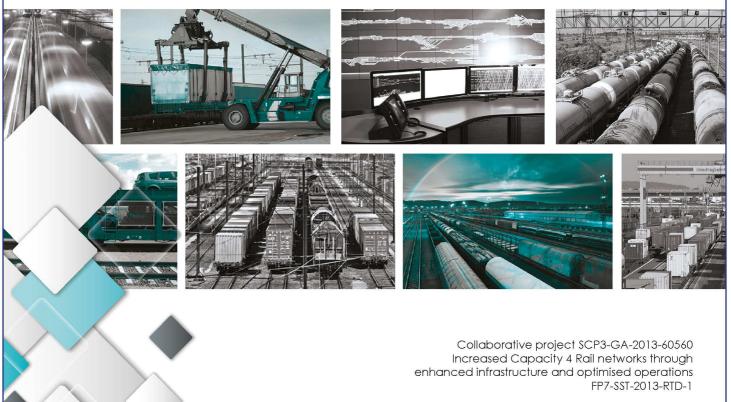


Towards an affordable, resilient, innovative and high-capacity European Railway System for 2030/2050

> Templates and tools for analysis of scenarios Submission date: 19/06/2015 Deliverable 52.2

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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.

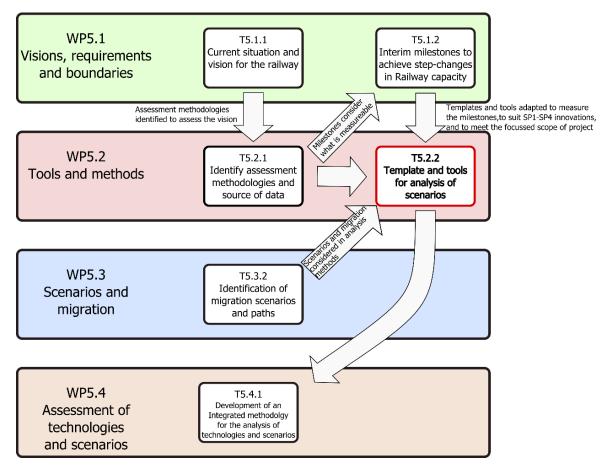


FIGURE 1- FIT OF TASK T5.2.2 WITHIN THE CONTEXT OF OTHER SP5 TASKS AND WORK PACKAGES

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.

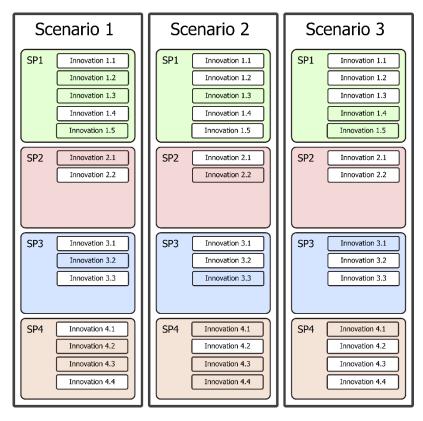


FIGURE 2- EXAMPLE OF SELECTION OF APPROPRIATE INNOVATIONS TO EACH SCENARIO NOT ALL INNOVATIONS ARE USED IN THE ASSESSMENT OF EACH SCENARIO.

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.

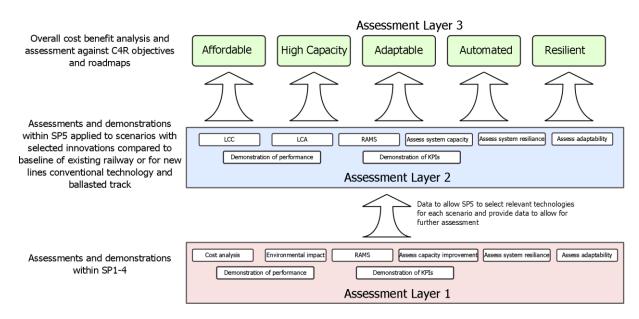


FIGURE 3- LAYERS OF ASSESSMENT CARRIED OUT WITHIN CAPACITY4RAIL PROJECT

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.

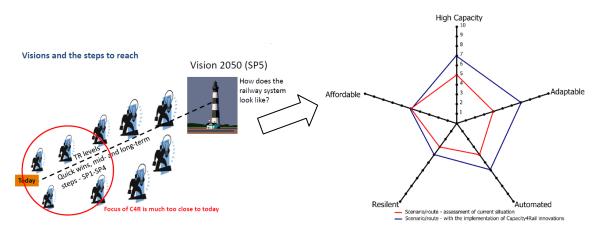


FIGURE 4- DIAGRAM DEMONSTRATING HOW THE OVERALL ASSESSMENT OF THE CAPACITY4RAIL INNOVATIONS MAY BE REPRESENTED FOR EACH SCENARIO/ROUTE SELECTED. PROJECT

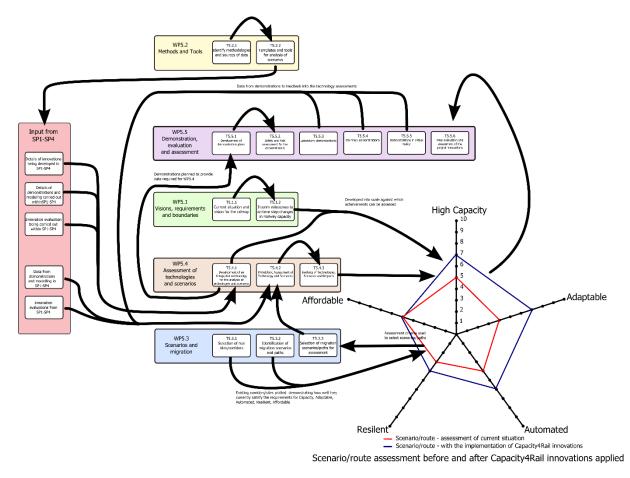


FIGURE 5- CONTEXT OF WP5.2 IN THE OVERALL ASSESSMENT SCHEME.

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.

<u>SP1</u>

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

<u>SP2</u>

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

<u>SP3</u>

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

<u>SP4</u>

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.

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						•**	'IN				
						Capacity	for Rail				
Conseitu (Deil Techa		F irel				+-					
Capacity4Rail Techn	ology	Eval	uatio	on te	пріа	te					
Subproject no											
Innovation name (title)											
Briefly describe the C4R innovation											
sherry describe the extrainovation											
Current technology readiness level of the											
innovation							Click here	for the de	finitions o	f TRLs	
											_
Expected technology readiness level at the											
end of the project											
Impact of the innovation on the C4R targets											
impact of the mnovation on the C4R targets	•										
Rank the innovation for each impact on eac	h of the C4R t	targets, It	's impact i	or each ta	get should	d be					
ranked as either: High positive impact, Posi											
impact, or no ranking possible/ not applica	ble		5		•						
	Ranking			Descriptio	n/notes						
Affordable railway							Click here	for the de	finition of	the C4R ta	rgets
Adaptable railway											
Automated railway											
Resilient railway											
High capacity railway											
Impact that innovation will have on:	Ranking			Descriptio	n/notes						-
Safety				put	,						
CO2 emissions and embedded CO2											
Noise and vibration											1

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 Activ	vities Template	-CAR-		
Subproject number		Capacity for Rail		
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		Impact of t	he innovation on the C4R targets	
Does it appear in DoW?		Rank the innovation for each impact on each of		arget should be ranked as either:
Estimated overall budget	Please fill in the table in	High positive impact, Positive impact, no impact applicable		
Current technology readiness level of the innovation	Click here for the defir	<u>Click here for the definition of the C4R ta</u> Affordable railway	rgets Ranking	Description/notes
Expected technology readiness level at the end of the project		Adaptable railway Automated railway Resilient railway High capacity railway		
		Impact that innovation will have on: Safety CO2 emissions and embedded CO2	Ranking	Description/notes
		Noise and vibration Other environmental impacts		
		Briefly describe the demonstration activitie due be carried out within the sub-project	e to	
		Explain how this demonstration shows progress towards the aims of the project - eg affordable,adaptable, automated, resilient, hig capacity railway. What will be the main KPIs evaluated in this demonstrator?		
		Explain if any special requirements are needed		
CAPACITY4RAIL		If you consider any other important factors than above mentioned, please mention below	the	

Name of the organisation: Contact Person: Designation: Tel. No.: E-mail	0 0 0 0 0	FIGURE 7- WP5.5 DE	EMONSTRATION TEMPLATE	
SP1-4.Assessments and da	ata provision Template			
General Des	• •			
Subproject number				
Work Package number	Сара	city for Rail		
Innovation name (title)				
into allor name (true)				
Assessments or guidelines which will be car	ried out within SP1-SP4 regarding each innova	ation.		
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 contribution of the innovation to the following C4R obje high capacity <u>Affordable railway</u> 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/	5			
longer life, FMEA.		Description of data generated within SP to support furt	her assessments in this area and the source/quality of this	s data
Description of data generated within SP to support furth eg - installation cost - calculated from bills of materials and assumed logistics and labour costs Component life - based on simulation outputs and expert opinion	er assessments in this area and the source/qual	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		
Reduced fuel costs - based on simulation outputs and existing fuel consumption		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 furth eg. Labour costs for set tasks before and after application of innovation - data from existing data on maintance costs for particular tasks	her assessments in this area and the source/quality of this	s data
FIGURE 8- FURTHER SHE	ETS ADDED BY WP5.2 TO	Resilient railway		
UNDERSTAND THE ASSES	SMENTS PLANNED WITHIN	Descriptions of assessments intended to be carried out Assessments of the recovery of the railway to		
SP1-SP4 AND DATA TH	HAT THEY WILL GENERATE	incidents. Eg evaluation of improved response to an incident.		
WHICH WILL AID ASS	ESSMENTS WITHIN SP5	Description of data generated within SP to support furth Eg - Time to system recovery from an incident - modelling / simulation results	her assessments in this area and the source/quality of this	s data
		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.		
CAPACITY4RAIL		Description of data generated within SP to support furtl 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	her assessments in this area and the source/quality of this	s data

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.

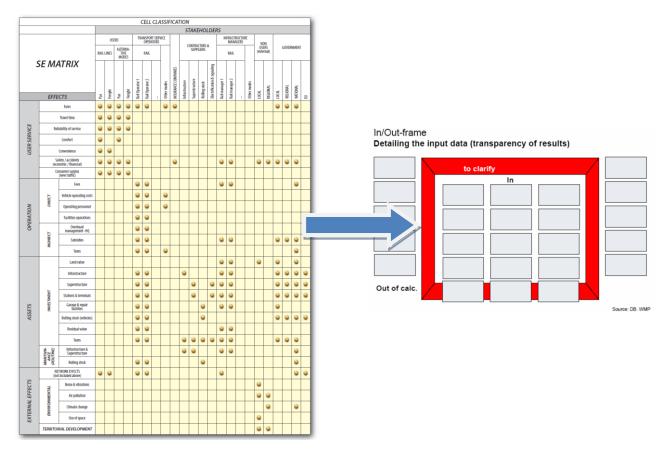
Alternatively, a more qualitative method of assessment may be adopted in WP5.4 in which case the templates developed within this deliverable centred around life cycle cost analysis, life cycle analysis and RAMS will still be useful in helping to define the assessment categories in a more qualitative 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	Comparable	comparable Comparable
Application of Capacity4Rail innovations – eg novel slab track		



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.

			STAKEHOLDER
Financial transfer cell	STAKEHOLDER	Financial transfer cell	PASSENGERS RAIL LINES – USERS
rinanciai transier celi	LOCAL, REGIONAL, NATIONAL – GOVERNMENT	EFFECT	DESCRIPTION:
			NPV of incremental fare that railway users have to pay. It is often necessary to divide them among existing, diverted and generated users.
EFFECT	DESCRIPTION:		CALCULATION:
	NPV of the difference in indirect taxes perceived by local, regional, national governments.		ldeally, for each of the three types of passengers: i) -ΣFare (€/passenger.km) x Traffic with this fare (passenger.km)
	CALCULATION:		→ Considering different fares
	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.		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:	S S S S S S S S S S S S S S S S S S S	SOME VALUES:
S z	The better known indirect taxes are VAT (% of expenditure falling on final consumer) and local taxes for some constructions.	FARES	0.12 (conventional line) to 0.25 (high-speed line) €/passenger/km (data from Spanish case)
And And	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	L R R R R R R R R R R R R R R R R R R R	CRITICAL ISSUES:
IAXES operation	will not affect results in a noticeable way.		Demand forecasts (see chapter "General Aspects"). Sophisticated traffic forecasting models are needed, in particular under yield management.
	CRITICAL ISSUES:		REMARKS:
	Revenue forecasts and tax evolution.		It is recommended to use method of calculation (i) and consider distribution
	REMARKS:		by classes (business class, etc.), season tickets & discounts.
	If these taxes are split among authorities and the issue is relevant (to show contributors and beneficiaries) all columns must be shown. Now 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).		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

			Fares
	User		Comfort
	Service		Convenience
			Fees – eg Track access charges
			Vehicle operating costs
		Direct	Operating personnel
	Operation		Facilities operations
	costs		Overhead management - HQ functions
			Subsidies
		Indirect	Taxes
			Consumer surplus (new traffic)
			Land value
			Infrastructure
			Superstructure
			Stations and terminal
		Investment	Garage & repair facilities
	Assets		Rolling stock (vehicles)
			Residual Value
Affordable/financial			Taxes
effects		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) unplannded repairs (actual costs)
			Rolling stock overhaul (actual costs)
		Disposal costs	
			Noise and vibrations
		Environmental	Air pollution (particulates, NOx, etc)
			Carbon impact (LCA) installation, maintenance, disposal

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

	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)
High Capacity	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 \in 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 CO₂, 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.

<u>SP1</u>

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.

<u>SP2</u>

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.

<u>SP3</u>

3.1 Ubiquitous data architecture and automated data exchange for railway operations3.2 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.

<u>SP4</u>

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 (CO₂ = 1 CO_{2e}, CH₄ = 25 CO_{2e}, N₂O = 298 CO_{2e})
- Financial value equivalent to greenhouse emissions
- CO_{2e} /passenger km, CO_{2e} /freight tonne km
- Air pollutants SO₂, 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.

<u>SP1</u>

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.

<u>SP2</u>

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.

<u>SP3</u>

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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ExternE – External Costs of Energy – http://www.externe.info

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

													S	tak	eho	lder	s								
	(SE Matrix			Us	ers		Transp	ort serv	rice oper	ators				and supp			astructu	re mana	agers	Non i (exte			Govern	nment
	•			Rail	lines	Alterr			Rail									Rail							
		Effects		xec	-reight		-reight	tail Operator 1	Rail Operator 2		Other modes	nsur ance comp an ies	nfrast ructure	Superstructure	Rolling Stock	Electrification & Signaling	Rail manager 1	tail manager 2		Other modes	ocal	Regional	ocal	Regional	National
	User		Fares Comfort			-		1	F			_		01			-	-		-	-				
	Service	Direct	Convenience Fees eg Track access charges Vehicle operating costs Operating personnel																						
	Operation costs	Indirect	Facilities operations Overhead management - HQ functions Subsidies																						
			Taxes Consumer surplus (new traffic) Land value Infrastructure																						
		Investment	Superstructure Stations and terminal Garage & repair facilities Rolling stock (vehicles) Residual Value																						
Affordable/financial effects			Infrastructure and Superstructure routine (time based) maintenance and inspection (actual costs) Infrastructure and Superstructure																						
	Assets	Maintenance (routine costs)	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	Noise and vibrations	L										_											
		Environmental	Air pollution (particulates, NOx, etc) Carbon impact (LCA)			E																			
Adaptable			Adaptability to increased service demands Interoperability across borders and railway systems																						
		Intelligent transport system and signalling	Optimisation of rail traffic movements - flexible routing Automation of timetabling Automation and optimisation of train control systems																						
Automated		Intelligent monitoring and	Automated inspection/maintenance of rolling stock (socio-economic impact of improved workforce safety and guality)																						
		maintenance	Automated inspection/maintenance of infrastructure (socio-economic impact of improved workforce safety and quality) Reliability of service (unplanned																						
Resilient			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 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																						
High Capacity			inspection (socio-economic impacts eg delays/alternative services) Infrastructure and Superstructure condition based maintenance (socio-																						
righ capacity			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)																						



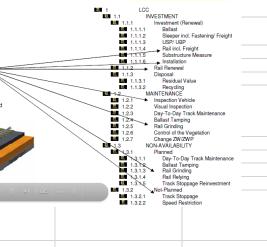


Appendix 2 - LCC Templates

			CAR Capacity for Rail		
Capacity4Rail Technolo	ogy Evaluatio	n template - LCC			
Sub-project:	SP1				
Innovation:	New Concepts	based on modular slab track - slab	track evaluated against ballasted	l track	Product Tree
Discount rate to be used for LCC calculations		%			1 TRACK 11 Rail 11 Rail 11.1 UIC 60
The life cycle cost analysis will start with a product the right shows an example product breakdown s	tructure				 1.4 Under Sleeper Pa 3 1.5 Ballast 1.6 Subsoli
R&D	Investment	> Operation & Maintenance	Disposal	>	
			Life cycle phases		
Scenario and boundard conditions for a	assessment				Source: INNOTRACK - Guide
Product breakdown structure					
Baseline case - ballasted track	Cub Component	Function of common out (sub common or			Innovation - Innovative mo
Component Sub-grade	Sub Component	Function of component/sub componen			Component



