection						
	-- Visual Inspection						
	-- Ultrasonic - Manual						
	-- Ultrasonic - Train based						
	-- Eddy current inspection - Train based						
	-- Track geometry - train based						
	-- Noise monitoring						
	- Preventative/condition based maintenance						
	-- Rail Change						
	-- Rail Transpose						
	-- Grinding						
	-- Lubrication						
	-- Fish Plate lubrication						
	-- IBJ replacement						
	-- Re-sleeper						
	-- Replace sleeper pads and insulators						
	-- Noise abatement						
	- Corrective maintenance						
	-- Rail Change - defects						
	-- Weld change - defects						
	-- Rail adjustment						
	-- Ballast reprofile						
	-- Wet bed removal						
	-- Tactical reballast						
	-- Plain line tamping						
	-- Stoneblowing						
	-- Geometry manual						
	-- replacement of pads and fasteners						
	- Renewals						
	--Rail, sleeper and Ballast renewal						
	-- Sleeper and ballast renewal						
	-- Tactical resleeper						
	--Ballast cleaning						
	- Off Track maintenance						
	-- Drainage						
	-- Fencing						
	-- Vegetation						
	Other quantifiable costs identified from S-E matrix/RAMS analysis						
	- Cost of non-availability during maintenance activities						
	-- Planned maintenance						
	-- Unplanned maintenance						

Innovation - Innovative slab track

	LCC Cost block	Cost (€) per km or Cost (€) per task	Stakeholder who benefits/pays financially	When and how frequently cost occurs in life cycle (eg every 20yrs)	Dependencies (eg relationship between cost or cost frequency upon boundary condtionitions such load (MGT), traffic type, curve etc)	Source of cost data - eg financial statements, model, expert estimate, total component and labour costs	Quality of data source and where possible accuracy of data (upper and lower limits)
CAPEX	**R&D costs**						
	Investment						
	- Project preparation						
	- Inputted Residual value						
	- Investment and installation						
	-- Ground preparation - geotechnical						
	--- Site investigation						
	--- Soil substitution						
	--- Reinforcement						
	--- Subgrade layers						
	--- Drainage						
	-- Slab positioning - Civil work						
	--- Concrete sublayer						
	--- Connector / stoppers						
	--- Slab laying						
	--- Positioning						
	--- Mortar / Fix the slab						
	--- Inspection / Quality control						
	-- Track laying - Track work						
	--- Rail laying						
	--- Pads						
	--- Sleepers						
	--- Fastenings						
	--- Clip/screw fastenings						
	--- Welding						
	- Testing and commissioning						
	-- Inspection/quality control						
	Disposal						
	- Decommission costs						
	- Removal costs						
	- Disposal costs/recycled value (rail and ballast recycling)						
	- Facilities						
	- Residual value						
OPEX	**Operation costs (non-maintenance)**						
	- Energy						
	-Personnel						
	-Training						
	- Facilities						
	- Fees						
	- Communications						
	- Facilities						
	Maintenance costs - see RAMS template						
	- Inspection						
	-- Visual Inspection						
	-- Ultrasonic - Manual						
	-- Ultrasonic - Train based						
	-- Eddy current inspection - Train based						
	-- Track geometry - train based						
	-- Slab monitoring for cracks and movement						
	-- Noise monitoring						
	- Preventative/condition based maintenance						
	-- Rail Change						
	-- Rail Transpose						
	-- Grinding						
	-- Lubrication						
	-- Fish Plate lubrication						
	-- IBJ replacement						
	-- Re-sleeper						
	-- Replace rail pads and insulators						
	-- Noise abatement						
	- Corrective maintenance						
	-- Rail Change - defects						
	-- Weld change - defects						
	-- Rail adjustment						
	-- Maintain drainage						
	-- Adjust fastening system for small defects						
	-- replacement of pads and fasteners						
	-- Correct cracks in slab						
	--- Replace slab - in case of derailment or accident (major damage)						
	--- Inject resin to protect steel						
	-- Correct settlement of slab						
	--- Inject cement or other products under slab						
	--- Expansive foam treatment						
	--- Micro piles						
	- Renewals						
	-- Slab replacement						
	-- Rail+pad+fasteners replacement						
	-- Rail + pad replacement only						
	-- Replace drainage system						
	- Off Track maintenance						
	-- Drainage						
	-- Fencing						
	-- Vegetation						
	Other quantifiable costs identified from S-E matrix/RAMS analysis						
	- Cost of non-availability during maintenance activities						
	-- Planned maintenance						
	-- Unplanned maintenance						

Capacity4Rail Technology Evaluation template - LCC

Sub-project: **SP1**

Innovation: **New Concepts based on modular slab track - innovative slab track evaluated against existing slab track**

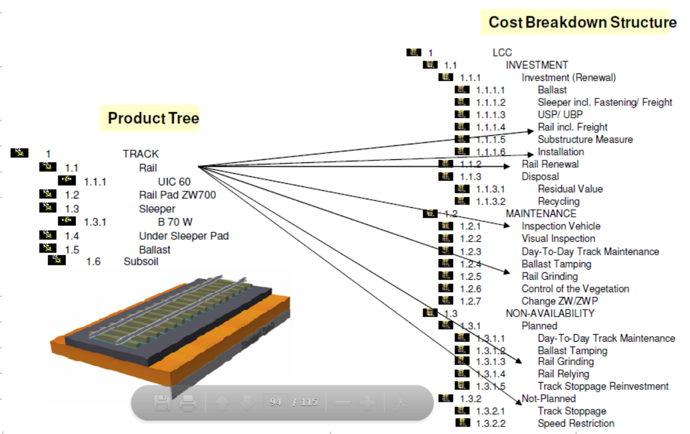
Discount rate to be used for LCC calculations [ ] %

The life cycle cost analysis will start with a product breakdown structure and will consider all of the life cycle stages from R&D through to disposal. The figure on the right shows an example product breakdown structure

R&D > Investment > Operation & Maintenance > Disposal

Life cycle phases

This sheet will mainly cover the costs from R&D, Investment (and installation), Operation and disposal. It is assumed that the majority of the maintenance data will be collected in the "RAMS data" sheet



Source: INNOTRACK - Guideline for LCC and RAMS analysis (2006)

Scenario and boundard conditions for assessment

Product breakdown structure

Baseline - existing slab track

Component	Sub Component	Function of component/sub component
Sub-grade		

Innovation - Innovative modular slab track

Component	Sub Component	Function of component/sub component

Cost categories and Life Cycle Phases

Baseline - existing slab track

	LCC Cost block	Cost (€) per km or Cost (€) per task	Stakeholder who benefits/pays financially	When and how frequently cost occurs in life cycle (eg every 20yrs)	Dependencies (eg relationship between cost or cost frequency upon boundary condtionitions such load (MGT), traffic type, curve etc)	Source of cost data - eg financial statements, model, expert estimate, total component and labour costs	Quality of data source and where possible accuracy of data (upper and lower limits)
CAPEX	**R&D costs**						
	Investment						
	- Project preparation						
	- Inputted Residual value						
	- Investment and installation						
	-- Ground preparation - geotechnical						
	--- Site investigation						
	--- Soil substitution						
	--- Reinforcement						
	--- Subgrade layers						
	--- Drainage						
	-- Slab positioning - Civil work						
	--- Concrete sublayer						
	--- Connector / stoppers						
	--- Slab laying						
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OPEX	**Operation costs (non-maintenance)**						
	- Energy						
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	- Facilities						
	- Fees						
	- Communications						
	- Facilities						
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	- Inspection						
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	- Preventative/condition based maintenance						
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	-- Rail Transpose						
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	-- Lubrication						
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	-- Drainage						
	-- Fencing						
	-- Vegetation						
	Other quantifiable costs identified from S-E matrix/RAMS analysis						
	- Cost of non-availability during maintenance activities						
	-- Planned maintenance						
	-- Unplanned maintenance						

Innovation - Innovative slab track

	LCC Cost block	Cost (€) per km or Cost (€) per task	Stakeholder who benefits/pays financially	When and how frequently cost occurs in life cycle (eg every 20yrs)	Dependencies (eg relationship between cost or cost frequency upon boundary condtionitions such load (MGT), traffic type, curve etc)	Source of cost data - eg financial statements, model, expert estimate, total component and labour costs	Quality of data source and where possible accuracy of data (upper and lower limits)
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	--- Site investigation						
	--- Soil substitution						
	--- Reinforcement						
	--- Subgrade layers						
	--- Drainage						
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	-- Rail + pad replacement only						
	-- Replace drainage system						
	- Off Track maintenance						
	-- Drainage						
	-- Fencing						
	-- Vegetation						
	Other quantifiable costs identified from S-E matrix/RAMS analysis						
	- Cost of non-availability during maintenance activities						
	-- Planned maintenance						
	-- Unplanned maintenance						

Capacity4Rail Technology Evaluation template - LCC

Sub-project: **SP1**

Innovation: **New track designs and specifications for very high speed lines (if innovation slab track)**

Discount rate to be used for LCC calculations | | %

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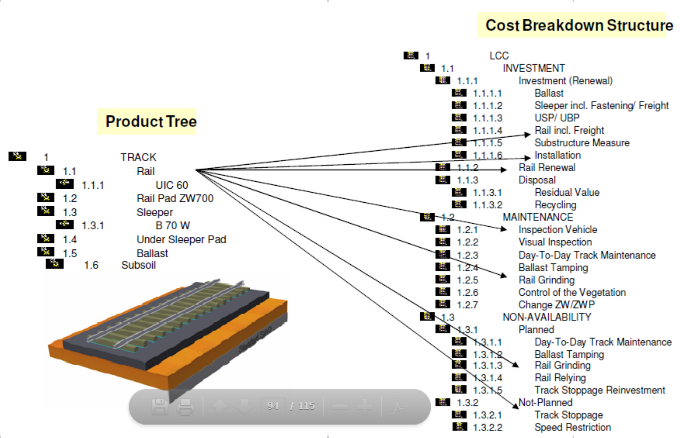

Source: INNOTRACK - Guideline for LCC and RAMS analysis (2006)

Scenario and boundard conditions for assessment

Product breakdown structure

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Sub-grade		

Innovation - Innovative slab track

Component	Sub Component	Function of component/sub component

Cost categories and Life Cycle Phases

Baseline case - ballasted track

	LCC Cost block	Cost (€) per km or Cost (€) per task	Stakeholder who benefits/pays financially	When and how frequently cost occurs in life cycle (eg every 20yrs)	Dependencies (eg relationship between cost or cost frequency upon boundary condtionitions such load (MGT), traffic type, curve etc)	Source of cost data - eg financial statements, model, expert estimate, total component and labour costs	Quality of data source and where possible accuracy of data (upper and lower limits)
CAPEX	R&D costs						
	Investment						
	- Project preparation						
	- Inputted Residual value						
	- Investment and installation						
	-- Ground preparation - geotechnical and civil						
	--- Site investigation						
	--- Soil substitution						
	--- Reinforcement						
	--- Subgrade layers						
	--- Drainage						
	-- Track laying - track work						
	--- Ballast						
	--- Pads						
	--- Sleepers						
	--- Fastenings						
	--- Rail						
	--- Welding						
	--- Tamping						
	- Testing and commissioning						
	-- Inspection/quality control						
	Disposal						
	- Decommission costs						
	- Removal costs						
	- Disposal costs/recycled value (rail and ballast recycling)						
	- Facilities						
	- Residual value						
OPEX	Operation costs (non-maintenance)						
	- Energy						
	-Personnel						
	-Training						
	- Facilities						
	- Fees						
	- Communications						
	- Facilities						
	Maintenance costs - see RAMS template						
	- Inspection						
	-- Visual Inspection						
	-- Ultrasonic - Manual						
	-- Ultrasonic - Train based						
	-- Eddy current inspection - Train based						
	-- Track geometry - train based						
	-- Noise monitoring						
	- Preventative/condition based maintenance						
	-- Rail Change						
	-- Rail Transpose						
	-- Grinding						
	-- Lubrication						
	-- Fish Plate lubrication						
	-- IBJ replacement						
	-- Re-sleeper						
	-- Replace sleeper pads and insulators						
	-- Noise abatement						
	- Corrective maintenance						
	-- Rail Change - defects						
	-- Weld change - defects						
	-- Rail adjustment						
	-- Ballast reprofile						
	-- Wet bed removal						
	-- Tactical reballast						
	-- Plain line tamping						
	-- Stoneblowing						
	-- Geometry manual						
	-- replacement of pads and fasteners						
	- Renewals						
	--Rail, sleeper and Ballast renewal						
	-- Sleeper and ballast renewal						
	-- Tactical resleeper						
	--Ballast cleaning						
	- Off Track maintenance						
	-- Drainage						
	-- Fencing						
	-- Vegetation						
	Other quantifiable costs identified from S-E matrix/RAMS analysis						
	- Cost of non-availability during maintenance activities						
	-- Planned maintenance						
	-- Unplanned maintenance						

Innovation - Innovative slab track

	LCC Cost block	Cost (€) per km or Cost (€) per task	Stakeholder who benefits/pays financially	When and how frequently cost occurs in life cycle (eg every 20yrs)	Dependencies (eg relationship between cost or cost frequency upon boundary condtionitions such load (MGT), traffic type, curve etc)	Source of cost data - eg financial statements, model, expert estimate, total component and labour costs	Quality of data source and where possible accuracy of data (upper and lower limits)
CAPEX	**R&D costs**						
	Investment						
	- Project preparation						
	- Inputted Residual value						
	- Investment and installation						
	-- Ground preparation - geotechnical						
	--- Site investigation						
	--- Soil substitution						
	--- Reinforcement						
	--- Subgrade layers						
	--- Drainage						
	-- Slab positioning - Civil work						
	--- Concrete sublayer						
	--- Connector / stoppers						
	--- Slab laying						
	--- Positioning						
	--- Mortar / Fix the slab						
	--- Inspection / Quality control						
	-- Track laying - Track work						
	--- Rail laying						
	--- Pads						
	--- Sleepers						
	--- Fastenings						
	--- Clip/screw fastenings						
	--- Welding						
	- Testing and commissioning						
	-- Inspection/quality control						
	Disposal						
	- Decommission costs						
	- Removal costs						
	- Disposal costs/recycled value (rail and ballast recycling)						
	- Facilities						
	- Residual value						
OPEX	**Operation costs (non-maintenance)**						
	- Energy						
	-Personnel						
	-Training						
	- Facilities						
	- Fees						
	- Communications						
	- Facilities						
	Maintenance costs - see RAMS template						
	- Inspection						
	-- Visual Inspection						
	-- Ultrasonic - Manual						
	-- Ultrasonic - Train based						
	-- Eddy current inspection - Train based						
	-- Track geometry - train based						
	-- Slab monitoring for cracks and movement						
	-- Noise monitoring						
	- Preventative/condition based maintenance						
	-- Rail Change						
	-- Rail Transpose						
	-- Grinding						
	-- Lubrication						
	-- Fish Plate lubrication						
	-- IBJ replacement						
	-- Re-sleeper						
	-- Replace rail pads and insulators						
	-- Noise abatement						
	- Corrective maintenance						
	-- Rail Change - defects						
	-- Weld change - defects						
	-- Rail adjustment						
	-- Maintain drainage						
	-- Adjust fastening system for small defects						
	-- replacement of pads and fasteners						
	-- Correct cracks in slab						
	--- Replace slab - in case of derailment or accident (major damage)						
	--- Inject resin to protect steel						
	-- Correct settlement of slab						
	--- Inject cement or other products under slab						
	--- Expansive foam treatment						
	--- Micro piles						
	- Renewals						
	-- Slab replacement						
	-- Rail+pad+fasteners replacement						
	-- Rail + pad replacement only						
	-- Replace drainage system						
	- Off Track maintenance						
	-- Drainage						
	-- Fencing						
	-- Vegetation						
	Other quantifiable costs identified from S-E matrix/RAMS analysis						
	- Cost of non-availability during maintenance activities						
	-- Planned maintenance						
	-- Unplanned maintenance						

Capacity4Rail Technology Evaluation template - LCC

Sub-project: **SP1**

Innovation: **New track designs and specifications for very high speed lines (if innovation ballasted track)**

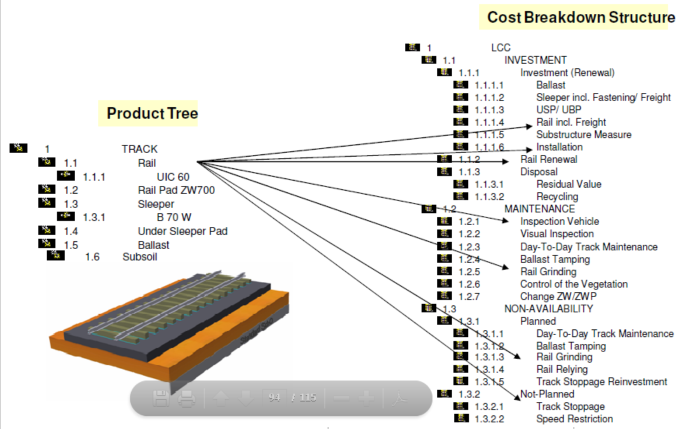
Discount rate to be used for LCC calculations ______ %

The life cycle cost analysis will start with a product breakdown structure and will consider all of the life cycle stages from R&D through to disposal. The figure on the right shows an example product breakdown structure

R&D > Investment > Operation & Maintenance > Disposal

Life cycle phases

This sheet will mainly cover the costs from R&D, Investment (and installation), Operation and disposal. It is assumed that the majority of the maintenance data will be collected in the "RAMS data" sheet



Source: INNOTRACK - Guideline for LCC and RAMS analysis (2006)

Scenario and boundard conditions for assessment

Product breakdown structure

Baseline case - ballasted track

Component	Sub Component	Function of component/sub component
Sub-grade		

Innovation - Innovative ballasted track

Component	Sub Component	Function of component/sub component

Cost categories and Life Cycle Phases

Baseline case - ballasted track

	LCC Cost block	Cost (€) per km or Cost (€) per task	Stakeholder who benefits/pays financially	When and how frequently cost occurs in life cycle (eg every 20yrs)	Dependencies (eg relationship between cost or cost frequency upon boundary condtionitions such load (MGT), traffic type, curve etc)	Source of cost data - eg financial statements, model, expert estimate, total component and labour costs	Quality of data source and where possible accuracy of data (upper and lower limits)
CAPEX	**R&D costs**						
	Investment						
	- Project preparation						
	- Inputted Residual value						
	- Investment and installation						
	-- Ground preparation - geotechnical and civil						
	--- Site investigation						
	--- Soil substitution						
	--- Reinforcement						
	--- Subgrade layers						
	--- Drainage						
	-- Track laying - track work						
	--- Ballast						
	--- Pads						
	--- Sleepers						
	--- Fastenings						
	--- Rail						
	--- Welding						
	--- Tamping						
	- Testing and commissioning						
	-- Inspection/quality control						
	Disposal						
	- Decommission costs						
	- Removal costs						
	- Disposal costs/recycled value (rail and ballast recycling)						
	- Facilities						
	- Residual value						
OPEX	**Operation costs (non-maintenance)**						
	- Energy						
	-Personnel						
	-Training						
	- Facilities						
	- Fees						
	- Communications						
	- Facilities						
	Maintenance costs - see RAMS template						
	- Inspection						
	-- Visual Inspection						
	-- Ultrasonic - Manual						
	-- Ultrasonic - Train based						
	-- Eddy current inspection - Train based						
	-- Track geometry - train based						
	-- Noise monitoring						
	- Preventative/condition based maintenance						
	-- Rail Change						
	-- Rail Transpose						
	-- Grinding						
	-- Lubrication						
	-- Fish Plate lubrication						
	-- IBJ replacement						
	-- Re-sleeper						
	-- Replace sleeper pads and insulators						
	-- Noise abatement						
	- Corrective maintenance						
	-- Rail Change - defects						
	-- Weld change - defects						
	-- Rail adjustment						
	-- Ballast reprofile						
	-- Wet bed removal						
	-- Tactical reballast						
	-- Plain line tamping						
	-- Stoneblowing						
	-- Geometry manual						
	-- replacement of pads and fasteners						
	- Renewals						
	--Rail, sleeper and Ballast renewal						
	-- Sleeper and ballast renewal						
	-- Tactical resleeper						
	--Ballast cleaning						
	- Off Track maintenance						
	-- Drainage						
	-- Fencing						
	-- Vegetation						
	Other quantifiable costs identified from S-E matrix/RAMS analysis						
	- Cost of non-availability during maintenance activities						
	-- Planned maintenance						
	-- Unplanned maintenance						

Innovation - Innovative ballasted track

	LCC Cost block	**Cost (€) per km or Cost (€) per task**	**Stakeholder who benefits/pays financially**	**When and how frequently cost occurs in life cycle (eg every 20yrs)**	**Dependencies (eg relationship between cost or cost frequency upon boundary condtionitions such load (MGT), traffic type, curve etc)**	**Source of cost data - eg financial statements, model, expert estimate, total component and labour costs**	**Quality of data source and where possible accuracy of data (upper and lower limits)**
CAPEX	**R&D costs**						
	Investment						
	- Project preparation						
	- Inputted Residual value						
	- Investment and installation						
	-- Ground preparation - geotechnical and civil						
	--- Site investigation						
	--- Soil substitution						
	--- Reinforcement						
	--- Subgrade layers						
	--- Drainage						
	-- Track laying - track work						
	--- Ballast						
	--- Pads						
	--- Sleepers						
	--- Fastenings						
	--- Rail						
	--- Welding						
	--- Tamping						
	- Testing and commissioning						
	-- Inspection/quality control						
	Disposal						
	- Decommission costs						
	- Removal costs						
	- Disposal costs/recycled value (rail and ballast recycling)						
	- Facilities						
	- Residual value						
OPEX	**Operation costs (non-maintenance)**						
	- Energy						
	-Personnel						
	-Training						
	- Facilities						
	- Fees						
	- Communications						
	- Facilities						
	Maintenance costs - see RAMS template						
	- Inspection						
	-- Visual Inspection						
	-- Ultrasonic - Manual						
	-- Ultrasonic - Train based						
	-- Eddy current inspection - Train based						
	-- Track geometry - train based						
	-- Noise monitoring						
	- Preventative/condition based maintenance						
	-- Rail Change						
	-- Rail Transpose						
	-- Grinding						
	-- Lubrication						
	-- Fish Plate lubrication						
	-- IBJ replacement						
	-- Re-sleeper						
	-- Replace sleeper pads and insulators						
	-- Noise abatement						
	- Corrective maintenance						
	-- Rail Change - defects						
	-- Weld change - defects						
	-- Rail adjustment						
	-- Ballast reprofile						
	-- Wet bed removal						
	-- Tactical reballast						
	-- Plain line tamping						
	-- Stoneblowing						
	-- Geometry manual						
	-- replacement of pads and fasteners						
	- Renewals						
	--Rail, sleeper and Ballast renewal						
	-- Sleeper and ballast renewal						
	-- Tactical resleeper						
	--Ballast cleaning						
	- Off Track maintenance						
	-- Drainage						
	-- Fencing						
	-- Vegetation						
	Other quantifiable costs identified from S-E matrix/RAMS analysis						
	- Cost of non-availability during maintenance activities						
	-- Planned maintenance						
	-- Unplanned maintenance						

Capacity4Rail Technology Evaluation template - LCC

Sub-project: **SP1**

Innovation: **New concepts for Switches and Crossings based on failure modes analysis**

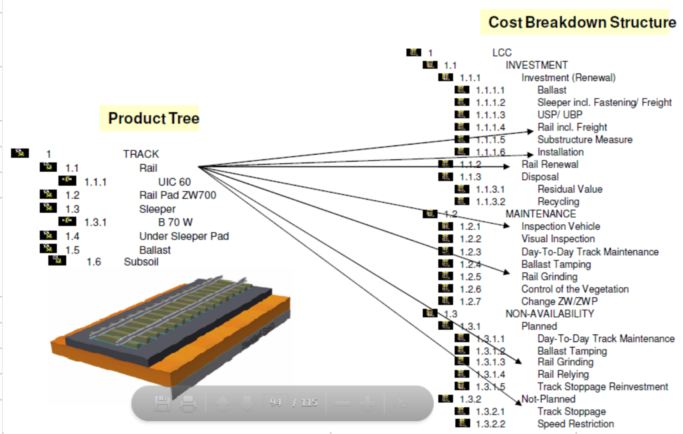
Discount rate to be used for LCC calculations ____ %

The life cycle cost analysis will start with a product breakdown structure and will consider all of the life cycle stages from R&D through to disposal. The figure on the right shows an example product breakdown structure

R&D > Investment > Operation & Maintenance > Disposal

Life cycle phases

This sheet will mainly cover the costs from R&D, Investment (and installation), Operation and disposal. It is assumed that the majority of the maintenance data will be collected in the "RAMS data" sheet



Source: INNOTRACK - Guideline for LCC and RAMS analysis (2006)

Scenario and boundard conditions for assessment

Product breakdown structure

Baseline case - Existing switch design - use as a basis a design which is commonly used in the scenario given

Component	Sub Component	Function of component/sub component
Sub-grade		

Innovation - Innovative switch design

Component	Sub Component	Function of component/sub component

Cost categories and Life Cycle Phases

Baseline case - Existing switch design - use as a basis a design which is commonly used in the scenario given