Cost Breakdown Structure



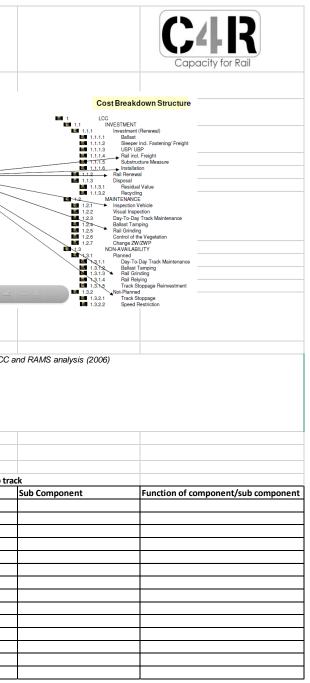
line for LCC and RAMS analysis (2006)

ular slab trac	:k	
	Sub Component	Function of component/sub component
	-	

	Cost categories and Life Cycle Phases						
	Baseline case - ballasted track LCC Cost block	Cost (€) per km or	Stakeholder who henefits (nove	When and how frequently cost occurs in	Dependencies (og relationskin hotuson	Source of cost data -	Quality of data source and whore
	R&D costs	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 relationsnip 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)
	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						
CAPEX	Sleepers						
Q	Fastenings						
	Rail						
	Welding						
	Tamping - Testing and commissioning						
	Inspection/quality control						
	Disessed						
	Disposal - Decommission costs						
	- Removal costs						
	- Disposal costs/recycled value (rail and ballast recycling)					
	- Facilities						
	- Residual value						
	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						
DE	Noise abatement						
OPEX							
OPE	Noise abatement - Corrective maintenance - Rail Change - defects Weld change - defects						
OPE	Noise abatement - Corrective maintenance Rail Change - defects Weld change - defects Rail adjustment						
OPE	Noise abatement Corrective maintenance - Rail Change - defects - Weld change - defects - Weld change - defects - Rail adjustment - Ballast reprofile						
OPE	Noise abatement - Corrective maintenance - Rail Change - defects - Weld change - defects - Rail adjustment - Ballast reprofile - Wet bed removal - Tactical reballast						
OPE	Noise abatement Corrective maintenance - Rail Change - defects - Weld change - defects - Rail adjustment - Ballast reprofile - Wet bed removal - Tactical reballast - Plain line tamping						
OPE	Noise abatement Corrective maintenance Rail Change - defects Weld change - defects Weld change - defects Ballast reprofile Wet bed removal Tactical reballast Plain line tamping Stoneblowing						
OPE	Noise abatement Corrective maintenance - Rail Change - defects - Weld change - defects - Rail adjustment - Ballast reprofile - Wet bed removal - Tactical reballast - Plain line tamping						
OPE	Noise abatement Corrective maintenance Rail Change - defects Weld change - defects Weld change - defects Ballast reprofile Wet bed removal Tactical reballast Plain line tamping Stoneblowing Geometry manual replacement of pads and fasteners Renewals						
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OPE	 Noise abatement Corrective maintenance Rail Change - defects Weld change - defects Ballast repofile Wet bed removal Tactical reballast Plain line tamping Stoneblowing Geometry manual replacement of pads and fasteners Renewals Sleeper and Ballast renewal Sleeper and Ballast renewal Tactical resleeper Ballast cleaning Off Track maintenance Drainage 						
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OPE	Noise abatement Corrective maintenance Rail Change - defects Weld change - defects Stoneblowing Geometry manual - replacement of pads and fasteners Renewals Renewals Renewals - Ratil, sleeper and ballast renewal - Tactical resleeper - Ballast cleaning Off Track maintenance - Drainage - Fencing - Vegetation Other quantifiable costs identified from S-E matrix/RAM Cost of non-availability during maintenance activities	S analysis					
OPE	 Noise abatement Corrective maintenance Rail Change - defects Weld change - defects Rail adjustment Ballast reprofile Wet bed removal Tactical reballast Plain line tamping Geometry manual - replacement of pads and fasteners Renewals -Rail, sleeper and Ballast renewal - Sleeper and ballast renewal - Tactical resleeper -Ballast cleaning Off Track maintenance - Vegetation Other quantifiable costs identified from S-E matrix/RAAV - Cost of non-availability during maintenance activities - Plane maintenance 	S analysis					
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	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	Quality of data source and where possible accuracy of data (upper and lower limits)
	R&D costs					labour 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						
CAPEX	Mortar / Fix the slab Inspection / Quality control						
CA	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						
	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						
5	Noise abatement						
OPEX	- Corrective maintenance						
0	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 (majo Inject resin to protect steel	r 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/RAM	IS analysis					
	- Cost of non-availability during maintenance activities Planned maintenance						
	Unplanned maintenance						
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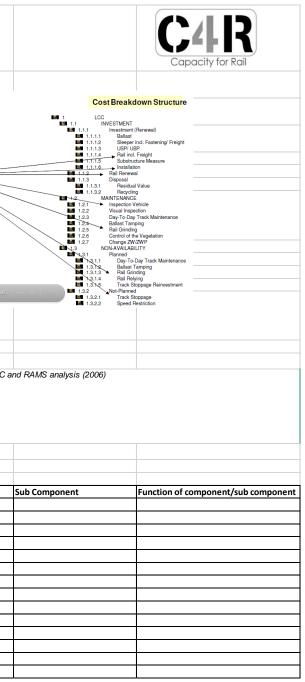
			C4R Capacity for Rail		
Capacity4Rail Tech	nology Evaluatio	on template - LCC			
Sub-project:	SP1				
Innovation:	New Concepts	based on modular slab track - inn	ovative slab track evaluated agains	st existing slab track	Product Tree
Discount rate to be used for LCC calculat	tions	%			1 TRACK 11 Rail 11 Rail 11.1 UIC 60 12 Rail Pad ZW700 12 Sileeper 13 Sileeper
The life cycle cost analysis will start with the right shows an example product bre		d will consider all of the life cycle stages fro	om R&D through to disposal. The figure on		I.3.1 B70 W I.4 Under Steeper Pa I.5 Ballast I.6 Subsoli
R&D	Investment	> Operation & Maintenance	Dis posal	>	
			Life cycle phases		
will be collected in the "RAMS data" she	eet	on), Operation and disposal. It is assumed th	hat the majority of the maintenance data		Source: INNOTRACK - Guide
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	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)
	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						
CAPEX	Inspection / Quality control						
5	Track laying - Track work						
	Rail laying Pads						
	Sleepers						
	Fastenings						
	Clip/screw fastenings Welding						
	- Testing and commissioning						
	Inspection/quality control						
	<u>Disposal</u>						
	- Decommission costs						
	- Removal costs	\					
	 Disposal costs/recycled value (rail and ballast recycling Facilities)					
	- Residual value						
	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						
OPEX	- Corrective maintenance						
-	Rail Change - defects						
	Weld change - defects Rail adjustment						
	Maintain drainage						
	Adjust fastening system for small defects replacement of pads and fasteners						
	replacement of pads and fasteners Correct cracks in slab						
	Replace slab - in case of derailment or accident (majo	r 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/RAN	15 analysis					
	- Cost of non-availability during maintenance activities Planned maintenance						
CAPA	Planned maintenance		PUBLIC		Page 52		
			_				

	Innovation Innovative slab treak						
	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	Quality of data source and where possible accuracy of data (upper and lower limits)
-						labour costs	
	<u>R&D costs</u> 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						
Ш	Mortar / Fix the slab						
CAPEX	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						
	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						
OPEX	Noise abatement - Corrective maintenance						
0	Rail Change - defects						
	Weld change - defects						
	Rail adjustment Maintain drainage						
	 Maintain drainage Adjust fastening system for small defects 						
	replacement of pads and fasteners						
	Correct cracks in slab	r damaga'					
	Replace slab - in case of derailment or accident (majo Inject resin to protect steel	uamage)					
	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						
1	- Off Track maintenance						
	Drainage						
1	Fencing						
	 Vegetation Other quantifiable costs identified from S-E matrix/RAN 	IS analysis					
1	 Cost of non-availability during maintenance activities 						
	Planned maintenance						
	Unplanned maintenance		PUBLIC		Page 53		
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			C4	2		
0 : -			Capacity for R	ail		
Capacity4Rail Tech	nnology Evaluati	on template - LCC				_
Sub-project:	SP1					
Innovation:	New track de	signs and specifications for very h	nigh speed lines (if innovation s	lab track)		
						Product Tree
Discount rate to be used for LCC calcula	tions	%				■ 1 TRACK ■ <u>1.1</u> Rail (
						1.1.1 UIC 60 1.2 Rail Pad ZW700
The life cycle cost analysis will start wit the right shows an example product bre		nd will consider all of the life cycle stages f	rom R&D through to disposal. The figure	2 on		1.3 Sleeper II.3.1 B 70 W II.4 Under Sleeper Pa II.5 Ballast II.6 Subsoil
> R&D		> Operation & Maintenance) Dis posal			
	Investment	>> Operation & Maintenance				
			Life cycle phases			
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		ion), Operation and disposal. It is assumed	that the majority of the maintenance d	lata		
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will be collected in the "RAMS data" she	eet	ion), Operation and disposal. It is assumed	that the majority of the maintenance d	lata		Source: INNOTRACK - Guide
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	Cost categories and Life Cycle Phases						
	Cost categories and the cycle Flases						
	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)
	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						
X	Pads						
CAPEX	Sleepers						
0	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						
	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						
OPEX	Noise abatement - Corrective maintenance						
0	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/RAM - Cost of non-availability during maintenance activities	15 analysis					
	Planned maintenance						
	Unplanned maintenance						

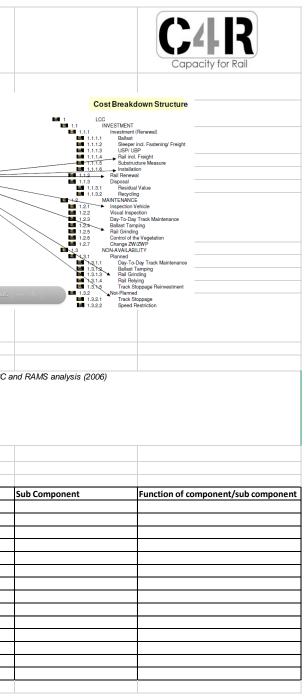
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	Innovation - Innovative slab track LCC Cost block	Cost (€) per km or Cost (€) per task	Stakeholder who benefits/pays financially	When and how frequently cost occurs in life cycle (eg every 20yrs)	Dependencies (eg relationship between cost or cost frequency upon boundary condtionitions such load (MGT), traffic type, curve etc)	Source of cost data - eg financial statements, model, expert estimate, total component and	Quality of data source and where possible accuracy of data (upper and lower limits)
	R&D costs					labour 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						
CAPEX	Mortar / Fix the slab						
CAF	Inspection / Quality control Track laying Track work						
0	Rail laying						
	Pads						
	Sleepers						
	Fastenings Clip/screw fastenings						
	Welding						
	- Testing and commissioning Inspection/quality control						
	Inspection/quarty control						
	Disposal						
	- Decommission costs						
	 Removal costs Disposal costs/recycled value (rail and ballast recycling)					
	- Facilities	, 					
	- Residual value						
	Operation costs (non-maintenance)						
	- Energy						
	-Personnel -Training						
	- Facilities						
	- Fees						
	- Communications - Facilities						
	- radiities						
	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						
OPEX	- Corrective maintenance						
ō	Rail Change - defects Weld 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 (majo	r 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						
	Fencing Vegetation						
	Other quantifiable costs identified from S-E matrix/RAM	IS analysis					
	 Cost of non-availability during maintenance activities Planned maintenance 						
	Unplanned maintenance						
CAPA	CITY4RAIL		PUBLIC		Page 56		
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				;4 R		C4LR Capacity for Pail
Capacity4Rail Technolo	gy Evaluatio	n template - LC		pacity for Rail		
Sub-project:	SP1					
Innovation:	New track desig	gns and specifications for	very high speed lines (if in	novation ballasted track)		Cost Breakdown Structure
Discount rate to be used for LCC calculations		%			Product Tree	Image LCC Image 1.1 Investment (Renewal) Image 1.1.1 Ballast Image 1.1.1 Selepting Image 1.1.1.3 USP/USP Image 1.1.1.3 Selepting Image 1.1.1.3 Selepting Image 1.1.1.3 Substructure Measure Image Substructure Measure Image Image Image Image Image
The life cycle cost analysis will start with a produc the right shows an example product breakdown st		will consider all of the life cycle	stages from R&D through to dispos	al. The figure on	Image: Second	Image: 11.1.2 Pall Penewal Image: 11.1.3 Diaposal Image: 11.1.3.1 Peskula Value Image: 11.1.3.2 Recycling Image: 11.1.3.2 Recycling Image: 11.1.3.1 Recycling
R&D	Investment	Operation & Mainter		al	■ 1.5 Ballast ■ 1.6 Subsoil	I 2.3 Day-To-Day Track Maintenance I 2.4 Ballast Tumping I 2.5 Rall Giriding I 2.6 Control of the Vegetation
			Life cycle phases			La 1.2.7 Change ZW/ZWP
	nvestment (and installation	n), Operation and disposal. It is a	assumed that the majority of the m	aintenance data		23 31.1 Day To-Day Track Maintenance 24 3.1.3 Ballast Tamping 25 3.1.4 Rail Folding 24 4.1.5 Track Stoppage Reinvestment 25 7.1.5 Track Stoppage 24 7.1.5 Track Stoppage 24 7.1.5 Track Stoppage 25 7.1.5 Track Stoppage 26 1.3.2.2 Speed Restriction
This sheet will mainly cover the costs from R&D, In will be collected in the "RAMS data" sheet Scenario and boundard conditions for a		n), Operation and disposal. It is a	assumed that the majority of the m	aintenance data	Source: INNOTRACK - Guideline	All Helying Track Stoppage Reinvestment I 13.2 Intrack Stoppage I 13.2 Intrack Stoppage I 13.2 Intrack Stoppage I 13.2 Speed Restriction
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	Cost sategories and Life Cycle Phases						
	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)
	R&D costs						
	Investment - Project preparation						
	- Inputted Residual value						
	- Investment and installation						
	Ground preparation - geotechnical and civil Site investigation						
	Soil substitution						
	Reinforcement Subgrade layers						
	Subgrade layers Drainage						
	Track laying - track work						
×	Ballast						
CAPEX	Pads Sleepers						
2	Fastenings						
	Rail						
	Welding Tamping						
	- Testing and commissioning						
	Inspection/quality control						
	<u>Disposal</u>						
	- Decommission costs						
	 Removal costs Disposal costs/recycled value (rail and ballast recycling 	\					
	- Facilities	,					
	- Residual value						
	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						
OPEX	Noise abatement - Corrective maintenance						
0	- Corrective maintenance Rail Change - defects						
	Weld change - defects						
	Rail adjustment Ballast reprofile						
	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/RAM	IS analysis					
	- Cost of non-availability during maintenance activities	<u></u>					
	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)
	R&D costs						
l	Investment - Project preparation						
l	- Inputted Residual value						
l	- Investment and installation						
l	Ground preparation - geotechnical and civil						
l	Site investigation Soil substitution						
	Reinforcement						
	Subgrade layers			· · · · · · · · · · · · · · · · · · ·			
	Drainage						
	Track laving - track work Ballast						
X	Pads						
CAPEX	Sleepers						
J	Fastenings						
l	Rail Welding						
l	Tamping						
l	- Testing and commissioning						
l	Inspection/quality control						
l	Disposal						
	- Decommission costs						
l	- Removal costs						
l	 Disposal costs/recycled value (rail and ballast recycling)					
	- Facilities - Residual value						
1	Operation costs (non-maintenance)						
	- Energy -Personnel						
l	-rraining						
l	- Facilities						
	- Fees						
l	- Communications - Facilities						
	- racinties						
	Maintenance costs - see RAMS template						
l	- Inspection						
l	Visual Inspection Ultrasonic - Manual						
l	Ultrasonic - Train based						
	Eddy current inspection - Train based						
l	Track geometry - train based Noise monitoring						
l	- Preventative/condition based maintenance						
l	Rail Change						
	Rail Transpose						
	Grinding Lubrication						
l	Fish Plate lubrication						
	IBJ replacement						
	Re-sleeper						
PEX	Replace sleeper pads and insulators Noise abatement						
Ā							
ō	- Corrective maintenance						
10	Rail Change - defects						
ō	Rail Change - defects Weld change - defects						
ō	Rail Change - defects Weld change - defects Rail adjustment						
ō	Rail Change - defects Weld change - defects Rail adjustment Ballast reprofile Wet bed removal						
ō	Rail Change - defects Weld change - defects Rail adjustment Ballast reprofile Wet bed removal Tactical reballast						
ō	Rail Change - defects Weld change - defects Rail adjustment Ballast reprofile Wet bed removal Tactical reballast Plain line tamping						
ō	Rail Change - defects Weld change - defects Rail adjustment Ballast reprofile Wet bed removal Tactical reballast Plain line tamping Stoneblowing						
ō	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						
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Ō	Rail Change - defects Weld change - defects Rail adjustment Bailast reprofile Tactical reballast Tactical reballast Plain line tamping Stoneblowing Geometry manual replacement of pads and fasteners Renewals Renewals Sleeper and Ballast renewal Slauger and ballast renewal						
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Ō	Rail Change - defects Weld change - defects Rail adjustment Ballast reprofile Tactical reballast Plain line tamping Tactical reballast Plain line tamping stoneblowing stoneblowing stoneblowing replacement of pads and fasteners Rail, sleeper and Ballast renewal Rail, sleeper and Ballast renewal Sallest cleaning Off Track maintenance Drainage Frencing Vegetation						
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Ō	Rail Change - defects Weld change - defects Rail adjustment Bailast reprofile Tactical reballast Tactical reballast Plain line tamping Stoneblowing Geometry manual replacement of pads and fasteners Renewals Rail, sleeper and Ballast renewal Sleeper and Ballast renewal Sleeper and Ballast renewal Tactical resleeper	S analysis					
Ō	Rail Change - defects Weld change - defects Rail adjustment Ballast reprofile Tactical reballast Plain line tamping Stoneblowing Geometry manual replacement of pads and fasteners Remeals Rail, sleeper and Ballast renewal 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/RAM	S analysis					
Ō	Rail Change - defects Weld Change - defects Rail adjustment Ballast reprofile Tactical reballast Plain line tamping Tactical reballast Plain line tamping stoneblowing Geometry manual replacement of pads and fasteners Rail, sleeper and Ballast renewal Rail, sleeper and Ballast renewal Sleeper and Ballast renewal Sallast cleaning Off Track maintenance Drainage Vegetation Other quantifiable costs identified from S-E matrix/RAM Cost of non-availability during maintenance activities Planned maintenance	IS analysis					

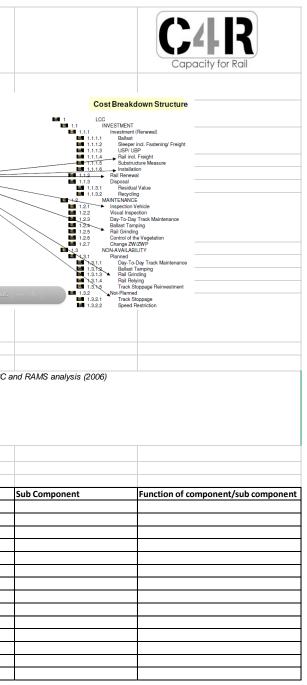
			C4R Capacity for Rail	
Capacity4Rail Technolo	gy Evaluatio	on template - LCC		
Sub-project:	SP1			
Innovation:	New concepts	for Switches and Crossings based	d on failure modes analysis	Product Tree
Discount rate to be used for LCC calculations		%		■ 1 TRACK ■ 1.1 Rail ■ 1.1.1 UIC 60
The life cycle cost analysis will start with a product the right shows an example product breakdown str		d will consider all of the life cycle stages fro	om R&D through to disposal. The figure on	Image: Strength of the stren
R&D	Investment	> Operation & Maintenance	> Disposal	
			Life cycle phases	
This sheet will mainly cover the costs from R&D, In	nvestment (and installation	on), Operation and disposal. It is assumed t	that the majority of the maintenance data	
This sheet will mainly cover the costs from R&D, In will be collected in the "RAMS data" sheet Scenario and boundard conditions for a		on), Operation and disposal. It is assumed t	that the majority of the maintenance data	
		on), Operation and disposal. It is assumed t	that the majority of the maintenance data	Source: INNOTRACK - Guidel
will be collected in the "RAMS data" sheet		on), Operation and disposal. It is assumed t	that the majority of the maintenance data	Source: INNOTRACK - Guidel
will be collected in the "RAMS data" sheet Scenario and boundard conditions for a	assessment	monly used in the scenario given	Image: Sector	
will be collected in the "RAMS data" sheet Scenario and boundard conditions for a Product breakdown structure Baseline case - Existing switch design - use as a bas Component	assessment		Image: Sector	
will be collected in the "RAMS data" sheet Scenario and boundard conditions for a Product breakdown structure Baseline case - Existing switch design - use as a bas	sis a design which is comr	monly used in the scenario given	Image: Sector	Innovation - Innovative switc
will be collected in the "RAMS data" sheet Scenario and boundard conditions for a Product breakdown structure Baseline case - Existing switch design - use as a bas Component	sis a design which is comr	monly used in the scenario given	Image: Sector	Innovation - Innovative switc
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will be collected in the "RAMS data" sheet Scenario and boundard conditions for a Product breakdown structure Baseline case - Existing switch design - use as a bas Component	sis a design which is comr	monly used in the scenario given	Image: Sector	Innovation - Innovative switc
will be collected in the "RAMS data" sheet Scenario and boundard conditions for a Product breakdown structure Baseline case - Existing switch design - use as a bas Component	sis a design which is comr	monly used in the scenario given	Image: Sector	Source: INNOTRACK - Guideli Source: INNOTRACK - Guideli Innovation - Innovative switc Component
will be collected in the "RAMS data" sheet Scenario and boundard conditions for a Product breakdown structure Baseline case - Existing switch design - use as a bas Component	sis a design which is comr	monly used in the scenario given	Image: Sector	Innovation - Innovative switc
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will be collected in the "RAMS data" sheet Scenario and boundard conditions for a Product breakdown structure Baseline case - Existing switch design - use as a bas Component	sis a design which is comr	monly used in the scenario given	Image: Sector	Innovation - Innovative switc
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will be collected in the "RAMS data" sheet Scenario and boundard conditions for a Product breakdown structure Baseline case - Existing switch design - use as a bas Component	sis a design which is comr	monly used in the scenario given	Image: Sector	Innovation - Innovative switc
will be collected in the "RAMS data" sheet Scenario and boundard conditions for a Product breakdown structure Baseline case - Existing switch design - use as a bas Component	sis a design which is comr	monly used in the scenario given	Image: Sector	Innovation - Innovative switc



	Cost categories and Life Cycle Phases						
	Baseline case - Existing switch design - use as a basis a d						
	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)
	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					
X	Welding						
CAPEX	Tamping/geometry						
3	Signalling and electrical						
	- Testing and commissioning						
	Inspection/quality control						
	Disposal - Decommission costs						
	- Decommission costs - Removal costs						
	 Disposal costs/recycled value (rail and ballast recycling)					
	- Residual value						
	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						
OPEX	Adjust drive - Corrective maintenance						
9 D	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 switch motor and drive 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 r		cking				
	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)
	Investment						
	- Project preparation						
	- Investment and installation						
	Switch installation costs						
	Removal of existing switch						
	Transport costs and logistics of delivering new switch	layout					
CAPEX	Welding						
ΑF	Tamping/geometry						
C	Signalling and electrical						
	- Testing and commissioning						
	Inspection/quality control						
	Disposal						
	- Decommission costs						
	- Removal costs						
	 Disposal costs/recycled value (rail and ballast recycling)					
	- Residual value						
	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						
OPEX	Adjust drive						
E C	- Corrective maintenance						
0	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 r	ail preventing switch loc	king				
	Damage to switch drive from flying ballast, ice falling f						
	Stretcher bar failure						
	Derailment due to switch rail wear						

			C4R	
Conscitu/Dail Tax	hnology Evoluctio	n tomplata ICC	Capacity for Rail	
сараснучкан тес	hnology Evaluatio	on template - LCC		
Sub-project:	SP1			
Innovation:	New designs fo	or switches resilient to extreme w	eather conditions	Product Tree
Discount rate to be used for LCC calcu	lations	%		Ma 1 TRACK
				K⊒ 1.1 Rail M⊆ 1.1.1 UIC 60 M⊒ 1.2 Rail Pad ZW/700
The life cycle cost analysis will start w the right shows an example product b		will consider all of the life cycle stages from	n R&D through to disposal. The figure on	Solution Solut
R&D	>> Investment	Operation & Maintenance	Disposal	
			Life cycle phases	
will be collected in the "RAMS data" s	heet	n), Operation and disposal. It is assumed th		
will be collected in the "RAMS data" s	heet	n), Operation and disposal. It is assumed th o should include extreme weathe		
will be collected in the "RAMS data" s	heet			Source: INNOTRACK - Guide
will be collected in the "RAMS data" s	heet tions for assessment - Scenari			Source: INNOTRACK - Guide
will be collected in the "RAMS data" s	heet tions for assessment - Scenari			Source: INNOTRACK - Guide
will be collected in the "RAMS data" s Scenario and boundard condi Product breakdown structure	heet tions for assessment - Scenari	o should include extreme weather	events	
will be collected in the "RAMS data" s Scenario and boundard condi Product breakdown structure Baseline case - Existing switch design Component	heet tions for assessment - Scenari	o should include extreme weather	events	
will be collected in the "RAMS data" s Scenario and boundard condi Product breakdown structure Baseline case - Existing switch design	heet tions for assessment - Scenari	o should include extreme weather	events	Innovation - Innovative swi
will be collected in the "RAMS data" s Scenario and boundard condi Product breakdown structure Baseline case - Existing switch design Component	heet tions for assessment - Scenari	o should include extreme weather	events	Innovation - Innovative swi
will be collected in the "RAMS data" s Scenario and boundard condi Product breakdown structure Baseline case - Existing switch design Component	heet tions for assessment - Scenari	o should include extreme weather	events	Innovation - Innovative swi
will be collected in the "RAMS data" s Scenario and boundard condi Product breakdown structure Baseline case - Existing switch design Component	heet tions for assessment - Scenari	o should include extreme weather	events	Innovation - Innovative swi
will be collected in the "RAMS data" s Scenario and boundard condi Product breakdown structure Baseline case - Existing switch design Component	heet tions for assessment - Scenari	o should include extreme weather	events	Innovation - Innovative swi
will be collected in the "RAMS data" s Scenario and boundard condi Product breakdown structure Baseline case - Existing switch design Component	heet tions for assessment - Scenari	o should include extreme weather	events	Innovation - Innovative swi
will be collected in the "RAMS data" s Scenario and boundard condi Product breakdown structure Baseline case - Existing switch design Component	heet tions for assessment - Scenari	o should include extreme weather	events	Innovation - Innovative swi
will be collected in the "RAMS data" s Scenario and boundard condi Product breakdown structure Baseline case - Existing switch design Component	heet tions for assessment - Scenari	o should include extreme weather	events	Innovation - Innovative swi
will be collected in the "RAMS data" s Scenario and boundard condi Product breakdown structure Baseline case - Existing switch design Component	heet tions for assessment - Scenari	o should include extreme weather	events	Innovation - Innovative swi
will be collected in the "RAMS data" s Scenario and boundard condi Product breakdown structure Baseline case - Existing switch design Component	heet tions for assessment - Scenari	o should include extreme weather	events	Innovation - Innovative swi
will be collected in the "RAMS data" s Scenario and boundard condi Product breakdown structure Baseline case - Existing switch design Component	heet tions for assessment - Scenari	o should include extreme weather	events	Innovation - Innovative swi
will be collected in the "RAMS data" s Scenario and boundard condi Product breakdown structure Baseline case - Existing switch design Component	heet tions for assessment - Scenari	o should include extreme weather	events	Innovation - Innovative swi



	Cost categories and Life Cycle Phases						
	Baseline case - Existing switch design - use as a basis a d						
	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)
	R&D costs					labour costs	
	Investment						
	- Project preparation						
	- Investment and installation						
	Switch installation costs						
	Removal of existing switch Transport costs and logistics of delivering new switch	lavout					
×	Welding	layout					
CAPEX	Tamping/geometry						
S	Signalling and electrical						
	- Testing and commissioning						
	Inspection/quality control						
	Disposal						
	- Decommission costs						
	 Removal costs Disposal costs/recycled value (rail and ballast recycling)					
	 Disposal costs/recycled value (rail and ballast recycling Residual value 	/					
	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 						
Ш	Adjust drive						
OPEX	- Corrective maintenance						
	Half set replacement Crossing replacement	1					
	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						
	Flooding Signalling/electrical failures						
	Ice, ballast or other object between switch and stock r	ail preventing switch lo	cking				
	Damage to switch drive from flying ballast, ice falling f						
	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)
	R&D costs						
	Investment						
	- Project preparation - Investment and installation						
	Switch installation costs						
	Removal of existing switch						
	Transport costs and logistics of delivering new switch	lavout					
×	Welding	layout					
CAPEX	Tamping/geometry						
Ċ	Signalling and electrical						
	- Testing and commissioning						
	Inspection/quality control						
	Disposal						
	- Decommission costs						
	 Removal costs Disposal costs/recycled value (rail and ballast recycling)					
	Residual value	/					
	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						
OPEX	- Corrective maintenance						
0	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	L					
	Ice, ballast or other object between switch and stock r		cking				
	Damage to switch drive from flying ballast, ice falling f Stretcher bar failure	rom vehicles					
	Derailment due to switch rail wear						
				1	1		I

			. ,				
Capacity4Rail Technolo	ogy Evaluatio	n template - LCC					
Sub-project:	SP1				B4 1	Cost Breakdown Structur	e
	51 1					LCC 1.1 INVESTMENT I.1.1 Investment (Renewal)	
Innovation:	Optimised S&C	sensor strategies				 1.1.1.1 Ballast 1.1.1.2 Sleeper incl. Fastening/ Freigh 	A
	•			Proc	duct Tree	I.1.1.3 USP/ UBP I.1.1.4 Rail incl. Freight I.1.1.5 Substructure Measure	
Discount rate to be used for LCC calculations		%		1. TR.	ACK Rail	I.1.1.5 Installation	
				· 111	UIC 60 Rail Pad ZW700	1.1.3 Disposal 1.1.3.1 Residual Value	
The life cycle cost analysis will start with a produc the right shows an example product breakdown s		will consider all of the life cycle stages from F	R&D through to disposal. The figure on	¹³ 1.3 1.3.1 1.5 1.5	Sleeper B 70 W Under Sleeper Pad Ballast Deol	Lift 1.1.3.2 Recycling 4-2 MINITENANCE Inspection Vehicle 11.2.1 Inspection Vehicle Inspection Vehicle 11.2.2 Visual Inspection Visual Inspection 11.2.3 Day-To-Day Track Maintenance Balast Tamping 11.2.5 Rail Grinding Control of the Vegetation 12.4.6 Control of the Vegetation Change ZW/ZWP 1.3. NON-AVAILABILITY Non-AVAILABILITY	
> R&D >>	Investment	> Operation & Maintenance >	Disposal			1.3 NON-AVAILABILITY	
	mesement		Life cycle phases			1.3 NON-AVAILABILITY 1.3 NON-AVAILABILITY 1.3.1 Planned 1.3.1 Day-To-Day Track Maintenanc 1.3.1.3 Realiast Tamping 1.3.1.3 Realiast Tamping 1.3.1.4 Realiast Relying 1.3.1.4 Reali Relying	3
			ene cycle phases				
					[법봉]순장[폐/팩]는수[사]]	I.3.2 Not-Planned I.3.2.1 Track Stoppage I.3.2.2 Speed Restriction	
will be collected in the "RAMS data" sheet Scenario and boundard conditions for a	assessment - Scenario	should include extreme weather e	avents				
		Silouid include extreme weather e	svents	Source: INNOTRA	ACK - Guideline for LCC and RAMS analy	rsis (2006)	
Product breakdown structure							
Product breakdown structure							
Baseline case - Existing switch design - with curre	ant sensor technology			Innovation - Swit	tch with optimised sensor strategy		
Component	Sub Component	Function of component/sub component		Component	Sub Compone	ent Function of	component/sub component
Sub-grade							<u></u>
		+					
	I					I	

iso	or strategy	
	Sub Component	Function of component/sub component

	Cost categories and Life Cycle Phases						
	Baseline case - Existing switch design - with current sense						
	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 an lower limits)
	R&D costs						
	Investment - Project preparation						
	- Investment and installation						
	Switch installation costs						
	Removal of existing switch						
	Transport costs and logistics of delivering new switch	lavout					
~	Welding						
ŝ	Tamping/geometry						
CAPEX	Signalling and electrical						
0	Installation of sensor technology						
	- Testing and commissioning						
	Inspection/quality control						
	Disposal						
	- Decommission costs						
	 Removal costs Disposal costs/recycled value (rail and ballast recycling 	1					
	- Residual value	ĺ					
	Operation costs (non-maintenance)		1				
	- Energy						
	-Personnel						
	-Training						
	- Facilities						
	- Fees						
	 Communications - operating costs of use of mobile net Data processing/analysis of data 	works for communicati	on or data				
	- Facilities						
	Maintenance costs - see RAMS template						
	- Corrective maintenance of sensor						
	Repair of sensors damaged due to flying ballast, ice, m	noisture, fatigue, high a	cceleration 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						
X	Grinding						
OPEX	Tighten/adjust stretcher bars						
0	Adjust drive						
	- Corrective maintenance of switch						
	Half set replacement						
	Crossing replacement						
	Crossing weld repair Replace bearers						
	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 mainten	ance 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, m	noisture, fatigue, high a I	cceleration forces,				
	Flooding						
	Signalling/electrical failures Ice, ballast or other object between switch and stock r	ail preventing switch is					
	Ice, ballast or other object between switch and stock r Damage to switch drive from flying ballast, ice falling i						
	Stretcher bar failure						
	Derailment due to switch rail wear						

	Innovation - Switch with optimised sensor strategy						
	LCC Cost block	Cost (€) per km or	Stakeholder who benefits/pays	When and how frequently cost occurs in	Dependencies (eg relationship between	Source of cost data -	Quality of data source and where
		Cost (€) per task	financially	life cycle (eg every 20yrs)	cost or cost frequency upon boundary condtionitions such load (MGT), traffic type, curve etc)	eg financial statements, model, expert estimate, total component and labour costs	possible accuracy of data (upper and lower limits)
	R&D costs						
	Investment						
	- Project preparation						
	- Investment and installation Switch installation costs						
	Removal of existing switch						
	Transport costs and logistics of delivering new switch	lavout					
\sim	Welding						
CAPEX	Tamping/geometry						
AF.	Signalling and electrical						
U	Installation of sensor technology						
	- Testing and commissioning						
	Inspection/quality control						
	Disposal Decommission costs						
	- Decommission costs - Removal costs						
	 Disposal costs/recycled value (rail and ballast recycling) 	1					
	- Residual value						
	Operation costs (non-maintenance)						
	- Energy						
	-Personnel						
	-Training						
	- Facilities						
	 Fees Communications - operating costs of use of mobile net 	works for communicati	on 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, m	noisture, fatigue, high a	cceleration 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						
OPEX	Grinding Tighten/adjust stretcher bars						
0	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 mainten	ance 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, m	ı noisture, fatigue. hiøh a	cceleration forces,				
	Flooding						
	Signalling/electrical failures						
	Ice, ballast or other object between switch and stock r		ocking				
	Damage to switch drive from flying ballast, ice falling f	from vehicles					
	Stretcher bar failure						
	Derailment due to switch rail wear	1	1			1	1

				C4R Capacity for Rail					C4R Capacity for Rail	
Capacity4Rail Technology Evaluation template - LCC										
Sub-project:		SP2								
Innovation:		Innovations in T	Innovations in Trains/Wagons – optimised length, speed, performance, central/automatic coupler, EP/electronic braking, electrification, automation, weight							
Discount rate to be u	used for LCC calculations		%							
the right shows an e	nalysis will start with a product example product breakdown str		will consider all of the life cycle stages fr	rom R&D through to disposal. The figure on						
		Investment		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 bo	oundard conditions for as	ssessment								



Baseline case - existing ballasted track and existing vehi						
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 w possible accuracy of data (upp lower limits)
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						
- 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/RAM	5 analysis					
- Cost of non-availability during maintenance activities Planned maintenance						
Unplanned maintenance						

	Innovation - ballasted track with vehicle and wagon inno						
	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)
	R&D costs						
	Investment Project and another						
	- Project preparation - Vehicles/Wagons						
	Vehicle modifications						
	New vehicles						
	- Infrastructure upgrades						
	- Signalling system (for longer trains)						
	Signalling block length						
	Signal position and junction layouts						
CAPEX	- Other infrastructure changes to accommodate longer tr	rains					
AP	 Infrastructure upgrades to gauge envelope 						
0	- 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						
	Operation costs (non-maintenance)						
	- Energy - (cost savings in traction energy per tonne of fr						
	- Fees - (increase in access charges to IM from improved	capacity)					
	-Personnel						
	-Training						
	- Facilities						
	- Communications - Facilities						
	Taunaes						
	Maintenance costs - see RAMS template - impact of great	ater loading, improved a	cceleration and braking on existing mail	tenance 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						
OPEX	IBJ replacement						
ō	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/RAM	1S analysis					
	- Cost of non-availability during maintenance activities						
	Planned maintenance						
	Unplanned maintenance						

Capacity4Rai	I Technolo	gy Evaluati	on template - LCC					
Sub-project:		SP2						
Innovation:		Innovations i	Innovations in Freight Operation - wagon shunting, intelligence for vehicles in terminals, terminal operation					
			%					
	ill start with a product		nd will consider all of the life cycle stages f	rom R&D through to disposal. The figure on	n			
The life cycle cost analysis w the right shows an example	ill start with a product	ructure			ı			
The life cycle cost analysis w	ill start with a product		nd will consider all of the life cycle stages f	> Disposal				
The life cycle cost analysis w the right shows an example	ill start with a product	ructure						
The life cycle cost analysis w the right shows an example 	ill start with a product product breakdown str	ructure Investment	> Operation & Maintenance	> Disposal				

	Cost categories and Life Cycle Phases						
	Baseline case - existing terminal technology and existing	ng 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 possible accuracy of data (u lower limits)
	Operation costs						
	- Traction energy						
	- Fees - Freight terminal charges per tonne freight						
	-Personnel						
	-Training						
	- Facilities						
~	- Communications						
OPEX	- Facilities						
Ö							
	Other quantifiable costs identified from S-E matrix/RA	MS analysis					
	- Cost of non-availability due						
	Planned maintenance						
	Unplanned maintenance						
	Innovation - freight terminal innovations in wagon shu	unting, intelligent vehicle	es, terminal operation				
	LCC Cost block	Cost (€) per km or	Stakeholder who benefits/pays	When and how frequently cost occurs in	Dependencies (eg relationship between	Source of cost data -	Quality of data source and
		Cost (€) per task, cost per tonne of Freight (€), cost per tonner of Freight per year	financially	life cycle (eg every 20yrs)	cost or cost frequency upon boundary condtionitions such load (MGT), traffic type, curve etc)	eg financial statements, model, expert estimate, total component and labour costs	possible accuracy of data (u lower limits)
	R&D costs						
	Investment						
×	- Vehicles/Wagons						
ЪË	Wagon modifications and shunting vehicles Shunting vehicles						
CAPEX	- Infrastructure upgrades						
Ŭ	- Upgrade of terminal layout						
	- Loading and unloading equipment						
	Operation costs (non-maintenance)						
	- Traction energy						
	- Fees - Freight terminal charges per tonne freight						
	-Personnel						
	-Personnel -Training						
	-Personnel -Training - Facilities						
X	-Personnel -Training - Facilities - Communications						
DPEX	-Personnel -Training - Facilities						
OPEX	-Personnel -Training - Facilities - Communications - Facilities	MS analysis					
OPEX	-Personnel -Training - Facilities - Communications	MS analysis					
OPEX	-Personnel -Training - Facilities - Communications - Facilities Other quantifiable costs identified from S-E matrix/RA	MS analysis					
OPEX	-Personnel -Training - Facilities - Communications - Facilities <u>Other quantifiable costs identified from S-E matrix/RA</u> - Cost of non-availability due	MS analysis					
OPEX	-Personnel -Training - Facilities - Communications - Facilities Other quantifiable costs identified from S-E matrix/RA - Cost of non-availability due Planned maintenance	MS analysis					
OPEX	-Personnel -Training - Facilities - Communications - Facilities Other quantifiable costs identified from S-E matrix/RA - Cost of non-availability due Planned maintenance	MS analysis		Image: Constraint of the sector of the se			