	LCC Cost block	Cost (€) per km or Cost (€) per task	Stakeholder who benefits/pays financially	When and how frequently cost occurs in life cycle (eg every 20yrs)	Dependencies (eg relationship between cost or cost frequency upon boundary condtionitions such load (MGT), traffic type, curve etc)	Source of cost data - eg financial statements, model, expert estimate, total component and labour costs	Quality of data source and where possible accuracy of data (upper and lower limits)
CAPEX	**R&D costs**						
	Investment						
	- Project preparation						
	- Investment and installation						
	-- Switch installation costs						
	--- Removal of existing switch						
	--- Transport costs and logistics of delivering new switch layout						
	--- Welding						
	--- Tamping/geometry						
	---Signalling and electrical						
	- Testing and commissioning						
	-- Inspection/quality control						
	Disposal						
	- Decommission costs						
	- Removal costs						
	- Disposal costs/recycled value (rail and ballast recycling)						
	- Residual value						
OPEX	**Operation costs (non-maintenance)**						
	- Energy						
	-Personnel						
	-Training						
	- Facilities						
	- Fees						
	- Communications						
	- Facilities						
	Maintenance costs - see RAMS template						
	- Inspection						
	-- Visual Inspection						
	-- Ultrasonic - Manual						
	-- Ultrasonic - Train based						
	-- Eddy current inspection - Train based						
	-- Track geometry - train based						
	-- Noise monitoring						
	-- Train based high speed image capture inspection						
	- Preventative/condition based maintenance						
	-- S&C adjustment						
	-- Lubrication						
	-- Grinding						
	-- Tighten/adjust stretcher bars						
	-- Adjust drive						
	- Corrective maintenance						
	-- Half set replacement						
	-- Crossing replacement						
	-- Crossing weld repair						
	-- Replace bearers						
	-- S&C tactical reballast						
	-- S&C tamping						
	-- Manual S&C geometry correction						
	-- Repair/replace switch motor and drive mechanisms						
	-- Repair/replace locking mechanisms						
	-- Repair electrical/signalling/interlocking failures						
	- Renewals						
	-- S&C renewal						
	Cost of service affecting failures/maintenance						
	- Cost of non-availability during maintenance activities						
	-- Planned maintenance						
	-- Unplanned maintenance						
	- Cost of non-availability and damage due to failures						
	-- Flooding						
	-- Signalling/electrical failures						
	-- Ice, ballast or other object between switch and stock rail preventing switch locking						
	-- Damage to switch drive from flying ballast, ice falling from vehicles						
	-- Stretcher bar failure						
	-- Derailment due to switch rail wear						

Innovation - Innovative switch design

	LCC Cost block	Cost (€) per km or Cost (€) per task	Stakeholder who benefits/pays financially	When and how frequently cost occurs in life cycle (eg every 20yrs)	Dependencies (eg relationship between cost or cost frequency upon boundary condtionitions such load (MGT), traffic type, curve etc)	Source of cost data - eg financial statements, model, expert estimate, total component and labour costs	Quality of data source and where possible accuracy of data (upper and lower limits)
CAPEX	**R&D costs**						
	Investment						
	- Project preparation						
	- Investment and installation						
	-- Switch installation costs						
	--- Removal of existing switch						
	--- Transport costs and logistics of delivering new switch layout						
	--- Welding						
	--- Tamping/geometry						
	---Signalling and electrical						
	- Testing and commissioning						
	-- Inspection/quality control						
	Disposal						
	- Decommission costs						
	- Removal costs						
	- Disposal costs/recycled value (rail and ballast recycling)						
	- Residual value						
OPEX	**Operation costs (non-maintenance)**						
	- Energy						
	-Personnel						
	-Training						
	- Facilities						
	- Fees						
	- Communications						
	- Facilities						
	Maintenance costs - see RAMS template						
	- Inspection						
	-- Visual Inspection						
	-- Ultrasonic - Manual						
	-- Ultrasonic - Train based						
	-- Eddy current inspection - Train based						
	-- Track geometry - train based						
	-- Noise monitoring						
	-- Train based high speed image capture inspection						
	- Preventative/condition based maintenance						
	-- S&C adjustment						
	-- Lubrication						
	-- Grinding						
	-- Tighten/adjust stretcher bars						
	-- Adjust drive						
	- Corrective maintenance						
	-- Half set replacement						
	-- Crossing replacement						
	-- Crossing weld repair						
	-- Replace bearers						
	-- S&C tactical reballast						
	-- S&C tamping						
	-- Manual S&C geometry correction						
	-- Repair/replace switch motor and drive mechanisms						
	-- Repair/replace locking mechanisms						
	-- Repair electrical/signalling/interlocking failures						
	- Renewals						
	-- S&C renewal						
	Cost of service affecting failures/maintenance						
	- Cost of non-availability during maintenance activities						
	-- Planned maintenance						
	-- Unplanned maintenance						
	- Cost of non-availability and damage due to failures						
	-- Flooding						
	-- Signalling/electrical failures						
	-- Ice, ballast or other object between switch and stock rail preventing switch locking						
	-- Damage to switch drive from flying ballast, ice falling from vehicles						
	-- Stretcher bar failure						
	-- Derailment due to switch rail wear						

Capacity4Rail Technology Evaluation template - LCC

Sub-project: **SP1**

Innovation: **New designs for switches resilient to extreme weather conditions**

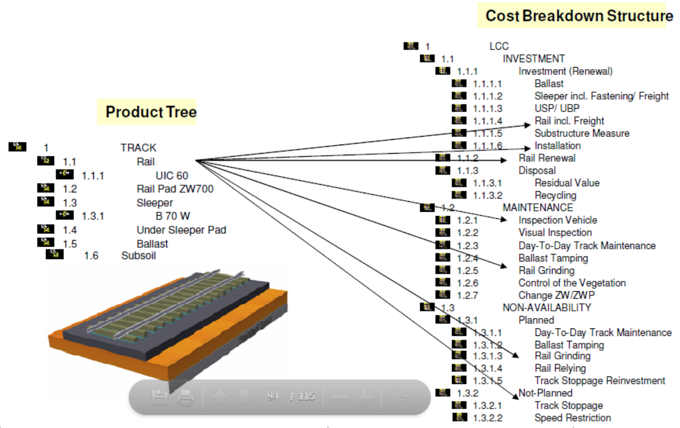
Discount rate to be used for LCC calculations [ ] %

The life cycle cost analysis will start with a product breakdown structure and will consider all of the life cycle stages from R&D through to disposal. The figure on the right shows an example product breakdown structure

R&D > Investment > Operation & Maintenance > Disposal

Life cycle phases

This sheet will mainly cover the costs from R&D, Investment (and installation), Operation and disposal. It is assumed that the majority of the maintenance data will be collected in the "RAMS data" sheet



Source: INNOTRACK - Guideline for LCC and RAMS analysis (2006)

Scenario and boundard conditions for assessment - Scenario should include extreme weather events

Product breakdown structure

Baseline case - Existing switch design - use as a basis a design which is commonly used in the scenario given

Component	**Sub Component**	**Function of component/sub component**
Sub-grade		

Innovation - Innovative switch design

Component	**Sub Component**	**Function of component/sub component**

Cost categories and Life Cycle Phases

Baseline case - Existing switch design - use as a basis a design which is commonly used in the scenario given

	LCC Cost block	Cost (€) per km or Cost (€) per task	Stakeholder who benefits/pays financially	When and how frequently cost occurs in life cycle (eg every 20yrs)	Dependencies (eg relationship between cost or cost frequency upon boundary condtionitions such load (MGT), traffic type, curve etc)	Source of cost data - eg financial statements, model, expert estimate, total component and labour costs	Quality of data source and where possible accuracy of data (upper and lower limits)
CAPEX	**R&D costs**						
	Investment						
	- Project preparation						
	- Investment and installation						
	-- Switch installation costs						
	--- Removal of existing switch						
	--- Transport costs and logistics of delivering new switch layout						
	--- Welding						
	--- Tamping/geometry						
	---Signalling and electrical						
	- Testing and commissioning						
	-- Inspection/quality control						
	Disposal						
	- Decommission costs						
	- Removal costs						
	- Disposal costs/recycled value (rail and ballast recycling)						
	- Residual value						
OPEX	**Operation costs (non-maintenance)**						
	- Energy						
	-Personnel						
	-Training						
	- Facilities						
	- Fees						
	- Communications						
	- Facilities						
	Maintenance costs - see RAMS template						
	- Inspection						
	-- Visual Inspection						
	-- Ultrasonic - Manual						
	-- Ultrasonic - Train based						
	-- Eddy current inspection - Train based						
	-- Track geometry - train based						
	-- Noise monitoring						
	-- Train based high speed image capture inspection						
	- Preventative/condition based maintenance						
	-- S&C adjustment						
	-- Lubrication						
	-- Grinding						
	-- Tighten/adjust stretcher bars						
	-- Adjust drive						
	- Corrective maintenance						
	-- Half set replacement						
	-- Crossing replacement						
	-- Crossing weld repair						
	-- Replace bearers						
	-- S&C tactical reballast						
	-- S&C tamping						
	-- Manual S&C geometry correction						
	-- Repair/replace switch motor and drive mechanisms						
	-- Repair/replace locking mechanisms						
	-- Repair electrical/signalling/interlocking failures						
	- Renewals						
	-- S&C renewal						
	Cost of service affecting failures/maintenance						
	- Cost of non-availability during maintenance activities						
	-- Planned maintenance						
	-- Unplanned maintenance						
	- Cost of non-availability and damage due to failures						
	-- Flooding						
	-- Signalling/electrical failures						
	-- Ice, ballast or other object between switch and stock rail preventing switch locking						
	-- Damage to switch drive from flying ballast, ice falling from vehicles						
	-- Stretcher bar failure						
	-- Derailment due to switch rail wear						

Innovation - Innovative switch design

	LCC Cost block	Cost (€) per km or Cost (€) per task	Stakeholder who benefits/pays financially	When and how frequently cost occurs in life cycle (eg every 20yrs)	Dependencies (eg relationship between cost or cost frequency upon boundary condtionitions such load (MGT), traffic type, curve etc)	Source of cost data - eg financial statements, model, expert estimate, total component and labour costs	Quality of data source and where possible accuracy of data (upper and lower limits)
CAPEX	**R&D costs**						
	Investment						
	- Project preparation						
	- Investment and installation						
	-- Switch installation costs						
	--- Removal of existing switch						
	--- Transport costs and logistics of delivering new switch layout						
	--- Welding						
	--- Tamping/geometry						
	---Signalling and electrical						
	- Testing and commissioning						
	-- Inspection/quality control						
	Disposal						
	- Decommission costs						
	- Removal costs						
	- Disposal costs/recycled value (rail and ballast recycling)						
	- Residual value						
OPEX	**Operation costs (non-maintenance)**						
	- Energy						
	-Personnel						
	-Training						
	- Facilities						
	- Fees						
	- Communications						
	- Facilities						
	Maintenance costs - see RAMS template						
	- Inspection						
	-- Visual Inspection						
	-- Ultrasonic - Manual						
	-- Ultrasonic - Train based						
	-- Eddy current inspection - Train based						
	-- Track geometry - train based						
	-- Noise monitoring						
	-- Train based high speed image capture inspection						
	- Preventative/condition based maintenance						
	-- S&C adjustment						
	-- Lubrication						
	-- Grinding						
	-- Tighten/adjust stretcher bars						
	-- Adjust drive						
	- Corrective maintenance						
	-- Half set replacement						
	-- Crossing replacement						
	-- Crossing weld repair						
	-- Replace bearers						
	-- S&C tactical reballast						
	-- S&C tamping						
	-- Manual S&C geometry correction						
	-- Repair/replace switch motor and drive mechanisms						
	-- Repair/replace locking mechanisms						
	-- Repair electrical/signalling/interlocking failures						
	- Renewals						
	-- S&C renewal						
	Cost of service affecting failures/maintenance						
	- Cost of non-availability during maintenance activities						
	-- Planned maintenance						
	-- Unplanned maintenance						
	- Cost of non-availability and damage due to failures						
	-- Flooding						
	-- Signalling/electrical failures						
	-- Ice, ballast or other object between switch and stock rail preventing switch locking						
	-- Damage to switch drive from flying ballast, ice falling from vehicles						
	-- Stretcher bar failure						
	-- Derailment due to switch rail wear						

Capacity4Rail Technology Evaluation template - LCC

Sub-project: **SP1**

Innovation: **Optimised S&C sensor strategies**

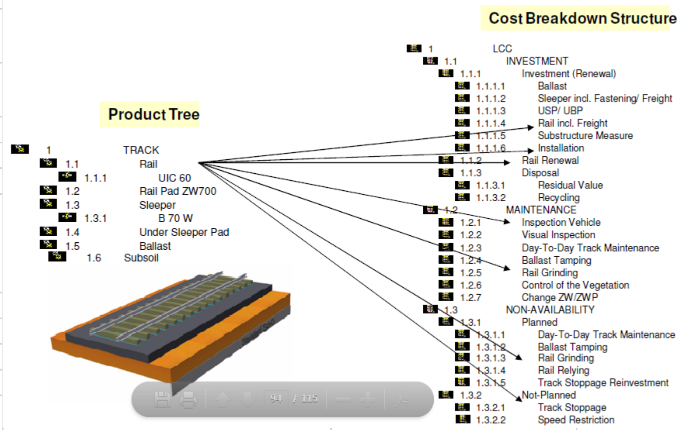
Discount rate to be used for LCC calculations ______ %

The life cycle cost analysis will start with a product breakdown structure and will consider all of the life cycle stages from R&D through to disposal. The figure on the right shows an example product breakdown structure

R&D › Investment › Operation & Maintenance › Disposal

Life cycle phases

This sheet will mainly cover the costs from R&D, Investment (and installation), Operation and disposal. It is assumed that the majority of the maintenance data will be collected in the "RAMS data" sheet



Source: INNOTRACK - Guideline for LCC and RAMS analysis (2006)

Scenario and boundard conditions for assessment - Scenario should include extreme weather events

Product breakdown structure

Baseline case - Existing switch design - with current sensor technology

Component	Sub Component	Function of component/sub component
Sub-grade		

Innovation - Switch with optimised sensor strategy

Component	Sub Component	Function of component/sub component

Cost categories and Life Cycle Phases

Baseline case - Existing switch design - with current sensor technology

	LCC Cost block	Cost (€) per km or Cost (€) per task	Stakeholder who benefits/pays financially	When and how frequently cost occurs in life cycle (eg every 20yrs)	Dependencies (eg relationship between cost or cost frequency upon boundary condtionitions such load (MGT), traffic type, curve etc)	Source of cost data - eg financial statements, model, expert estimate, total component and labour costs	Quality of data source and where possible accuracy of data (upper and lower limits)
CAPEX	R&D costs						
	Investment						
	- Project preparation						
	- Investment and installation						
	-- Switch installation costs						
	--- Removal of existing switch						
	--- Transport costs and logistics of delivering new switch layout						
	--- Welding						
	--- Tamping/geometry						
	---Signalling and electrical						
	-- Installation of sensor technology						
	- Testing and commissioning						
	-- Inspection/quality control						
	Disposal						
	- Decommission costs						
	- Removal costs						
	- Disposal costs/recycled value (rail and ballast recycling)						
	- Residual value						
OPEX	Operation costs (non-maintenance)						
	- Energy						
	-Personnel						
	-Training						
	- Facilities						
	- Fees						
	- Communications - operating costs of use of mobile networks for communication of data						
	- Data processing/analysis of data						
	- Facilities						
	Maintenance costs - see RAMS template						
	- Corrective maintenance of sensor						
	-- Repair of sensors damaged due to flying ballast, ice, moisture, fatigue, high acceleration forces,						
	- Other maintenance of sensor equipment						
	-- Battery replacement						
	-- Sensor position and realignment						
	-- Data retrieval						
	- Inspection of switch						
	-- Visual Inspection						
	-- Ultrasonic - Manual						
	-- Ultrasonic - Train based						
	-- Eddy current inspection - Train based						
	-- Track geometry - train based						
	-- Noise monitoring						
	-- Train based high speed image capture inspection						
	- Preventative/condition based maintenance of switch						
	-- S&C adjustment						
	-- Lubrication						
	-- Grinding						
	-- Tighten/adjust stretcher bars						
	-- Adjust drive						
	- Corrective maintenance of switch						
	-- Half set replacement						
	-- Crossing replacement						
	-- Crossing weld repair						
	-- Replace bearers						
	-- S&C tactical reballast						
	-- S&C tamping						
	-- Manual S&C geometry correction						
	-- Repair/replace switch motor and drive mechanisms						
	-- Repair/replace locking mechanisms						
	-- Repair electrical/signalling/interlocking failures						
	- Renewals of switch						
	-- S&C renewal						
	Cost of service affecting failures/maintenance						
	- Cost of non-availability during normal railway maintenance activities						
	-- Planned maintenance						
	-- Unplanned maintenance						
	- Cost of non-availability and damage due to failures						
	-- Cost of unavailability due to sensor failure						
	-- Repair of sensors damaged due to flying ballast, ice, moisture, fatigue, high acceleration forces,						
	-- Flooding						
	-- Signalling/electrical failures						
	-- Ice, ballast or other object between switch and stock rail preventing switch locking						
	-- Damage to switch drive from flying ballast, ice falling from vehicles						
	-- Stretcher bar failure						
	-- Derailment due to switch rail wear						

	Innovation - Switch with optimised sensor strategy						
	LCC Cost block	**Cost (€) per km or Cost (€) per task**	**Stakeholder who benefits/pays financially**	**When and how frequently cost occurs in life cycle (eg every 20yrs)**	**Dependencies (eg relationship between cost or cost frequency upon boundary condtionitions such load (MGT), traffic type, curve etc)**	**Source of cost data - eg financial statements, model, expert estimate, total component and labour costs**	**Quality of data source and where possible accuracy of data (upper and lower limits)**
CAPEX	**R&D costs**						
	Investment						
	- Project preparation						
	- Investment and installation						
	-- Switch installation costs						
	--- Removal of existing switch						
	--- Transport costs and logistics of delivering new switch layout						
	--- Welding						
	--- Tamping/geometry						
	---Signalling and electrical						
	-- Installation of sensor technology						
	- Testing and commissioning						
	-- Inspection/quality control						
	Disposal						
	- Decommission costs						
	- Removal costs						
	- Disposal costs/recycled value (rail and ballast recycling)						
	- Residual value						
OPEX	**Operation costs (non-maintenance)**						
	- Energy						
	-Personnel						
	-Training						
	- Facilities						
	- Fees						
	- Communications - operating costs of use of mobile networks for communication of data						
	- Data processing/analysis of data						
	- Facilities						
	Maintenance costs - see RAMS template						
	- Corrective maintenance of sensor						
	-- Repair of sensors damaged due to flying ballast, ice, moisture, fatigue, high acceleration forces,						
	- Other maintenance of sensor equipment						
	-- Battery replacement						
	-- Sensor position and realignment						
	-- Data retrieval						
	- Inspection of switch						
	-- Visual Inspection						
	-- Ultrasonic - Manual						
	-- Ultrasonic - Train based						
	-- Eddy current inspection - Train based						
	-- Track geometry - train based						
	-- Noise monitoring						
	-- Train based high speed image capture inspection						
	- Preventative/condition based maintenance of switch						
	-- S&C adjustment						
	-- Lubrication						
	-- Grinding						
	-- Tighten/adjust stretcher bars						
	-- Adjust drive						
	- Corrective maintenance of switch						
	-- Half set replacement						
	-- Crossing replacement						
	-- Crossing weld repair						
	-- Replace bearers						
	-- S&C tactical reballast						
	-- S&C tamping						
	-- Manual S&C geometry correction						
	-- Repair/replace switch motor and drive mechanisms						
	-- Repair/replace locking mechanisms						
	-- Repair electrical/signalling/interlocking failures						
	- Renewals of switch						
	-- S&C renewal						
	Cost of service affecting failures/maintenance						
	- Cost of non-availability during normal railway maintenance activities						
	-- Planned maintenance						
	-- Unplanned maintenance						
	- Cost of non-availability and damage due to failures						
	-- Cost of unavailability due to sensor failure						
	-- Repair of sensors damaged due to flying ballast, ice, moisture, fatigue, high acceleration forces,						
	-- Flooding						
	-- Signalling/electrical failures						
	-- Ice, ballast or other object between switch and stock rail preventing switch locking						
	-- Damage to switch drive from flying ballast, ice falling from vehicles						
	-- Stretcher bar failure						
	-- Derailment due to switch rail wear						

Capacity4Rail Technology Evaluation template - LCC

Sub-project:	**SP2**
Innovation:	**Innovations in Trains/Wagons – optimised length, speed, performance, central/automatic coupler, EP/electronic braking, electrification, automation, weight**
Discount rate to be used for LCC calculations	%

The life cycle cost analysis will start with a product breakdown structure and will consider all of the life cycle stages from R&D through to disposal. The figure on the right shows an example product breakdown structure

R&D → Investment → Operation & Maintenance → Disposal

Life cycle phases

This sheet will mainly cover the costs from R&D, Investment (and installation), Operation and disposal. It is assumed that the majority of the maintenance data will be collected in the "RAMS data" sheet

Scenario and boundard conditions for assessment

Cost categories and Life Cycle Phases

Baseline case - existing ballasted track and existing vehicles - no CAPEX

	LCC Cost block	Cost (€) per km or Cost (€) per task	Stakeholder who benefits/pays financially	When and how frequently cost occurs in life cycle (eg every 20yrs)	Dependencies (eg relationship between cost or cost frequency upon boundary condtionitions such load (MGT), traffic type, curve etc)	Source of cost data - eg financial statements, model, expert estimate, total component and labour costs	Quality of data source and where possible accuracy of data (upper and lower limits)
OPEX	**Operation costs (non-maintenance)**						
	- Traction energy						
	- Fees - track access charges						
	-Personnel						
	-Training						
	- Facilities						
	- Communications						
	- Facilities						
	Maintenance costs - see RAMS template						
	Rolling stock						
	- Inspection						
	- Preventative/condition based maintenance						
	- Corrective maintenance						
	- Rolling stock refurbishment						
	Infrastructure						
	- Inspection						
	-- Visual Inspection						
	-- Ultrasonic - Manual						
	-- Ultrasonic - Train based						
	-- Eddy current inspection - Train based						
	-- Track geometry - train based						
	-- Noise monitoring						
	- Preventative/condition based maintenance						
	-- Rail Change						
	-- Rail Transpose						
	-- Grinding						
	-- Lubrication						
	-- Fish Plate lubrication						
	-- IBJ replacement						
	-- Re-sleeper						
	-- Replace sleeper pads and insulators						
	-- Noise abatement						
	- Corrective maintenance						
	-- Rail Change - defects						
	-- Weld change - defects						
	-- Rail adjustment						
	-- Ballast reprofile						
	-- Wet bed removal						
	-- Tactical reballast						
	-- Plain line tamping						
	-- Stoneblowing						
	-- Geometry manual						
	-- replacement of pads and fasteners						
	- Renewals						
	--Rail, sleeper and Ballast renewal						
	-- Sleeper and ballast renewal						
	-- Tactical resleeper						
	--Ballast cleaning						
	- Off Track maintenance						
	-- Drainage						
	-- Fencing						
	-- Vegetation						
	Other quantifiable costs identified from S-E matrix/RAMS analysis						
	- Cost of non-availability during maintenance activities						
	-- Planned maintenance						
	-- Unplanned maintenance						

	Innovation - ballasted track with vehicle and wagon innovations						
	LCC Cost block	**Cost (€) per km or Cost (€) per task or CostCost (€) per km or Cost (€) per task or Cost per Vehicle (€) per Vehicle**	**Stakeholder who benefits/pays financially**	**When and how frequently cost occurs in life cycle (eg every 20yrs)**	**Dependencies (eg relationship between cost or cost frequency upon boundary condtionitions such load (MGT), traffic type, curve etc)**	**Source of cost data - eg financial statements, model, expert estimate, total component and labour costs**	**Quality of data source and where possible accuracy of data (upper and lower limits)**
CAPEX	**R&D costs**						
	Investment						
	- Project preparation						
	- Vehicles/Wagons						
	-- Vehicle modifications						
	-- New vehicles						
	- Infrastructure upgrades						
	- Signalling system (for longer trains)						
	-- Signalling block length						
	-- Signal position and junction layouts						
	- Other infrastructure changes to accommodate longer trains						
	- Infrastructure upgrades to gauge envelope						
	- Electrification of non-electrified infrastructure						
	- Upgrade of track and structures to carry greater load						
	Disposal						
	- Decommission costs						
	- Removal costs						
	- Disposal costs/recycled value (rail and ballast recycling)						
	- Facilities						
	- Residual value						
OPEX	**Operation costs (non-maintenance)**						
	- Energy - (cost savings in traction energy per tonne of freight)						
	- Fees - (increase in access charges to IM from improved capacity)						
	-Personnel						
	-Training						
	- Facilities						
	- Communications						
	- Facilities						
	Maintenance costs - see RAMS template - impact of greater loading, improved acceleration and braking on existing maitenance costs						
	Rolling stock						
	- Inspection						
	- Preventative/condition based maintenance						
	- Corrective maintenance						
	- Rolling stock refurbishment						
	Infrastructure						
	- Inspection						
	-- Visual Inspection						
	-- Ultrasonic - Manual						
	-- Ultrasonic - Train based						
	-- Eddy current inspection - Train based						
	-- Track geometry - train based						
	-- Noise monitoring						
	- Preventative/condition based maintenance						
	-- Rail Change						
	-- Rail Transpose						
	-- Grinding						
	-- Lubrication						
	-- Fish Plate lubrication						
	-- IBJ replacement						
	-- Re-sleeper						
	-- Replace sleeper pads and insulators						
	-- Noise abatement						
	- Corrective maintenance						
	-- Rail Change - defects						
	-- Weld change - defects						
	-- Rail adjustment						
	-- Ballast reprofile						
	-- Wet bed removal						
	-- Tactical reballast						
	-- Plain line tamping						
	-- Stoneblowing						
	-- Geometry manual						
	-- replacement of pads and fasteners						
	- Renewals						
	--Rail, sleeper and Ballast renewal						
	-- Sleeper and ballast renewal						
	-- Tactical resleeper						
	--Ballast cleaning						
	- Off Track maintenance						
	-- Drainage						
	-- Fencing						
	-- Vegetation						
	Other quantifiable costs identified from S-E matrix/RAMS analysis						
	- Cost of non-availability during maintenance activities						
	-- Planned maintenance						
	-- Unplanned maintenance						

Capacity4Rail Technology Evaluation template - LCC

Sub-project: **SP2**

Innovation: **Innovations in Freight Operation - wagon shunting, intelligence for vehicles in terminals, terminal operation**

Discount rate to be used for LCC calculations ______ %

The life cycle cost analysis will start with a product breakdown structure and will consider all of the life cycle stages from R&D through to disposal. The figure on the right shows an example product breakdown structure

R&D > Investment > Operation & Maintenance > Disposal

Life cycle phases

This sheet will mainly cover the costs from R&D, Investment (and installation), Operation and disposal. It is assumed that the majority of the maintenance data will be collected in the "RAMS data" sheet