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			C4R Capacity for Rail	J
Capacity4Rail Technolo	ogy Evaluat	ion template - LCC		
Sub-project:	SP3			
Innovation:	Optimised st	trategies to manage major disturb	ances	
Discount rate to be used for LCC calculations		%		
the right shows an example product breakdown s			rom R&D through to disposal. The figure on	
		and will consider all of the life cycle stages f	> > Disposal	>
The life cycle cost analysis will start with a product the right shows an example product breakdown s	tructure			
the right shows an example product breakdown s R&D R This sheet will mainly cover the costs from R&D, I	tructure Investment	> Operation & Maintenance	Disposal Life cycle phases	
the right shows an example product breakdown s R&D R&D This sheet will mainly cover the costs from R&D, I will be collected in the "RAMS data" sheet	nvestment (and installa	> Operation & Maintenance	Disposal Life cycle phases	
the right shows an example product breakdown s R&D R This sheet will mainly cover the costs from R&D, I	nvestment (and installa	> Operation & Maintenance	Disposal Life cycle phases	
the right shows an example product breakdown s R&D R&D This sheet will mainly cover the costs from R&D, I will be collected in the "RAMS data" sheet	nvestment (and installa	> Operation & Maintenance	Disposal Life cycle phases	
the right shows an example product breakdown s R&D R&D This sheet will mainly cover the costs from R&D, I will be collected in the "RAMS data" sheet	nvestment (and installa	> Operation & Maintenance	Disposal Life cycle phases	
the right shows an example product breakdown s R&D R&D This sheet will mainly cover the costs from R&D, I will be collected in the "RAMS data" sheet	nvestment (and installa	> Operation & Maintenance	Disposal Life cycle phases	

	Cost categories and Life Cycle Phases						
	Baseline case - existing ballasted track and existing veh	icles - 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 v possible accuracy of data (up; lower limits)
	Operation costs (non-maintenance)						
	- Traction energy						
	- Fees - track access charges						
	-Personnel						
	-Training						
	- Facilities						
	- Communications						
OPEX	- Facilities						
g		an abasis					
	Other quantifiable costs identified from S-E matrix/RAM - Cost of non-availability during maintenance activities						
	Planned maintenance						
	Unplanned maintenance						
	Baseline case - ballasted track with vehicle and wagon i	nnovations					
	LCC Cost block	Cost (€) per km or Cost (€) per task or	Stakeholder who benefits/pays financially	When and how frequently cost occurs in life cycle (eg every 20yrs)	cost or cost frequency upon boundary	Source of cost data - eg financial	Quality of data source and w possible accuracy of data (upp
		CostCost (€) per km or Cost (€) per task or Cost per Vehicle (€) per Vehicle			condtionitions such load (MGT), traffic type, curve etc)	statements, model, expert estimate, total component and labour costs	lower limits)
	Operation costs (non-maintenance)	Cost (€) per task or Cost per Vehicle (€)				expert estimate, total component and	lower limits)
		Cost (€) per task or Cost per Vehicle (€) per Vehicle				expert estimate, total component and	lower limits)
	Operation costs (non-maintenance) - Energy - (cost savings in traction energy per tonne of fi - Fees - (increase in access charges to IM from improved	Cost (€) per task or Cost per Vehicle (€) per Vehicle reight)				expert estimate, total component and	lower limits)
	- Energy - (cost savings in traction energy per tonne of f	Cost (€) per task or Cost per Vehicle (€) per Vehicle reight)				expert estimate, total component and	lower limits)
	 Energy - (cost savings in traction energy per tonne of fill Fees - (increase in access charges to IM from improved 	Cost (€) per task or Cost per Vehicle (€) per Vehicle reight)				expert estimate, total component and	lower limits)
	 Energy - (cost savings in traction energy per tonne of fill Fees - (increase in access charges to IM from improved Personnel 	Cost (€) per task or Cost per Vehicle (€) per Vehicle reight)				expert estimate, total component and	lower limits)
	 Energy - (cost savings in traction energy per tonne of file Fees - (increase in access charges to IM from improved Personnel Training 	Cost (€) per task or Cost per Vehicle (€) per Vehicle reight)				expert estimate, total component and	lower limits)
EX	 Energy - (cost savings in traction energy per tonne of fi Fees - (increase in access charges to IM from improved Personnel Training Facilities 	Cost (€) per task or Cost per Vehicle (€) per Vehicle reight)				expert estimate, total component and	lower limits)
OPEX	 Energy - (cost savings in traction energy per tonne of fi Fees - (increase in access charges to IM from improved Personnel Training Facilities Communications Facilities 	Cost (€) per task or Cost per Vehicle (€) per Vehicle reight) d capacity)				expert estimate, total component and	lower limits)
OPEX	Energy - (cost savings in traction energy per tonne of fi Fees - (increase in access charges to IM from improved -Personnel -Training - Facilities - Communications - Facilities Other guantifiable costs identified from S-E matrix/RAM	Cost (€) per task or Cost per Vehicle (€) per Vehicle reight) d capacity) MS analysis				expert estimate, total component and	lower limits)
OPEX	Energy - (cost savings in traction energy per tonne of fi Fees - (increase in access charges to IM from improved -Personnel -Training - Facilities - Communications - Facilities Other quantifiable costs identified from S-E matrix/RAM - Cost of non-availability during maintenance activities	Cost (€) per task or Cost per Vehicle (€) per Vehicle reight) d capacity) MS analysis				expert estimate, total component and	lower limits)
OPEX	Energy - (cost savings in traction energy per tonne of fi Fees - (increase in access charges to IM from improved -Personnel -Training - Facilities - Communications - Facilities Other quantifiable costs identified from S-E matrix/RAM - Cost of non-availability during maintenance activities Planned maintenance	Cost (€) per task or Cost per Vehicle (€) per Vehicle reight) d capacity) MS analysis				expert estimate, total component and	lower limits)
OPEX	Energy - (cost savings in traction energy per tonne of fi Fees - (increase in access charges to IM from improved -Personnel -Training - Facilities - Communications - Facilities Other quantifiable costs identified from S-E matrix/RAM - Cost of non-availability during maintenance activities	Cost (€) per task or Cost per Vehicle (€) per Vehicle reight) d capacity) MS analysis				expert estimate, total component and	lower limits)
OPEX	Energy - (cost savings in traction energy per tonne of fi Fees - (increase in access charges to IM from improved -Personnel -Training - Facilities - Communications - Facilities Other quantifiable costs identified from S-E matrix/RAM - Cost of non-availability during maintenance activities Planned maintenance	Cost (€) per task or Cost per Vehicle (€) per Vehicle reight) d capacity) MS analysis				expert estimate, total component and	lower limits)
OPEX	Energy - (cost savings in traction energy per tonne of fi Fees - (increase in access charges to IM from improved -Personnel -Training - Facilities - Communications - Facilities Other quantifiable costs identified from S-E matrix/RAM - Cost of non-availability during maintenance activities Planned maintenance	Cost (€) per task or Cost per Vehicle (€) per Vehicle reight) d capacity) MS analysis				expert estimate, total component and	lower limits)

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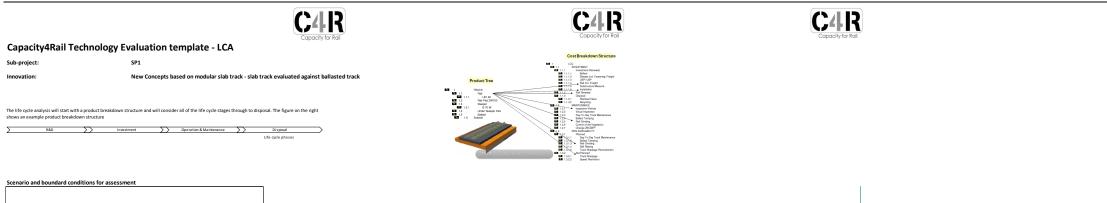
ub-project: novation: scount rate to be used t	or ICC calculations	New conce	ots and technologies for advanced	monitoring in embankm		
scount rate to be used t	or ICC calculations				ents, bridges, different	track types, switc
			%			
R&D	<u> </u>	Investment	> Operation & Maintenance) Disposal		
				Life cycle phases		
1						
is sheet will mainly cov	er the costs from R&D, Ir	nvestment (and install	ation), Operation and disposal. It is assume	ed that the majority of the main	tenance data	

D5.2.2 – Assessment Methodologies and Templates

	Cost categories and Life Cycle Phases						
	Baseline case - Track design - with current sensor techno	ology					
	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)
	Investment						
	- Project preparation - Investment and installation						
Ă	Installation of sensor technology and associated cablir - Testing and commissioning	ng and communication i	nfrastructure				
CAPEX	Inspection/quality control						
	Disposal - Decommission costs						
	- Removal costs - Disposal costs/recycled value						
	- Residual value						
	Operation costs (non-maintenance) - Energy						
	-Personnel						
	-Training - Facilities						
	 Fees Communications - operating costs of use of mobile net 	works for communicati	on 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, m	noisture, fatigue, high a	cceleration 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						
Ш	- Inspection of switch Visual Inspection						
OPEX	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 rein	forment corpusition -	e etc				
	Embankements						
	- Embankment inspection Visual inspection						
	Embankment movement monitoring						
	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			<u> </u>	<u> </u>		
		41.141					
	Cost of non-availability during normal railway mainten Planned maintenance	ance activities					
	Planned maintenance Unplanned maintenance	ance activities					
	Planned maintenance	ance activities					

	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)
	R&D costs						
	Investment - Project preparation						
	- Investment and installation						
X	Installation of sensor technology and associated cablin - Testing and commissioning	ng and communication i	nfrastructure				
CAPEX	- Inspection/quality control						
0	Disposal						
	- Decommission costs - Removal costs						
	- Nemoval costs - Disposal costs/recycled value						
	- Residual value						
	Operation costs (non-maintenance) - Energy						
	-Personnel						
	-Training						
	- Facilities - Fees						
	- Communications - operating costs of use of mobile net	works for communicati	on 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, m - Other maintenance of sensor equipment	ioisture, tatigue, nign a	cceleration forces,				
	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						
OPEX	Visual Inspection						
0	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 rein	forment, spray concret	e 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						
	- Kenewais of switch S&C renewal						
	- Renewals of bridge platform						
	Cost of service affecting failures/maintenance	ance activition					
	 Cost of non-availability during normal railway mainten Planned maintenance 	ance activities					
	Unplanned maintenance						
	Cost of non-availability and damage due to failures Cost of unavailability due to sensor failure						
	Cost of unavailability due to sensor failure Repair of sensors damaged due to flying ballast, ice, m	oisture, fatigue high a	cceleration forces.				
	in the second se						

Appendix 3 - LCA Templates



Product breakdown structure

eline case - ballasted track																				
			No	ise		Life	espan	Refer	ence unit		Materials			Climate chang	e emissions (kg)			Air poll	ution emissions (kg)	
Component	Sub Component	Description of component/sub component	Baseline noise performance (within scenario - dB(A))			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	N₂O Nitrous Oxide	CO2e 1x CO2 34x CH4 298x N2O	SO2 Sulphur dioxide	NO _x Nitrogen oxides	PM ₁₀ Particulate matter	NMVOC Non-methane Volatile Organic Compounds
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					Ξ.															
					gt															
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Innovation - Optimised sensor, communication and data strat	legy																			
			No	bise		Lifes	pan	Referer	nce unit		Materials			Material climate ch	ange emissions (kg)			Material air	pollution emissions (kg)	
Component	Sub Component	Description of component/su 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 ,)	CO2 Carbon dioxide	CH ₄ Methane	N20 Nitrous Oxide	CO2e 1x CO2 34x CH4 298x N2O	SO ₂ Sulphur dioxide	NO _x Nitrogen oxides	PM ₁₀ Particulate matter	NMVOC Non-methane Volatile Organic Compounds
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Baseline case - ballasted track																														
			Vehicle chara	Transport a acteristics	and logistics		Production			Machinery characteristics	Construction a	ind maintenance		Production		Opera Produc	tion		Data			Climate charge e	missions (kg/unit)	Emissio	on factors	Air pollution em	vissions (kz/unit)		Di	
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)			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)		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, Carbon dioxide	CH ₆ Methane	N ₂ O Nitrous Oxide	CO28 14 CD2 34 CH4	50 ₃ Sulphur dioxide	NO <u>.</u> Nitrogen oxides	PM ₁₀ Particulate matter	NMVOC Non-methane Volatile Organic Compounds	eg carbon reporting statements, model, expert	Quality of data source a where possible accuracy data (upper and lower limits)
Investment/Construction - Project preparation					1	1			1	1														298x N ₂ O						
- 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																														
Pads Sleepers																														
Fastenings Rail																														
- Rail - Welding																														
- Initial grinding																														
- Testing and commissioning																														
Inspection/quality control																														
Disposal - Decommission/removal works																														
Disposal costs/recycled value (rail and ballast recycling) Facilities																														
Operation activities (non-maintenance)																														
- Traction energy																														
Personnel - transport Facilities																														
Maintenance activities (see RAMS template)																														
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																														
Dynamic track behaviour - train based Noise monitoring																														
- Preventive/condition based maintenance																														
Rail Change																														
Rail Transpose Grinding																														
Lubrication Fish Plate lubrication																														
- IBJ replacement 5 - Re-sleeper																														
Replace sleeper pads and insulators Noise abatement																														
- Noise abatement - Re-fastening systems																														
5																														
- Corrective maintenance Rail Change - defects																														
Weld change - defects Rail adjustment											1				1									1						
Ballast reprofile	1										1				1									1						
Wet bed removal Tactical reballast											1				1									1						
Plain line tamping Stoneblowing	1										1				1									1						
Geometry manual											1				1									1						
replacement of pads and fasteners											1				1									1						
- Renewals Rail, sleeper and Ballast renewal											1				1									1						
Sleeper and ballast renewal	1										1				1									1						
Tactical resleeper Ballast cleaning	1										1				1									1						
- Off Track maintenance											1				1									1						
Drainage											1				1									1						
Fencing Embankments	1										1				1									1						
Civil structures (flyovers, underpass) Vegetation	1										1				1									1						
- vegesaudh											1													1						1

Innovation - innovative slab track	1																												
	Reference unit		Vehicle chara	Transport an acteristics	d logistics	Prot	luction			Machinery characteristics	Construction a	ind maintenance		Production		Oper a Produ	ation	Dependencies	Source of data	Quality of data source and where	7	Climate charge er	missions (kg/unit)		on factors	Air pollution er	missions (kg/unit)	Source of dat	Quality of data source and
LCA block	(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. tornes/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 (%)	(eg relationship between frequency of task upon boundary conditions such as load (MGT), traffic type, curve etc)		Quality of data source and where possible accuracy of data (upper and lower limits)	i co, Carbon dioxide	CH ₆ Methane	N ₂ O Nitrous Oxide	CO_e 1× CO2 34x CH2	s0, Sulphur dioxide	NO, Nitrogen axides	PM ₁₀ Particulate matter	NMVOC eg carbon report	ting where possible accuracy of data (upper and lower
Investment/Construction - Project preparation - Inputted Residual value																					1 1			298x N ₂ O					
- Inputted Residual value																													
Investment and installation Ground preparation - exotechnical																												1 1	
Ground preparation - geotechnical Site investigation Soil substitution																												1 1	
Reinforcement																													
Subgrade layers Drainage																													
Concrete sublayer Concrete sublayer Connector / stoppers																													
- Connector / stoppers - Slab laying																													
Control of an opport Sale baying																												1 1	
gu Track laving - Track work																												1 1	
- Rail laying																												1 1	
Seepers	1						1																		1		1		
Track laring. Track work Track work Track laring Track and Track laring Track and Track laring Track laring	1						1																		1		1		
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- Testing and commissioning	1						1																		1		1		
Inspection/quality control																													
Disposal - Decommission/removal works	1					I																			1				
 Disposal costs/recycled value (rail and C&DW aggregates recycling) 																													
- facilities																													
Operation activities (non-maintenance) - Traction energy	-																				-				-				
Traction energy Personnel - transport																												1 1	
- Facilities																												1 1	
Maintenance activities (see RAMS template) - Inspection																													
- Inspection Visual Inspection																												1 1	
Ultrasonic - Manual Ultrasonic - Train based																												1 1	
Eddy current inspection - Train based																													
Track geometry - train based Dynamic track behaviour - train based																												1 1	
Slab monitoring for cracks and movement Noise monitoring																													
Preventive/condition based maintenance Rail Change																												1 1	
Rail Transpose Grinding																												1 1	
Lubrication																												1 1	
Fish Plate lubrication IBJ replacement																												1 1	
Re-sleeper Renlace rail naris and insulators	1						1																		1		1		
- Noise abatement	1						1																		1		1		
- Corrective maintenance	1						1																		1		1		
Rail Change - defects	1						1																		1		1		
Head of the second	1						1																		1		1		
	1						1																		1		1		
replacement of pads and fasteners	1						1																		1		1		
Correct cracks in slab Replace slab - in case of derailment or accident (major	1						1																		1		1		
damage)	1						1																		1		1		
 Inject resin to protect steel 	1						1																		1		1		
Correct settlement of slab Inject cement or other products under slab	1						1																		1		1		
 Expansive foam treatment 	1						1																		1		1		
Micro piles						1																							
- Renewals Slab replacement	1						1																		1		1		
Rail+pad+fasteners replacement	1						1																		1		1		
Rail + pad replacement only Replace drainage system						1																							
- Off Track maintenance	1						1																		1		1		
Drainage	1						1																		1		1		
Drainage Fencing Embankments	1						1																		1		1		
Civil structures (flyowers, underpass) Vegetation	1						1																		1		1		
							1											1	1		1				1	1	1	1	1

			C4					CAB									
			Capacit	ty for Rail				Capacity for Rail	J								
Capacity4Rail Technolo	ogy Evaluation temp	late - LCA															
Sub-project:	SP1						•	Cost Breakdown Structure									
Innovation:	New Concepts based or	n modular slab track - inno	ovative slab track evalua	ted against existing sla	ab track	Product Tree		1.1.1 Investment (Renewal) 1.1.1 Ballast 1.1.1.2 Sleeper Incl. Fastening/ Freight 1.1.1.3 USP/ USP									
								I.1.1.4 Ball Incl. Freight II.1.1.5									
he life cycle analysis will start with a product bre hows an example product breakdown structure		the life cycle stages through to dis	sposal. The figure on the right			1 TRACK 11 TRACK 11 1.1 12 TRACK 12 TRACK 12 TRACK 13 1.2 14 TRACK 15 1.6 16 1.6 17 Track 18 1.6 1.6 Subsol		ConflexAdown Structure Conflexed									
RåD >>	investment >> Opera	tion & Maintenance	Disposal Life cycle phases	>				12.0 Control of the Vegetation 12.7 Changu ZW/ZWP NDN-AVAILABILITY NQ1 Planned									
			ute cycle phases					1.3.1. Day-To-Oay Track Maintenance 1.3.1% Balata Tamping 1.3.1% Balata Tamping 1.3.1% Balata Tamping 1.3.1% Bala Palying 1.3.1% Tools Stopage Reinvestment 1.3.2 Mod Parmed 1.3.2 Tools Stopage									
								1.3.2.2 opend Heartcon									
Scenario and boundard conditions for a	assessment					Source: INNOTRACK - Guidel	line for LCC and RAMS analysis	s (2006)									
Product breakdown structure																	
Baseline - existing slab track			N	oise		Innovation - Innovative mod	lular slab track ទទ្ធក្សា	Refere	nce unit		Materials			Climate chan	e emissions (kg)		
Component	Sub Component	Description of component/su component	Baseline noise performance (within scenario - dB(A))	e 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	N20 Nitrous Oxide	CO2e 1x CO2 34x CH4 298x N2O	Sulphi
			_														
			_		turin –												
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					erial												
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			-		-												
Innovation - Optimised sensor, communication and	no data strategy		N	olse		Life	span	Refere	nce unit		Materials			Material climate o	hange emissions (kg)		
Component	Sub Component	Description of component/su component	b 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 ₂ O Nitrous Oxide	CO2e 1x CO2 34x CH4 298x N2O	Sulphu
			_		turi												
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					erial mar												
					Material ma												

	Air pollu	tion emissions (kg)	
SO ₂	NO,	PM10	NMVOC
Sulphur dioxide	Nitrogen oxides	Particulate matter	Non-methane Volatile Organic Compounds
			Non-methane Volatile Organic Compounds
	Nitrogen oxides	Particulate matter	Non-methane Volatile Organic Compounds
Sulphur dioxide	Nitrogen oxides	Particulate matter	Compounds
	Nitrogen oxides	Particulate matter	Non-methane Volatile Organic Compounds NMVOC Non-methane Volatile Organic Compounds
Sulphur dioxide	Nitrogen oxides	Particulate matter	Compounds
Sulphur dioxide	Nitrogen oxides	Particulate matter	Compounds
Sulphur dioxide	Nitrogen oxides	Particulate matter	Compounds
Sulphur dioxide	Nitrogen oxides	Particulate matter	Compounds
Sulphur dioxide	Nitrogen oxides	Particulate matter	Compounds
Sulphur dioxide	Nitrogen oxides	Particulate matter	Compounds
Sulphur dioxide	Nitrogen oxides	Particulate matter	Compounds
Sulphur dioxide	Nitrogen oxides	Particulate matter	Compounds

Baseline - existing slab track																														
				Transport a	and logistics	•					Construction a	and maintenance				Oper	ration		Data					Emission	in factors	•			Data	4
	Reference unit		Vehide da		1	Produ	ction			Machinery characteristics				Production		Produ	luction	Dependencies	Source of data	Quality of data source and where		Climate charge e	missions (kg/unit)			Air pollution en	sissions (kg/unit)		Source of data C	Quality of data source and
LCA block	(e.g. km, m ³ , tonne, train,		Load capacity	Fuel consumption (e.g.l/100 km)	Energy consumption	Distance travelled	Activity time		Production	Power	Fuel consumption	Energy consumption		Unit	Working time	Energy		(eg relationship between frequency of	eg carbon reporting statements,	possible accuracy of data (upper and	co.	CH.	N,0	CO ₂ e	so.	NO,	PM	NMVOC	eg carbon reporting w	where possible accuracy of
	wagon, terminal)	Transport mode	Load capacity (tonnes)	(e.gl/100 km)	(e.g kWh)	(Km)	(Hours)	Equipment	(e.g. tonnes/h, m3/h, km/h)	(kW, hp)	Fuel consumption (e.g.l/100 km)	(e.g.kWh)	Quantity	(e.g. tonnes, km)	Working time (hours)	(Direct use of energy in task, processing)	Utilisation rate (%)	task upon boundary conditions such as load (MGT), traffic type, curve etc)	model, expert estimate	lower limits)	co, Carbon dioxide	CH ₄ Methane	Nitrous Oxide	1x CD2 34x CH4	SO ₂ Sulphur dioxide	Nitrogen oxides	Particulate matter	Non-methane Volatile Organic Compounds	statements, model, expert estimate	data (upper and lower limits)
									Kinyitaay							processing		total (mon), traine type, curve exc)						298x N ₂ O				organic compounds	escinace	
Investment/Construction - Project preparation				1																										
- Inputted Residual value						-		-																						
 Investment and installation 																														
- Ground preparation - exotechnical Site investigation																														
Site investigation																														
Soil substitution																														
Reinforcement						-										-														
Subgrade layers Drainage						-																								
- Slab ossitionine - Ovil work Concrete soblayer Connector / stoppers																														
- Concrete sublayer																														
Connector/stoppers						-																								
Besitionies				-																						-				
D Slab laying Positioning Mortar / Fix the slab				-																										
- Inspection / Quality control																														
6																														
- Track laving - Track work																														
- nan laying				-																										
- Sleepers				1	1											1	1	1		1		1		1	1					
E Fastenings																														
— Clip/screw fastenings		-		1	1	1		-				1			-	1	1		L			1		I	1	-				
e		1	1	1	1	1						1			1		1		-					1	1	1				
- maarginang				1								1										1								
- Testing and commissioning				1								1	-									1								
- Inspection/multity control																														
Disposal Decomposition from the standar			1	1	1										1	1	1							1	1					
- Decommission/removal works				1	1	1						1			1	1	1					1		I	1	1				
 Disposal costs/recycled value (rail and C&DW 	N appresates					-		-																						
- Facilities																														
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																														
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Grinding Lubrication					-	-																								
Fish Plate lubrication				L	1												1								1					
IBJ replacement				1																					1					
Re-sleeper Replace rail pads and insulators				-	1	1						1				1	1					1			1					
Replace rail pads and insulators Noise abatement				1	1	1						1			1	1	1	1		1		1		I	1	1				
		1	1	1	1	1						1			1	1	1	1	1	1		1		1	1	1				
Corrective maintenance					1												1								1					
Rail Change - defects				1																					1					
- Weld charge - defects				1	1	1		-		-		1			1	1	1					1		I	1	1				
Ho Rail adjustment				1	1	1		-		-		1			1	1	1	1		1		1		1	1	1				
 Adjust fastening system for small defects 				1	1	1						1			1	1	1	1	1	1		1		1	1	1				
replacement of pads and fasteners																														
				1																					1					
Correct cracks in slab Replace slab - in case of derailment or accide	ident (mainr	1		1	1	1						1			1	1	1					1			1	1				
damate)			1	1	1	1		1	1				1		1	1	1	1	1	1	1	1	1	1	1	1				
Inject resin to protect steel				L	1												1								1					
Correct settlement of slab				1		1										1	1		-			1			1					
 Inject cement or other products under slab Expansive foam treatment 	3			1	1	+						1			1	1	1		-			1		I	1	1				
Expansive foam treatment Micro piles			1	1	1	1						1			1	1	1					1		1	1	1				
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- Renewals																														
Slab replacement		-		-	1	1						1			-		1								1					
Rail+pad+fasteners replacement Rail + pad replacement only		1	1	1	1	1		-				1			1	1	1		1			1		1	1	1				
Rail + pad replacement only Replace drainage system			1	1	1	1						1	-		1	1	1	1	1	1		1		1	1	1				
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- Off Track maintenance																														
Drainage				1	1	1						1				1	1	1		1		1		I	1	1				
- Fencing Embankments		1	1	1	1	1		-				1			1	1	1	1		1		1		1	1	1				
Embankments Civil structures (flyovers, underpass)		1	1	1	1	1						1			1	1	1	1	1	1		1		1	1	1				
Vegetation				1	1											1	1	1		1		1		1	1					
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Innovation	Innovative slab track																													
					Transport ar	nd logistics		Production				Construction an	d maintenance	Production		Oper	ration		Data			Climate chance er		Emission	n factors		vissions (kr/unit)		Da	12
		Reference unit		Vehicle charac	cteristics						Machinery characteristics			Production		Produ	uction	Dependencies	Source of data	Quality of data source and where		Climate charge en	missions (kg/unit)	(0.e		Air pollution en	sissions (kg/unit)		Source of data	Quality of data source and
	LCA block	(e.g. km, m ¹ , tonne, train, wagon, terminal)	Transport mode	Load capacity	Fuel consumption	Energy consumption	Distance travelled	d Activity time	Equipment	Production (e.g. tonnes/h, m3/h,	Power	Fuel consumption	Energy consumption Quantity	Unit	Working time	Energy (Direct use of energy in task	Utilisation rate (%)	(eg relationship between frequency of task upon boundary conditions such as	eg carbon reporting statements,	possible accuracy of data (upper and	co,	CH ₄ Methane	N_0	1x CD ₂ 34x CH ₄	so,	NO,	PM ₁₀	NMVOC Non-methane Volatile	eg carbon reporting statements, model, expert	where possible accuracy of data furner and lower
		wagon, terminar)	maniportmode	(tonnes)	(e.gl/100 km)	(e.g kWh)	(Km)	(Hours)	Liquipment	km/h)	(kW, hp)	(e.g.l/100 km)	(e.g.kWh) Quantity	(e.g. tonnes, km)	(hours)	processing)	, ourse on rate (sty	load (MGT), traffic type, curve etc)	model, expert estimate	lower limits)	Carbon dioxide	Methane	Nitrous Oxide	34x CH ₄ 298x N-O	Sulphur dioxide	Nitrogen oxides	Particulate matter	Organic Compounds	estimate	limits)
Investmen	/Construction																							2000 Higo						<u> </u>
- Project p	/Construction operation																													
- Inputted	esidual value et and installation																													
- Ground	reparation - seotechnical						-																							1
Site inv	reparation - exotechnical stigation																													
Soil sub Reinfor Subgra Drainag	titution																													
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Siab pos	ionine - Civil work sublayer or / stoppers						_																							f
Connec	ar / stoppers																													
Slab lag	18 ng Fix the slab																													
p Positio	ng																													(
- Inspert	in / Quality control						-																							1
5																														
E Track lan	ne - Track work																													(
- Rail lay	u de la companya de la					1	1			1				1	-		1	1	1	1		1		1	-	1				1
- Sleepe						1				1				1	1			1	1	1		1		1	1	1				1
E Fasteni	na - Track work K K Si V fastenings					1				1				1												1				
⊆ Clip/sci	w fasterings						-			1															1					1
Weldin Initial g						1	1	-	-	1				1			1	-	1	1				1	-	1				1
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Inspecti	n/quality control						-			1																				1
Disposal			+ +				-			1						1	1	+	1	1				l						<u> </u>
	sion/removal works					1	1			1				1		1	1	1	1	1		1		1		1				1
- Disposal	osts/recycled value (rail and C&DW aggregates rec	cycling)																												(]
- Facilities						1				1																				1
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- Traction	sergy - transport																													
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- Facilities																														
Maintena	e activities (see RAMS template) pection																													
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Slab mo	toring for cracks and movement						_																							1
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Re-sleep	ement ir ail pads and insulators																													1
Replace	ail pads and insulators itement					1	1			1				1				-								1				1
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O Rail Cha	ge - defects nge - defects		I			1	1			1				1		1			1	1		1	L			1				1
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replacer	ent of pads and fasteners		I			1	-	-		1				1		1			1	1						1				1
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Rail+pac	fasteners replacement					1	-			1				1						1		1								1
Kail + pa	replacement only rainage system					1	1	1	-	1				1		1	1		1	1		1		I		1				t
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Drainag										1						1						-								()
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Civil stru	tures (flyovers, underpass)					1				1				1					1			1				1				1
Vegetat	m																													
						1				1				1	1	1	1	1		1		1			1					1

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			C 4	IR				C4R									
Capacity4Rail Technolo	or Fvaluation temp	ate - I CA	Capacit	y for Rail				Capacity for Rail									
Sub-project:	SP1							Cost Breakdown Structure									
Innovation:		pecifications for very high	n speed lines (if innovati	ion slab track)				INVESTMENT I.1.1 Investment (Reserved) I.1.1.1 Balant I.1.1.2 Sleeper ind. Fastening/ Freight									
						Product Tree		Inf 1.1.1.3 USP/USP USP/USP Inf 1.1.1.4 Pail incl. Proight Inf 1.1.1.5 Substructure Measure Inf 1.1.1.5 Inf Decement Inf Decement									
The life cycle analysis will start with a product bre shows an example product breakdown structure	akdown structure and will consider all of t	ne life cycle stages through to dis	posal. The figure on the right			1 TRACK 11 TRACK 12 1.1.1 13 12.1 13 13.0 14 1.3 15.1 8.70 w 15.1 8.70 w 15.1 8.80 w 15.1 9.00 w 15.1 5.00 w 15.1 5.00 w 15.1 5.00 w	B	Contraction Structure Contraction Contrel Contraction Contraction									
R&D >>	Investment >> Operat	ion & Maintenance	Disposal	>				12.5 Pail Grinding 12.0 Control of the Vegetation 12.7 Change ZW/ZWP 3 NON-AVAILABILITY									
			Life cycle phases					A.1 Planned Day To Day Track Maintenance J.1.1 Day To Day Track Maintenance J.1.3.1 Ball Griding District Temping District Part Provider									
						C. A. D	\$ w m - + 5) M	1.3.2 Tack Stoppage Reinwatment 1.3.2 No Parmed 1.3.2 Speed Restricton									
Scenario and boundard conditions for a	assessment					Source: INNOTRACK - Guide											
						Source: INNOT MACK - Guide	ne for LCC and KAMS analysi	(2006)									
Product breakdown structure			-														
Baseline case - ballasted track						Innovation - Innovative mod	ılar slab track										
				pise		Life	ipan	Refere	nce unit		Materials			Climate chang	e emissions (kg)	CO ₂ e	
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 ₆ Methane	N20 Nitrous Oxide	1x CO ₂ 34x CH ₄ 298x N ₂ O	Sul
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Innovation - Optimised sensor, communication an	nd data strategy																
Component	Sub Component	Description of component/sub component		Key components		Life Value	Unit	Refere Value	unit Unit	Type of material (e.g. steel, concrete,	Materials Quantity	Unit	CO ₂	CH.	nange emissions (kg) N ₂ O	CO2e 1x CO2	
			(within scenario - dB(A))	(contribution to noise)			[MGT, years]			copper,)		(e.g. t, kg, m ³ ,)	Carbon dioxide	Methane	Nitrous Oxide	34x CH ₄ 298x N ₂ O	Su
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	Alexa 10	tion emissions (kg)	
SO ₂	NOx	PM ₁₀	NMVOC Non-methane Volatile Organic
Sulphur dioxide	Nitrogen oxides	Particulate matter	Compounds
		Particulate matter	
	Nitrogen oxides		
	Nitrogen oxides	Particulate matter	
	Nitrogen oxides		
Sulphur dioxide	Nitrogen oxides	solution entisions (kg)	Compounds
Sulphur dioxide	Nitrogen oxides	solution entisions (kg)	Compounds
Sulphur dioxide	Nitrogen oxides	solution entisions (kg)	Compounds
Sulphur dioxide	Nitrogen oxides	solution entisions (kg)	Compounds
Sulphur dioxide	Nitrogen oxides	solution entisions (kg)	Compounds
Sulphur dioxide	Nitrogen oxides	solution entisions (kg)	Compounds
Sulphur dioxide	Nitrogen oxides	solution entisions (kg)	Compounds
Sulphur dioxide	Nitrogen oxides	solution entisions (kg)	Compounds
Sulphur dioxide	Nitrogen oxides	solution entisions (kg)	Compounds