Scenario and boundard conditions for assessment

Cost categories and Life Cycle Phases

Baseline case - existing terminal technology and existing vehicles - no CAPEX

	LCC Cost block	Cost (€) per km or Cost (€) per task, cost per tonne of Freight (€)	Stakeholder who benefits/pays financially	When and how frequently cost occurs in life cycle (eg every 20yrs)	Dependencies (eg relationship between cost or cost frequency upon boundary condtionitions such load (MGT), traffic type, curve etc)	Source of cost data - eg financial statements, model, expert estimate, total component and labour costs	Quality of data source and where possible accuracy of data (upper and lower limits)
OPEX	**Operation costs**						
	- Traction energy						
	- Fees - Freight terminal charges per tonne freight						
	-Personnel						
	-Training						
	- Facilities						
	- Communications						
	- Facilities						
	Other quantifiable costs identified from S-E matrix/RAMS analysis						
	- Cost of non-availability due						
	-- Planned maintenance						
	-- Unplanned maintenance						

Innovation - freight terminal innovations in wagon shunting, intelligent vehicles, terminal operation

	LCC Cost block	Cost (€) per km or Cost (€) per task, cost per tonne of Freight (€), cost per tonner of Freight per year	Stakeholder who benefits/pays financially	When and how frequently cost occurs in life cycle (eg every 20yrs)	Dependencies (eg relationship between cost or cost frequency upon boundary condtionitions such load (MGT), traffic type, curve etc)	Source of cost data - eg financial statements, model, expert estimate, total component and labour costs	Quality of data source and where possible accuracy of data (upper and lower limits)
CAPEX	**R&D costs**						
	Investment						
	- Vehicles/Wagons						
	-- Wagon modifications and shunting vehicles						
	-- Shunting vehicles						
	- Infrastructure upgrades						
	- Upgrade of terminal layout						
	- Loading and unloading equipment						
OPEX	**Operation costs (non-maintenance)**						
	- Traction energy						
	- Fees - Freight terminal charges per tonne freight						
	-Personnel						
	-Training						
	- Facilities						
	- Communications						
	- Facilities						
	Other quantifiable costs identified from S-E matrix/RAMS analysis						
	- Cost of non-availability due						
	-- Planned maintenance						
	-- Unplanned maintenance						

Capacity4Rail Technology Evaluation template - LCC

Sub-project: **SP3**

Innovation: **Optimised strategies to manage major disturbances**

Discount rate to be used for LCC calculations [ ] %

The life cycle cost analysis will start with a product breakdown structure and will consider all of the life cycle stages from R&D through to disposal. The figure on the right shows an example product breakdown structure

R&D > Investment > Operation & Maintenance > Disposal

Life cycle phases

This sheet will mainly cover the costs from R&D, Investment (and installation), Operation and disposal. It is assumed that the majority of the maintenance data will be collected in the "RAMS data" sheet

Scenario and boundard conditions for assessment

Cost categories and Life Cycle Phases

Baseline case - existing ballasted track and existing vehicles - no CAPEX

	LCC Cost block	Cost (€) per km or Cost (€) per task	Stakeholder who benefits/pays financially	When and how frequently cost occurs in life cycle (eg every 20yrs)	Dependencies (eg relationship between cost or cost frequency upon boundary condtionitions such load (MGT), traffic type, curve etc)	Source of cost data - eg financial statements, model, expert estimate, total component and labour costs	Quality of data source and where possible accuracy of data (upper and lower limits)
OPEX	**Operation costs (non-maintenance)**						
	- Traction energy						
	- Fees - track access charges						
	-Personnel						
	-Training						
	- Facilities						
	- Communications						
	- Facilities						
	Other quantifiable costs identified from S-E matrix/RAMS analysis						
	- Cost of non-availability during maintenance activities						
	-- Planned maintenance						
	-- Unplanned maintenance						

Baseline case - ballasted track with vehicle and wagon innovations

	LCC Cost block	Cost (€) per km or Cost (€) per task or CostCost (€) per km or Cost (€) per task or Cost per Vehicle (€) per Vehicle	Stakeholder who benefits/pays financially	When and how frequently cost occurs in life cycle (eg every 20yrs)	Dependencies (eg relationship between cost or cost frequency upon boundary condtionitions such load (MGT), traffic type, curve etc)	Source of cost data - eg financial statements, model, expert estimate, total component and labour costs	Quality of data source and where possible accuracy of data (upper and lower limits)
OPEX	**Operation costs (non-maintenance)**						
	- Energy - (cost savings in traction energy per tonne of freight)						
	- Fees - (increase in access charges to IM from improved capacity)						
	-Personnel						
	-Training						
	- Facilities						
	- Communications						
	- Facilities						
	Other quantifiable costs identified from S-E matrix/RAMS analysis						
	- Cost of non-availability during maintenance activities						
	-- Planned maintenance						
	-- Unplanned maintenance						

Capacity4Rail Technology Evaluation template - LCC

Sub-project: **SP4**

Innovation: **New concepts and technologies for advanced monitoring in embankments, bridges, different track types, switches etc**

Discount rate to be used for LCC calculations [ ] %

The life cycle cost analysis will start with a product breakdown structure and will consider all of the life cycle stages from R&D through to disposal. The figure on the right shows an example product breakdown structure

R&D > Investment > Operation & Maintenance > Disposal

Life cycle phases

This sheet will mainly cover the costs from R&D, Investment (and installation), Operation and disposal. It is assumed that the majority of the maintenance data will be collected in the "RAMS data" sheet

Scenario and boundard conditions for assessment - Scenario should include extreme weather events

Cost categories and Life Cycle Phases

Baseline case - Track design - with current sensor technology

	LCC Cost block	Cost (€) per km or Cost (€) per task	Stakeholder who benefits/pays financially	When and how frequently cost occurs in life cycle (eg every 20yrs)	Dependencies (eg relationship between cost or cost frequency upon boundary condtionitions such load (MGT), traffic type, curve etc)	Source of cost data - eg financial statements, model, expert estimate, total component and labour costs	Quality of data source and where possible accuracy of data (upper and lower limits)
CAPEX	**R&D costs**						
	Investment						
	- Project preparation						
	- Investment and installation						
	-- Installation of sensor technology and associated cabling and communication infrastructure						
	- Testing and commissioning						
	-- Inspection/quality control						
	Disposal						
	- Decommission costs						
	- Removal costs						
	- Disposal costs/recycled value						
	- Residual value						
OPEX	**Operation costs (non-maintenance)**						
	- Energy						
	-Personnel						
	-Training						
	- Facilities						
	- Fees						
	- Communications - operating costs of use of mobile networks for communication of data						
	- Data processing/data analysis						
	- Facilities						
	Maintenance costs - see RAMS template						
	Sensor						
	- Corrective maintenance of sensor						
	-- Repair of sensors damaged due to flying ballast, ice, moisture, fatigue, high acceleration forces,						
	- Other maintenance of sensor equipment						
	-- Battery replacement						
	-- Sensor position and realignment						
	-- Data retrieval						
	Track						
	- Inspection of track						
	-- Visual Inspection						
	-- Ultrasonic - Manual						
	-- Ultrasonic - Train based						
	-- Eddy current inspection - Train based						
	-- Track geometry - train based						
	-- Noise monitoring						
	- Preventative/condition based track maintenance						
	-- Rail Change						
	-- Rail Transpose						
	-- Grinding						
	-- Lubrication						
	-- Fish Plate lubrication						
	-- IBJ replacement						
	-- Re-sleeper						
	-- Replace sleeper pads and insulators						
	-- Noise abatement						
	- Corrective track maintenance						
	-- Rail Change - defects						
	-- Weld change - defects						
	-- Rail adjustment						
	-- Ballast reprofile						
	-- Wet bed removal						
	-- Tactical reballast						
	-- Plain line tamping						
	-- Stoneblowing						
	-- Geometry manual						
	-- replacement of pads and fasteners						
	- Off Track maintenance						
	-- Drainage						
	-- Fencing						
	-- Vegetation						
	Switch						
	- Inspection of switch						
	-- Visual Inspection						
	-- Ultrasonic - Manual						
	-- Ultrasonic - Train based						
	-- Eddy current inspection - Train based						
	-- Track geometry - train based						
	-- Noise monitoring						
	-- Train based high speed image capture inspection						
	- Preventative/condition based maintenance of switch						
	-- S&C adjustment						
	-- Lubrication						
	-- Grinding						
	-- Tighten/adjust stretcher bars						
	-- Adjust drive						
	- Corrective maintenance of switch						
	-- Half set replacement						
	-- Crossing replacement						
	-- Crossing weld repair						
	-- Replace bearers						
	-- S&C tactical reballast						
	-- S&C tamping						
	-- Manual S&C geometry correction						
	-- Repair/replace switch motor and drive mechanisms						
	-- Repair/replace locking mechanisms						
	-- Repair electrical/signalling/interlocking failures						
	Bridges						
	- Inspection of bridge						
	-- Visual Inspection						
	-- Bridge monitoring eg optical monitoring of movement						
	-- Other bridge inspection						
	- Predictive/conditin based maintenance						
	-- Bridge strengthening - eg fibre reinforment, steel reinforment, spray concrete etc						
	Embankements						
	- Embankment inspection						
	-- Visual inspection						
	-- Embankment movement monitoring						
	- Embankment stabalisation						
	-- Geotextiles						
	-- Concrete piles						
	- Renewals						
	--Rail, sleeper and Ballast renewal						
	-- Sleeper and ballast renewal						
	-- Tactical resleeper						
	--Ballast cleaning						
	- Renewals of switch						
	-- S&C renewal						
	- Renewals of bridge platform						
	Cost of service affecting failures/maintenance						
	- Cost of non-availability during normal railway maintenance activities						
	-- Planned maintenance						
	-- Unplanned maintenance						
	- Cost of non-availability and damage due to failures						
	-- Cost of unavailability due to sensor failure						
	-- Repair of sensors damaged due to flying ballast, ice, moisture, fatigue, high acceleration forces,						

Innovation - Optimised sensor, communication and data strategy

	LCC Cost block	Cost (€) per km or Cost (€) per task	Stakeholder who benefits/pays financially	When and how frequently cost occurs in life cycle (eg every 20yrs)	Dependencies (eg relationship between cost or cost frequency upon boundary condtionitions such load (MGT), traffic type, curve etc)	Source of cost data - eg financial statements, model, expert estimate, total component and labour costs	Quality of data source and where possible accuracy of data (upper and lower limits)
CAPEX	**R&D costs**						
	Investment						
	- Project preparation						
	- Investment and installation						
	-- Installation of sensor technology and associated cabling and communication infrastructure						
	- Testing and commissioning						
	-- Inspection/quality control						
	Disposal						
	- Decommission costs						
	- Removal costs						
	- Disposal costs/recycled value						
	- Residual value						
OPEX	**Operation costs (non-maintenance)**						
	- Energy						
	-Personnel						
	-Training						
	- Facilities						
	- Fees						
	- Communications - operating costs of use of mobile networks for communication of data						
	- Data processing/data analysis						
	- Facilities						
	Maintenance costs - see RAMS template						
	Sensor						
	- Corrective maintenance of sensor						
	-- Repair of sensors damaged due to flying ballast, ice, moisture, fatigue, high acceleration forces,						
	- Other maintenance of sensor equipment						
	-- Battery replacement						
	-- Sensor position and realignment						
	-- Data retrieval						
	Track						
	- Inspection of track						
	-- Visual Inspection						
	-- Ultrasonic - Manual						
	-- Ultrasonic - Train based						
	-- Eddy current inspection - Train based						
	-- Track geometry - train based						
	-- Noise monitoring						
	- Preventative/condition based track maintenance						
	-- Rail Change						
	-- Rail Transpose						
	-- Grinding						
	-- Lubrication						
	-- Fish Plate lubrication						
	-- IBJ replacement						
	-- Re-sleeper						
	-- Replace sleeper pads and insulators						
	-- Noise abatement						
	- Corrective track maintenance						
	-- Rail Change - defects						
	-- Weld change - defects						
	-- Rail adjustment						
	-- Ballast reprofile						
	-- Wet bed removal						
	-- Tactical reballast						
	-- Plain line tamping						
	-- Stoneblowing						
	-- Geometry manual						
	-- replacement of pads and fasteners						
	- Off Track maintenance						
	-- Drainage						
	-- Fencing						
	-- Vegetation						
	Switch						
	- Inspection of switch						
	-- Visual Inspection						
	-- Ultrasonic - Manual						
	-- Ultrasonic - Train based						
	-- Eddy current inspection - Train based						
	-- Track geometry - train based						
	-- Noise monitoring						
	-- Train based high speed image capture inspection						
	- Preventative/condition based maintenance of switch						
	-- S&C adjustment						
	-- Lubrication						
	-- Grinding						
	-- Tighten/adjust stretcher bars						
	-- Adjust drive						
	- Corrective maintenance of switch						
	-- Half set replacement						
	-- Crossing replacement						
	-- Crossing weld repair						
	-- Replace bearers						
	-- S&C tactical reballast						
	-- S&C tamping						
	-- Manual S&C geometry correction						
	-- Repair/replace switch motor and drive mechanisms						
	-- Repair/replace locking mechanisms						
	-- Repair electrical/signalling/interlocking failures						
	Bridges						
	- Inspection of bridge						
	-- Visual Inspection						
	-- Bridge monitoring eg optical monitoring of movement						
	-- Other bridge inspection						
	- Predictive/conditin based maintenance						
	-- Bridge strengthening - eg fibre reinforment, steel reinforment, spray concrete etc						
	Embankements						
	- Embankment inspection						
	-- Visual inspection						
	-- Embankment movement monitoring						
	- Embankment stabalisation						
	-- Geotextiles						
	-- Concrete piles						
	- Renewals						
	--Rail, sleeper and Ballast renewal						
	-- Sleeper and ballast renewal						
	-- Tactical resleeper						
	--Ballast cleaning						
	- Renewals of switch						
	-- S&C renewal						
	- Renewals of bridge platform						
	Cost of service affecting failures/maintenance						
	- Cost of non-availability during normal railway maintenance activities						
	-- Planned maintenance						
	-- Unplanned maintenance						
	- Cost of non-availability and damage due to failures						
	-- Cost of unavailability due to sensor failure						
	-- Repair of sensors damaged due to flying ballast, ice, moisture, fatigue, high acceleration forces,						

Appendix 3 - LCA Templates

Capacity4Rail Technology Evaluation template - LCA

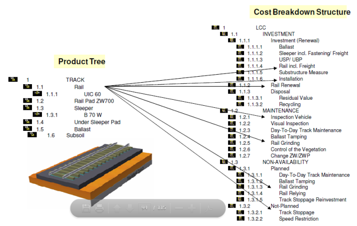
Sub-project: **SP1**

Innovation: **New Concepts based on modular slab track - slab track evaluated against ballasted track**

The life cycle analysis will start with a product breakdown structure and will consider all of the life cycle stages through to disposal. The figure on the right shows an example product breakdown structure

R&D	Investment	Operation & Maintenance	Disposal

Life cycle phases



Scenario and boundard conditions for assessment

Product breakdown structure

Baseline case - ballasted track

			Noise			Lifespan		Reference unit		Materials			Climate change emissions (kg)				Air pollution emissions (kg)			
Component	**Sub Component**	**Description of component/sub component**	**Baseline noise performance** (within scenario - dB(A))	**Key components** (contribution to noise)		**Value**	**Unit** [MGT, years]	**Value**	**Unit** [km, each, ...]	**Type of material** (e.g. steel, concrete, copper, ...)	**Quantity**	**Unit** (e.g. t, kg, m^3, ...)	**CO_2** Carbon dioxide	**CH_4** Methane	**N_2O** Nitrous Oxide	**CO_2e** 1x CO_2 34x CH_4 298x N_2O	**SO_2** Sulphur dioxide	**NO_x** Nitrogen oxides	**PM_{10}** Particulate matter	**NMVOC** Non-methane Volatile Organic Compounds
					Material manufacturing															

Innovation - Optimised sensor, communication and data strategy

			Noise			Lifespan		Reference unit		Materials			Material climate change emissions (kg)				Material air pollution emissions (kg)			
Component	**Sub Component**	**Description of component/sub component**	**Innovation noise performance** (within scenario - dB(A))	**Key components** (contribution to noise)		**Value**	**Unit** [MGT, years]	**Value**	**Unit**	**Type of material** (e.g. steel, concrete, copper, ...)	**Quantity**	**Unit** (e.g. t, kg, m^3, ...)	**CO_2** Carbon dioxide	**CH_4** Methane	**N_2O** Nitrous Oxide	**CO_2e** 1x CO_2 34x CH_4 298x N_2O	**SO_2** Sulphur dioxide	**NO_x** Nitrogen oxides	**PM_{10}** Particulate matter	**NMVOC** Non-methane Volatile Organic Compounds
					Material manufacturing															

Baseline case - ballasted track

			Transport and logistics						Construction and maintenance								Operation		Data			Emission factors								Data	
				Vehicle characteristics			Production		Machinery characteristics					Production			Production					Climate change emissions (kg/unit)				Air pollution emissions (kg/unit)					
	LCA block	**Reference unit** (e.g. km, m^3, tonne, train, wagon, terminal...)	**Transport mode**	**Load capacity** (tonnes)	**Fuel consumption** (e.g l/100 km)	**Energy consumption** (e.g kWh)	**Distance travelled** (Km)	**Activity time** (Hours)	**Equipment**	**Production** (e.g. tonnes/h, m3/h, km/h...)	**Power** (kW, hp)	**Fuel consumption** (e.g l/100 km)	**Energy consumption** (e.g kWh)	**Quantity**	**Unit** (e.g. tonnes, km...)	**Working time** (hours)	**Energy** (Direct use of energy in task, processing)	**Utilisation rate (%)**	**Dependencies** (eg relationship between frequency of task upon boundary conditions such as load (MGT), traffic type, curve etc)	**Source of data** eg carbon reporting statements, model, expert estimate	**Quality of data source** and where possible **accuracy of data** (upper and lower limits)	**CO_2** Carbon dioxide	**CH_4** Methane	**N_2O** Nitrous Oxide	**CO_2e** 1x CO_2 34x CH_4 298x N_2O	**SO_2** Sulphur dioxide	**NO_x** Nitrogen oxides	**PM_{10}** Particulate matter	**NMVOC** Non-methane Volatile Organic Compounds	**Source of data** eg carbon reporting statements, model, expert estimate	**Quality of data source** and where possible **accuracy of data** (upper and lower limits)
Infrastructure embedded carbon	**Investment/Construction** **- Project preparation** **- Inputted Residual value** **- Investment and installation** -- Ground preparation - geotechnical and civil --- Site investigation --- Soil substitution --- Reinforcement --- Subgrade layers --- Drainage -- Track laying - track work --- Ballast --- Pads --- Sleepers --- Fastenings --- Rail --- Welding --- Tamping --- Dynamic stabilisation --- Initial grinding **- Testing and commissioning** -- Inspection/quality control																														
	Disposal - Decommission/removal works - Disposal costs/recycled value (rail and ballast recycling) - Facilities																														
Operational carbon	**Operation activities (non-maintenance)** - Traction energy - Personnel - transport - Facilities																														
	Maintenance activities (see RAMS template) **- Inspection** -- Visual Inspection -- Ultrasonic - Manual -- Ultrasonic - Train based -- Eddy current inspection - Train based -- Track geometry - train based -- Dynamic track behaviour - train based -- Noise monitoring **- Preventive/condition based maintenance** -- Rail Change -- Rail Transpose -- Grinding -- Lubrication -- Fish Plate lubrication -- IBJ replacement -- Re-sleeper -- Replace sleeper pads and insulators -- Noise abatement -- Re-fastening systems **- Corrective maintenance** -- Rail Change - defects -- Weld change - defects -- Rail adjustment -- Ballast reprofile -- Wet bed removal -- Tactical reballast -- Plain line tamping -- Stoneblowing -- Geometry manual -- replacement of pads and fasteners **- Renewals** --Rail, sleeper and Ballast renewal -- Sleeper and ballast renewal -- Tactical resleeper -- Ballast cleaning **- Off Track maintenance** -- Drainage -- Fencing -- Embankments -- Civil structures (flyovers, underpass) -- Vegetation																														

Innovation - innovative slab track

			Transport and logistics							Construction and maintenance							Operation		Data			Emission factors								Data	
			Vehicle characteristics				Production			Machinery characteristics				Production			Production					Climate change emissions (kg/unit)				Air pollution emissions (kg/unit)					
	LCA block	**Reference unit** (e.g. km, m^3, tonne, train, wagon, terminal...)	**Transport mode**	**Load capacity** (tonnes)	**Fuel consumption** (e.g l/100 km)	**Energy consumption** (e.g kWh)	**Distance travelled** (Km)	**Activity time** (Hours)	**Equipment**	**Production** (e.g. tonnes/h, m3/h, km/h...)	**Power** (kW, hp)	**Fuel consumption** (e.g l/100 km)	**Energy consumption** (e.g kWh)	**Quantity**	**Unit** (e.g. tonnes, km...)	**Working time** (hours)	**Energy** (Direct use of energy in task, processing)	**Utilisation rate (%)**	**Dependencies** (eg relationship between frequency of task upon boundary conditions such as load (MGT), traffic type, curve etc)	**Source of data** eg carbon reporting statements, model, expert estimate	**Quality of data source** and where possible **accuracy of data** (upper and lower limits)	**CO_2** Carbon dioxide	**CH_4** Methane	**N_2O** Nitrous Oxide	**CO_2e** 1x CO_2 34x CH_4 298x N_2O	**SO_2** Sulphur dioxide	**NO_x** Nitrogen oxides	**PM_{10}** Particulate matter	**NMVOC** Non-methane Volatile Organic Compounds	**Source of data** eg carbon reporting statements, model, expert estimate	**Quality of data source** and where possible **accuracy of data** (upper and lower limits)
Infrastructure embedded carbon	**Investment/Construction** **- Project preparation** **- Inputted Residual value** **- Investment and installation** -- Ground preparation - geotechnical --- Site investigation --- Soil substitution --- Reinforcement --- Subgrade layers --- Drainage -- Slab positioning - Civil work --- Concrete sublayer --- Connector / stoppers --- Slab laying --- Positioning --- Mortar / Fix the slab --- Inspection / Quality control -- Track laying - Track work --- Rail laying --- Pads --- Sleepers --- Fastenings --- Clip/screw fastenings --- Welding --- Initial grinding **- Testing and commissioning** -- Inspection/quality control																														
	Disposal - Decommission/removal works - Disposal costs/recycled value (rail and C&DW aggregates recycling) - Facilities																														
Operational carbon	**Operation activities (non-maintenance)** - Traction energy - Personnel - transport - Facilities																														
	Maintenance activities (see RAMS template) **- Inspection** -- Visual Inspection -- Ultrasonic - Manual -- Ultrasonic - Train based -- Eddy current inspection - Train based -- Track geometry - train based -- Dynamic track behaviour - train based -- Slab monitoring for cracks and movement -- Noise monitoring **- Preventive/condition based maintenance** -- Rail Change -- Rail Transpose -- Grinding -- Lubrication -- Fish Plate lubrication -- IBJ replacement -- Re-sleeper -- Replace rail pads and insulators -- Noise abatement **- Corrective maintenance** -- Rail Change - defects -- Weld change - defects -- Rail adjustment -- Maintain drainage -- Adjust fastening system for small defects -- replacement of pads and fasteners -- Correct cracks in slab --- Replace slab - in case of derailment or accident (major damage) --- Inject resin to protect steel -- Correct settlement of slab --- Inject cement or other products under slab --- Expansive foam treatment --- Micro piles **- Renewals** -- Slab replacement -- Rail+pad+fasteners replacement -- Rail + pad replacement only -- Replace drainage system **- Off Track maintenance** -- Drainage -- Fencing -- Embankments -- Civil structures (flyovers, underpass) -- Vegetation																														

C4R Capacity for Rail

Capacity4Rail Technology Evaluation template - LCA

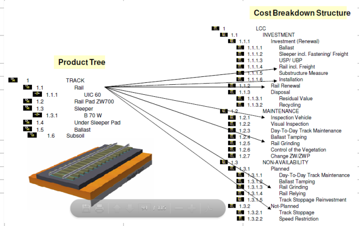
Sub-project: SP1

Innovation: New Concepts based on modular slab track - innovative slab track evaluated against existing slab track

The life cycle analysis will start with a product breakdown structure and will consider all of the life cycle stages through to disposal. The figure on the right shows an example product breakdown structure

R&D › Investment › Operation & Maintenance › Disposal

Life cycle phases



Source: INNOTRACK - Guideline for LCC and RAMS analysis (2006)

Scenario and boundard conditions for assessment

Product breakdown structure

Baseline - existing slab track / **Innovation - Innovative modular slab track**

			Noise			Lifespan		Reference unit		Materials			Climate change emissions (kg)				Air pollution emissions (kg)			
Component	**Sub Component**	**Description of component/sub component**	**Baseline noise performance** (within scenario - dB(A))	**Key components** (contribution to noise)		**Value**	**Unit** [MGT, years]	**Value**	**Unit** [km, each, ...]	**Type of material** (e.g. steel, concrete, copper, ...)	**Quantity**	**Unit** (e.g. t, kg, m^3, ...)	**CO_2** Carbon dioxide	**CH_4** Methane	**N_2O** Nitrous Oxide	**CO_2e** 1x CO_2 34x CH_4 298x N_2O	**SO_2** Sulphur dioxide	**NO_x** Nitrogen oxides	**PM_{10}** Particulate matter	**NMVOC** Non-methane Volatile Organic Compounds
					Material manufacturing															

Innovation - Optimised sensor, communication and data strategy

			Noise			Lifespan		Reference unit		Materials			Material climate change emissions (kg)				Material air pollution emissions (kg)			
Component	**Sub Component**	**Description of component/sub component**	**Innovation noise performance** (within scenario - dB(A))	**Key components** (contribution to noise)		**Value**	**Unit** [MGT, years]	**Value**	**Unit**	**Type of material** (e.g. steel, concrete, copper, ...)	**Quantity**	**Unit** (e.g. t, kg, m^3, ...)	**CO_2** Carbon dioxide	**CH_4** Methane	**N_2O** Nitrous Oxide	**CO_2e** 1x CO_2 34x CH_4 298x N_2O	**SO_2** Sulphur dioxide	**NO_x** Nitrogen oxides	**PM_{10}** Particulate matter	**NMVOC** Non-methane Volatile Organic Compounds
					Material manufacturing															