Name Name <th< th=""><th>Baseline case - ballasted track</th><th></th><th></th><th></th><th></th><th></th><th></th><th></th><th></th><th></th><th></th><th></th><th></th><th></th><th></th><th></th><th></th><th></th><th></th><th></th><th></th><th></th><th></th><th></th><th></th><th></th><th></th><th></th><th></th></th<>	Baseline case - ballasted track																												
					Transport an	nd logistics		÷				Construction and	maintenance				Operation		Data					Emissio	n factors		· ·		Data
Photo Photo Photo Photo Photo Photo		teference unit		Vehicle char	racteristics		Prod	Suction			Machinery characteristics				Production		Production	Dependencies				Climate charge en	missions (kg/unit)			Air pollution em	sissions (kg/unit)		Source of data Quality of data source and
Image Image <th< th=""><th>LCA block (e.e.</th><th>m. m¹. tonne, train.</th><th></th><th></th><th></th><th></th><th></th><th></th><th></th><th>Production</th><th></th><th></th><th></th><th></th><th></th><th></th><th>Energy</th><th></th><th>Source of data</th><th>Quality of data source and where</th><th></th><th></th><th></th><th></th><th></th><th></th><th></th><th>NMVOC</th><th>eg carbon reporting where possible accuracy of</th></th<>	LCA block (e.e.	m. m ¹ . tonne, train.								Production							Energy		Source of data	Quality of data source and where								NMVOC	eg carbon reporting where possible accuracy of
	wi	gon, terminal)	Transport mode	Load capacity	Fuel consumption	Energy consumption	Distance travelled	Activity time	Equipment	(e.g. tonnes/h, m3/h,	Power	Fuel consumption	Energy consumption	Quantity	Unit	Working time	(Direct use of energy in task, Utilisation rate (%)	task upon boundary conditions such as	eg carbon reporting statements,	possible accuracy of data (upper and	co,	CH ₆	N ₃ O	1x CD ₂	so,		PM ₁₀	Non-methane Volatile	statements, model, expert data (upper and lower
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	Investment/Construction																							and not					
	- Project preparation																												
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	Initial grinding			1	1	1		1	1	1	1			1	1		1		1		1			1	1				
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	- Traction energy																												
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	Maintenance activities (see RAMS template)																												
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	Ballast reprofile			1	1	1		1	1	1	1			1	1		1				1			1	1				
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Innovation - Innovative modular slab track																											
			•	Transport a	and logistics	•	÷			c	struction and maintenance				Operation		Data					Emissio	in factors				Data
	Reference unit		Vehicle cha	aracteristics	1	Prod	duction		1	Machinery characteristics			Production		Production	Dependencies	Source of data	Quality of data source and where		Climate charge e	missions (kg/unit)			Air pollution err	nissions (kg/unit)		Source of data Quality of data source and
LCA block	(e.g. km, m ¹ , tonne, train,		Load capacity	Fuel consumption	Energy consumption	Distance travelled	Activity time		Production	Power Fuel con	mption Energy consump	on .	Unit	Working time	Energy	(eg relationship between frequency of	of eg carbon reporting statements,	possible accuracy of data (upper and	co,	СН,	N ₂ O	CO ₂ e	so,	NO,	PM.,	NMVOC	eg carbon reporting where possible accuracy of
	wagon, terminal)	Transport mode	(tonnes)	(e.g1/100 km)	(e.g kWh)	(Km)	(Hours)	Equipment	(e.g. tonnes/h, m3/h, km/h)	(kW, hp) (e.g.l/	0km) (e.g.kWh)	Quantity	(e.g. tonnes, km)	(hours)	(Direct use of energy in task, Utilisation rate (%) processing)	task upon boundary conditions such a load (MGT), traffic type, curve etc)		lower limits)	Carbon dioxide	CH _e Methane	Nitrous Oxide	1x CD ₂ 34x CH ₄	Sulphur dioxide	Nitrogen oxides	PM ₁₀ Particulate matter	Non-methane Volatile Organic Compounds	statements, model, expert data (upper and lower estimate limits)
terre at the state of the state									Kingitang				_		processing	ions (mar), traine type, carve ever						298x N ₂ O				organic compounds	estimate mints
Investment/Construction - Project preparation - Inputted Residual value				_		_																					
- Inputted Residual value																											
Ground preparation - secret/nical Site investigation Soli substitution Reinforcement																											
Site investigation		_		-	-												-										
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Subgrade layers Drainage																											
Sector Stab positioning - Civil work																											
2 Concrete sublayer			-	-										-													
8 Slab laving				-																							
- Positioning																											
Connector / stoppers																											
- Inspection / Quality control																											
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- Bail laving																											
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Fastenings Cinforme furtacione		-	1	1	1		1	1	1				-	1	1	1	-		-			I	1				
Welding		1	1	1	1		1	1	1				1	1	1 1	1	1		1			1	1	-			
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- Testing and commissioning					1		1						-				1						1				
Inspection/quality control		-	1	+	+	1	1	1	1			-	-	1		1			1	1		1	1	-			
Disposal		1	1	1	1	1	1	1	1	1 1		-	1	1	1 1	1	1		-	1		1	1				
Disposal - Decommission/removal works							1					1		1													
- Disposal costs/recycled value (rail and C&DW aggregates																											
recycling) - facilities																											
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Operation activities (non-maintenance)							1																				
- Traction energy																											
-Personnel - transport																											
- facilities																											
Maintenance artivities (see BAMS template)																											
Maintenance activities (see RAMS template) - kspection - Visual Inspection - Ultrasonic - Manual - Ultrasonic - Train based - Eddy current inspection - Train based						-																					
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Otheronic - Train based				-	-																						
Dynamic track behaviour - train based																											
Slab monitoring for cracks and movement				_																							
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Preventive/condition based maintenance Rail Change Rail Transpose Grinding Lubrication																											
Rail Change																											
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unitaing		-		-									_														
IBJ replacement																											
tBJ replacement Re-sleeper					1		1						-				1						1				
Replace rail pads and insulators		-	1	1	+		+	1	1				-	-	1	1	-		-			1	1				
6 Noise abatement			1			-	1							1													
C - Corrective maintenance			1		1		1	1															1				
Corrective maintenance Rail Change - defects Corrective maintenance					1		1																1				
O Weld change - defects			1	1	1		1	1					-	1	1	1	1		-			I	1				
- Rail adjustment Maintain drainage		1	1	1	1	1	1	1	1				1	1	1 1	1	1		1			1	1				
- Adjust fastening system for small defects			1	1	1	1	1	1	t i	1			1	1	1	1			1	1		1	1				
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Correct cracks in slab Peplace slab - in case of derailment or accident (major				1	+			1	1				-	1	1	1	1		-			I	1				
 Replace slab - in case of deraitment or accident (major damage) 						1	1							1				1				1	1	1			
Inject resin to protect steel							1					1		1													
- Correct settlement of slab					1		1																				
Inject cement or other products under slab		-	1	1	1	1	1	1	1				-	1	1	1	-		-			I	1				
Inject cement or other products under slab Expansive foam treatment Micro piles						-	1					1		1			1							1			
			1		1		1	1					1										1				
- Renewals Slab replacement					1		1																				
Slab replacement			1	-	1		1						-		1	-	1						1				
Rail+pad+fasteners replacement Rail + pad replacement only		-	1	1	1	-	1	1	1				1	1	1 1	1	1		1			I	1				
Replace drainage system		1	1	1	1	-	1	1	1	1		1	1	1	1		1		1	1		1	1				
			1		1		1	1															1				
- Off Track maintenance					1		1																1				
Drainage		-	1	1	1	-	1		1			-	-	1					1	1		1	1	-			
Fencing Embankments Givil structures (flyovers, underpass)		1	1	1	1	-	1	1	1	1			1	1		1				1		1	1				
Civil structures (flyovers, underpass)			1	1	1	1	1	1	1	1			1	1	1	1			1	1		1	1				
Vegetation			1		1		1																1				
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			C4	IR				C4R									
			Capacit	ty for Rail				Capacity for Rail									
Capacity4Rail Technolo	ogy Evaluation temp	late - LCA															
Sub-project:	SP1						•	Cost Breakdown Structure									
Innovation:	New track designs and	specifications for very hig	h speed lines (if innovat	ion ballasted track)		Product Tree		Investment (Renewal) Investment (Renewal) I.1.1 Balast I.1.1.2 Sizepar ind. Fastering Freight I.1.1.3 USP (USP									
								1.1.1.4 Rail incl. Freight 1.1.1.5 Substructure Measure 1.1.1.5 Installation 1.1.2 Rail Reserval									
The life cycle analysis will start with a product br shows an example product breakdown structure		the life cycle stages through to di	sposal. The figure on the right			1 THACK 1 I ALI 1.1 Rat 1.1 UIC 60 1.1 UIC 60		Cost Breakdown Structure Cost									
R&D >>	Investment >> Opera	tion & Maintenance	Disposal Life cycle phases	>				12.6 Control of the Vegetation 1.2.7 Change ZW/ZWP NDN-AVAL/ABLITY 52.1 Planned									
			the cycle phases					Sci.1 Day 1-0 Day Track Maintenance Sci.1 Share Tarping Sci.1 Rel Giveding Sci.1 Rel Relying Sci.1 Rel Relying Sci.1 Tack Soccease Science Sci.2 Net Planned Sci.2 Soccease									
								1.3.2.2 Speed Pestriction									
Scenario and boundard conditions for	assessment					Source: INNOTRACK - Guide	line for LCC and RAMS analysis	(2006)									
						_											
Product breakdown structure																	
Baseline case - ballasted track																	
Component	Sub Component	Description of component/su component		oise Key components (contribution to noise)		Value	Unit [MGT, years]	Refere Value	unit Unit [km, each,]	Type of material (e.g. steel, concrete, copper,)	Materials Quantity	Unit (e.g. t, kg, m ³ ,)	CO ₂ Carbon dioxide	Climate chan CH ₄ Methane	ge emissions (kg) N ₂ O Nitrous Oxide	CO2e 1x CO2 34x CH4 298x N2O	Sulphu
			_														
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Innovation - Optimised sensor, communication a	nd data strategy																
		Description of component/su	b Innovation noise	oise		Life	espan	Refere	nce unit	Type of material	Materials				hange emissions (kg)	CO ₂ e	
Component	Sub Component	component	performance (within scenario - dB(A))	Key components (contribution to noise)		Value	Unit [MGT, years]	Value	Unit	(e.g. steel, concrete, copper,)	Quantity	Unit (e.g. t, kg, m ³ ,)	CO ₂ Carbon dioxide	CH ₄ Methane	N20 Nitrous Oxide	1x CO ₂ 34x CH ₄ 298x N ₂ O	Sulphu
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			-		- in												
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	Air pollu	tion emissions (kg)	
SO ₂	NO,	PM10	NMVOC
Sulphur dioxide	Nitrogen oxides	Particulate matter	Non-methane Volatile Organic Compounds
			Non-methane Volatile Organic Compounds
	Nitrogen oxides	Particulate matter	Non-methane Volatile Organic Compounds
Sulphur dioxide	Nitrogen oxides	Particulate matter	Compounds
	Nitrogen oxides	Particulate matter	Non-methane Volatile Organic Compounds NMVOC Non-methane Volatile Organic Compounds
Sulphur dioxide	Nitrogen oxides	Particulate matter	Compounds
Sulphur dioxide	Nitrogen oxides	Particulate matter	Compounds
Sulphur dioxide	Nitrogen oxides	Particulate matter	Compounds
Sulphur dioxide	Nitrogen oxides	Particulate matter	Compounds
Sulphur dioxide	Nitrogen oxides	Particulate matter	Compounds
Sulphur dioxide	Nitrogen oxides	Particulate matter	Compounds
Sulphur dioxide	Nitrogen oxides	Particulate matter	Compounds
Sulphur dioxide	Nitrogen oxides	Particulate matter	Compounds

Baseline case - ballasted track		1		1																										
daterine care - canalord track					and logistics						Construction an						ration		Data						on factors				á an the second s	
			Vehicle cha	Transport	and logistics		duction			Marbinery characteristics	construction at	na mainteachtea		Production		Ope	luction		0758					Emission	on factors		nissions (kg/unit)			
	Reference unit		Vehicle cha	indeteristics		Pro	duction			Machinery characteristics				Production			luction	Dependencies				Climate charge e	missions (kg/unit)			Air pollution err	nissions (kg/unit)		Source of data Q	Quality of data source and
LCA block	(e.g. km, m ³ , tonne, train,								Production (e.g. tormes/h, m3/h,							Energy		(eg relationship between frequency of	Source of data	Quality of data source and where				CO ₂ e				NMVOC	eg carbon reporting with	where possible accuracy of
	wagon, terminal)	Transport mode	Load capacity (tonnes)	Fuel consumption	Energy consumption	Distance travelled	Activity time	Equipment	(e.e. tonnes/h. m3/h.	Power	Fuel consumption	Energy consumption	Quantity	Unit	Working time	(Direct use of energy in task	Utilisation rate (%)	task upon boundary conditions such as	eg carbon reporting statements,	possible accuracy of data (upper and	CO2	CH4	N ₂ O	1x CD ₃	SO ₂	NO,	PM ₁₀	Non-methane Volatile	statements, model, expert	data (upper and lower
			(tonnes)	(e.gl/100 km)	(e.g kWh)	(Km)	(Hours)		km/h)	Power (kW, hp)	(e.g l/100 km)	(e.g.kWh)		(e.g. tonnes, km)	(hours)	processing)		load (MGT), traffic type, curve etc)	model, expert estimate	lower limits)	Carbon dioxide	Methane	Nitrous Oxide	1x CD2 34x CH4	Sulphur dioxide	Nitrogen oxides	Particulate matter	Organic Compounds	estimate	limits)
									Kangitang							processings		iono (mor), marie type, carve exc)						298x N ₂ O				organic compounds	escenace	minut
Investment/Construction - Project preparation																							1	1						
- Project preparation																														
- Inputted Residual value																														
- Investment and installation																														
Ground preparation - geotechnical and civil																													-	
Site investigation					-		-																							
Soil substitution								-																-						
Soli substitution Reinforcement																													-	
Neinforcement																														
5 Subgrade layers																														
- Drainage																														
8																														
- Track laving - track work																														
- Ballast																														
- Pads																														
- Sleepers																														
Ci Fastenines																														
CS particular track work — Track laster track work — Dallast — Dallast — Patternings — Fractionings — Nail — Working																														
5 Woldies																													-	
2 Tamping					1	1		1				1					1	1							1				1	
5 Constant State				1	1	1	1	1				1 1		1	1	1	1	1				1	1	1	1 1		1		+ +	
- Dynamic stabilisation		1				1		1				1		1		1	1	1				1			1 1				+ +	
- Initial grinding		1		1	1	1	1	1				1		1		1	1	1				1			1				4	
- Testing and commissioning						-											1	-							1 1				4	
- Testing and commissioning		1			1	1	1										1								1					
Inspection/quality control																	1								1					
Disposal - Decommission/removal works																														
- Decommission/removal works		1										1																		
- Disposal costs/recycled value (rail and ballast recycling)	e)											1																		
- Facilities																														
Operation activities (non-maintenance)								1																1					+	
- Traction energy																									1				++-	
Personnel - transport					-		-																							
Personnel - transport						-		-																					-	
- Facilities																													-	
														-		-						-							++	
Maintenance activities (see RAMS template)																														
- Inspection Visual 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																														
Bail Change						-																								
Rail Change Rail Transpose Grinding Lubrication						-																								
Criedies																													+	
- Grinning					-		-																							
Fish Plate lubrication		1			1	1		1				1 1					1								1 1				++	
		1		1	1	1	1	1				1		1		1	1	1				1			+ +				+	
C - IBJ replacement		1				1						1					1	-							1				+ +	
-Re-sleeper		1				1		1				1					1	-							1				4	
- Replace sleeper pads and insulators		1		1	1	1	1	1				1		1		1	1	1	I			1	1	1	1		-		+	
- Noise abatement		1		1	1	1	1	1				1		1		1	1	1	l			1	1	-	1		-		+	
- Re-fastening systems		1				1		1				1		1		1	1	1				1			1 1				+	
<u>8</u>		1				1		1						1		1	1					1			1 1				+	
- Corrective maintenance							1																							
Q Rail Change - defects					1			1								1	1													
- Weld change - defects					1											1	1					1								
Rail adjustment																	1								1					
Ballast reprofile		1										1																		
Wet bed removal								1						1		1	1					1	1	1						
Tactical reballast			1	1				1	1					1	1	1	1					1	1							
Plain line tamping		1		1		1	1										1	1							1				1	
Stoneblowing	1	1		1	1	1	1	1				1		1	1	1	1	1				1	1	1	1				1 1	
Sconectowing Geometry manual		1		1	1	1	1	1				1		1		1	1	1				1	1		1				1	
registered of andr and factories		1										1					1	1							1 1				+	
replacement of pads and fasteners		1		1	1	1	1	1				1		1		1	1	1				1	1	-	1				+	
	-	1		1	1	1	1					I		-		-	1	1				-			+ +				+	
- Renewals Rail, sleeper and Ballast renewal		1				-		-				1		-		-	1	1				-			1 1				+	
Rail, steeper and Ballast renewal		1			1	1	1	I									1								1				-	
Sleeper and ballast renewal					1		1									1	1													
Tactical resleeper		1															1													
Ballast cleaning												1													1					
								1						1		1	1					1	1	1						
- Off Track maintenance				1		1	1										1	1											1	
- Or Trace mandemance Drainage	1	1	1	1	1	1	1	1	1			1		1	1	1	1	1				1	1	1	1				1	
English		1										1					1	1							1 1				+	
Fencing Embankments		1		1	1	1	1	1				1		1		1	1	1				1	1		1				+	
- sourcements		1		1	1	1	1	1				1		1		1	1	1				1	1		1				1	
- Civil structures (flyovers, underpass)				1			1	1						1		1	1					1			1				+	
Vegetation							1	1						1		1						1							-	
1		1	1	1	1	1	1	1						1		1	1	1	1	1	1	1	1		1		1		1	

Innovation - Innovative ballasted track																										
			Vehicle cha	Transport	t and logistics	Produ	alian.			Marhinary characteristics	Construction	and maintenance		Production		Ope	ration		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.gl/200 km)	Energy consumption (e.g kWh)	Distance travelled (Km)	Activity time (Hours)	Equipment	Production (e.g. tormes/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	, Utilisation rate (%)	Dependencies (eg relationship between frequency of task upon boundary conditions such as load (MGT), traffic type, curve etc)		Quality of data source and where possible accuracy of data (upper and lower limits) Carbon dioxide	CH ₄ N ₂ O Methane Nitrous Oxide	CO3e SO3 1x CO3 SO3 14x CH4 Sulphur dioxide	NO, PM _{al} Nitrogen oxides Particulate	NMVOC Non-methane Vo Organic Compo	latile statements, model, expert	Quality of data source where possible accura data (upper and low limits)
Investment/Construction - Project preparation																						298x N ₂ O				-
Project preparation Inputted Residual value																_										
Investment and installation																										
Ground preparation - evotechnical and civil																										
Site investigation																										
Soil substitution Reinforcement				-		-																				
Subgrade lavers				-		-																				-
Subgrade layers Drainage																										
Track laying - track work																_										
Pads																										-
Sleepers																										
Fastenings																							-			
Tamping																										-
Dynamic stabilisation																										
Tatal Juing Tatak work Malai Mala		-		1	-											1		1	1	1	1 1		1 1		- 1	-
- Testing and commissioning	-	1		1	-	-						1			1	1	1	1	1	1	1	1	1		- 1	-
Inspection/quality control																			1						1	
																			-							-
Disposal - Decommission/removal works		1		-	1											1		1	+	1	1	1	1 1			+
 Decommission/removal works Disposal costs/recycled value (rail and ballast recycling 	ne)		1																				1			-
Facilities	-	1																	1						1	
Operation activities (non-maintenance)																										_
Traction energy Personnel - transport												-														
- Facilities																										
Maintenance activities (see RAMS template) - Inspection																										_
- 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																_					-					-
Kall Change																-										-
- Rail Change - Rail Transpose - Grinding - Lubrication																										-
Lubrication																										
Fish Plate lubrication												1				-		1	-				1			
IBJ replacement Re-sleeper	-	1		1	1	1		1				1			1	1	1	1	1	1 1	1 1	1	1 1			+
 Replace rail pads and insulators 	1	1	1	1	1			1	1			1			1	1	1	1	1	1		1	1 1		1	1
Noise abatement																										_
Re-fastening systems		1		-		1						1				-		1	1	1	1	1	1 1			_
- Corrective maintenance	-	1		1	1	1		1				1			1	1	1	1	1	1	1 1	1	+ +		- 1	+
Corrective maintenance Rail Change - defects Weld change - defects Weld change - defects Rail adjustment		1																	1						1	
Weld change - defects																										
Rail adjustment Moletile deleses		1		1	1	1		1				1				1		1	1	1	1	1	1 1			+
Maintain drainage Adjust fastening system for small defects	-	1		1	1	1		1				1			1	1	1	1	1	1 1	1 1	1	1 1			+
replacement of pads and fasteners		1	1																							
				L																					- (_
Correct cracks in slab Replace slab - in case of derailment or accident (majo	dan daman d	1		-	1											-		1	1	1	1	1	1 1			
 Replace slab - in case of derailment or accident (majo — Inject resin to protect steel 	ajor damage)		1																				1			
																1			1						1	
Correct settlement of slab Inject cement or other products under slab																										
Inject cement or other products under slab Expansive foam treatment		1			-	_						1				1		1	+	1	1 1		1 1			-
Expansive foam treatment Micro piles			1		-	1						1				1		1	1	1	1 1		1 1			
		1	1	1	1	1		1	1			1			1	1	1	1	1	1		1	1 1		1	1
- Renewals																										-
Slab replacement			1																							-
Rail+pad+fasteners replacement Rail + pad replacement only			1	1	-	1						1				1		1	1		1		1 1			
Rail + pad replacement only Replace drainage system	1	1	1	1	1	1									1	1	1	1	1	1	1	1	1 1		1	+
		1			1			1								1			1				1		1	1
- Off Track maintenance																										
Drainage		1		1	-											1		1	1	1 1	1 1		+		- 1	-
Fencing Embankments	-	1	-	1	-	1						1			1	1	1		1	1		1	1		- 1	-
Embankments Civil structures (flyowers, underpass)			1													1					1		1			-
Conterpass) Vegetation		1		1	1	1		1				1			1	1	1	1	1	1			1 1		1	1
															1				1							