Baseline - existing slab track

			Transport and logistics								Construction and maintenance						Operation		Data					Emission factors						Data	
				Vehicle characteristics			Production				Machinery characteristics				Production		Production						Climate change emissions (kg/unit)				Air pollution emissions (kg/unit)				
	LCA block	**Reference unit** (e.g. km, m^3, tonne, train, wagon, terminal...)	**Transport mode**	**Load capacity** (tonnes)	**Fuel consumption** (e.g l/100 km)	**Energy consumption** (e.g kWh)	**Distance travelled** (Km)	**Activity time** (Hours)	**Equipment**	**Production** (e.g. tonnes/h, m3/h, km/h...)	**Power** (kW, hp)	**Fuel consumption** (e.g l/100 km)	**Energy consumption** (e.g kWh)	**Quantity**	**Unit** (e.g. tonnes, km...)	**Working time** (hours)	**Energy** (Direct use of energy in task, processing)	**Utilisation rate (%)**	**Dependencies** (eg relationship between frequency of task upon boundary conditions such as load (MGT), traffic type, curve etc)	**Source of data** eg carbon reporting statements, model, expert estimate	**Quality of data source** and where possible **accuracy of data** (upper and lower limits)	**CO_2** Carbon dioxide	**CH_4** Methane	**N_2O** Nitrous Oxide	**CO_2e** 1x CO_2 34x CH_4 298x N_2O	**SO_2** Sulphur dioxide	**NO_x** Nitrogen oxides	**PM_{10}** Particulate matter	**NMVOC** Non-methane Volatile Organic Compounds	**Source of data** eg carbon reporting statements, model, expert estimate	**Quality of data source** and where possible **accuracy of data** (upper and lower limits)
Infrastructure embedded carbon	**Investment/Construction**																														
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	-- Embankments																														
	-- Civil structures (flyovers, underpass)																														
	-- Vegetation																														

Innovation - Innovative slab track

			Transport and logistics						Construction and maintenance								Operation		Data			Emission factors								Data	
			Vehicle characteristics				Production		Machinery characteristics					Production			Production					Climate change emissions (kg/unit)				Air pollution emissions (kg/unit)					
	LCA block	**Reference unit** (e.g. km, m^3, tonne, train, wagon, terminal...)	**Transport mode**	**Load capacity** (tonnes)	**Fuel consumption** (e.g l/100 km)	**Energy consumption** (e.g kWh)	**Distance travelled** (Km)	**Activity time** (Hours)	**Equipment**	**Production** (e.g. tonnes/h, m3/h, km/h...)	**Power** (kW, hp)	**Fuel consumption** (e.g l/100 km)	**Energy consumption** (e.g kWh)	**Quantity**	**Unit** (e.g. tonnes, km...)	**Working time** (hours)	**Energy** (Direct use of energy in task, processing)	**Utilisation rate (%)**	**Dependencies** (eg relationship between frequency of task upon boundary conditions such as load (MGT), traffic type, curve etc)	**Source of data** eg carbon reporting statements, model, expert estimate	**Quality of data source** and where possible **accuracy of data** (upper and lower limits)	**CO_2** Carbon dioxide	**CH_4** Methane	**N_2O** Nitrous Oxide	**CO_2e** 1x CO_2 34x CH_4 298x N_2O	**SO_2** Sulphur dioxide	**NO_x** Nitrogen oxides	**PM_{10}** Particulate matter	**NMVOC** Non-methane Volatile Organic Compounds	**Source of data** eg carbon reporting statements, model, expert estimate	**Quality of data source** and where possible **accuracy of data** (upper and lower limits)
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OPEX	**Operation activities (non-maintenance)**																														
	- Traction energy																														
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Capacity4Rail Technology Evaluation template - LCA

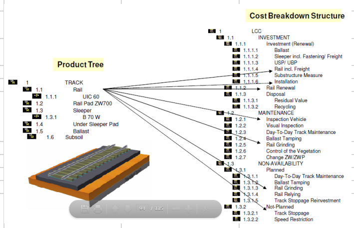
Sub-project: **SP1**

Innovation: **New track designs and specifications for very high speed lines (if innovation slab track)**

The life cycle analysis will start with a product breakdown structure and will consider all of the life cycle stages through to disposal. The figure on the right shows an example product breakdown structure

R&D > Investment > Operation & Maintenance > Disposal

Life cycle phases



Source: INNOTRACK - Guideline for LCC and RAMS analysis (2006)

Scenario and boundard conditions for assessment

Product breakdown structure

Baseline case - ballasted track

Innovation - Innovative modular slab track

			Noise			Lifespan		Reference unit			Materials		Climate change emissions (kg)				Air pollution emissions (kg)			
Component	**Sub Component**	**Description of component/sub component**	**Baseline noise performance** (within scenario - dB(A))	**Key components** (contribution to noise)		**Value**	**Unit** [MGT, years]	**Value**	**Unit** [km, each, ...]	**Type of material** (e.g. steel, concrete, copper, ...)	**Quantity**	**Unit** (e.g. t, kg, m^3, ...)	**CO_2** Carbon dioxide	**CH_4** Methane	**N_2O** Nitrous Oxide	**CO_2e** 1x CO_2 34x CH_4 298x N_2O	**SO_2** Sulphur dioxide	**NO_x** Nitrogen oxides	**PM_{10}** Particulate matter	**NMVOC** Non-methane Volatile Organic Compounds
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Innovation - Optimised sensor, communication and data strategy

			Noise			Lifespan		Reference unit			Materials		Material climate change emissions (kg)				Material air pollution emissions (kg)			
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					Material manufacturing															

Baseline case - ballasted track

			Transport and logistics						Construction and maintenance							Operation		Data			Emission factors								Data	
			Vehicle characteristics				Production		Machinery characteristics					Production			Production					Climate change emissions (kg/unit)				Air pollution emissions (kg/unit)					
	LCA block	**Reference unit** (e.g. km, m^3, tonne, train, wagon, terminal...)	**Transport mode**	**Load capacity** (tonnes)	**Fuel consumption** (e.g l/100 km)	**Energy consumption** (e.g kWh)	**Distance travelled** (Km)	**Activity time** (Hours)	**Equipment**	**Production** (e.g. tonnes/h, m3/h, km/h...)	**Power** (kW, hp)	**Fuel consumption** (e.g l/100 km)	**Energy consumption** (e.g kWh)	**Quantity**	**Unit** (e.g. tonnes, km...)	**Working time** (hours)	**Energy** (Direct use of energy in task, processing)	**Utilisation rate (%)**	**Dependencies** (eg relationship between frequency of task upon boundary conditions such as load (MGT), traffic type, curve etc)	**Source of data** eg carbon reporting statements, model, expert estimate	**Quality of data source** and where possible **accuracy of data** (upper and lower limits)	**CO_2** Carbon dioxide	**CH_4** Methane	**N_2O** Nitrous Oxide	**CO_2e** 1x CO_2 34x CH_4 298x N_2O	**SO_2** Sulphur dioxide	**NO_x** Nitrogen oxides	**PM_{10}** Particulate matter	**NMVOC** Non-methane Volatile Organic Compounds	**Source of data** eg carbon reporting statements, model, expert estimate	**Quality of data source** and where possible **accuracy of data** (upper and lower limits)
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Innovation - Innovative modular slab track

			Transport and logistics						Construction and maintenance								Operation		Data			Emission factors								Data	
			Vehicle characteristics				Production		Machinery characteristics					Production			Production					Climate change emissions (kg/unit)				Air pollution emissions (kg/unit)					
	LCA block	**Reference unit** (e.g. km, m^3, tonne, train, wagon, terminal...)	**Transport mode**	**Load capacity** (tonnes)	**Fuel consumption** (e.g l/100 km)	**Energy consumption** (e.g kWh)	**Distance travelled** (Km)	**Activity time** (Hours)	**Equipment**	**Production** (e.g. tonnes/h, m3/h, km/h...)	**Power** (kW, hp)	**Fuel consumption** (e.g l/100 km)	**Energy consumption** (e.g kWh)	**Quantity**	**Unit** (e.g. tonnes, km...)	**Working time** (hours)	**Energy** (Direct use of energy in task, processing)	**Utilisation rate (%)**	**Dependencies** (eg relationship between frequency of task upon boundary conditions such as load (MGT), traffic type, curve etc)	**Source of data** eg carbon reporting statements, model, expert estimate	**Quality of data source** and where possible **accuracy of data** (upper and lower limits)	**CO_2** Carbon dioxide	**CH_4** Methane	**N_2O** Nitrous Oxide	**CO_2e** 1x CO_2 34x CH_4 298x N_2O	**SO_2** Sulphur dioxide	**NO_x** Nitrogen oxides	**PM_{10}** Particulate matter	**NMVOC** Non-methane Volatile Organic Compounds	**Source of data** eg carbon reporting statements, model, expert estimate	**Quality of data source** and where possible **accuracy of data** (upper and lower limits)
Infrastructure embedded carbon	**Investment/Construction**																														
	- Project preparation																														
	- Inputted Residual value																														
	- Investment and installation																														
	-- Ground preparation - geotechnical																														
	--- Site investigation																														
	--- Soil substitution																														
	--- Reinforcement																														
	--- Subgrade layers																														
	--- Drainage																														
	-- Slab positioning - Civil work																														
	--- Concrete sublayer																														
	--- Connector / stoppers																														
	--- Slab laying																														
	--- Positioning																														
	--- Mortar / Fix the slab																														
	--- Inspection / Quality control																														
	-- Track laying - Track work																														
	--- Rail laying																														
	--- Pads																														
	--- Sleepers																														
	--- Fastenings																														
	--- Clip/screw fastenings																														
	--- Welding																														
	--- Initial grinding																														
	- Testing and commissioning																														
	-- Inspection/quality control																														
	Disposal																														
	- Decommission/removal works																														
	- Disposal costs/recycled value (rail and C&DW aggregates recycling)																														
	- Facilities																														
Operational carbon	**Operation activities (non-maintenance)**																														
	- Traction energy																														
	-Personnel - transport																														
	- Facilities																														
	Maintenance activities (see RAMS template)																														
	- Inspection																														
	-- Visual Inspection																														
	-- Ultrasonic - Manual																														
	-- Ultrasonic - Train based																														
	-- Eddy current inspection - Train based																														
	-- Track geometry - train based																														
	-- Dynamic track behaviour - train based																														
	-- Slab monitoring for cracks and movement																														
	-- Noise monitoring																														
	- Preventive/condition based maintenance																														
	-- Rail Change																														
	-- Rail Transpose																														
	-- Grinding																														
	-- Lubrication																														
	-- Fish Plate lubrication																														
	-- IBJ replacement																														
	-- Re-sleeper																														
	-- Replace rail pads and insulators																														
	-- Noise abatement																														
	- Corrective maintenance																														
	-- Rail Change - defects																														
	-- Weld change - defects																														
	-- Rail adjustment																														
	-- Maintain drainage																														
	-- Adjust fastening system for small defects																														
	-- replacement of pads and fasteners																														
	-- Correct cracks in slab																														
	--- Replace slab - in case of derailment or accident (major damage)																														
	--- Inject resin to protect steel																														
	-- Correct settlement of slab																														
	--- Inject cement or other products under slab																														
	--- Expansive foam treatment																														
	--- Micro piles																														
	- Renewals																														
	-- Slab replacement																														
	-- Rail+pad+fasteners replacement																														
	-- Rail + pad replacement only																														
	-- Replace drainage system																														
	- Off Track maintenance																														
	-- Drainage																														
	-- Fencing																														
	-- Embankments																														
	-- Civil structures (flyovers, underpass)																														
	-- Vegetation																														

Capacity4Rail Technology Evaluation template - LCA

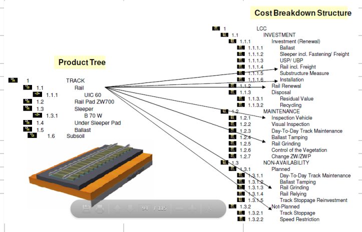
Sub-project: SP1

Innovation: New track designs and specifications for very high speed lines (if innovation ballasted track)

The life cycle analysis will start with a product breakdown structure and will consider all of the life cycle stages through to disposal. The figure on the right shows an example product breakdown structure

R&D > Investment > Operation & Maintenance > Disposal

Life cycle phases



Source: INNOTRACK - Guideline for LCC and RAMS analysis (2006)

Scenario and boundard conditions for assessment

Product breakdown structure

Baseline case - ballasted track

			Noise			Lifespan		Reference unit		Materials			Climate change emissions (kg)				Air pollution emissions (kg)			
Component	**Sub Component**	**Description of component/sub component**	**Baseline noise performance** (within scenario - dB(A))	**Key components** (contribution to noise)		**Value**	**Unit** [MGT, years]	**Value**	**Unit** [km, each, ...]	**Type of material** (e.g. steel, concrete, copper, ...)	**Quantity**	**Unit** (e.g. t, kg, m^3, ...)	**CO_2** Carbon dioxide	**CH_4** Methane	**N_2O** Nitrous Oxide	**CO_2e** 1x CO_2 34x CH_4 298x N_2O	**SO_2** Sulphur dioxide	**NO_x** Nitrogen oxides	**PM_{10}** Particulate matter	**NMVOC** Non-methane Volatile Organic Compounds
					Material manufacturing															

Innovation - Optimised sensor, communication and data strategy

			Noise			Lifespan		Reference unit		Materials			Material climate change emissions (kg)				Material air pollution emissions (kg)			
Component	**Sub Component**	**Description of component/sub component**	**Innovation noise performance** (within scenario - dB(A))	**Key components** (contribution to noise)		**Value**	**Unit** [MGT, years]	**Value**	**Unit**	**Type of material** (e.g. steel, concrete, copper, ...)	**Quantity**	**Unit** (e.g. t, kg, m^3, ...)	**CO_2** Carbon dioxide	**CH_4** Methane	**N_2O** Nitrous Oxide	**CO_2e** 1x CO_2 34x CH_4 298x N_2O	**SO_2** Sulphur dioxide	**NO_x** Nitrogen oxides	**PM_{10}** Particulate matter	**NMVOC** Non-methane Volatile Organic Compounds
					Material manufacturing															

Baseline case - ballasted track

			Transport and logistics							Construction and maintenance							Operation		Data			Emission factors								Data	
				Vehicle characteristics			Production			Machinery characteristics					Production		Production					Climate change emissions (kg/unit)				Air pollution emissions (kg/unit)					
	LCA block	**Reference unit** (e.g. km, m^3, tonne, train, wagon, terminal...)	**Transport mode**	**Load capacity** (tonnes)	**Fuel consumption** (e.g l/100 km)	**Energy consumption** (e.g kWh)	**Distance travelled** (Km)	**Activity time** (Hours)	**Equipment**	**Production** (e.g. tonnes/h, m3/h, km/h...)	**Power** (kW, hp)	**Fuel consumption** (e.g l/100 km)	**Energy consumption** (e.g kWh)	**Quantity**	**Unit** (e.g. tonnes, km...)	**Working time** (hours)	**Energy** (Direct use of energy in task, processing)	**Utilisation rate (%)**	**Dependencies** (eg relationship between frequency of task upon boundary conditions such as load (MGT), traffic type, curve etc)	**Source of data** eg carbon reporting statements, model, expert estimate	**Quality of data source** and where possible **accuracy of data** (upper and lower limits)	**CO_2** Carbon dioxide	**CH_4** Methane	**N_2O** Nitrous Oxide	**CO_2e** 1x CO_2 34x CH_4 298x N_2O	**SO_2** Sulphur dioxide	**NO_x** Nitrogen oxides	**PM_{10}** Particulate matter	**NMVOC** Non-methane Volatile Organic Compounds	**Source of data** eg carbon reporting statements, model, expert estimate	**Quality of data source** and where possible **accuracy of data** (upper and lower limits)
Infrastructure embedded carbon	**Investment/Construction**																														
	- Project preparation																														
	- Inputted Residual value																														
	- Investment and installation																														
	-- Ground preparation - geotechnical and civil																														
	--- Site investigation																														
	--- Soil substitution																														
	--- Reinforcement																														
	--- Subgrade layers																														
	--- Drainage																														
	-- Track laying - track work																														
	--- Ballast																														
	--- Pads																														
	--- Sleepers																														
	--- Fastenings																														
	--- Rail																														
	--- Welding																														
	--- Tamping																														
	--- Dynamic stabilisation																														
	--- Initial grinding																														
	- Testing and commissioning																														
	-- Inspection/quality control																														
	Disposal																														
	- Decommission/removal works																														
	- Disposal costs/recycled value (rail and ballast recycling)																														
	- Facilities																														
Operational carbon	**Operation activities (non-maintenance)**																														
	- Traction energy																														
	- Personnel - transport																														
	- Facilities																														
	Maintenance activities (see RAMS template)																														
	- Inspection																														
	-- Visual Inspection																														
	-- Ultrasonic - Manual																														
	-- Ultrasonic - Train based																														
	-- Eddy current inspection - Train based																														
	-- Track geometry - train based																														
	-- Dynamic track behaviour - train based																														
	-- Noise monitoring																														
	- Preventive/condition based maintenance																														
	-- Rail Change																														
	-- Rail Transpose																														
	-- Grinding																														
	-- Lubrication																														
	-- Fish Plate lubrication																														
	-- IBJ replacement																														
	-- Re-sleeper																														
	-- Replace sleeper pads and insulators																														
	-- Noise abatement																														
	-- Re-fastening systems																														
	- Corrective maintenance																														
	-- Rail Change - defects																														
	-- Weld change - defects																														
	-- Rail adjustment																														
	-- Ballast reprofile																														
	-- Wet bed removal																														
	-- Tactical reballast																														
	-- Plain line tamping																														
	-- Stoneblowing																														
	-- Geometry manual																														
	-- replacement of pads and fasteners																														
	- Renewals																														
	--Rail, sleeper and Ballast renewal																														
	-- Sleeper and ballast renewal																														
	-- Tactical resleeper																														
	-- Ballast cleaning																														
	- Off Track maintenance																														
	-- Drainage																														
	-- Fencing																														
	-- Embankments																														
	-- Civil structures (flyovers, underpass)																														
	-- Vegetation																														

Innovation - Innovative ballasted track

			Transport and logistics							Construction and maintenance							Operation		Data			Emission factors								Data	
				Vehicle characteristics			Production			Machinery characteristics					Production		Production					Climate change emissions (kg/unit)				Air pollution emissions (kg/unit)					
	LCA block	**Reference unit** (e.g. km, m^3, tonne, train, wagon, terminal...)	**Transport mode**	**Load capacity** (tonnes)	**Fuel consumption** (e.g l/100 km)	**Energy consumption** (e.g kWh)	**Distance travelled** (Km)	**Activity time** (Hours)	**Equipment**	**Production** (e.g. tonnes/h, m3/h, km/h...)	**Power** (kW, hp)	**Fuel consumption** (e.g l/100 km)	**Energy consumption** (e.g kWh)	**Quantity**	**Unit** (e.g. tonnes, km...)	**Working time** (hours)	**Energy** (Direct use of energy in task, processing)	**Utilisation rate (%)**	**Dependencies** (eg relationship between frequency of task upon boundary conditions such as load (MGT), traffic type, curve etc)	**Source of data** eg carbon reporting statements, model, expert estimate	**Quality of data source** and where possible **accuracy of data** (upper and lower limits)	**CO_2** Carbon dioxide	**CH_4** Methane	**N_2O** Nitrous Oxide	**CO_2e** 1x CO_2 34x CH_4 298x N_2O	**SO_2** Sulphur dioxide	**NO_x** Nitrogen oxides	**PM_{10}** Particulate matter	**NMVOC** Non-methane Volatile Organic Compounds	**Source of data** eg carbon reporting statements, model, expert estimate	**Quality of data source** and where possible **accuracy of data** (upper and lower limits)
Infrastructure embedded carbon	**Investment/Construction**																														
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	--- Reinforcement																														
	--- Subgrade layers																														
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	--- Ballast																														
	--- Pads																														
	--- Sleepers																														
	--- Fastenings																														
	--- Rail																														
	--- Welding																														
	--- Tamping																														
	--- Dynamic stabilisation																														
	--- Initial grinding																														
	- Testing and commissioning																														
	-- Inspection/quality control																														
	Disposal																														
	- Decommission/removal works																														
	- Disposal costs/recycled value (rail and ballast recycling)																														
	- Facilities																														
Operational carbon	**Operation activities (non-maintenance)**																														
	- Traction energy																														
	-Personnel - transport																														
	- Facilities																														
	Maintenance activities (see RAMS template)																														
	- Inspection																														
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	-- Ultrasonic - Manual																														
	-- Ultrasonic - Train based																														
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	-- Slab monitoring for cracks and movement																														
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	-- IBJ replacement																														
	-- Re-sleeper																														
	-- Replace rail pads and insulators																														
	-- Noise abatement																														
	-- Re-fastening systems																														
	- Corrective maintenance																														
	-- Rail Change - defects																														
	-- Weld change - defects																														
	-- Rail adjustment																														
	-- Maintain drainage																														
	-- Adjust fastening system for small defects																														
	-- replacement of pads and fasteners																														
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	--- Replace slab - in case of derailment or accident (major damage)																														
	--- Inject resin to protect steel																														
	-- Correct settlement of slab																														
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	-- Slab replacement																														
	-- Rail+pad+fasteners replacement																														
	-- Rail + pad replacement only																														
	-- Replace drainage system																														
	- Off Track maintenance																														
	-- Drainage																														
	-- Fencing																														
	-- Embankments																														
	-- Civil structures (flyovers, underpass)																														
	-- Vegetation																														

Capacity4Rail Technology Evaluation template - LCA

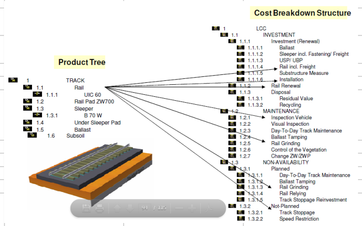
Sub-project: SP1

Innovation: New concepts for Switches and Crossings based on failure modes analysis

The life cycle analysis will start with a product breakdown structure and will consider all of the life cycle stages through to disposal. The figure on the right shows an example product breakdown structure

R&D > Investment > Operation & Maintenance > Disposal

Life cycle phases



Source: INNOTRACK - Guideline for LCC and RAMS analysis (2006)

Scenario and boundard conditions for assessment

Product breakdown structure

Baseline case - Existing switch design - use as a basis a design which is commonly used in the scenario given

			Noise			Lifespan		Reference unit		Materials			Climate change emissions (kg)				Air pollution emissions (kg)			
Component	**Sub Component**	**Description of component/sub component**	**Baseline noise performance** (within scenario - dB(A))	**Key components** (contribution to noise)		**Value**	**Unit** [MGT, years]	**Value**	**Unit** [km, each, ...]	**Type of material** (e.g. steel, concrete, copper, ...)	**Quantity**	**Unit** (e.g. t, kg, m^3, ...)	**CO_2** Carbon dioxide	**CH_4** Methane	**N_2O** Nitrous Oxide	**CO_2e** 1x CO_2 34x CH_4 298x N_2O	**SO_2** Sulphur dioxide	**NO_x** Nitrogen oxides	**PM_{10}** Particulate matter	**NMVOC** Non-methane Volatile Organic Compounds
					Material manufacturing															

Innovation - Optimised sensor, communication and data strategy

			Noise			Lifespan		Reference unit		Materials			Material climate change emissions (kg)				Material air pollution emissions (kg)			
Component	**Sub Component**	**Description of component/sub component**	**Innovation noise performance** (within scenario - dB(A))	**Key components** (contribution to noise)		**Value**	**Unit** [MGT, years]	**Value**	**Unit**	**Type of material** (e.g. steel, concrete, copper, ...)	**Quantity**	**Unit** (e.g. t, kg, m^3, ...)	**CO_2** Carbon dioxide	**CH_4** Methane	**N_2O** Nitrous Oxide	**CO_2e** 1x CO_2 34x CH_4 298x N_2O	**SO_2** Sulphur dioxide	**NO_x** Nitrogen oxides	**PM_{10}** Particulate matter	**NMVOC** Non-methane Volatile Organic Compounds
					Material manufacturing															

Baseline case - Existing switch design - use as a basis a design which is commonly used in the scenario given

			Transport and logistics						Construction and maintenance								Operation		Data			Emission factors								Data	
				Vehicle characteristics			Production				Machinery characteristics				Production		Production					Climate change emissions (kg/unit)				Air pollution emissions (kg/unit)					
	LCA block	**Reference unit** (e.g. km, m^3, tonne, train, wagon, terminal...)	**Transport mode**	**Load capacity** (tonnes)	**Fuel consumption** (e.g l/100 km)	**Energy consumption** (e.g kWh)	**Distance travelled** (Km)	**Activity time** (Hours)	**Equipment**	**Production** (e.g. tonnes/h, m3/h, km/h...)	**Power** (kW, hp)	**Fuel consumption** (e.g l/100 km)	**Energy consumption** (e.g kWh)	**Quantity**	**Unit** (e.g. tonnes, km...)	**Working time** (hours)	**Energy** (Direct use of energy in task, processing)	**Utilisation rate (%)**	**Dependencies** (eg relationship between frequency of task upon boundary conditions such as load (MGT), traffic type, curve etc)	**Source of data** eg carbon reporting statements, model, expert estimate	**Quality of data source** and where possible **accuracy of data** (upper and lower limits)	**CO_2** Carbon dioxide	**CH_4** Methane	**N_2O** Nitrous Oxide	**CO_2e** 1x CO_2 34x CH_4 298x N_2O	**SO_2** Sulphur dioxide	**NO_x** Nitrogen oxides	**PM_{10}** Particulate matter	**NMVOC** Non-methane Volatile Organic Compounds	**Source of data** eg carbon reporting statements, model, expert estimate	**Quality of data source** and where possible **accuracy of data** (upper and lower limits)
Infrastructure embedded carbon	**Investment**																													
	- Project preparation																													
	- Investment and installation																													
	-- Switch installation costs																													
	--- Removal of existing switch																													
	--- Transport costs and logistics of delivering new switch layout																													
	--- Welding																													
	--- Tamping/geometry																													
	--- Signalling and electrical																													
	- Testing and commissioning																													
	-- Inspection/quality control																													
	Disposal																													
	- Decommission/removal works																													
	- Disposal costs/recycled value																													
Operational carbon	**Operation activities (non-maintenance)**																													
	- Traction energy																													
	- Personnel - transport																													
	- Facilities																													
	Maintenance activities (see RAMS template)																													
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	-- Ultrasonic - Manual																													
	-- Ultrasonic - Train based																													
	-- Eddy current inspection - Train based																													
	-- Track geometry - train based																													
	-- Dynamic track behaviour - train based																													
	-- Noise monitoring																													
	-- Train based high speed image capture inspection																													
	- Preventive/condition based maintenance of switch																													
	-- S&C adjustment																													
	-- Lubrication																													
	-- Grinding																													
	-- Tighten/adjust stretcher bars																													
	-- Adjust drive																													
	- Corrective maintenance																													
	-- Half set replacement																													
	-- Crossing replacement																													
	-- Crossing weld repair																													
	-- Replace bearers																													
	-- S&C tactical reballast																													
	-- S&C tamping																													
	-- Manual S&C geometry correction																													
	-- Repair/replace switch motor and drive mechanisms																													
	-- Repair/replace locking mechanisms																													
	-- Repair electrical/signalling/interlocking failures																													
	- Renewals																													
	-- S&C renewal																													