			C						C4R Capacity for Roll												
Capacity4Rail Technolog	· Evaluation temp	late - LCA	Capc	city for Rali																	
Sub-project:	SP1							14 1	Cost Breakdown Structure												
novation:	New concepts for Swite	hes and Crossings bas	sed on failure modes analy	sis		ProductT			Investment (Renewal) 1.1.1 Ballast 1.1.2 Sleeper Incl. Fastering/ Freight 1.1.3 USP URP												
						1 TRACK	ree		1.1.4 Ral Incl. Freight T.1.5 Substructure Measure 1.1.4 Installation Ral Receival												
e life cycle analysis will start with a product breakd ows an example product breakdown structure	wn structure and will consider all of t	he life cycle stages through	n to disposal. The figure on the rig	nt		1 TPACK 1 1 Fail 1 1.1 Fail 1 1.1 Hill 1 1.2 Fail Paid 1 1.3 Skepper 1 1.3.1 B'r 1.4 Under S Skepel 1.4 Under S 1.6 1.4 Skepel Skepel	E0 IZW700 I W Ieegoer Pad		CostBenekadown Structure Cont												
RắD >>	Investment >> Opera	tion & Maintenance	Disposal	\supset				120 127 04,127	Control of the Vegetation Change 2W/2WP NON-AVALABILITY Planned												
			Life cycle phases				510 C R 142		Al.1. Day-To-Day Teck Maintenance Arts. Balase Tamping Ana. Anal Gending Anal And Gending Anal Relying Mot Planned Mot Planned Anal Toxic Scopage Anaz Social Planned												
cenario and boundard conditions for ass	ssment																				
						Source: INNOTRACK -	Guideline for LCC a	and RAMS analysis (2	006)												
Product breakdown structure																					
aseline case - Existing switch design - use as a basis	design which is commonly used in th	e scenario given		Noise			Lifespan		Refere	nce unit			Materi	als			Climate change e	missions (kg)			_
Component	Sub Component	Description of componen component	ent/sub Baseline noise performa (within scenario - dB(A			Value		Unit IGT, years]	Value	U [km, e	nit ach,]	Type of material (e.g. steel, concrete, copper,)	Quant		Unit e.g. t, kg, m ³ ,)	CO ₂ Carbon dioxide	CH₄ Methane	N ₂ O Nitrous Oxide	1	CO2e x CO2 4x CH4 8x N2O	Sulphu
													_						_		
					turiu -																_
					nufac																_
					mar																
					Material														_		_
					Ma														_		
																					_
novation - Optimised sensor, communication and d	ta strategy																				
Component	Sub Component	Description of componen component	ent/sub Innovation noise performance (within scenario - dB(A	Key components (contribution to noise)		Value	Lifespan [M	Unit IGT, years]	Refere	nce unit U		Type of material (e.g. steel, concrete, copper,)	Materi Quant		Unit e.g. t, kg, m ³ ,)	CO2 Carbon dioxide	Material climate char CH ₄ Methane	ge emissions (kg) N ₂ O Nitrous Oxide	1	CO2e x CO2 4x CH4	Sulphu
					_														29	8x N2O	_
					jug .																_
					lfactu														_		_
					2																
					Material ma														_		
					Aater																
																					_
				•																	
Baseline case - Existing switch design - use as a basis a design which		Valida de marca	Transport and logistics		l		Madalanan eksenerteristis	Construction	and maintenance		Bundualise		Oper	ation		Data			(Sente dare	a contrational (the foreign)	
LCA block (e.	Reference unit km, m ³ , tonne, train, vagon, terminal) Transport mode	Load capacity ((tonnes)	Fuel consumption Energy consumption (e.g.l/100 km) (e.g.kWh)	Distance travelled Ac (Km)	tivitytime (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 task upon boundary conditions such load (MGT), traffic type, curve etc	of 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	N2O Nitrous Oxide	
Investment Project preparation Project preparation Project and Lettellation Project Preparation Project Pr																					_
- Investment and installation Switch installation costs Removal of existing switch																					
 Transport costs and logistics of delivering new switch 																					
Byout Welding																					
Testing and commissioning Inspection/quality control																					
Disease Disease - Decommission/removal works																					_
- Disposal costs/recycled value	1			1				1	1			1					1	1		1	

ë																			
1 5	Disposal																		
-	 Decommission/removal works 																		
	- Disposal costs/recycled value																		
	- spene construction of the																		
_	Operation activities (non-maintenance)							-						-					
	- Traction energy						-												-
	- Personnel - transport																		
	- Facilities						-									 			
	- Facilities						-									 			-
	Maintenance activities (see RAMS template)																		
	- Inspection						-												
	Visual Inspection					-				 						 			
	Visual Inspection Ultrasonic - Manual																		
	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																		
b b																			
	- Preventive/condition based maintenance of switch																		
3	S&C adjustment																		
9	Lubrication																		
5	Grinding																		
at i	Tighten/adjust stretcher bars																		
- La	Adjust drive										1								
1 8											1								
	- Corrective maintenance										1								
	Half set replacement										1								
	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																		
1	Repair/replace locking mechanisms				1		1		1	1				1					1
1	Repair electrical/signalling/interlocking failures				1		1		1	1		1		1					1
1	and the second sec				1		1		1	1		1		1			1		1
1	- Renewals	1			1		1		1	1		1		1			1		1
1	S&C renewal	1	1	1	1	1	1	1	1	1	1	1	1	1		1	1	1	1
	- Juc leitewa																		-

	Air pollu	tion emissions (kg)	
SO 2 Sulphur dioxide	NO _x Nitrogen oxides	PM ₁₀ Particulate matter	NMVOC Non-methane Volatile Organic Compounds
	Materialair	sollution emissions (kg)	
s0, Sulphur dloxide	Material bir NQ, Nitrogen oxides	salaction emissions (kg) PMus Particulate matter	NMVOC Non-methane Volatile Organic Compounds
SO ₄ Sulphur dioxide	NOx	PM10	Non-methane Volatile Organic
s0, Sulphur dioxide	NOx	PM10	Non-methane Volatile Organic
SO ₂ , Sulphur dloxide	NOx	PM10	Non-methane Volatile Organic
SO ₂ Sulphur dioxide	NOx	PM10	Non-methane Volatile Organic
SQ, Sulphur dioxide	NOx	PM10	Non-methane Volatile Organic
50, Sulphur dloxide	NOx	PM10	Non-methane Volatile Organic
SO 2 Sulphur dioxide	NOx	PM10	Non-methane Volatile Organic
SO ₂ Sulphur dioxide	NOx	PM10	Non-methane Volatile Organic
SQ, Sulphur dloxide	NOx	PM10	Non-methane Volatile Organic
SO ₂ Sulphur dioxide	NOx	PM10	Non-methane Volatile Organic

		Air pollution err	issions (kg/unit)		Source of data	Quality of data source and
CO2e				NMVOC	eg carbon reporting	where possible accuracy of
1x CO2	50 ₂	NO,	PM22			
34x CH ₂	Sulphur dioxide	Nitrogen oxides	Particulate matter	Non-methane Volatile	statements, model, expert	data (upper and lower
JEX CH4	sulpruraicolde	Netrogen dis des	Particulate matter	Organic Compounds	estimate	limits)
298x Nj.O				g		
			-	-		
				-		
	1					
			-	-		
			1	1		
	1					
			1	1		
	1					
	1					
	1					

Innovation - Innovative switch design					Transport an	al Instanton						Construction an	d					ration		Data						n factors				Data
-1				Vehicle char	Transport an	in inflation	Brok	duction			Machinery characteristics	construction an	one integer i Co		Production		Ope	uction		-754			Climate change e	missions (for foreigh	Emissio	IL FLOOD	Air pollution em	(colore (ha look)		611
	Referer			Vencoe com	13(00)05		P10	-224300			responsity transferrings				20010000			Dettor	Dependencies	, Source of data	Quality of data source and where		Climite christer e	minatera (xg/sain)	COje		Air ptelution em	issicas (xg/unit)		Source of data Quality of data source and
LCA block	(e.g. km, m ¹ ,			Load capacity	Fuel consumption	Energy consumption	Distance travelled	Activity time		Production	Power	Fuel consumption	Energy consumption		Unit	Working time	Energy		(eg relationship between frequency of	f eg carbon reporting statements,	possible accuracy of data (upper and	c0 ₂	CH ₄	N ₂ O	1x CO ₃	50 ₂	NO,	PM ₃₀	NMVOC	egcarbon reporting where possible accuracy of
	wagon, te	rminal) To	Transport mode	(tonnes)	(e.g1/100 km)	(e.g.kWh)	(Km)	(Hours)	Equipment	(e.g. tonnes/h, m3/h, km/h)	(kW, hp)	(e.g.l/100 km)	(e.g.kWh)	Quantity	(e.g. tonnes, km)	(hours)	(Direct use of energy in task processing)	. Utilisation rate (%)	task upon boundary conditions such as load (MGT), traffic type, curve etc)	s model, expert estimate	lower limits)	Carbon dioxide	Methane	Nitrous Oxide	14 CH4	Sulphur dioxide	Nitrogen oxides	Particulate matter	Non-methane Volatile Organic Compounds	statements, model, expert data (upper and lower estimate limits)
Investment																									110 100					
- Project preparation																	_													
 Investment and installation 							-		-																					
Switch installation costs																														
 Removal of existing switch 																														
- Transport costs and logistics of deliveri	ring new switch layout																													
Welding																														
Tamping/geometry							-		-																					
Signalling and electrical																														
- Testing and commissioning																														
Inspection/quality control							-																							
Disposal - Decommission/removal works																														
Disposal costs/recycled value							-		-																					
Operation activities (non-maintenance) - Traction energy																	-													
Personnel - transport									-																					
- Facilities																														
Maintenance activities (see RAMS templa	late)																													
- 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 in	inspection																													
- Preventive/condition based maintenance	en of emitch								-								_													
- S&C adjustment							-		1					1						1										
- Lubrication							1							1				1		1						1				
Lubrication Grinding							1							1																
Tighten/adjust stretcher bars					1		1		1	1				1				1												
Adjust drive																														
- Corrective maintenance																														
Half set replacement														1						1										
Crossing replacement							-							1						1										
Crossing weld repair							-							1																
Replace bearers S&C tactical reballast							1							1						1										
SAC tactical reparant S&C tamping									-																					
S&C tamping Manual S&C geometry correction	- 1				1	1	1	1	1	1				1	1		1	1		1					1	1				
- Repair/replace switch motor and drive i	mechanisms						1	1						1				1		1						1				
Repair/replace locking mechanisms					1									1																
Repair electrical/signalling/interlocking	g failures				1	1		1	1	1				1				1				1								
					1		1			1				1																
- Renewals																														
S&C renewal																														

				IR				C4R Capacity for Rail											
Capacity4Rail Technolo	gy Evaluation temp	ate - LCA	Cupuci																
Sub-project:	SP1							Cost Breakdown Structure											
Innovation:	New designs for switch	es resilient to extrem	e weather conditions			P. 1		1.1.1 Eventment (Renewal) 1.1.1 Balast 1.1.1.2 Steeper Incl. Fastering/ Freight 1.1.1.2 USD											
						Product Tree		11.1.1.4 Rail incl. Freight 11.1.1.4 Rail incl. Freight Substructure Measure 11.1.4 Herailation 11.2 Rail Recoveral											
he life cycle analysis will start with a product br hows an example product breakdown structure	akdown structure and will consider all of t	ne life cycle stages through	to disposal. The figure on the right			1 TPACK 1.1 Fail 1.1.1 Fail 1.2 Fail Pai2/87 1.2 Fail Pai2/87 1.3 Samper 1.3 F3 Samper 1.1.1 F3 W 1.4 Under Sampe 1.5 Subsol 1.6 Subsol	Pad	Cost Break down Structure CREATER CRE											
RåD >>	Investment >> Opera	ion & Maintenance	Disposal Life cycle phases	•				12.0 Control of the Vegetation											
							★ \$ \$\$\$ (\$\$\$\$ = \$ \$\$)	13.15 Ballas Tranping 13.13 Hall Ginding 13.13 Hall Ginding 13.14 Rail Ginding 13.25 Hool Stoppage Perivestment 1.32 Hool Parmed 1.32 Speed Pestition											
Scenario and boundard conditions for	assessment - Scenario should incl	ude extreme weathe	r events			Source: INNOTRACK - Gu	deline for LCC and RAMS analysi	s (2006)											
						_													
Product breakdown structure																			
Baseline case - Existing switch design - use as a b Component	isis a design which is commonly used in the Sub Component	Description of compone	nt/sub Baseline noise performance	ise Key components			ifespan Unit	Refere	nce unit Unit	Type of material	Materials		Unit	CO2	Climate change e CH ₄	emissions (kg) N ₂ O	CO2e 1x CO2		
Component	Sub component	component	(within scenario - dB(A))	(contribution to noise)		Value	[MGT, years]	Value	[km, each,]	(e.g. steel, concrete, copper,)	Quantity	(e.g	t. t, kg, m ³ ,)	Carbon dioxide	Methane	Nitrous Oxide	1x CO ₂ 34x CH ₄ 298x N ₂ O	-	ulp
					turing												<u> </u>		=
					anufactu												<u> </u>		=
					erial m.												<u> </u>		
					Mater												<u>+</u>		
																			_
nnovation - Optimised sensor, communication a	nd data strategy		N	SP			ifespan	Refere	nce unit		Materials				Material climate char	nge emissions (kg)			
Component	Sub Component	Description of compone component	nt/sub 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	(e.g	Unit ;. t, kg, m ³ ,)	CO ₂ Carbon dioxide	CH4 Methane	N ₂ O Nitrous Oxide	CO2e 1x CO2 34x CH4 298x N2O	-	ulp
					- ing														
					lfactu												<u> </u>		
					man														
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					Material man														_
Barlin car-folgin pilet dette, san a store skolar	which is comparing and is the oracio states				te														
Rantino cas - Exising solità dirigo - ses in chesis a dirigo ICA Most	Reference unit	Vehicle observation	Transport and Tophics Transport and Tophics Transport and Tophics Tel assumption Tel argumentation Tel	Production Distance transition	Mater	Production (e.g. torseal/h, m.l/h,	Control Contro Control Control Control Control Control Co	tion and multiterance	Protections	Working Uma	Operative Concerning Index	20 25 Utilisation rate (%)	Dispendencies gerklationslich between fregurny y	Dita Source of data ecclose inputing sciencement	Quality of data source and where	Cables generate	Climic object emission Other	ent (kg/mil) Ni,O	
LCA block		Velide deserver	Transport and logitics too Unit commution (c.q.(2020 km))	Production Distance transition of a (Cm) d a	Mater	Production (e.g. toroscyle, mille, www	Pear Feat answer(s) Pear Feat answer(s) (NC, h) Feat answer(s)	Store for a function and a function of the fun	Quantity (a g larens, in	-) Working time (Decos)	Operating Polodi Energy a clearge in tak, processing	20 an Utilisation rate (5) E	Cypendensis g relationship between frequency ak upon boundary conditions such suad (MOT), traffic type, curve drij		Quality of data source and where possible accuracy of data (upper and Court (init))	co, Carbon dioxide	Clinut churg ministe Of, Methane	est (kg/mit) N ₂ O Nitrou Oxide	
LCA Meck	Reference unit	Vehica deserviting	Transport and fogitists Transport and fogitists (r.g. kittin) (r.g. kittin)	Defauer traveling to the traveling of the traveling to th	Mater	Production (c.g. torrach, mith, torrach, mith,	Neury Duractions Constru-	store and anticotherance a teng communities (e.g. sole)	Production Guartity Unit (e.g. stores, km	Deces)	Operating Products Energy (Decta or of energy in task, processing)	201. 201. 202. 203. 203. 204. 204. 204. 204. 204. 204. 204. 204	g relationship between frequency of		Quality of data serves in it where positive assume of data (upper and beer (inst.)	0), Carton disola	C Cost object induced	kes (k//mi) N,O NErous Daide	
LCA block Monstantial -Najing preparation -Najing preparation -Switch installation costs	Reference unit	valido grandi a	Transport and Egyttics: Sis Exerging canonytion (e.g. VDD line) Exerging canonytion (e.g. VDD) Exerging canonytion (e.g. VDD) Exerging canonytion (e.g. VDD) Exerging canonytion (e.g. VDD) Exerging canonytion (e.g. VDD) Exerging canonytion (e.g. VDD) (e.g. VDD) (e.g	Extension Action	Mater	Production (reg. surrey), http://	Parar (VK-Tro) Feat assumption (VK-Tro) Feat assumption (VK-Tro) Feat assumption	tion and prototenance Energy commution (c & VOI)	Duration Guesting Unit (s.g. tones, km		Operation of the second	20 mm mm UEIStation rate [5]	g relationship between frequency of		Quality of data source and where positive accuracy of data (upper and bower limits)	Carbon Banada	Class charge and the class of t	soti (vz/anit) NyO Nitrous Oxide	
LCA Mack	Reference unit	Under parents	Transet and lightics	Extend toolid At a	Mater	(4 g somet/h mith, so/h)	Norry Current (Inc. Pour (VR.16)) Fuel Consumption (VR.16) Fuel Consumption (VR.16)	Clot and multichance Tota and multichance Renergy comunities (e.g. VM)	Questing Unit (de g tornes, but	_) Working Sme (Doors)	Operating the second se	Shation rate (K)	g relationship between frequency of		Quality of data source and where position accuracy of data (oper and boar rimit.)	(0), Grine stanis	Class charge emission On Mathema	ent (Jag/unit) N.O NEtrova Childe	
LCA Meck	Reference unit	Votels Serveral Last ceptory	Transport and lightics	Prédition Distance travelled Act (Cm) (Mater	Production (e.g. transact/n, m3/n, km/n3	New Second doc Peres (200, 5p) Fell consequences (200, 5p)	Con ext multitearce Energy consumption (e & MM)	Guardity Dok	_) Working Gene (Pours)	Conserved and a conserved and	DUBLIC OF CALL OF CALLO OF CALL OF CAL	g relationship between frequency of		Quality of data sources and where possible accinery of data (upper and lower (inst))	(9), Créan daoise	Churst days gamma	en Stjantj KO Nitros Osia	
LES Mod	Reference unit	Votor document	Transport and TopUTCH TopUTCH Television Tel	Production Distance travelled (fem)	Mater	Production (e.g. surracy), m30, suryh3	Солария 	tion of multiceance	Quantity Generation	-) (Press)	Openant Instant Energy (Dect or of anergy in tak, processing)	All and the second seco	g relationship between frequency of		Quality of data source and where process and where and where source (series)	Cathon disolds	Classification of the second s	No Och	
LES Mark	Reference unit	Vehica deserviti	Transport and Taglatics Teamport and Taglatics Team (e.g. 41000) (e.g. 41000)	Polaridan Distance travelled (Con)	Mater	Production (* g. tariho, m.th, (* g. tariho,)	Sharey durated allow Perer (XYC 1y) Field emunytic (e.g. (7.001m))	a Engrand and a constraints and a constraint of a constraint o	Guantity Ge stores, br		Copyright Control of Copyright	Distantion rate (b)	g relationship between frequency of		Quality of data spins inf where positive assurage of data (spice and baser (inst.)	Cotos danda	Class (Sectorities October Delbare	se sylvetit	
LEX.Mox8	Reference unit		Transport and logitics Temport and logitics Tempor	Defaner travelide (Cm)	Mater	(reg. second) (r	Ning (base) to find the second	ICIC Ref Rotitionance ICIC Ref Rotitionance Re	Questity Unit for tores, be	_) Working dear Down)	Operating of the second		g relationship between frequency of		Quality of data source and where positive assurance of data (upper and baser limits)	Calue danie	Class of bog of enclose	Norma Data	
LEX.Mox8	Reference unit		Transport and logitics Transport and logitics Teamplication (e.g.(2020-in))	Detanes travella (Con)	Mater	(e.g. series), h. ub), sub), s	New Out and the second	IGO Ref Rotitoance IGO Ref Rotitoance IGO Ref Rotitoance IC(e g XXh) IC(e g XX	Production Genetity (sig torong, low		Operating of the second		g relationship between frequency of		Quality of data source and where positive assurance of data (upper and baser limits)	Calue danie	Class of bar of entries	Norma Data	
USA block	Reference unit		Transport and logitics Teampoint (e.4/203.Hz)	Detana toselid (Con)	Mater	Production (r g. series), (k, 0), (r g. series), (k, 0), (k	Norr Our source Construct Pour (NOC.10) Feat consumption (Construct)	ISO els Autorance	Guardine Contraction		Operating Indext		g relationship between frequency of		Quality of data source and where positive assurance of data (upper and baser limits)	Calue danie	Class of bot of controls	An an address of the second seco	
	Reference unit		Transport and logitics Teampoint (e.4/2021-in)	Defaner traveling Act	Mater	Production (r g. series), h, (b), (r g. series), h, (b), (r g. series), h, (b), (r g. series), h, (c), (r g. series), h, (c), h	Nary duration Control Pear Fed consequence (NO, Hp) Fed consequence	Side and multichance	Guarding Garding		Operating Indext		g relationship between frequency of		Quality of data source and where positive assurance of data (upper and baser limits)	Calue danie	Class of bog excision	Norma Data	
LEX block	Reference unit		Transport and logitics Transport and logitics Team of the second	Defaner travelide (COII)	Mater	Production (r g series), h, b, b, s (r g series), h, s (r g series),	New Construction Power (NOL 19) Power (NOL 19) Powe	Side and multichance	Guardina Caracteria		Operating Index Concernence (Concernence) (g relationship between frequency of		Quality of data source and where positive assurance of data (upper and baser limits)	Calue dania	Canada a barge entities	Nores Date	