	Innovation - Innovative switch design		Transport and logistics						Construction and maintenance								Operation		Data			Emission factors								Data	
			Vehicle characteristics				Production		Machinery characteristics					Production			Production					Climate change emissions (kg/unit)				Air pollution emissions (kg/unit)					
	LCA block	**Reference unit** (e.g. km, m^3, tonne, train, wagon, terminal...)	**Transport mode**	**Load capacity** (tonnes)	**Fuel consumption** (e.g l/100 km)	**Energy consumption** (e.g kWh)	**Distance travelled** (Km)	**Activity time** (Hours)	**Equipment**	**Production** (e.g. tonnes/h, m3/h, km/h...)	**Power** (kW, hp)	**Fuel consumption** (e.g l/100 km)	**Energy consumption** (e.g kWh)	**Quantity**	**Unit** (e.g. tonnes, km...)	**Working time** (hours)	**Energy** (Direct use of energy in task, processing)	**Utilisation rate (%)**	**Dependencies** (eg relationship between frequency of task upon boundary conditions such as load (MGT), traffic type, curve etc)	**Source of data** eg carbon reporting statements, model, expert estimate	**Quality of data source** and where possible **accuracy of data** (upper and lower limits)	**CO_2** Carbon dioxide	**CH_4** Methane	**N_2O** Nitrous Oxide	**CO_2e** 1x CO_2 34x CH_4 298x N_2O	**SO_2** Sulphur dioxide	**NO_x** Nitrogen oxides	**PM_{10}** Particulate matter	**NMVOC** Non-methane Volatile Organic Compounds	**Source of data** eg carbon reporting statements, model, expert estimate	**Quality of data source** and where possible **accuracy of data** (upper and lower limits)
Infrastructure embedded carbon	**Investment**																														
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	--- Removal of existing switch																														
	--- Transport costs and logistics of delivering new switch layout																														
	--- Welding																														
	--- Tamping/geometry																														
	--- Signalling and electrical																														
	- Testing and commissioning																														
	-- Inspection/quality control																														
	Disposal																														
	- Decommission/removal works																														
	- Disposal costs/recycled value																														
Operational carbon	**Operation activities (non-maintenance)**																														
	- Traction energy																														
	- Personnel - transport																														
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	Maintenance activities (see RAMS template)																														
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	-- Ultrasonic - Train based																														
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	-- Train based high speed image capture inspection																														
	- Preventive/condition based maintenance of switch																														
	-- S&C adjustment																														
	-- Lubrication																														
	-- Grinding																														
	-- Tighten/adjust stretcher bars																														
	-- Adjust drive																														
	- Corrective maintenance																														
	-- Half set replacement																														
	-- Crossing replacement																														
	-- Crossing weld repair																														
	-- Replace bearers																														
	-- S&C tactical reballast																														
	-- S&C tamping																														
	-- Manual S&C geometry correction																														
	-- Repair/replace switch motor and drive mechanisms																														
	-- Repair/replace locking mechanisms																														
	-- Repair electrical/signalling/interlocking failures																														
	- Renewals																														
	-- S&C renewal																														

Capacity4Rail Technology Evaluation template - LCA

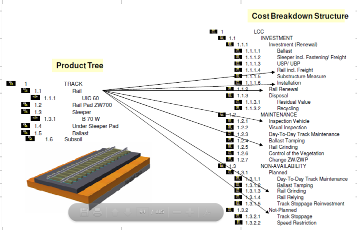
Sub-project: **SP1**

Innovation: **New designs for switches resilient to extreme weather conditions**

The life cycle analysis will start with a product breakdown structure and will consider all of the life cycle stages through to disposal. The figure on the right shows an example product breakdown structure

R&D > Investment > Operation & Maintenance > Disposal

Life cycle phases



Source: INNOTRACK - Guideline for LCC and RAMS analysis (2006)

Scenario and boundard conditions for assessment - Scenario should include extreme weather events

Product breakdown structure

Baseline case - Existing switch design - use as a basis a design which is commonly used in the scenario given

Component	Sub Component	Description of component/sub component	Noise: Baseline noise performance (within scenario - dB(A))	Noise: Key components (contribution to noise)		Lifespan: Value	Lifespan: Unit [MGT, years]	Reference unit: Value	Reference unit: Unit [km, each, ...]	Materials: Type of material (e.g. steel, concrete, copper, ...)	Materials: Quantity	Materials: Unit (e.g. t, kg, m^3, ...)	Climate change emissions (kg): CO_2 Carbon dioxide	CH_4 Methane	N_2O Nitrous Oxide	CO_2e 1x CO_2 34x CH_4 298x N_2O	Air pollution emissions (kg): SO_2 Sulphur dioxide	NO_x Nitrogen oxides	PM_{10} Particulate matter	NMVOC Non-methane Volatile Organic Compounds
					Material manufacturing															

Innovation - Optimised sensor, communication and data strategy

Component	Sub Component	Description of component/sub component	Noise: Innovation noise performance (within scenario - dB(A))	Noise: Key components (contribution to noise)		Lifespan: Value	Lifespan: Unit [MGT, years]	Reference unit: Value	Reference unit: Unit	Materials: Type of material (e.g. steel, concrete, copper, ...)	Materials: Quantity	Materials: Unit (e.g. t, kg, m^3, ...)	Material climate change emissions (kg): CO_2 Carbon dioxide	CH_4 Methane	N_2O Nitrous Oxide	CO_2e 1x CO_2 34x CH_4 298x N_2O	Material air pollution emissions (kg): SO_2 Sulphur dioxide	NO_x Nitrogen oxides	PM_{10} Particulate matter	NMVOC Non-methane Volatile Organic Compounds
					Material manufacturing															

Baseline case - Existing switch design - use as a basis a design which is commonly used in the scenario given

	LCA block	Reference unit (e.g. km, m^3, tonne, train, wagon, terminal...)	Transport and logistics: Transport mode	Vehicle characteristics: Load capacity (tonnes)	Fuel consumption (e.g l/100 km)	Energy consumption (e.g kWh)	Production: Distance travelled (Km)	Activity time (Hours)	Equipment	Construction and maintenance / Machinery characteristics: Production (e.g. tonnes/h, m3/h, km/h...)	Power (kW, hp)	Fuel consumption (e.g l/100 km)	Energy consumption (e.g kWh)	Quantity	Production: Unit (e.g. tonnes, km...)	Working time (hours)	Operation / Production: Energy (Direct use of energy in task, processing)	Utilisation rate (%)	Data: Dependencies (eg relationship between frequency of task upon boundary conditions such as load (MGT), traffic type, curve etc)	Source of data eg carbon reporting statements, model, expert estimate	Quality of data source and where possible accuracy of data (upper and lower limits)	Emission factors / Climate change emissions (kg/unit): CO_2 Carbon dioxide	CH_4 Methane	N_2O Nitrous Oxide	CO_2e 1x CO_2 34x CH_4 298x N_2O	Air pollution emissions (kg/unit): SO_2 Sulphur dioxide	NO_x Nitrogen oxides	PM_{10} Particulate matter	NMVOC Non-methane Volatile Organic Compounds	Data: Source of data eg carbon reporting statements, model, expert estimate	Quality of data source and where possible accuracy of data (upper and lower limits)
Infrastructure embedded carbon	**Investment**																														
	- Project preparation																														
	- Investment and installation																														
	-- Switch installation costs																														
	--- Removal of existing switch																														
	--- Transport costs and logistics of delivering new switch layout																														
	--- Welding																														
	--- Tamping/geometry																														
	--- Signalling and electrical																														
	- Testing and commissioning																														
	-- Inspection/quality control																														
	Disposal																														
	- Decommission/removal works																														
	- Disposal costs/recycled value																														
Operational carbon	**Operation activities (non-maintenance)**																														
	- Traction energy																														
	- Personnel - transport																														
	- Facilities																														
	Maintenance activities (see RAMS template)																														
	- Inspection																														
	-- Visual Inspection																														
	-- Ultrasonic - Manual																														
	-- Ultrasonic - Train based																														
	-- Eddy current inspection - Train based																														
	-- Track geometry - train based																														
	-- Dynamic track behaviour - train based																														
	-- Noise monitoring																														
	-- Train based high speed image capture inspection																														
	- Preventive/condition based maintenance of switch																														
	-- S&C adjustment																														
	-- Lubrication																														
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	-- Adjust drive																														
	- Corrective maintenance																														
	-- Half set replacement																														
	-- Crossing replacement																														
	-- Crossing weld repair																														
	-- Replace bearers																														
	-- S&C tactical reballast																														
	-- S&C tamping																														
	-- Manual S&C geometry correction																														
	-- Repair/replace switch motor and drive mechanisms																														
	-- Repair/replace locking mechanisms																														
	-- Repair electrical/signalling/interlocking failures																														
	- Renewals																														
	-- S&C renewal																														
	- Activities related to cost of non-availability and damage due to failures																														
	-- Flooding																														
	-- Signalling/electrical failures																														
	-- Ice, ballast or other object between switch and stock rail preventing switch locking																														
	-- Damage to switch drive from flying ballast, ice falling from vehicles																														
	-- Stretcher bar failure																														
	-- Derailment due to switch rail wear																														

Innovation - Innovative switch design

			Transport and logistics – Vehicle characteristics				Transport and logistics – Production		Construction and maintenance – Machinery characteristics					Construction and maintenance – Production			Operation – Production		Data			Climate change emissions (kg/unit)			Emission factors	Air pollution emissions (kg/unit)				Data	
	LCA block	**Reference unit** (e.g. km, m^3, tonne, train, wagon, terminal...)	**Transport mode**	**Load capacity** (tonnes)	**Fuel consumption** (e.g l/100 km)	**Energy consumption** (e.g kWh)	**Distance travelled** (Km)	**Activity time** (Hours)	**Equipment**	**Production** (e.g. tonnes/h, m3/h, km/h...)	**Power** (kW, hp)	**Fuel consumption** (e.g l/100 km)	**Energy consumption** (e.g kWh)	**Quantity**	**Unit** (e.g. tonnes, km...)	**Working time** (hours)	**Energy** (Direct use of energy in task, processing)	**Utilisation rate (%)**	**Dependencies** (eg relationship between frequency of task upon boundary conditions such as load (MGT), traffic type, curve etc)	**Source of data** eg carbon reporting statements, model, expert estimate	**Quality of data source** and where possible **accuracy of data** (upper and lower limits)	**CO_2** Carbon dioxide	**CH_4** Methane	**N_2O** Nitrous Oxide	**CO_2e** 1x CO_2 34x CH_4 298x N_2O	**SO_2** Sulphur dioxide	**NO_x** Nitrogen oxides	**PM_{10}** Particulate matter	**NMVOC** Non-methane Volatile Organic Compounds	**Source of data** eg carbon reporting statements, model, expert estimate	**Quality of data source** and where possible **accuracy of data** (upper and lower limits)
Infrastructure embedded carbon	**Investment**																														
	- Project preparation																														
	- Investment and installation																														
	-- Switch installation costs																														
	--- Removal of existing switch																														
	--- Transport costs and logistics of delivering new switch layout																														
	--- Welding																														
	--- Tamping/geometry																														
	--- Signalling and electrical																														
	- Testing and commissioning																														
	-- Inspection/quality control																														
	Disposal																														
	- Decommission/removal works																														
	- Disposal costs/recycled value																														
Operational carbon	**Operation activities (non-maintenance)**																														
	- Traction energy																														
	- Personnel - transport																														
	- Facilities																														
	Maintenance activities (see RAMS template)																														
	- Inspection																														
	-- Visual Inspection																														
	-- Ultrasonic - Manual																														
	-- Ultrasonic - Train based																														
	-- Eddy current inspection - Train based																														
	-- Track geometry - train based																														
	-- Dynamic track behaviour - train based																														
	-- Noise monitoring																														
	-- Train based high speed image capture inspection																														
	- Preventive/condition based maintenance of switch																														
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	-- Crossing replacement																														
	-- Crossing weld repair																														
	-- Replace bearers																														
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	-- S&C tamping																														
	-- Manual S&C geometry correction																														
	-- Repair/replace switch motor and drive mechanisms																														
	-- Repair/replace locking mechanisms																														
	-- Repair electrical/signalling/interlocking failures																														
	- Renewals																														
	-- S&C renewal																														
	- Activities related to cost of non-availability and damage due to failures																														
	-- Flooding																														
	-- Signalling/electrical failures																														
	-- Ice, ballast or other object between switch and stock rail preventing switch locking																														
	-- Damage to switch drive from flying ballast, ice falling from vehicles																														
	-- Stretcher bar failure																														
	-- Derailment due to switch rail wear																														

Capacity4Rail Technology Evaluation template - LCA

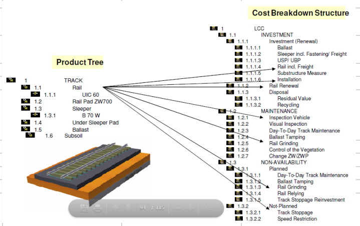
Sub-project: SP1

Innovation: Optimised S&C sensor strategies

The life cycle analysis will start with a product breakdown structure and will consider all of the life cycle stages through to disposal. The figure on the right shows an example product breakdown structure

R&D > Investment > Operation & Maintenance > Disposal

Life cycle phases



Source: INNOTRACK - Guideline for LCC and RAMS analysis (2006)

Scenario and boundard conditions for assessment - Scenario should include extreme weather events

Product breakdown structure

Baseline case - Existing switch design - with current sensor technology

			Noise			Lifespan		Reference unit		Materials			Climate change emissions (kg)				Air pollution emissions (kg)			
Component	Sub Component	Description of component/sub component	Baseline noise performance (within scenario - dB(A))	Key components (contribution to noise)		Value	Unit [MGT, years]	Value	Unit [km, each, ...]	Type of material (e.g. steel, concrete, copper, ...)	Quantity	Unit (e.g. t, kg, m^3, ...)	CO_2 Carbon dioxide	CH_4 Methane	N_2O Nitrous Oxide	CO_2e 1x CO_2 34x CH_4 298x N_2O	SO_2 Sulphur dioxide	NO_x Nitrogen oxides	PM_{10} Particulate matter	NMVOC Non-methane Volatile Organic Compounds
					Material manufacturing															

Innovation - Optimised sensor, communication and data strategy

			Noise			Lifespan		Reference unit		Materials			Material climate change emissions (kg)				Material air pollution emissions (kg)			
Component	Sub Component	Description of component/sub component	Innovation noise performance (within scenario - dB(A))	Key components (contribution to noise)		Value	Unit [MGT, years]	Value	Unit	Type of material (e.g. steel, concrete, copper, ...)	Quantity	Unit (e.g. t, kg, m^3, ...)	CO_2 Carbon dioxide	CH_4 Methane	N_2O Nitrous Oxide	CO_2e 1x CO_2 34x CH_4 298x N_2O	SO_2 Sulphur dioxide	NO_x Nitrogen oxides	PM_{10} Particulate matter	NMVOC Non-methane Volatile Organic Compounds
					Material manufacturing															

Baseline case - Existing switch design - with current sensor technology

			Transport and logistics							Construction and maintenance							Operation		Data			Emission factors								Data	
				Vehicle characteristics			Production		Machinery characteristics					Production			Production					Climate change emissions (kg/unit)				Air pollution emissions (kg/unit)					
	LCA block	Reference unit (e.g. km, m^3, tonne, train, wagon, terminal...)	Transport mode	Load capacity (tonnes)	Fuel consumption (e.g l/100 km)	Energy consumption (e.g kWh)	Distance travelled (Km)	Activity time (Hours)	Equipment	Production (e.g. tonnes/h, m3/h, km/h...)	Power (kW, hp)	Fuel consumption (e.g l/100 km)	Energy consumption (e.g kWh)	Quantity	Unit (e.g. tonnes, km...)	Working time (hours)	Energy (Direct use of energy in task, processing)	Utilisation rate (%)	Dependencies (eg relationship between frequency of task upon boundary conditions such as load (MGT), traffic type, curve etc)	Source of data eg carbon reporting statements, model, expert estimate	Quality of data source and where possible accuracy of data (upper and lower limits)	CO_2 Carbon dioxide	CH_4 Methane	N_2O Nitrous Oxide	CO_2e 1x CO_2 34x CH_4 298x N_2O	SO_2 Sulphur dioxide	NO_x Nitrogen oxides	PM_{10} Particulate matter	NMVOC Non-methane Volatile Organic Compounds	Source of data eg carbon reporting statements, model, expert estimate	Quality of data source and where possible accuracy of data (upper and lower limits)
Infrastructure embedded carbon	**Investment**																														
	- Project preparation																														
	- Investment and installation																														
	-- Switch installation costs																														
	--- Removal of existing switch																														
	--- Transport costs and logistics of delivering new switch layout																														
	--- Welding																														
	--- Tamping/geometry																														
	--- Signalling and electrical																														
	--- Installation of sensor technology																														
	- Testing and commissioning																														
	-- Inspection/quality control																														
	Disposal																														
	- Decommission/removal works																														
	- Disposal costs/recycled value																														
Operational carbon	**Operation activities (non-maintenance)**																														
	- Traction energy																														
	- Personnel - transport																														
	- Facilities																														
	Maintenance activities (see RAMS template)																														
	- Corrective maintenance of sensor																														
	-- Repair of sensors damaged due to flying ballast, ice, moisture, fatigue, high acceleration forces,																														
	- Other maintenance of sensor equipment																														
	-- Battery replacement																														
	-- Sensor position and realignment																														
	-- Data retrieval																														
	- Inspection of switch																														
	-- Visual Inspection																														
	-- Ultrasonic - Manual																														
	-- Ultrasonic - Train based																														
	-- Eddy current inspection - Train based																														
	-- Track geometry - train based																														
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	- Renewals of switch																														
	-- S&C renewal																														
	Activities related to cost of service affecting failures/maintenance																														
	-- Repair of sensors damaged due to flying ballast, ice, moisture, fatigue, high acceleration forces,																														
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	-- Ice, ballast or other object between switch and stock rail preventing switch locking																														
	-- Damage to switch drive from flying ballast, ice falling from vehicles																														
	-- Stretcher bar failure																														
	-- Derailment due to switch rail wear																														

Innovation - Switch with optimised sensor strategy

			Transport and logistics							Construction and maintenance							Operation		Data			Emission factors								Data	
				Vehicle characteristics			Production		Machinery characteristics					Production			Production					Climate change emissions (kg/unit)				Air pollution emissions (kg/unit)					
	LCA block	Reference unit (e.g. km, m^3, tonne, train, wagon, terminal...)	Transport mode	Load capacity (tonnes)	Fuel consumption (e.g l/100 km)	Energy consumption (e.g kWh)	Distance travelled (Km)	Activity time (Hours)	Equipment	Production (e.g. tonnes/h, m3/h, km/h...)	Power (kW, hp)	Fuel consumption (e.g l/100 km)	Energy consumption (e.g kWh)	Quantity	Unit (e.g. tonnes, km...)	Working time (hours)	Energy (Direct use of energy in task, processing)	Utilisation rate (%)	Dependencies (eg relationship between frequency of task upon boundary conditions such as load (MGT), traffic type, curve etc)	Source of data eg carbon reporting statements, model, expert estimate	Quality of data source and where possible accuracy of data (upper and lower limits)	CO_2 Carbon dioxide	CH_4 Methane	N_2O Nitrous Oxide	CO_2e 1x CO_2 34x CH_4 298x N_2O	SO_2 Sulphur dioxide	NO_x Nitrogen oxides	PM_{10} Particulate matter	NMVOC Non-methane Volatile Organic Compounds	Source of data eg carbon reporting statements, model, expert estimate	Quality of data source and where possible accuracy of data (upper and lower limits)
Infrastructure embedded carbon	**Investment**																														
	- Project preparation																														
	- Investment and installation																														
	-- Switch installation costs																														
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	--- Transport costs and logistics of delivering new switch layout																														
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	- Testing and commissioning																														
	-- Inspection/quality control																														
	Disposal																														
	- Decommission/removal works																														
	- Disposal costs/recycled value																														
Operational carbon	**Operation activities (non-maintenance)**																														
	- Traction energy																														
	- Personnel - transport																														
	- Facilities																														
	Maintenance activities (see RAMS template)																														
	- Corrective maintenance of sensor																														
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	-- Damage to switch drive from flying ballast, ice falling from vehicles																														
	-- Stretcher bar failure																														
	-- Derailment due to switch rail wear																														

Capacity4Rail Technology Evaluation template - LCA

Sub-project: SP2

Innovation: Innovations in Trains/Wagons – optimised length, speed, performance, central/automatic coupler, EP/electronic braking, electrification, automation, weight

The life cycle analysis will start with a product breakdown structure and will consider all of the life cycle stages through to disposal. The figure on the right shows an example product breakdown structure

R&D > Investment > Operation & Maintenance > Disposal

Life cycle phases

Scenario and boundard conditions for assessment

Baseline case - existing vehicles

Component	Sub Component	Description of component/sub component	Noise: Baseline noise performance (within scenario - dB(A))	Noise: Key components (contribution to noise)		Lifespan: Value	Lifespan: Unit [MGT, years]	Reference unit: Value	Reference unit: Unit [km, each, ...]	Materials: Type of material (e.g. steel, concrete, copper, ...)	Materials: Quantity	Materials: Unit (e.g. t, kg, m^3, ...)	Climate change emissions (kg): CO_2 Carbon dioxide	CH_4 Methane	N_2O Nitrous Oxide	CO_2e 1x CO_2 34x CH_4 298x N_2O	Air pollution emissions (kg): SO_2 Sulphur dioxide	NO_x Nitrogen oxides	PM_{10} Particulate matter	NMVOC Non-methane Volatile Organic Compounds
					Material manufacturing															

Innovation - Optimised sensor, communication and data strategy

Component	Sub Component	Description of component/sub component	Noise: Innovation noise performance (within scenario - dB(A))	Noise: Key components (contribution to noise)		Lifespan: Value	Lifespan: Unit [MGT, years]	Reference unit: Value	Reference unit: Unit	Materials: Type of material (e.g. steel, concrete, copper, ...)	Materials: Quantity	Materials: Unit (e.g. t, kg, m^3, ...)	Material climate change emissions (kg): CO_2 Carbon dioxide	CH_4 Methane	N_2O Nitrous Oxide	CO_2e 1x CO_2 34x CH_4 298x N_2O	Material air pollution emissions (kg): SO_2 Sulphur dioxide	NO_x Nitrogen oxides	PM_{10} Particulate matter	NMVOC Non-methane Volatile Organic Compounds
					Material manufacturing															

Cost categories and Life Cycle Phases

Baseline case - existing ballasted track and existing vehicles - no CAPEX

	LCA block	Reference unit (e.g. km, m^3, tonne, train, wagon, terminal...)	Transport and logistics – Vehicle characteristics: Transport mode	Load capacity (tonnes)	Fuel consumption (e.g l/100 km)	Energy consumption (e.g kWh)	Production: Distance travelled (Km)	Activity time (Hours)	Equipment	Construction and maintenance – Machinery characteristics: Production (e.g. tonnes/h, m3/h, km/h...)	Power (kW, hp)	Fuel consumption (e.g l/100 km)	Energy consumption (e.g kWh)	Production: Quantity	Unit (e.g. tonnes, km...)	Working time (hours)	Operation – Production: Energy (Direct use of energy in task, processing)	Utilisation rate (%)	Data: Dependencies (eg relationship between frequency of task upon boundary conditions such as load (MGT), traffic type, curve etc)	Source of data eg carbon reporting statements, model, expert estimate	Quality of data source and where possible accuracy of data (upper and lower limits)	Emission factors – Climate change emissions (kg/unit): CO_2 Carbon dioxide	CH_4 Methane	N_2O Nitrous Oxide	CO_2e 1x CO_2 34x CH_4 298x N_2O	Air pollution emissions (kg/unit): SO_2 Sulphur dioxide	NO_x Nitrogen oxides	PM_{10} Particulate matter	NMVOC Non-methane Volatile Organic Compounds	Data: Source of data eg carbon reporting statements, model, expert estimate	Quality of data source and where possible accuracy of data (upper and lower limits)
Operational carbon	**Operation activities (non-maintenance)**																														
	- Traction energy (emission savings per tonne of freight)																														
	- Personnel - transport																														
	- Facilities																														
	Maintenance activities - see RAMS template - impact of greater loading, improved acceleration and braking on existing maitenance activities																														
	Rolling stock																														
	- Inspection																														
	- Preventive/condition based maintenance																														
	- Corrective maintenance																														
	- Rolling stock refurbishment																														
	Infrastructure																														
	- Inspection																														
	-- Visual Inspection																														
	-- Ultrasonic - Manual																														
	-- Ultrasonic - Train based																														
	-- Eddy current inspection - Train based																														
	-- Track geometry - train based																														
	-- Dynamic track behaviour - train based																														
	-- Noise monitoring																														
	- Preventive/condition based maintenance																														
	-- Rail Change																														
	-- Rail Transpose																														
	-- Grinding																														
	-- Lubrication																														
	-- Fish Plate lubrication																														
	-- IBJ replacement																														
	-- Re-sleeper																														
	-- Replace sleeper pads and insulators																														
	-- Noise abatement																														
	-- Re-fastening systems																														
	- Corrective maintenance																														
	-- Rail Change - defects																														
	-- Weld change - defects																														
	-- Rail adjustment																														
	-- Ballast reprofile																														
	-- Wet bed removal																														
	-- Tactical reballast																														
	-- Plain line tamping																														
	-- Stoneblowing																														
	-- Geometry manual																														
	-- replacement of pads and fasteners																														
	- Renewals																														
	--Rail, sleeper and Ballast renewal																														
	-- Sleeper and ballast renewal																														
	-- Tactical resleeper																														
	-- Ballast cleaning																														
	- Off Track maintenance																														
	-- Drainage																														
	-- Fencing																														
	-- Embankments																														
	-- Civil structures (flyovers, underpass)																														
	-- Vegetation																														

Innovation - ballasted track with vehicle and wagon innovations

			Transport and logistics							Construction and maintenance							Operation		Data			Emission factors								Data	
			Vehicle characteristics				Production			Machinery characteristics				Production			Production					Climate change emissions (kg/unit)				Air pollution emissions (kg/unit)					
	LCA block	**Reference unit** (e.g. km, m^3, tonne, train, wagon, terminal...)	**Transport mode**	**Load capacity** (tonnes)	**Fuel consumption** (e.g l/100 km)	**Energy consumption** (e.g kWh)	**Distance travelled** (Km)	**Activity time** (Hours)	**Equipment**	**Production** (e.g. tonnes/h, m3/h, km/h...)	**Power** (kW, hp)	**Fuel consumption** (e.g l/100 km)	**Energy consumption** (e.g kWh)	**Quantity**	**Unit** (e.g. tonnes, km...)	**Working time** (hours)	**Energy** (Direct use of energy in task, processing)	**Utilisation rate (%)**	**Dependencies** (eg relationship between frequency of task upon boundary conditions such as load (MGT), traffic type, curve etc)	**Source of data** eg carbon reporting statements, model, expert estimate	**Quality of data source** and where possible **accuracy of data** (upper and lower limits)	**CO_2** Carbon dioxide	**CH_4** Methane	**N_2O** Nitrous Oxide	**CO_2e** 1x CO_2 34x CH_4 298x N_2O	**SO_2** Sulphur dioxide	**NO_x** Nitrogen oxides	**PM_{10}** Particulate matter	**NMVOC** Non-methane Volatile Organic Compounds	**Source of data** eg carbon reporting statements, model, expert estimate	**Quality of data source** and where possible **accuracy of data** (upper and lower limits)
Infrastructure embedded carbon	**Investment**																														
	- Project preparation																														
	- Vehicles/Wagons																														
	-- Vehicle modifications																														
	-- New vehicles																														
	- Infrastructure upgrades																														
	- Signalling system (for longer trains)																														
	-- Signalling block length																														
	-- Signal position and junction layouts																														
	- Other infrastructure changes to accommodate longer trains																														
	- Infrastructure upgrades to gauge envelope																														
	- Electrification of non-electrified infrastructure																														
	- Upgrade of track and structures to carry greater load																														
	Disposal																														
	- Decommission/removal works																														
	- Disposal costs/recycled value																														
	- Facilities																														
Operational carbon	**Operation activities (non-maintenance)**																														
	- Traction energy - (emission savings per tonne of freight)																														
	- Personnel - transport																														
	- Facilities																														
	Maintenance activities - see RAMS template - impact of greater loading, improved acceleration and braking on existing maitenance activities																														
	Rolling stock																														
	- Inspection																														
	- Preventive/condition based maintenance																														
	- Corrective maintenance																														
	- Rolling stock refurbishment																														
	Infrastructure																														
	- Inspection																														
	-- Visual Inspection																														
	-- Ultrasonic - Manual																														
	-- Ultrasonic - Train based																														
	-- Eddy current inspection - Train based																														
	-- Track geometry - train based																														
	-- Dynamic track behaviour - train based																														
	-- Noise monitoring																														
	-Preventive/condition based maintenance																														
	-- Rail Change																														
	-- Rail Transpose																														
	-- Grinding																														
	-- Lubrication																														
	-- Fish Plate lubrication																														
	-- IBJ replacement																														
	-- Re-sleeper																														
	-- Replace sleeper pads and insulators																														
	-- Noise abatement																														
	-- Re-fastening systems																														
	- Corrective maintenance																														
	-- Rail Change - defects																														
	-- Weld change - defects																														
	-- Rail adjustment																														
	-- Ballast reprofile																														
	-- Wet bed removal																														
	-- Tactical reballast																														
	-- Plain line tamping																														
	-- Stoneblowing																														
	-- Geometry manual																														
	-- replacement of pads and fasteners																														
	- Renewals																														
	--Rail, sleeper and Ballast renewal																														
	-- Sleeper and ballast renewal																														
	-- Tactical resleeper																														
	-- Ballast cleaning																														
	- Off Track maintenance																														
	-- Drainage																														
	-- Fencing																														
	-- Embankments																														
	-- Civil structures (flyovers, underpass)																														
	-- Vegetation																														

Capacity4Rail Technology Evaluation template - LCA

Sub-project: **SP2**

Innovation: **Innovations in Freight Operation - wagon shunting, intelligence for vehicles in terminals, terminal operation**

The life cycle analysis will start with a product breakdown structure and will consider all of the life cycle stages through to disposal. The figure on the right shows an example product breakdown structure

R&D > Investment > Operation & Maintenance > Disposal

Life cycle phases

Scenario and boundard conditions for assessment

Baseline case - existing terminal technology and existing vehicles

Component	Sub Component	Description of component/sub component	Noise: Baseline noise performance (within scenario - dB(A))	Noise: Key components (contribution to noise)		Lifespan: Value	Lifespan: Unit [MGT, years]	Reference unit: Value	Reference unit: Unit [km, each, ...]	Materials: Type of material (e.g. steel, concrete, copper, ...)	Materials: Quantity	Materials: Unit (e.g. t, kg, m³, ...)	Climate change emissions (kg): CO_2 Carbon dioxide	CH_4 Methane	N_2O Nitrous Oxide	CO_2e 1x CO_2 34x CH_4 298x N_2O	Air pollution emissions (kg): SO_2 Sulphur dioxide	NO_x Nitrogen oxides	PM_{10} Particulate matter	NMVOC Non-methane Volatile Organic Compounds
					Material manufacturing															

Innovation - Optimised sensor, communication and data strategy

Component	Sub Component	Description of component/sub component	Noise: Innovation noise performance (within scenario - dB(A))	Noise: Key components (contribution to noise)		Lifespan: Value	Lifespan: Unit [MGT, years]	Reference unit: Value	Reference unit: Unit	Materials: Type of material (e.g. steel, concrete, copper, ...)	Materials: Quantity	Materials: Unit (e.g. t, kg, m³, ...)	Material climate change emissions (kg): CO_2 Carbon dioxide	CH_4 Methane	N_2O Nitrous Oxide	CO_2e 1x CO_2 34x CH_4 298x N_2O	Material air pollution emissions (kg): SO_2 Sulphur dioxide	NO_x Nitrogen oxides	PM_{10} Particulate matter	NMVOC Non-methane Volatile Organic Compounds
					Material manufacturing															

Cost categories and Life Cycle Phases

Baseline case - existing terminal technology and existing vehicles - no CAPEX

	LCA block	Reference unit (e.g. km, m³, tonne, train, wagon, terminal...)	Transport and logistics – Vehicle characteristics: Transport mode	Load capacity (tonnes)	Fuel consumption (e.g l/100 km)	Energy consumption (e.g kWh)	Production: Distance travelled (Km)	Activity time (Hours)	Equipment	Construction and maintenance – Machinery characteristics: Production (e.g. tonnes/h, m3/h, km/h...)	Power (kW, hp)	Fuel consumption (e.g l/100 km)	Energy consumption (e.g kWh)	Quantity	Production: Unit (e.g. tonnes, km...)	Working time (hours)	Operation – Production: Energy (Direct use of energy in task, processing)	Utilisation rate (%)	Data: Dependencies (eg relationship between frequency of task upon boundary conditions such as load (MGT), traffic type, curve etc)	Source of data eg carbon reporting statements, model, expert estimate	Quality of data source and where possible accuracy of data (upper and lower limits)	Emission factors – Climate change emissions (kg/unit): CO_2 Carbon dioxide	CH_4 Methane	N_2O Nitrous Oxide	CO_2e 1x CO_2 34x CH_4 298x N_2O	Air pollution emissions (kg/unit): SO_2 Sulphur dioxide	NO_x Nitrogen oxides	PM_{10} Particulate matter	NMVOC Non-methane Volatile Organic Compounds	Data: Source of data eg carbon reporting statements, model, expert estimate	Quality of data source and where possible accuracy of data (upper and lower limits)
Operational carbon	**Operation activities (non-maintenance)** - Traction energy - (emission savings per tonne of freight) - Personnel - transport - Facilities - Loading and unloading energy																														

Innovation - freight terminal innovations in wagon shunting, intelligent vehicles, terminal operation

	LCA block	Reference unit (e.g. km, m³, tonne, train, wagon, terminal...)	Transport and logistics – Vehicle characteristics: Transport mode	Load capacity (tonnes)	Fuel consumption (e.g l/100 km)	Energy consumption (e.g kWh)	Production: Distance travelled (Km)	Activity time (Hours)	Equipment	Construction and maintenance – Machinery characteristics: Production (e.g. tonnes/h, m3/h, km/h...)	Power (kW, hp)	Fuel consumption (e.g l/100 km)	Energy consumption (e.g kWh)	Quantity	Production: Unit (e.g. tonnes, km...)	Working time (hours)	Operation – Production: Energy (Direct use of energy in task, processing)	Utilisation rate (%)	Data: Dependencies (eg relationship between frequency of task upon boundary conditions such as load (MGT), traffic type, curve etc)	Source of data eg carbon reporting statements, model, expert estimate	Quality of data source and where possible accuracy of data (upper and lower limits)	Emission factors – Climate change emissions (kg/unit): CO_2 Carbon dioxide	CH_4 Methane	N_2O Nitrous Oxide	CO_2e 1x CO_2 34x CH_4 298x N_2O	Air pollution emissions (kg/unit): SO_2 Sulphur dioxide	NO_x Nitrogen oxides	PM_{10} Particulate matter	NMVOC Non-methane Volatile Organic Compounds	Data: Source of data eg carbon reporting statements, model, expert estimate	Quality of data source and where possible accuracy of data (upper and lower limits)
Infrastructure embedded carbon	**Investment** **- Vehicles/Wagons** -- Wagon modifications and shunting vehicles -- Shunting vehicles **- Infrastructure upgrades** - Upgrade of terminal layout - Loading and unloading equipment																														
Operational carbon	**Operation activities (non-maintenance)** - Traction energy - (emission savings per tonne of freight) - Personnel - transport - Facilities - Loading and unloading energy																														

Capacity4Rail Technology Evaluation template - LCA

Sub-project: SP3

Innovation: Optimised strategies to manage major disturbances

The life cycle analysis will start with a product breakdown structure and will consider all of the life cycle stages through to disposal. The figure on the right shows an example product breakdown structure

R&D > Investment > Operation & Maintenance > Disposal

Life cycle phases

Scenario and boundard conditions for assessment

Cost categories and Life Cycle Phases

Baseline case - existing strategies

LCA block	Reference unit (e.g. km, m^3, tonne, train, wagon, terminal...)	Transport and logistics – Vehicle characteristics: Transport mode	Load capacity (tonnes)	Fuel consumption (e.g l/100 km)	Energy consumption (e.g kWh)	Production: Distance travelled (Km)	Activity time (Hours)	Equipment	Production (e.g. tonnes/h, m3/h, km/h...)
Operation activities (non-maintenance)									
- Traction energy - (emission savings per tonne of freight)									

LCA block	Construction and maintenance – Machinery characteristics: Power (kW, hp)	Fuel consumption (e.g l/100 km)	Energy consumption (e.g kWh)	Production: Quantity	Unit (e.g. tonnes, km...)	Working time (hours)	Operation – Production: Energy (Direct use of energy in task, processing)	Utilisation rate (%)
Operation activities (non-maintenance)								
- Traction energy - (emission savings per tonne of freight)								

LCA block	Data: Dependencies (eg relationship between frequency of task upon boundary conditions such as load (MGT), traffic type, curve etc)	Source of data eg carbon reporting statements, model, expert estimate	Quality of data source and where possible accuracy of data (upper and lower limits)	Emission factors – Climate change emissions (kg/unit): CO_2 Carbon dioxide	CH_4 Methane	N_2O Nitrous Oxide	CO_2e 1x CO_2 34x CH_4 298x N_2O	Air pollution emissions (kg/unit): SO_2 Sulphur dioxide	NO_x Nitrogen oxides	PM_{10} Particulate matter	NMVOC Non-methane Volatile Organic Compounds	Data: Source of data eg carbon reporting statements, model, expert estimate	Quality of data source and where possible accuracy of data (upper and lower limits)
Operation activities (non-maintenance)													
- Traction energy - (emission savings per tonne of freight)													

Innovation - new strategies

LCA block	Reference unit (e.g. km, m^3, tonne, train, wagon, terminal...)	Transport and logistics – Vehicle characteristics: Transport mode	Load capacity (tonnes)	Fuel consumption (e.g l/100 km)	Energy consumption (e.g kWh)	Production: Distance travelled (Km)	Activity time (Hours)	Equipment	Production (e.g. tonnes/h, m3/h, km/h...)
Operation activities (non-maintenance)									
- Traction energy - (emission savings per tonne of freight)									

LCA block	Construction and maintenance – Machinery characteristics: Power (kW, hp)	Fuel consumption (e.g l/100 km)	Energy consumption (e.g kWh)	Production: Quantity	Unit (e.g. tonnes, km...)	Working time (hours)	Operation – Production: Energy (Direct use of energy in task, processing)	Utilisation rate (%)
Operation activities (non-maintenance)								
- Traction energy - (emission savings per tonne of freight)								

LCA block	Data: Dependencies (eg relationship between frequency of task upon boundary conditions such as load (MGT), traffic type, curve etc)	Source of data eg carbon reporting statements, model, expert estimate	Quality of data source and where possible accuracy of data (upper and lower limits)	Emission factors – Climate change emissions (kg/unit): CO_2 Carbon dioxide	CH_4 Methane	N_2O Nitrous Oxide	CO_2e 1x CO_2 34x CH_4 298x N_2O	Air pollution emissions (kg/unit): SO_2 Sulphur dioxide	NO_x Nitrogen oxides	PM_{10} Particulate matter	NMVOC Non-methane Volatile Organic Compounds	Data: Source of data eg carbon reporting statements, model, expert estimate	Quality of data source and where possible accuracy of data (upper and lower limits)
Operation activities (non-maintenance)													
- Traction energy - (emission savings per tonne of freight)													

Capacity4Rail Technology Evaluation template - LCA

Sub-project: **SP4**

Innovation: **New concepts and technologies for advanced monitoring in embankments, bridges, different track types, switches etc**

The life cycle analysis will start with a product breakdown structure and will consider all of the life cycle stages through to disposal. The figure on the right shows an example product breakdown structure

R&D > Investment > Operation & Maintenance > Disposal

Life cycle phases

Scenario and boundard conditions for assessment - Scenario should include extreme weather events

Baseline case - current sensor technology

			Noise			Lifespan		Reference unit		Materials			Climate change emissions (kg)				Air pollution emissions (kg)				
Component	**Sub Component**	**Description of component/sub component**	**Baseline noise performance** (within scenario - dB(A))	**Key components** (contribution to noise)		**Value**	**Unit** [MGT, years]	**Value**	**Unit** [km, each, ...]	**Type of material** (e.g. steel, concrete, copper, ...)	**Quantity**	**Unit** (e.g. t, kg, m^3, ...)	**CO_2** Carbon dioxide	**CH_4** Methane	**N_2O** Nitrous Oxide	**CO_2e** 1x CO_2 34x CH_4 298x N_2O	**SO_2** Sulphur dioxide	**NO_x** Nitrogen oxides	**PM_{10}** Particulate matter	**NMVOC** Non-methane Volatile Organic Compounds	
					Material manufacturing																

Innovation - Optimised sensor, communication and data strategy

			Noise			Lifespan		Reference unit		Materials			Material climate change emissions (kg)				Material air pollution emissions (kg)				
Component	**Sub Component**	**Description of component/sub component**	**Innovation noise performance** (within scenario - dB(A))	**Key components** (contribution to noise)		**Value**	**Unit** [MGT, years]	**Value**	**Unit**	**Type of material** (e.g. steel, concrete, copper, ...)	**Quantity**	**Unit** (e.g. t, kg, m^3, ...)	**CO_2** Carbon dioxide	**CH_4** Methane	**N_2O** Nitrous Oxide	**CO_2e** 1x CO_2 34x CH_4 298x N_2O	**SO_2** Sulphur dioxide	**NO_x** Nitrogen oxides	**PM_{10}** Particulate matter	**NMVOC** Non-methane Volatile Organic Compounds	
					Material manufacturing																

Cost categories and Life Cycle Phases

Baseline case - Track design - with current sensor technology

			Transport and logistics							Construction and maintenance							Operation		Data			Emission factors								Data	
			Vehicle characteristics				Production			Machinery characteristics				Production			Production					Climate change emissions (kg/unit)				Air pollution emissions (kg/unit)					
	LCA block	**Reference unit** (e.g. km, m^3, tonne, train, wagon, terminal...)	**Transport mode**	**Load capacity** (tonnes)	**Fuel consumption** (e.g l/100 km)	**Energy consumption** (e.g kWh)	**Distance travelled** (Km)	**Activity time** (Hours)	**Equipment**	**Production** (e.g. tonnes/h, m3/h, km/h...)	**Power** (kW, hp)	**Fuel consumption** (e.g l/100 km)	**Energy consumption** (e.g kWh)	**Quantity**	**Unit** (e.g. tonnes, km...)	**Working time** (hours)	**Energy** (Direct use of energy in task, processing)	**Utilisation rate (%)**	**Dependencies** (eg relationship between frequency of task upon boundary conditions such as load (MGT), traffic type, curve etc)	**Source of data** eg carbon reporting statements, model, expert estimate	**Quality of data source** and where possible **accuracy of data** (upper and lower limits)	**CO_2** Carbon dioxide	**CH_4** Methane	**N_2O** Nitrous Oxide	**CO_2e** 1x CO_2 34x CH_4 298x N_2O	**SO_2** Sulphur dioxide	**NO_x** Nitrogen oxides	**PM_{10}** Particulate matter	**NMVOC** Non-methane Volatile Organic Compounds	**Source of data** eg carbon reporting statements, model, expert estimate	**Quality of data source** and where possible **accuracy of data** (upper and lower limits)
Infrastructure embedded carbon	**Investment**																														
	- Project preparation																														
	- Investment and installation																														
	-- Installation of sensor technology and associated cabling and communication infrastructure																														
	- Testing and commissioning																														
	-- Inspection/quality control																														
	Disposal																														
	- Decommission/removal works																														
	- Disposal costs/recycled value																														
Operational carbon	**Operation activities (non-maintenance)**																														
	- Traction energy																														
	- Personnel - transport																														
	- Facilities																														
	- Data processing/data analysis																														
	Maintenance activities (see RAMS template)																														
	Sensor																														
	- Corrective maintenance of sensor																														
	-- Repair of sensors damaged due to flying ballast, ice, moisture, fatigue, high acceleration forces,																														
	- Other maintenance of sensor equipment																														
	-- Battery replacement																														
	-- Sensor position and realignment																														
	-- Data retrieval																														
	Track																														
	- Inspection of track																														
	-- Visual Inspection																														
	-- Ultrasonic - Manual																														
	-- Ultrasonic - Train based																														
	-- Eddy current inspection - Train based																														
	-- Track geometry - train based																														
	-- Dynamic track behaviour - train based																														
	-- Slab monitoring for cracks and movement																														
	-- Noise monitoring																														
	- Preventive/condition based maintenance																														
	-- Rail Change																														
	-- Rail Transpose																														
	-- Grinding																														
	-- Lubrication																														
	-- Fish Plate lubrication																														
	-- IBJ replacement																														
	-- Re-sleeper																														
	-- Replace sleeper pads and insulators																														
	-- Noise abatement																														
	- Corrective track maintenance																														
	-- Rail Change - defects																														
	-- Weld change - defects																														
	-- Rail adjustment																														
	-- Ballast reprofile																														
	-- Wet bed removal																														
	-- Tactical reballast																														
	-- Plain line tamping																														
	-- Stoneblowing																														
	-- Geometry manual																														
	-- replacement of pads and fasteners																														
	-- Re-fastening systems																														
	- Off Track maintenance																														
	-- Drainage																														
	-- Fencing																														
	-- Civil structures (flyovers, underpass)																														
	-- Vegetation																														
	Switch																														
	- Inspection of switch																														
	-- Visual Inspection																														
	-- Ultrasonic - Manual																														
	-- Ultrasonic - Train based																														
	-- Eddy current inspection - Train based																														
	-- Track geometry - train based																														
	-- Dynamic track behaviour - train based																														
	-- Noise monitoring																														
	-- Train based high speed image capture inspection																														
	- Preventive/condition based maintenance of switch																														
	-- S&C adjustment																														
	-- Lubrication																														
	-- Grinding																														
	-- Tighten/adjust stretcher bars																														
	-- Adjust drive																														
	- Corrective maintenance of switch																														
	-- Half set replacement																														
	-- Crossing replacement																														
	-- Crossing weld repair																														
	-- Replace bearers																														
	-- S&C tactical reballast																														
	-- S&C tamping																														
	-- Manual S&C geometry correction																														
	-- Repair/replace switch motor and drive mechanisms																														
	-- Repair/replace locking mechanisms																														
	-- Repair electrical/signalling/interlocking failures																														
	Bridges																														
	- Inspection of bridge																														
	-- Visual Inspection																														
	-- Bridge monitoring eg optical monitoring of movement																														
	-- Other bridge inspection																														
	- Predictive/conditin based maintenance																														
	-- Bridge strengthening - eg fibre reinforment, steel reinforment, spray concrete etc																														
	Embankements																														
	- Embankment inspection																														
	-- Visual inspection																														
	-- Embankment movement monitoring																														
	- Embankment stabilisation																														
	-- Geotextiles																														
	-- Concrete piles																														
	- Renewals																														
	-- Rail, sleeper and Ballast renewal																														
	-- Sleeper and ballast renewal																														
	-- Tactical resleeper																														
	-- Ballast cleaning																														
	- Renewals of switch																														
	-- S&C renewal																														
	- Renewals of bridge platform																														

Innovation - Optimised sensor, communication and data strategy

			Transport and logistics						Construction and maintenance								Operation		Data			Emission factors								Data	
				Vehicle characteristics			Production			Machinery characteristics				Production			Production						Climate change emissions (kg/unit)				Air pollution emissions (kg/unit)				
	LCA block	Reference unit (e.g. km, m^3, tonne, train, wagon, terminal...)	Transport mode	Load capacity (tonnes)	Fuel consumption (e.g l/100 km)	Energy consumption (e.g kWh)	Distance travelled (Km)	Activity time (Hours)	Equipment	Production (e.g. tonnes/h, m3/h, km/h...)	Power (kW, hp)	Fuel consumption (e.g l/100 km)	Energy consumption (e.g kWh)	Quantity	Unit (e.g. tonnes, km...)	Working time (hours)	Energy (Direct use of energy in task, processing)	Utilisation rate (%)	Dependencies (eg relationship between frequency of task upon boundary conditions such as load (MGT), traffic type, curve etc)	Source of data eg carbon reporting statements, model, expert estimate	Quality of data source and where possible accuracy of data (upper and lower limits)	CO_2 Carbon dioxide	CH_4 Methane	N_2O Nitrous Oxide	CO_2e 1x CO_2, 34x CH_4, 298x N_2O	SO_2 Sulphur dioxide	NO_x Nitrogen oxides	PM_{10} Particulate matter	NMVOC Non-methane Volatile Organic Compounds	Source of data eg carbon reporting statements, model, expert estimate	Quality of data source and where possible accuracy of data (upper and lower limits)
Infrastructure embedded carbon	**Investment**																														
	- Project preparation																														
	- Investment and installation																														
	-- Installation of sensor technology and associated cabling and communication infrastructure																														
	- Testing and commissioning																														
	-- Inspection/quality control																														
	Disposal																														
	- Decommission/removal works																														
	- Disposal costs/recycled value																														
Operational carbon	**Operation activities (non-maintenance)**																														
	- Traction energy																														
	- Personnel - transport																														
	- Facilities																														
	- Data processing/data analysis																														
	Maintenance activities (see RAMS template)																														
	Sensor																														
	- Corrective maintenance of sensor																														
	-- Repair of sensors damaged due to flying ballast, ice, moisture, fatigue, high acceleration forces,																														
	- Other maintenance of sensor equipment																														
	-- Battery replacement																														
	-- Sensor position and realignment																														
	-- Data retrieval																														
	Track																														
	- Inspection of track																														
	-- Visual Inspection																														
	-- Ultrasonic - Manual																														
	-- Ultrasonic - Train based																														
	-- Eddy current inspection - Train based																														
	-- Track geometry - train based																														
	-- Dynamic track behaviour - train based																														
	-- Slab monitoring for cracks and movement																														
	-- Noise monitoring																														
	- Preventive/condition based maintenance																														
	-- Rail Change																														
	-- Rail Transpose																														
	-- Grinding																														
	-- Lubrication																														
	-- Fish Plate lubrication																														
	-- IBJ replacement																														
	-- Re-sleeper																														
	-- Replace sleeper pads and insulators																														
	-- Noise abatement																														
	- Corrective track maintenance																														
	-- Rail Change - defects																														
	-- Weld change - defects																														
	-- Rail adjustment																														
	-- Ballast reprofile																														
	-- Wet bed removal																														
	-- Tactical reballast																														
	-- Plain line tamping																														
	-- Stoneblowing																														
	-- Geometry manual																														
	-- replacement of pads and fasteners																														
	-- Re-fastening systems																														
	- Off Track maintenance																														
	-- Drainage																														
	-- Fencing																														
	-- Civil structures (flyovers, underpass)																														
	-- Vegetation																														
	Switch																														
	- Inspection of switch																														
	-- Visual Inspection																														
	-- Ultrasonic - Manual																														
	-- Ultrasonic - Train based																														
	-- Eddy current inspection - Train based																														
	-- Track geometry - train based																														
	-- Dynamic track behaviour - train based																														
	-- Noise monitoring																														
	-- Train based high speed image capture inspection																														
	- Preventive/condition based maintenance of switch																														
	-- S&C adjustment																														
	-- Lubrication																														
	-- Grinding																														
	-- Tighten/adjust stretcher bars																														
	-- Adjust drive																														
	- Corrective maintenance of switch																														
	-- Half set replacement																														
	-- Crossing replacement																														
	-- Crossing weld repair																														
	-- Replace bearers																														
	-- S&C tactical reballast																														
	-- S&C tamping																														
	-- Manual S&C geometry correction																														
	-- Repair/replace switch motor and drive mechanisms																														
	-- Repair/replace locking mechanisms																														
	-- Repair electrical/signalling/interlocking failures																														
	Bridges																														
	- Inspection of bridge																														
	-- Visual Inspection																														
	-- Bridge monitoring eg optical monitoring of movement																														
	-- Other bridge inspection																														
	- Predictive/condition based maintenance																														
	-- Bridge strengthening - eg fibre reinforment, steel reinforment, spray concrete etc																														
	Embankements																														
	- Embankment inspection																														
	-- Visual inspection																														
	-- Embankment movement monitoring																														
	- Embankment stabilisation																														
	-- Geotextiles																														
	-- Concrete piles																														
	- Renewals																														
	-- Rail, sleeper and Ballast renewal																														
	-- Sleeper and ballast renewal																														
	-- Tactical resleeper																														
	-- Ballast cleaning																														
	- Renewals of switch																														
	-- S&C renewal																														
	- Renewals of bridge platform																														

Appendix 4 - RAMS Templates

Capacity4Rail Technology Evaluation template - RAMS data

Sub-project: SP1

Innovation: New Concepts based on modular slab track - slab track evaluated against ballasted track

Maintenance and inspection tasks

Maintenance/ inspection task	New task required for innovation? Y/N	Stakeholders impacted	Frequency of task		Time to maintain/inspect (MTM Mean time Maintain)		Unavailability of infrastructure during maintenance task (time infrastructure unable for and min. number of lines, spped limits on neighbouring lines etc		Maintenance cost (cost of parts, cost of labour, number of persons required, logistic costs, handling, cost of track unavailability		Sources of data used - statistical data, models. Detail assumptions made and where possible uncertainty limits or distributions for frequency and time maintain. If data changes based on traffic type, MGT, track curvature, cant etc. Please detail how this will change and reference any models (eg wear rate, fatigue models etc) which could be used for sensitivity analysis.	
			Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation
- Inspection												
-- Visual Inspection												
-- Ultrasonic - Manual												
-- Ultrasonic - Train based												
-- Eddy current inspection - Train based												
-- Track geometry - train based												
-- Noise monitoring												
- Preventative/condition based maintenance												
-- Rail Change												
-- Rail Transpose												
-- Grinding												
-- Lubrication												
-- Fish Plate lubrication												
-- IBJ replacement												
-- Re-sleeper												
-- Replace sleeper pads and insulators												
-- Noise abatement												
-- Slab monitoring for cracks and movement												
- Corrective maintenance												
-- Rail Change - defects												
-- Weld change - defects												
-- Rail adjustment												
-- Ballast reprofile												
-- Wet bed removal												
-- Tactical reballast												
-- Plain line tamping												
-- Stoneblowing												
-- Geometry manual												
-- replacement of pads and fasteners												
-- Maintain drainage												
-- Adjust fastening system for small defects												
-- replacement of pads and fasteners												
-- Correct cracks in slab												
--- Replace slab - in case of derailment or accident (major damage)												
--- Inject resin to protect steel												
-- Correct settlement of slab												
--- Inject cement or other products under slab												
--- Expansive foam treatment												
--- Micro piles												
- Off Track maintenance												
-- Drainage												
-- Fencing												
-- Vegetation												

Failure

Failure mode (eg from FMEA)	New failure mode due to innovation? Y/N	Stakeholders impacted	Frequency of failure, Mean time between failure, Weibull		Time to repair (MTR Mean time to Repair)		Unavailability of infrastructure during repair task (time infrastructure unable for and min. number of lines, spped limits on neighbouring lines etc		Repair cost (cost of parts, cost of labour, number of persons required, logistic costs, handling, cost of track unavailability		Sources of data used - statistical data, models. Detail assumptions made and where possible uncertainty limits or distributions for frequency and time maintain. If data changes based on traffic type, MGT, track curvature, cant etc. Please detail how this will change and reference any models (eg wear rate, fatigue models etc) which could be used for sensitivity analysis.	
			Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation
Flooding of track												
Rail defect identified - clamp and/or speed limits applied												
Derailment/delays - Rail break												
Derailment/delays - track alignment fault												
Derailment/delays - wheel profile/rolling stock failure												
Derailment/delays - landslide												
Derailment/delays - hitting object./animal on track												
Failure of slab												
Earthwork failure												

Renewal/replacement tasks

Renewal/replacement task	New task required for innovation? Y/N	Stakeholders impacted	Frequency of renewal task		Time to renew/replace		Unavailability of infrastructure during renewal task (time infrastructure unable for and min. number of lines, speed limits on neighbouring lines etc		Renewal cost (cost of parts, cost of labour, number of persons required, logistic costs, handling, cost of track unavailability		Sources of data used - statistical data, models. Detail assumptions made and where possible uncertainty limits or distributions for frequency and time maintain. If data changes based on traffic type, MGT, track curvature, cant etc. Please detail how this will change and reference any models (eg wear rate, fatigue models etc) which could be used for sensitivity analysis.	
			Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation
- Renewals												
--Rail, sleeper and Ballast renewal												
-- Sleeper and ballast renewal												
-- Tactical resleeper												
--Ballast cleaning												
-- Slab replacement												
-- Rail+pad+fasteners replacement												
-- Rail + pad replacement only												
-- Replace drainage system												

Safety impacts - for safety critical failures - the impact on safety must be considered

Describe how the frequency of failure/injury and impact differ between the baseline case innovation for each failure mode considered. An FMEA and risk assessment process should be carried out before completing this table

Failure mode/injury type	New failure mode/hazard due to innovation? Y/N	Stakeholders impacted	Frequency/likelihood of failure/injury		Impact of failure/injury	
			Baseline case	Innovation	Baseline case	Innovation
Flooding of track						
Rail defect identified - clamp and/or speed limits applied						
Derailment/delays - Rail break						
Derailment/delays - track alignment fault						
Derailment/delays - wheel profile/rolling stock failure						
Derailment/delays - landslide						
Derailment/delays - hitting object./animal on track						
Failure of slab						
Earthwork failure						
Track worker injury/fatality - crushed by train						
Track worker injury/fatality - injured by train						
Track worker injury/fatality - slips, trips and falls						
Track worker injury/fatality - manual lifting/machine or tool operation						
Track worker injury/fatality - fall from height						

Capacity4Rail Technology Evaluation template - RAMS data

Sub-project: SP1

Innovation: New Concepts based on modular slab track - innovative slab track evaluated against existing slab track

Maintenance and inspection tasks

Maintenance/ inspection task	New task required for innovation? Y/N	Stakeholders impacted	Frequency of task		Time to maintain/inspect (MTM Mean time Maintain)		Unavailability of infrastructure during maintenance task (time infrastructure unable for and min. number of lines, spped limits on neighbouring lines etc		Maintenance cost (cost of parts, cost of labour, number of persons required, logistic costs, handling, cost of track unavailability		Sources of data used - statistical data, models. Detail assumptions made and where possible uncertainty limits or distributions for frequency and time maintain. If data changes based on traffic type, MGT, track curvature, cant etc. Please detail how this will change and reference any models (eg wear rate, fatigue models etc) which could be used for sensitivity analysis.	
			Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation
Maintenance costs - see RAMS template												
- Inspection												
-- Visual Inspection												
-- Ultrasonic - Manual												
-- Ultrasonic - Train based												
-- Eddy current inspection - Train based												
-- Track geometry - train based												
-- Slab monitoring for cracks and movement												
-- Noise monitoring												
- Preventative/condition based maintenance												
-- Rail Change												
-- Rail Transpose												
-- Grinding												
-- Lubrication												
-- Fish Plate lubrication												
-- IBJ replacement												
-- Re-sleeper												
-- Replace rail pads and insulators												
-- Noise abatement												
- Corrective maintenance												
-- Rail Change - defects												
-- Weld change - defects												
-- Rail adjustment												
-- Maintain drainage												
-- Adjust fastening system for small defects												
-- replacement of pads and fasteners												
-- Correct cracks in slab												
--- Replace slab - in case of derailment or accident (major damage)												
--- Inject resin to protect steel												
-- Correct settlement of slab												
--- Inject cement or other products under slab												
--- Expansive foam treatment												
--- Micro piles												
- Off Track maintenance												
-- Drainage												
-- Fencing												
-- Vegetation												

Failure

Failure mode (eg from FMEA)	New failure mode due to innovation? Y/N	Stakeholders impacted	Frequency of failure, Mean time between failure, Weibull		Time to repair (MTR Mean time to Repair)		Unavailability of infrastructure during repair task (time infrastructure unable for and min. number of lines, spped limits on neighbouring lines etc		Repair cost (cost of parts, cost of labour, number of persons required, logistic costs, handling, cost of track unavailability		Sources of data used - statistical data, models. Detail assumptions made and where possible uncertainty limits or distributions for frequency and time maintain. If data changes based on traffic type, MGT, track curvature, cant etc. Please detail how this will change and reference any models (eg wear rate, fatigue models etc) which could be used for sensitivity analysis.	
			Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation
Flooding of track												
Rail defect identified - clamp and/or speed limits applied												
Derailment/delays - Rail break												
Derailment/delays - track alignment fault												
Derailment/delays - wheel profile/rolling stock failure												
Derailment/delays - landslide												
Derailment/delays - hitting object./animal on track												
Failure of slab												
Earthwork failure												

Renewal/replacement tasks

Renewal/replacement task	New task required for innovation? Y/N	Stakeholders impacted	Frequency of renewal task		Time to renew/replace		Unavailability of infrastructure during renewal task (time infrastructure unable for and min. number of lines, speed limits on neighbouring lines etc		Renewal cost (cost of parts, cost of labour, number of persons required, logistic costs, handling, cost of track unavailability		Sources of data used - statistical data, models. Detail assumptions made and where possible uncertainty limits or distributions for frequency and time maintain. If data changes based on traffic type, MGT, track curvature, cant etc. Please detail how this will change and reference any models (eg wear rate, fatigue models etc) which could be used for sensitivity analysis.	
			Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation
- Renewals												
-- Slab replacement												
-- Rail+pad+fasteners replacement												
-- Rail + pad replacement only												
-- Replace drainage system												

Safety impacts - for safety critical failures - the impact on safety must be considered

Describe how the frequency of failure/injury and impact differ between the baseline case innovation for each failure mode considered. An FMEA and risk assessment process should be carried out before completing this table

Failure mode/injury type	New failure mode/hazard due to innovation? Y/N	Stakeholders impacted	Frequency/likelihood of failure/injury		Impact of failure/injury	
			Baseline case	Innovation	Baseline case	Innovation
Flooding of track						
Rail defect identified - clamp and/or speed limits applied						
Derailment/delays - Rail break						
Derailment/delays - track alignment fault						
Derailment/delays - wheel profile/rolling stock failure						
Derailment/delays - landslide						
Derailment/delays - hitting object./animal on track						
Failure of slab						
Earthwork failure						
Track worker injury/fatality - crushed by train						
Track worker injury/fatality - injured by train						
Track worker injury/fatality - slips, trips and falls						
Track worker injury/fatality - manual lifting/machine or tool operation						
Track worker injury/fatality - fall from height						

Capacity4Rail Technology Evaluation template - RAMS data

Sub-project: SP1

Innovation: New track designs and specifications for very high speed lines (if innovation slab track)

Maintenance and inspection tasks

Maintenance/ inspection task	New task required for innovation? Y/N	Stakeholders impacted	Frequency of task		Time to maintain/inspect (MTM Mean time Maintain)		Unavailability of infrastructure during maintenance task (time infrastructure unable for and min. number of lines, spped limits on neighbouring lines etc		Maintenance cost (cost of parts, cost of labour, number of persons required, logistic costs, handling, cost of track unavailability		Sources of data used - statistical data, models. Detail assumptions made and where possible uncertainty limits or distributions for frequency and time maintain. If data changes based on traffic type, MGT, track curvature, cant etc. Please detail how this will change and reference any models (eg wear rate, fatigue models etc) which could be used for sensitivity analysis.	
			Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation
- Inspection												
-- Visual Inspection												
-- Ultrasonic - Manual												
-- Ultrasonic - Train based												
-- Eddy current inspection - Train based												
-- Track geometry - train based												
-- Noise monitoring												
- Preventative/condition based maintenance												
-- Rail Change												
-- Rail Transpose												
-- Grinding												
-- Lubrication												
-- Fish Plate lubrication												
-- IBJ replacement												
-- Re-sleeper												
-- Replace sleeper pads and insulators												
-- Noise abatement												
-- Slab monitoring for cracks and movement												
- Corrective maintenance												
-- Rail Change - defects												
-- Weld change - defects												
-- Rail adjustment												
-- Ballast reprofile												
-- Wet bed removal												
-- Tactical reballast												
-- Plain line tamping												
-- Stoneblowing												
-- Geometry manual												
-- replacement of pads and fasteners												
-- Maintain drainage												
-- Adjust fastening system for small defects												
-- replacement of pads and fasteners												
-- Correct cracks in slab												
--- Replace slab - in case of derailment or accident (major damage)												
--- Inject resin to protect steel												
-- Correct settlement of slab												
--- Inject cement or other products under slab												
--- Expansive foam treatment												
--- Micro piles												
- Off Track maintenance												
-- Drainage												
-- Fencing												
-- Vegetation												

Failure

Failure mode (eg from FMEA)	New failure mode due to innovation? Y/N	Stakeholders impacted	Frequency of failure, Mean time between failure, Weibull		Time to repair (MTR Mean time to Repair)		Unavailability of infrastructure during repair task (time infrastructure unable for and min. number of lines, spped limits on neighbouring lines etc		Repair cost (cost of parts, cost of labour, number of persons required, logistic costs, handling, cost of track unavailability		Sources of data used - statistical data, models. Detail assumptions made and where possible uncertainty limits or distributions for frequency and time maintain. If data changes based on traffic type, MGT, track curvature, cant etc. Please detail how this will change and reference any models (eg wear rate, fatigue models etc) which could be used for sensitivity analysis.	
			Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation
Flooding of track												
Rail defect identified - clamp and/or speed limits applied												
Derailment/delays - Rail break												
Derailment/delays - track alignment fault												
Derailment/delays - wheel profile/rolling stock failure												
Derailment/delays - landslide												
Derailment/delays - hitting object./animal on track												
Failure of slab												
Earthwork failure												

Renewal/replacement tasks

Renewal/replacement task	New task required for innovation? Y/N	Stakeholders impacted	Frequency of renewal task		Time to renew/replace		Unavailability of infrastructure during renewal task (time infrastructure unable for and min. number of lines, speed limits on neighbouring lines etc		Renewal cost (cost of parts, cost of labour, number of persons required, logistic costs, handling, cost of track unavailability		Sources of data used - statistical data, models. Detail assumptions made and where possible uncertainty limits or distributions for frequency and time maintain. If data changes based on traffic type, MGT, track curvature, cant etc. Please detail how this will change and reference any models (eg wear rate, fatigue models etc) which could be used for sensitivity analysis.	
			Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation
- Renewals												
--Rail, sleeper and Ballast renewal												
-- Sleeper and ballast renewal												
-- Tactical resleeper												
--Ballast cleaning												
-- Slab replacement												
-- Rail+pad+fasteners replacement												
-- Rail + pad replacement only												
-- Replace drainage system												

Safety impacts - for safety critical failures - the impact on safety must be considered

Describe how the frequency of failure/injury and impact differ between the baseline case innovation for each failure mode considered. An FMEA and risk assessment process should be carried out before completing this table

Failure mode/injury type	New failure mode/hazard due to innovation? Y/N	Stakeholders impacted	Frequency/likelihood of failure/injury		Impact of failure/injury	
			Baseline case	Innovation	Baseline case	Innovation
Flooding of track						
Rail defect identified - clamp and/or speed limits applied						
Derailment/delays - Rail break						
Derailment/delays - track alignment fault						
Derailment/delays - wheel profile/rolling stock failure						
Derailment/delays - landslide						
Derailment/delays - hitting object./animal on track						
Failure of slab						
Earthwork failure						
Track worker injury/fatality - crushed by train						
Track worker injury/fatality - injured by train						
Track worker injury/fatality - slips, trips and falls						
Track worker injury/fatality - manual lifting/machine or tool operation						
Track worker injury/fatality - fall from height						

Capacity4Rail Technology Evaluation template - RAMS data

Sub-project: SP1

Innovation: New track designs and specifications for very high speed lines (if innovation ballasted track)

Maintenance and inspection tasks

Maintenance/ inspection task	New task required for innovation? Y/N	Stakeholders impacted	Frequency of task		Time to maintain/inspect (MTM Mean time Maintain)		Unavailability of infrastructure during maintenance task (time infrastructure unable for and min. number of lines, spped limits on neighbouring lines etc		Maintenance cost (cost of parts, cost of labour, number of persons required, logistic costs, handling, cost of track unavailability		Sources of data used - statistical data, models. Detail assumptions made and where possible uncertainty limits or distributions for frequency and time maintain. If data changes based on traffic type, MGT, track curvature, cant etc. Please detail how this will change and reference any models (eg wear rate, fatigue models etc) which could be used for sensitivity analysis.	
			Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation
- Inspection												
-- Visual Inspection												
-- Ultrasonic - Manual												
-- Ultrasonic - Train based												
-- Eddy current inspection - Train based												
-- Track geometry - train based												
-- Noise monitoring												
- Preventative/condition based maintenance												
-- Rail Change												
-- Rail Transpose												
-- Grinding												
-- Lubrication												
-- Fish Plate lubrication												
-- IBJ replacement												
-- Re-sleeper												
-- Replace sleeper pads and insulators												
-- Noise abatement												
- Corrective maintenance												
-- Rail Change - defects												
-- Weld change - defects												
-- Rail adjustment												
-- Ballast reprofile												
-- Wet bed removal												
-- Tactical reballast												
-- Plain line tamping												
-- Stoneblowing												
-- Geometry manual												
-- replacement of pads and fasteners												
- Off Track maintenance												
-- Drainage												
-- Fencing												
-- Vegetation												

Failure

Failure mode (eg from FMEA)	New failure mode due to innovation? Y/N	Stakeholders impacted	Frequency of failure, Mean time between failure, Weibull		Time to repair (MTR Mean time to Repair)		Unavailability of infrastructure during repair task (time infrastructure unable for and min. number of lines, spped limits on neighbouring lines etc		Repair cost (cost of parts, cost of labour, number of persons required, logistic costs, handling, cost of track unavailability		Sources of data used - statistical data, models. Detail assumptions made and where possible uncertainty limits or distributions for frequency and time maintain. If data changes based on traffic type, MGT, track curvature, cant etc. Please detail how this will change and reference any models (eg wear rate, fatigue models etc) which could be used for sensitivity analysis.	
			Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation
Flooding of track												
Rail defect identified - clamp and/or speed limits applied												
Derailment/delays - Rail break												
Derailment/delays - track alignment fault												
Derailment/delays - wheel profile/rolling stock failure												
Derailment/delays - landslide												
Derailment/delays - hitting object./animal on track												
Failure of slab												
Earthwork failure												

Renewal/replacement tasks

Renewal/replacement task	New task required for innovation? Y/N	Stakeholders impacted	Frequency of renewal task		Time to renew/replace		Unavailability of infrastructure during renewal task (time infrastructure unable for and min. number of lines, speed limits on neighbouring lines etc		Renewal cost (cost of parts, cost of labour, number of persons required, logistic costs, handling, cost of track unavailability		Sources of data used - statistical data, models. Detail assumptions made and where possible uncertainty limits or distributions for frequency and time maintain. If data changes based on traffic type, MGT, track curvature, cant etc. Please detail how this will change and reference any models (eg wear rate, fatigue models etc) which could be used for sensitivity analysis.	
			Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation
- Renewals												
--Rail, sleeper and Ballast renewal												
-- Sleeper and ballast renewal												
-- Tactical resleeper												
--Ballast cleaning												

Safety impacts - for safety critical failures - the impact on safety must be considered

Describe how the frequency of failure/injury and impact differ between the baseline case innovation for each failure mode considered. An FMEA and risk assessment process should be carried out before completing this table

Failure mode/injury type	New failure mode/hazard due to innovation? Y/N	Stakeholders impacted	Frequency/likelihood of failure/injury		Impact of failure/injury	
			Baseline case	Innovation	Baseline case	Innovation
Flooding of track						
Rail defect identified - clamp and/or speed limits applied						
Derailment/delays - Rail break						
Derailment/delays - track alignment fault						
Derailment/delays - wheel profile/rolling stock failure						
Derailment/delays - landslide						
Derailment/delays - hitting object./animal on track						
Earthwork failure						
Track worker injury/fatality - crushed by train						
Track worker injury/fatality - injured by train						
Track worker injury/fatality - slips, trips and falls						
Track worker injury/fatality - manual lifting/machine or tool operation						
Track worker injury/fatality - fall from height						

Capacity4Rail Technology Evaluation template - RAMS data

Sub-project: SP1

Innovation: New concepts for Switches and Crossings based on failure modes analysis

Maintenance and inspection tasks

Maintenance/ inspection task	New task required for innovation? Y/N	Stakeholders impacted	Frequency of task		Time to maintain/inspect (MTM Mean time Maintain)		Unavailability of infrastructure during maintenance task (time infrastructure unable for and min. number of lines, spped limits on neighbouring lines etc		Maintenance cost (cost of parts, cost of labour, number of persons required, logistic costs, handling, cost of track unavailability		Sources of data used - statistical data, models. Detail assumptions made and where possible uncertainty limits or distributions for frequency and time maintain. If data changes based on traffic type, MGT, track curvature, cant etc. Please detail how this will change and reference any models (eg wear rate, fatigue models etc) which could be used for sensitivity analysis.	
			Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation
- Inspection												
-- Visual Inspection												
-- Ultrasonic - Manual												
-- Ultrasonic - Train based												
-- Eddy current inspection - Train based												
-- Track geometry - train based												
-- Noise monitoring												
-- Train based high speed image capture inspection												
- Preventative/condition based maintenance												
-- S&C adjustment												
-- Lubrication												
-- Grinding												
-- Tighten/adjust stretcher bars												
-- Adjust drive												
- Corrective maintenance												
-- Half set replacement												
-- Crossing replacement												
-- Crossing weld repair												
-- Replace bearers												
-- S&C tactical reballast												
-- S&C tamping												
-- Manual S&C geometry correction												
-- Repair/replace switch motor and drive mechanisms												
-- Repair/replace locking mechanisms												
-- Repair electrical/signalling/interlocking failures												

Failure

Failure mode (eg from FMEA)	New failure mode due to innovation? Y/N	Stakeholders impacted	Frequency of failure, Mean time between failure, Weibull		Time to repair (MTR Mean time to Repair)		Unavailability of infrastructure during repair task (time infrastructure unable for and min. number of lines, spped limits on neighbouring lines etc		Repair cost (cost of parts, cost of labour, number of persons required, logistic costs, handling, cost of track unavailability		Sources of data used - statistical data, models. Detail assumptions made and where possible uncertainty limits or distributions for frequency and time maintain. If data changes based on traffic type, MGT, track curvature, cant etc. Please detail how this will change and reference any models (eg wear rate, fatigue models etc) which could be used for sensitivity analysis.	
			Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation
-- Flooding												
-- Signalling/electrical failures												
-- Ice, ballast or other object between switch and stock rail preventing switch locking												
-- Damage to switch drive from flying ballast, ice falling from vehicles												
-- Stretcher bar failure												
-- Derailment due to switch rail wear												

Renewal/replacement tasks

Renewal/replacement task	New failure mode due to innovation? Y/N	Stakeholders impacted	Frequency of renewal task		Time to renew/replace		Unavailability of infrastructure during renewal task (time infrastructure unable for and min. number of lines, speed limits on neighbouring lines etc		Renewal cost (cost of parts, cost of labour, number of persons required, logistic costs, handling, cost of track unavailability		Sources of data used - statistical data, models. Detail assumptions made and where possible uncertainty limits or distributions for frequency and time maintain. If data changes based on traffic type, MGT, track curvature, cant etc. Please detail how this will change and reference any models (eg wear rate, fatigue models etc) which could be used for sensitivity analysis.	
			Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation
- Renewals												
-- S&C renewal												

Safety impacts - for safety critical failures - the impact on safety must be considered

Describe how the frequency of failure/injury and impact differ between the baseline case innovation for each failure mode considered. An FMEA and risk assessment process should be carried out before completing this table

Failure mode/injury type	New failure mode/hazard due to innovation? Y/N	Stakeholders impacted	Frequency/likelihood of failure/injury		Impact of failure/injury	
			Baseline case	Innovation	Baseline case	Innovation
-- Flooding						
-- Signalling/electrical failures						
-- Ice, ballast or other object between switch and stock rail preventing switch locking						
-- Damage to switch drive from flying ballast, ice falling from vehicles						
-- Stretcher bar failure						
-- Derailment due to switch rail wear						
Track worker injury/fatality - crushed by train						
Track worker injury/fatality - injured by train						
Track worker injury/fatality - slips, trips and falls						
Track worker injury/fatality - manual lifting/machine or tool operation						
Track worker injury/fatality - fall from height						

Capacity4Rail Technology Evaluation template - RAMS data

Sub-project: **SP1**

Innovation: **New designs for switches resilient to extreme weather conditions**

Maintenance and inspection tasks

Maintenance/ inspection task	New task required for innovation? Y/N	Stakeholders impacted	Frequency of task		Time to maintain/inspect (MTM Mean time Maintain)		Unavailability of infrastructure during maintenance task (time infrastructure unable for and min. number of lines, spped limits on neighbouring lines etc		Maintenance cost (cost of parts, cost of labour, number of persons required, logistic costs, handling, cost of track unavailability		Sources of data used - statistical data, models. Detail assumptions made and where possible uncertainty limits or distributions for frequency and time maintain. If data changes based on traffic type, MGT, track curvature, cant etc. Please detail how this will change and reference any models (eg wear rate, fatigue models etc) which could be used for sensitivity analysis.	
			Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation
- Inspection												
-- Visual Inspection												
-- Ultrasonic - Manual												
-- Ultrasonic - Train based												
-- Eddy current inspection - Train based												
-- Track geometry - train based												
-- Noise monitoring												
-- Train based high speed image capture inspection												
- Preventative/condition based maintenance												
-- S&C adjustment												
-- Lubrication												
-- Grinding												
-- Tighten/adjust stretcher bars												
-- Adjust drive												
- Corrective maintenance												
-- Half set replacement												
-- Crossing replacement												
-- Crossing weld repair												
-- Replace bearers												
-- S&C tactical reballast												
-- S&C tamping												
-- Manual S&C geometry correction												
-- Repair/replace switch motor and drive mechanisms												
-- Repair/replace locking mechanisms												
-- Repair electrical/signalling/interlocking failures												

Failure

Failure mode (eg from FMEA)	New failure mode due to innovation? Y/N	Stakeholders impacted	Frequency of failure, Mean time between failure, Weibull		Time to repair (MTR Mean time to Repair)		Unavailability of infrastructure during repair task (time infrastructure unable for and min. number of lines, spped limits on neighbouring lines etc		Repair cost (cost of parts, cost of labour, number of persons required, logistic costs, handling, cost of track unavailability		Sources of data used - statistical data, models. Detail assumptions made and where possible uncertainty limits or distributions for frequency and time maintain. If data changes based on traffic type, MGT, track curvature, cant etc. Please detail how this will change and reference any models (eg wear rate, fatigue models etc) which could be used for sensitivity analysis.	
			Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation
-- Flooding												
-- Signalling/electrical failures												
-- Ice, ballast or other object between switch and stock rail preventing switch locking												
-- Damage to switch drive from flying ballast, ice falling from vehicles												
-- Stretcher bar failure												
-- Derailment due to switch rail wear												

Renewal/replacement tasks

Renewal/replacement task	New task required for innovation? Y/N	Stakeholders impacted	Frequency of renewal task		Time to renew/replace		Unavailability of infrastructure during renewal task (time infrastructure unable for and min. number of lines, speed limits on neighbouring lines etc		Renewal cost (cost of parts, cost of labour, number of persons required, logistic costs, handling, cost of track unavailability		Sources of data used - statistical data, models. Detail assumptions made and where possible uncertainty limits or distributions for frequency and time maintain. If data changes based on traffic type, MGT, track curvature, cant etc. Please detail how this will change and reference any models (eg wear rate, fatigue models etc) which could be used for sensitivity analysis.	
			Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation
- Renewals												
-- S&C renewal												

Safety impacts - for safety critical failures - the impact on safety must be considered

Describe how the frequency of failure/injury and impact differ between the baseline case innovation for each failure mode considered. An FMEA and risk assessment process should be carried out before completing this table

Failure mode/injury type	New failure mode/hazard due to innovation? Y/N	Stakeholders impacted	Frequency/likelihood of failure/injury		Impact of failure/injury	
			Baseline case	Innovation	Baseline case	Innovation
-- Flooding						
-- Signalling/electrical failures						
-- Ice, ballast or other object between switch and stock rail preventing switch locking						
-- Damage to switch drive from flying ballast, ice falling from vehicles						
-- Stretcher bar failure						
-- Derailment due to switch rail wear						
Track worker injury/fatality - crushed by train						
Track worker injury/fatality - injured by train						
Track worker injury/fatality - slips, trips and falls						
Track worker injury/fatality - manual lifting/machine or tool operation						
Track worker injury/fatality - fall from height						

Capacity4Rail Technology Evaluation template - RAMS data

Sub-project: SP1

Innovation: Optimised S&C sensor strategies

Maintenance and inspection tasks

Maintenance/ inspection task	New task required for innovation? Y/N	Stakeholders impacted	Frequency of task		Time to maintain/inspect (MTM Mean time Maintain)		Unavailability of infrastructure during maintenance task (time infrastructure unable for and min. number of lines, spped limits on neighbouring lines etc		Maintenance cost (cost of parts, cost of labour, number of persons required, logistic costs, handling, cost of track unavailability		Sources of data used - statistical data, models. Detail assumptions made and where possible uncertainty limits or distributions for frequency and time maintain. If data changes based on traffic type, MGT, track curvature, cant etc. Please detail how this will change and reference any models (eg wear rate, fatigue models etc) which could be used for sensitivity analysis.	
			Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation
- Corrective maintenance of sensor												
-- Repair of sensors damaged due to flying ballast, ice, moisture, fatigue, high acceleration forces,												
- Other maintenance of sensor equipment												
-- Battery replacement												
-- Sensor position and realignment												
-- Data retrieval												
- Inspection of switch												
-- Visual Inspection												
-- Ultrasonic - Manual												
-- Ultrasonic - Train based												
-- Eddy current inspection - Train based												
-- Track geometry - train based												
-- Noise monitoring												
-- Train based high speed image capture inspection												
- Preventative/condition based maintenance of switch												
-- S&C adjustment												
-- Lubrication												
-- Grinding												
-- Tighten/adjust stretcher bars												
-- Adjust drive												
- Corrective maintenance of switch												
-- Half set replacement												
-- Crossing replacement												
-- Crossing weld repair												
-- Replace bearers												
-- S&C tactical reballast												
-- S&C tamping												
-- Manual S&C geometry correction												
-- Repair/replace switch motor and drive mechanisms												
-- Repair/replace locking mechanisms												
-- Repair electrical/signalling/interlocking failures												

Failure

Failure mode (eg from FMEA)	New failure mode due to innovation? Y/N	Stakeholders impacted	Frequency of failure, Mean time between failure, Weibull		Time to repair (MTR Mean time to Repair)		Unavailability of infrastructure during repair task (time infrastructure unable for and min. number of lines, spped limits on neighbouring lines etc		Repair cost (cost of parts, cost of labour, number of persons required, logistic costs, handling, cost of track unavailability		Sources of data used - statistical data, models. Detail assumptions made and where possible uncertainty limits or distributions for frequency and time maintain. If data changes based on traffic type, MGT, track curvature, cant etc. Please detail how this will change and reference any models (eg wear rate, fatigue models etc) which could be used for sensitivity analysis.	
			Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation
-- Cost of unavailability due to sensor failure												
-- Repair of sensors damaged due to flying ballast, ice, moisture, fatigue, high acceleration forces,												
-- Flooding												
-- Signalling/electrical failures												
-- Ice, ballast or other object between switch and stock rail preventing switch locking												
-- Damage to switch drive from flying ballast, ice falling from vehicles												
-- Stretcher bar failure												
-- Derailment due to switch rail wear												

Renewal/replacement tasks

Renewal/replacement task	New task required for innovation? Y/N	Stakeholders impacted	Frequency of renewal task		Time to renew/replace		Unavailability of infrastructure during renewal task (time infrastructure unable for and min. number of lines, speed limits on neighbouring lines etc		Renewal cost (cost of parts, cost of labour, number of persons required, logistic costs, handling, cost of track unavailability		Sources of data used - statistical data, models. Detail assumptions made and where possible uncertainty limits or distributions for frequency and time maintain. If data changes based on traffic type, MGT, track curvature, cant etc. Please detail how this will change and reference any models (eg wear rate, fatigue models etc) which could be used for sensitivity analysis.	
			Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation
- Renewals of switch												
-- S&C renewal												

Safety impacts - for safety critical failures - the impact on safety must be considered

Describe how the frequency of failure/injury and impact differ between the baseline case innovation for each failure mode considered. An FMEA and risk assessment process should be carried out before completing this table

Failure mode/injury type	New failure mode/hazard due to innovation? Y/N	Stakeholders impacted	Frequency/likelihood of failure/injury		Impact of failure/injury	
			Baseline case	Innovation	Baseline case	Innovation
-- Cost of unavailability due to sensor failure						
-- Repair of sensors damaged due to flying ballast, ice, moisture, fatigue, high acceleration forces,						
-- Flooding						
-- Signalling/electrical failures						
-- Ice, ballast or other object between switch and stock rail preventing switch locking						
-- Damage to switch drive from flying ballast, ice falling from vehicles						
-- Stretcher bar failure						
-- Derailment due to switch rail wear						
Track worker injury/fatality - crushed by train						
Track worker injury/fatality - injured by train						
Track worker injury/fatality - slips, trips and falls						
Track worker injury/fatality - manual lifting/machine or tool operation						
Track worker injury/fatality - fall from height						

Capacity4Rail Technology Evaluation template - RAMS data

Sub-project: **SP2**

Innovation: **Innovations in Trains/Wagons - optimised length, speed, performance, central/automatic coupler, EP/electronic braking, electification, automation, weight**

Maintenance and inspection tasks

Maintenance/ inspection task	**New task required for innovation? Y/N**	**Stakeholders impacted**	**Frequency of task**		**Time to maintain/inspect (MTM Mean time Maintain)**		**Unavailability of infrastructure during maintenance task (time infrastructure unable for and min. number of lines, spped limits on neighbouring lines etc**		**Maintenance cost (cost of parts, cost of labour, number of persons required, logistic costs, handling, cost of track unavailability**		**Sources of data used - statistical data, models. Detail assumptions made and where possible uncertainty limits or distributions for frequency and time maintain. If data changes based on traffic type, MGT, track curvature, cant etc. Please detail how this will change and reference any models (eg wear rate, fatigue models etc) which could be used for sensitivity analysis.**	
			Baseline case	**Innovation**	**Baseline case**	**Innovation**	**Baseline case**	**Innovation**	**Baseline case**	**Innovation**	**Baseline case**	**Innovation**
Rolling stock												
- Inspection												
- Preventative/condition based maintenance												
- Corrective maintenance												
Infrastructure												
- Inspection												
-- Visual Inspection												
-- Ultrasonic - Manual												
-- Ultrasonic - Train based												
-- Eddy current inspection - Train based												
-- Track geometry - train based												
-- Noise monitoring												
- Preventative/condition based maintenance												
-- Rail Change												
-- Rail Transpose												
-- Grinding												
-- Lubrication												
-- Fish Plate lubrication												
-- IBJ replacement												
-- Re-sleeper												
-- Replace sleeper pads and insulators												
-- Noise abatement												
- Corrective maintenance												
-- Rail Change - defects												
-- Weld change - defects												
-- Rail adjustment												
-- Ballast reprofile												
-- Wet bed removal												
-- Tactical reballast												
-- Plain line tamping												
-- Stoneblowing												
-- Geometry manual												
-- replacement of pads and fasteners												
- Off Track maintenance												
-- Drainage												
-- Fencing												
-- Vegetation												

Failure

Failure mode (eg from FMEA)	New failure mode due to innovation? Y/N	Stakeholders impacted	Frequency of failure, Mean time between failure, Weibull		Time to repair (MTR Mean time to Repair)		Unavailability of infrastructure during repair task (time infrastructure unable for and min. number of lines, spped limits on neighbouring lines etc		Repair cost (cost of parts, cost of labour, number of persons required, logistic costs, handling, cost of track unavailability		Sources of data used - statistical data, models. Detail assumptions made and where possible uncertainty limits or distributions for frequency and time maintain. If data changes based on traffic type, MGT, track curvature, cant etc. Please detail how this will change and reference any models (eg wear rate, fatigue models etc) which could be used for sensitivity analysis.	
			Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation
Track												
Flooding of track												
Rail defect identified - clamp and/or speed limits applied												
Derailment/delays - Rail break												
Derailment/delays - track alignment fault												
Derailment/delays - wheel profile/rolling stock failure												
Derailment/delays - landslide												
Derailment/delays - hitting object./animal on track												
Earthwork failure												
Rolling stock												
Traction power failure												
Other rolling stock failures												
Operational/signalling												
Train collision - Signal passed at danager - driver error												
Train collision - Signalling failure/S&C/traffic management system failure												

Renewal/replacement tasks

Renewal/replacement task	New task required for innovation? Y/N	Stakeholders impacted	Frequency of renewal task		Time to renew/replace		Unavailability of infrastructure during renewal task (time infrastructure unable for and min. number of lines, speed limits on neighbouring lines etc		Renewal cost (cost of parts, cost of labour, number of persons required, logistic costs, handling, cost of track unavailability		Sources of data used - statistical data, models. Detail assumptions made and where possible uncertainty limits or distributions for frequency and time maintain. If data changes based on traffic type, MGT, track curvature, cant etc. Please detail how this will change and reference any models (eg wear rate, fatigue models etc) which could be used for sensitivity analysis.	
			Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation
- Renewals												
--Rail, sleeper and Ballast renewal												
-- Sleeper and ballast renewal												
-- Tactical resleeper												
--Ballast cleaning												
- Rolling stock refurbishment												

Safety impacts - for safety critical failures - the impact on safety must be considered

Describe how the frequency of failure/injury and impact differ between the baseline case innovation for each failure mode considered. An FMEA and risk assessment process should be carried out before completing this table

Failure mode/injury type	New failure mode/hazard due to innovation? Y/N	Stakeholders impacted	Frequency/likelihood of failure/injury		Impact of failure/injury	
			Baseline case	Innovation	Baseline case	Innovation
Track						
Flooding of track						
Rail defect identified - clamp and/or speed limits applied						
Derailment/delays - Rail break						
Derailment/delays - track alignment fault						
Derailment/delays - wheel profile/rolling stock failure						
Derailment/delays - landslide						
Derailment/delays - hitting object./animal on track						
Earthwork failure						
Rolling stock						
Traction power failure						
Other rolling stock failures						
Operational/signalling						
Train collision - Signal passed at danager - driver error						
Train collision - Signalling failure/S&C/traffic management system failure						
Track worker injury/fatality - crushed by train						
Track worker injury/fatality - injured by train						
Track worker injury/fatality - slips, trips and falls						
Track worker injury/fatality - manual lifting/machine or tool operation						
Track worker injury/fatality - fall from height						

Capacity4Rail Technology Evaluation template - RAMS data

Sub-project: SP2

Innovation: Innovations in Freight Operation - wagon shunting, intelligence for vehicles in terminals, terminal operation

Failure

Failure mode (eg from FMEA)	New failure mode due to innovation? Y/N	Stakeholders impacted	Frequency of failure, Mean time between failure, Weibull		Time to repair (MTR Mean time to Repair)		Unavailability of infrastructure during repair task (time infrastructure unable for and min. number of lines, spped limits on neighbouring lines etc		Repair cost (cost of parts, cost of labour, number of persons required, logistic costs, handling, cost of track unavailability		Sources of data used - statistical data, models. Detail assumptions made and where possible uncertainty limits or distributions for frequency and time maintain. If data changes based on traffic type, MGT, track curvature, cant etc. Please detail how this will change and reference any models (eg wear rate, fatigue models etc) which could be used for sensitivity analysis.	
			Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation
Track												
Flooding of track												
Rail defect identified - clamp and/or speed limits applied												
Derailment/delays - Rail break												
Derailment/delays - track alignment fault												
Derailment/delays - wheel profile/rolling stock failure												
Derailment/delays - landslide												
Derailment/delays - hitting object./animal on track												
Earthwork failure												
S&C												
Flooding												
Signalling/electrical failures												
Ice, ballast or other object between switch and stock rail preventing switch locking												
Damage to switch drive from flying ballast, ice falling from vehicles												
Stretcher bar failure												
Derailment due to switch rail wear												
Crossing failure												
Rolling stock												
Traction power failure												
Other rolling stock failures												
Operational/signalling												
Train collision - Signal passed at danager - driver error												
Train collision - Signalling failure/S&C/traffic management system failure												
Failure of innovative shunting system												
Laoding and unloading												
Failure of loading and unloading mechinary												

Safety impacts - for safety critical failures - the impact on safety must be considered

Describe how the frequency of failure/injury and impact differ between the baseline case innovation for each failure mode considered. An FMEA and risk assessment process should be carried out before completing this table

Failure mode/injury type	New failure mode/hazard due to innovation? Y/N	Stakeholders impacted	Frequency/likelihood of failure/injury		Impact of failure/injury	
			Baseline case	Innovation	Baseline case	Innovation
Track						
Flooding of track						
Rail defect identified - clamp and/or speed limits applied						
Derailment/delays - Rail break						
Derailment/delays - track alignment fault						
Derailment/delays - wheel profile/rolling stock failure						
Derailment/delays - landslide						
Derailment/delays - hitting object./animal on track						
Earthwork failure						
S&C						
Flooding						
Signalling/electrical failures						
Ice, ballast or other object between switch and stock rail preventing switch locking						
Damage to switch drive from flying ballast, ice falling from vehicles						
Stretcher bar failure						
Derailment due to switch rail wear						
Crossing failure						
Rolling stock						
Traction power failure						
Other rolling stock failures						
Operational/signalling						
Train collision - Signal passed at danager - driver error						
Train collision - Signalling failure/S&C/traffic management system failure						
Failure of innovative shunting system						
Laoding and unloading						
Failure of loading and unloading mechinary						
Worker injury/fatality - crushed by train						
Worker injury/fatality - injured by train						
Worker injury/fatality - slips, trips and falls						
Worker injury/fatality - manual lifting/machine or tool operation						
Worker injury/fatality - fall from height						

Capacity4Rail Technology Evaluation template - RAMS data

Sub-project: SP3

Innovation: Optimal strategies to manage major disturbances

Failure

Failure mode (eg from FMEA)	New failure mode due to innovation? Y/N	Stakeholders impacted	Frequency of failure, Mean time between failure, Weibull		Time to repair (MTR Mean time to Repair)		Unavailability of infrastructure during repair task (time infrastructure unable for and min. number of lines, spped limits on neighbouring lines etc		Repair cost (cost of parts, cost of labour, number of persons required, logistic costs, handling, cost of track unavailability		Sources of data used - statistical data, models. Detail assumptions made and where possible uncertainty limits or distributions for frequency and time maintain. If data changes based on traffic type, MGT, track curvature, cant etc. Please detail how this will change and reference any models (eg wear rate, fatigue models etc) which could be used for sensitivity analysis.	
			Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation
Track												
Flooding of track												
Rail defect identified - clamp and/or speed limits applied												
Derailment/delays - Rail break												
Derailment/delays - track alignment fault												
Derailment/delays - wheel profile/rolling stock failure												
Derailment/delays - landslide												
Derailment/delays - hitting object./animal on track												
Earthwork failure												
S&C												
Flooding												
Signalling/electrical failures												
Ice, ballast or other object between switch and stock rail preventing switch locking												
Damage to switch drive from flying ballast, ice falling from vehicles												
Stretcher bar failure												
Derailment due to switch rail wear												
Crossing failure												
Rolling stock												
Traction power failure												
Other rolling stock failures												
Operational/signalling												
Train collision - Signal passed at danager - driver error												
Train collision - Signalling failure/S&C/traffic management system failure												

Safety impacts - for safety critical failures - the impact on safety must be considered

Describe how the frequency of failure/injury and impact differ between the baseline case innovation for each failure mode considered. An FMEA and risk assessment process should be carried out before completing this table

Failure mode/injury type	New failure mode/hazard due to innovation? Y/N	Stakeholders impacted	Frequency/likelihood of failure/injury		Impact of failure/injury	
			Baseline case	Innovation	Baseline case	Innovation
Track						
Flooding of track						
Rail defect identified - clamp and/or speed limits applied						
Derailment/delays - Rail break						
Derailment/delays - track alignment fault						
Derailment/delays - wheel profile/rolling stock failure						
Derailment/delays - landslide						
Derailment/delays - hitting object./animal on track						
Earthwork failure						
S&C						
Flooding						
Signalling/electrical failures						
Ice, ballast or other object between switch and stock rail preventing switch locking						
Damage to switch drive from flying ballast, ice falling from vehicles						
Stretcher bar failure						
Derailment due to switch rail wear						
Crossing failure						
Rolling stock						
Traction power failure						
Other rolling stock failures						
Operational/signalling						
Train collision - Signal passed at danager - driver error						
Train collision - Signalling failure/S&C/traffic management system failure						
Track worker injury/fatality - crushed by train						
Track worker injury/fatality - injured by train						
Track worker injury/fatality - slips, trips and falls						
Track worker injury/fatality - manual lifting/machine or tool operation						
Track worker injury/fatality - fall from height						

Capacity4Rail Technology Evaluation template - RAMS data

Sub-project: **SP4**

Innovation: **New concepts and technologies for advanced monitoring in embankments, bridges, different track types, switches etc**

Maintenance and inspection tasks

Maintenance/ inspection task	New task required for innovation? Y/N	Stakeholders impacted	Frequency of task		Time to maintain/inspect (MTM Mean time Maintain)		Unavailability of infrastructure during maintenance task (time infrastructure unable for and min. number of lines, spped limits on neighbouring lines etc		Maintenance cost (cost of parts, cost of labour, number of persons required, logistic costs, handling, cost of track unavailability		Sources of data used - statistical data, models. Detail assumptions made and where possible uncertainty limits or distributions for frequency and time maintain. If data changes based on traffic type, MGT, track curvature, cant etc. Please detail how this will change and reference any models (eg wear rate, fatigue models etc) which could be used for sensitivity analysis.	
			Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation
Sensor												
- Corrective maintenance of sensor												
-- Repair of sensors damaged due to flying ballast, ice, moisture, fatigue, high acceleration forces,												
- Other maintenance of sensor equipment												
-- Battery replacement												
-- Sensor position and realignment												
-- Data retrieval												
Track												
- Inspection of track												
-- Visual Inspection												
-- Ultrasonic - Manual												
-- Ultrasonic - Train based												
-- Eddy current inspection - Train based												
-- Track geometry - train based												
-- Noise monitoring												
- Preventative/condition based track maintenance												
-- Rail Change												
-- Rail Transpose												
-- Grinding												
-- Lubrication												
-- Fish Plate lubrication												
-- IBJ replacement												
-- Re-sleeper												
-- Replace sleeper pads and insulators												
-- Noise abatement												
- Corrective track maintenance												
-- Rail Change - defects												
-- Weld change - defects												
-- Rail adjustment												
-- Ballast reprofile												
-- Wet bed removal												
-- Tactical reballast												
-- Plain line tamping												
-- Stoneblowing												
-- Geometry manual												
-- replacement of pads and fasteners												
- Off Track maintenance												
-- Drainage												
-- Fencing												
-- Vegetation												
Switch												
- Inspection of switch												
-- Visual Inspection												
-- Ultrasonic - Manual												
-- Ultrasonic - Train based												
-- Eddy current inspection - Train based												
-- Track geometry - train based												
-- Noise monitoring												
-- Train based high speed image capture inspection												
- Preventative/condition based maintenance of switch												
-- S&C adjustment												
-- Lubrication												
-- Grinding												
-- Tighten/adjust stretcher bars												
-- Adjust drive												
- Corrective maintenance of switch												
-- Half set replacement												
-- Crossing replacement												
-- Crossing weld repair												
-- Replace bearers												
-- S&C tactical reballast												
-- S&C tamping												
-- Manual S&C geometry correction												
-- Repair/replace switch motor and drive mechanisms												
-- Repair/replace locking mechanisms												
-- Repair electrical/signalling/interlocking failures												
Bridges												
- Inspection of bridge												
-- Visual Inspection												
-- Bridge monitoring eg optical monitoring of movement												
-- Other bridge inspection												
- Predictive/conditin based maintenance												
-- Bridge strengthening - eg fibre reinforment, steel reinforment, spray concrete etc												
Embankements												
- Embankment inspection												
-- Visual inspection												
-- Embankment movement monitoring												
- Embankment stabalisation												
-- Geotextiles												
-- Concrete piles												

Failure

Failure mode (eg from FMEA)	New failure mode due to innovation? Y/N	Stakeholders impacted	Frequency of failure, Mean time between failure, Weibull		Time to repair (MTR Mean time to Repair)		Unavailability of infrastructure during repair task (time infrastructure unable for and min. number of lines, spped limits on neighbouring lines etc		Repair cost (cost of parts, cost of labour, number of persons required, logistic costs, handling, cost of track unavailability		Sources of data used - statistical data, models. Detail assumptions made and where possible uncertainty limits or distributions for frequency and time maintain. If data changes based on traffic type, MGT, track curvature, cant etc. Please detail how this will change and reference any models (eg wear rate, fatigue models etc) which could be used for sensitivity analysis.	
			Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation
Track												
Flooding of track												
Rail defect identified - clamp and/or speed limits applied												
Derailment/delays - Rail break												
Derailment/delays - track alignment fault												
Derailment/delays - wheel profile/rolling stock failure												
Derailment/delays - landslide												
Derailment/delays - hitting object./animal on track												
Earthwork failure												
S&C												
Flooding												
Signalling/electrical failures												
Ice, ballast or other object between switch and stock rail preventing switch locking												
Damage to switch drive from flying ballast, ice falling from vehicles												
Stretcher bar failure												
Derailment due to switch rail wear												
Crossing failure												
Bridge failures												
Road vehicle collision with bridge												
Bridge scour due to flooding												
Corrosion failure												
Masonary deterioration												
Embankment failures												
Landslide												

Renewal/replacement tasks

Renewal/replacement task	New task required for innovation? Y/N	Stakeholders impacted	Frequency of renewal task		Time to renew/replace		Unavailability of infrastructure during renewal task (time infrastructure unable for and min. number of lines, speed limits on neighbouring lines etc		Renewal cost (cost of parts, cost of labour, number of persons required, logistic costs, handling, cost of track unavailability		Sources of data used - statistical data, models. Detail assumptions made and where possible uncertainty limits or distributions for frequency and time maintain. If data changes based on traffic type, MGT, track curvature, cant etc. Please detail how this will change and reference any models (eg wear rate, fatigue models etc) which could be used for sensitivity analysis.	
			Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation
- Renewals												
--Rail, sleeper and Ballast renewal												
-- Sleeper and ballast renewal												
-- Tactical resleeper												
--Ballast cleaning												
- Renewals of switch												
-- S&C renewal												
- Renewals of bridge platform												

Safety impacts - for safety critical failures - the impact on safety must be considered

Describe how the frequency of failure/injury and impact differ between the baseline case innovation for each failure mode considered. An FMEA and risk assessment process should be carried out before completing this table

Failure mode/injury type	New failure mode/hazard due to innovation? Y/N	Stakeholders impacted	Frequency/likelihood of failure/injury		Impact of failure/injury	
			Baseline case	Innovation	Baseline case	Innovation
Track						
Flooding of track						
Rail defect identified - clamp and/or speed limits applied						
Derailment/delays - Rail break						
Derailment/delays - track alignment fault						
Derailment/delays - wheel profile/rolling stock failure						
Derailment/delays - landslide						
Derailment/delays - hitting object./animal on track						
Earthwork failure						
S&C						
Flooding						
Signalling/electrical failures						
Ice, ballast or other object between switch and stock rail preventing switch locking						
Damage to switch drive from flying ballast, ice falling from vehicles						
Stretcher bar failure						
Derailment due to switch rail wear						
Crossing failure						
Bridge failures						
Road vehicle collision with bridge						
Bridge scour due to flooding						
Corrosion failure						
Masonary deterioration						
Embankment failures						
Landslide						
Track worker injury/fatality - crushed by train						
Track worker injury/fatality - injured by train						
Track worker injury/fatality - slips, trips and falls						
Track worker injury/fatality - manual lifting/machine or tool operation						
Track worker injury/fatality - fall from height						