Corrective maintenan Half set replacement Crossing weld repair Replace bearers S&C tastical reballar S&C tastical reballar S&C tastical reballar Repair/replace set Repair/replace tool Repair/replace tool

Renewals
 S&C renewal
 Activities related to cost
 Flooding
 Signalling/electrical fail
 to, ballast or other obj

Sop Sulphur dioxide NA PMag NAVOC Sulphur dioxide Nittogen oxides PMag NAVOC Sulphur dioxide No. PMag No. Sulphur dioxide <td< th=""><th></th><th></th><th></th><th></th></td<>				
SO2. Sulphur dioxide NO3. Nitrogen oxides PMig Particulate matter NMOOC Image: SO2. Image: SO3. Image:				
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SO2. Sulphur dioxide NO3. Nitrogen oxides PMig Particulate matter NMOOC Image: SO2. Image: SO3. Image:		Air pollu	tion emissions (kg)	
SO ₂ NO ₂ PM ₁₀ NMVOC Solekon diraida			PM ₁₀ Particulate matter	Non-methane Volatile Organic
SO ₂ NO ₂ PM ₁₀ NMVOC Solekon diraida				
SO ₂ NO ₂ PM ₁₀ NMVOC Solekon diraida	-			
SO ₂ NO ₂ PM ₁₀ NMVOC Solekon diraida	_			
SO ₂ NO ₂ PM ₁₀ NMVOC Solekon diraida				
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SO ₂ NO ₂ PM ₁₀ NMVOC Solekon diraida				
SU2 NO2 PWN10 Non-methane Volatile Organic				
		Material air	sollution emissions (kg)	
		NOx	PM10	Non-methane Volatile Organic
		NOx	PM10	Non-methane Volatile Organic
		NOx	PM10	Non-methane Volatile Organic
		NOx	PM10	Non-methane Volatile Organic
		NOx	PM10	Non-methane Volatile Organic
		NOx	PM10	Non-methane Volatile Organic
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		NOx	PM10	Non-methane Volatile Organic
		NOx	PM10	Non-methane Volatile Organic
		NOx	PM10	Non-methane Volatile Organic
		NOx	PM10	Non-methane Volatile Organic

		Air pollution err	issions (kg/unit)		Source of data	e de la companya de la compa
CO ₂ e				NMVOC	eg carbon reporting	Quality of data source and where possible accuracy of
1x CO2	SO2	NO,	PM ₁₀	Non-methane Volatile	statements, model, expert	data (upper and lower
34x CH ₄	Sulphur dioxide	Nitrogen oxides	Particulate matter	Organic Compounds	estimate	limits)
298x N ₂ O				organic compounds	escillate	minital
		-	1	1		
	1	1	1	1		
	1	1	1	1	1	

Innovation - Innovative switch design				Transport	t and logistics						Construction	and maintenance				Operation		Data					Emission	factor			÷		Data
			Vehicle cha	Transpor	t and logistics	Beer	duction			Machinery characteristics	Construction	and maintenance		Production		Operation Production		0.96			Climate charge er	missions (in family)	511155101	1 factors	Air and balles on	issions (kg/unit)			
	Reference unit		ALL OF CLA			10	000000							Predictoren			Dependencies	Source of data	Quality of data source and where		Children Charley V	interest (cg/still)	CO ₂ e		All periodical eff	annonn (ogganne)		Source of data	
LCA block	(e.g. km, m ³ , tonne, train,		Load capacity	Fuel consumption	Energy consumption	Distance travelled	Activity time		Production	Power	Fuel consumption	Energy consumption		Unit	Working time	Energy	(eg relationship between frequen		possible accuracy of data (upper and	c02	CH ₄	N ₂ O	1x CD ₂	502	NO,	PM	NMVOC		
	wagon, terminal)	Transport mode	(tonnes)	(e.gl/100 km)	(e.g kWh)	(Km)	(Hours)	Equipment	(e.g. tonnes/h, m3/h,	(kW, hp)	(e.g l/100 km)	(e.g kWh)	Quantity	(e.g. tonnes, km)	(hours)	(Direct use of energy in task, Utilisation	n rate (%) task upon boundary conditions su		lower limits)	Carbon dioxide	Methane	Nitrous Oxide	34x CH ₄	Sulphur dioxide	Nitrogen axides	Particulate matter	Non-methane Volatile	statements, model, expert	ert data (upper and lower
			((e.8.) and mult	(1.8.11.1)	frank	(km/h)	((1.6.1.1.1.1.1.1.1.1.1.1.1.1.1.1.1.1.1.1	(fer8-month month	(processing)	load (MGT), traffic type, curve e	1¢)		Carbon Grounde	NVIE CITALINE	HERODIS GALDE	298x N.O	Julphul ultitude	neu ogen on des	Particulate matter	Organic Compounds	estimate	limits)
investment																													-
- Project preparation																													
- Investment and installation																													
- Switch installation costs Removal of existing switch																													
Removal of existing switch																													
Transport costs and logistics of delivering new switch																													
layout Welding Tamping/geometry																													
Welding												-				-													
Tamping/geometry				-		-						-				-			-								-		
Signalling and electrical						-																							-
- Testing and commissioning																													
Inspection/quality control			-	-		-	-	-												-							-		
						-																							
Disposal		1		1	1	1	1	1			1			1						1	1		1		1	1	1		-
- Decommission/removal works			1		1		1	1							1					1					1				
- Disposal costs/recycled value																													
Operation activities (non-maintenance)																													
- Traction energy																													
- Personnel - transport		1		-			1														1						-		_
- Facilities																													
Maintenance activities (see RAMS template)							-																						
Maintenance activities (see RAMS template)												-																	
- Inspection Visual Inspection Ultrasonic - Manual						_																							
Visual Inspection																											-		
Ultrasonic - Train based							-					1																	
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																													
Grinding																													
Tighten/adjust stretcher bars												-																	
Adjust drive		1	1	1	1	1	1				1	1		-		1		-	1										
- Corrective maintenance		1	1	1	1		1	1	1	1		1			1	1		-	1	1	1		1		1		1		+
- Half set replacement		1	1	1	1	-	1	1	1	1		1		1	1	1				1	1		1	1	1	1	1		-
- Crossing replacement			1		1	-	1	1			1	1			1	1			1	1	1		1		1		1		-
- Crossing weld repair			1	1	1	1	1	1			1									1			1						
Replace bearers			1		1		1	1			1				1					1					1				
S&C tactical reballast																													
S&C tamping																													
Manual S&C geometry correction																													
Repair/replace switch motor and drive mechanisms		1					1		1	1						1			-		1								_
Repair/replace locking mechanisms		-	1				1					1						-					-						
Repair electrical/signalling/interlocking failures			1		-	-						1				1			-								-		
- Renewals		1	1	1	-		1		1						1	1			-		1		1						_
- Renewals S&C renewal		1	1	1			1	1	1	1	-	-		-	1	1					1		1		1		1		-
- Jac Internation		1	1	1	1	1	1				1	1				1		-	1	1			1						-
- Activities related to cost of non-availability and damage due to	to failures	1	1	1		+	1	1	1	1		1				1		1	1	1	1		1		1		1		-
- Flooding			1	1	1	1	1	1			1	1								1			1						
Signalling/electrical failures		1	1	1			1	1		1					1	1 1				1	1		1		1				
Ice, ballast or other object between switch and stock rail		1	1		1	1	1	1			1				1					1					1				
preventing switch locking		1	1	1		1	1		1	1	1			1	1	1 1		1	1		1	1	1	1	1	1	1		1
Damage to switch drive from flying ballast, ice falling from																													
vehicles			1																										
Stretcher bar failure																													
Derailment due to switch rail wear			1																										
							1				1					1													

o			Capacit	FR y for Rail				CAPACITY For Rail									
Capacity4Rail Technol		olate - LCA						Cost Breakdown Structure									
Sub-project:	SP1							LCC 1 INVESTMENT 1.1.1 Investment (Penewal)									
Innovation:	Optimised S&C sensor	strategies				Product Tree		1.1.1.2 Seeper Incl. Fastering/ Freight 1.1.1.3 USPI USP 1.1.1.4 Ball Incl. Freight TTTTS Substantian Measure									
The life cycle analysis will start with a product b shows an example product breakdown structure	eakdown structure and will consider all of	the life cycle stages through to di	isposal. The figure on the right			1 TRACK 1.1 Fail 1.1 Fail 1.1 UC 60 1.2 Fail Paid 2477 1.2 Fail Paid 2477 1.2 Ucde Stepper W 1.4 Ucde Stepper W 1.5 Buttool	Pad Ba	Collection Structure Collection Collec									
R&D >>	Investment >> Oper	ation & Maintenance	Disposal	>				12.0 Control of the Vegetation 12.7 Okangu ZW/ZWP 2 NON-AVAILABILITY NON-AVAILABILITY NUSA1 Planned									
			Life cycle phases					Inf State Target State Target States Target States Target States Target States Target States Target States St									
Scenario and boundard conditions for	assessment - Scenario should inc	lude extreme weather ev	rents														
						Source: INNOTRACK - Gui	deline for LCC and RAMS analys	is (2006)									
Product breakdown structure																	
Baseline case - Existing switch design - with curr	ent sensor technology		N	nise			ifespan	Refere	nce unit		Materials			Climate chan	ze emissions (kg)		
Component	Sub Component	Description of component/su component	ub 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 ₂ O Nitrous Oxide	CO2e 1x CO2 34x CH4 298x N2O	Sulphu
			_														
			_		cturing									-			
					ufact												
			_		man												
					erial												
			1		Mater												
			-		-												
Innovation - Optimised sensor, communication	nd data strategy		N	oise			ifespan	Refere	nce unit		Materials			Material climate	hange emissions (kg)	1	
Component	Sub Component	Description of component/su component	ub 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 ₂ O Nitrous Oxide	CO2e 1x CO2 34x CH4 298x N2O	Sulphu
			_		<u>p</u>												
			1		Ē		-					-					-
			╡		ufactu												
				1	- E			1									
			_														
					rial ma												
					Material ma												

	Air pollu	tion emissions (kg)	
SO ₂	NO _x	PM10	NMVOC
Sulphur dioxide	Nitrogen oxides	Particulate matter	Non-methane Volatile Organic Compounds
			Non-methate Volatile Organic Compounds
			Non-methane Volatile Organic Compounds
	Nitrogen oxides	Particulate matter	Non-methate Volatile Organic Compounds
	Nitrogen oxides		Non-methane Volatile Organic Compounds Non-methane Volatile Organic Compounds
S0 ₂	Nitrogen oxides	Particulate matter	Compounds
S0 ₂	Nitrogen oxides	Particulate matter	Compounds
S0 ₂	Nitrogen oxides	Particulate matter	Compounds
S0 ₂	Nitrogen oxides	Particulate matter	Compounds
S0 ₂	Nitrogen oxides	Particulate matter	Compounds
S0 ₂	Nitrogen oxides	Particulate matter	Compounds
S0 ₂	Nitrogen oxides	Particulate matter	Compounds
S0 ₂	Nitrogen oxides	Particulate matter	Compounds

Baseline case - Existing switch design - with current sens				Transport as	and logistics			i i i			Construction a	and maintenance				Operati	ion		Data						on factors				Data
LCA block	Reference unit (e.g. km, m ¹ , tonne, train, wagon, terminal)		Vehicle char	racteristics		Distance travelled	Activity time		Production	Machinery characteristics Power				Production	Working time	Energy	ice	Dependencies (eg relationship between frequency of	of Source of data	Quality of data source and where possible accuracy of data (upper and	co,	Climate charge e	emissions (kg/anit) N+O	CO26	50,	Air politika	emissions (kg/unit) PM11	NMVOC	Source of data Quality of data source and eg carbon reporting where possible accuracy of
		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. tornes/h, m3/h, km/h)	Power (kW, hp)	Fuel consumption (e.g.//100 km)	Energy consumption (e.g kWh)	Quantity	Unit (e.g. tonnes, km)	Working time (hours) (Dir	Energy irect use of energy in task, processing)	Utilisation rate (%)	task upon boundary conditions such a load (MGT), traffic type, curve etc)	of eg carbon reporting statements, model, expert estimate	possible accuracy of data (upper and lower limits)	CO ₂ Carbon dioxide	CH ₄ Methane	N ₃ O Nitrous Oxide	1x CO ₃ 1x CO ₃ 24x CH ₆ 298x NoO	SO ₂ Sulphur dioxide	Nitrogen oxides	PM ₃₃ Particulate matter	NMVOC Non-methane Volatile Organic Compounds	eg carbon reporting statements, model, expert estimate limits
- Project preparation - Investment and installation																													
Switch installation costs Removal of existing switch Transport costs and basistics of deliverine new switch																													
layout 																													
Antipical generation - Index development - Instruction and Installation - Seatch installation costs - Removed of available available - Removed of available available - Removed of available available Royad - Workling - Tampangegeneraty - Tampangegeneraty - Installation avairs tablendogg																													
Testing and commissioning Jesperting/mailing/control																													
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		Life cycle phases																	
Scenario and boundard conditions for ass	essment																		
Baseline case - existing vehicles			Noise		Life	espan	Refer	ence unit		Materials			Climate chang	ge emissions (kg)			Air poll	rtion emissions (kg)	
Component	Sub Component	Description of component/sub component (within scenario	erformance Key components p - dB(A)) (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	CH₄ Methane	N ₂ O Nitrous Oxide	CO2e 1x CO2 34x CH4 298x N2O	SO₂ Sulphur dioxide	NO _x Nitrogen oxides	PM ₁₀ Particulate matter	NMVOC Non-methane Volatile Organi Compounds
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				un u															
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				manı															
				- lei															
				Mate															
				-															
Innovation - Optimised sensor, communication and d	ita strategy																		
Component	Sub Component	Description of component/sub component performa (within scenario	nce (contribution to poice)		Value	Unit [MGT, years]	Refer	ence unit Unit	Type of material (e.g. steel, concrete, copper,)	Materials Quantity	Unit (e.g. t, kg, m ³ ,)	CO ₂ Carbon dioxide	Material climate c CH ₄ Methane	:hange emissions (kg) N <u>2</u> 0 Nitrous Oxide	CO2e 1x CO2 34x CH4 298x N2O	SO 2 Sulphur dioxide	Material air NO _x Nitrogen oxides	pollution emissions (kg) PM ₁₀ Particulate matter	NMVOC Non-methane Volatile Organi Compounds
				ju B															
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				nufe			+					-							+
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Cost categories and Life Cycle Phases																														
Baseline case - existing ballasted track and existing	ng vehicles - no CAPEX																													
				Transport	rt and logistics						Construction	and maintenance				Ope	ation		Data					Emission	n factors				D	Data
	Reference unit		Vehicle ch	naracteristics		Pro	duction			Machinery characteristics				Production		Prod	uction	Dependencies				Climate change	emissions (kg/unit)			Air pollution er	vissions (kg/unit)		Source of data	Quality of data source a
LCA block	(e.g. km, m ¹ , 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. tormes/h, m3/h, km/h)	Power (kW, hp)	Fuel consumption (e.g.l/100km)	Energy consumption (e.g.kWh)	Quantity	Unit (e.g. tannes, km)	Working time (hours)	Energy (Direct use of energy in task processing)	Utilisation rate (%)	(eg relationship between frequency of task upon boundary conditions such as load (MGT), traffic type, curve etc)	of 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	N2O Nitrous Oxide	CO3e 1x CO3 34x CH4 2808 N-0	503 Sulphur dioxide	NO _x Nitrogen axides	PM ₃₀ Particulate matter	NMVOC Non-methane Volatile Organic Compounds		where possible accuracy of
Operation activities (non-maintenance)																														
- Traction energy (emission savings per tonne of fre	reight)																												, · · · · · · · · · · · · · · · · · · ·	
Personnel - transport																														
- Facilities																													· · · · · · · · · · · · · · · · · · ·	-
Maintenance activities - see RAMS template - impi	pact of greater loading, improved accelerat	tion and braking on existing maite	nance activities																											-
Rolling stock																													,	
- Inspection																													, · · · · ·	
 Preventive/condition based maintenance 																													· · · · · ·	-
Corrective maintenance Rolling stock refurbishment																													· · · · · ·	-
 Rolling stock refurbishment 												-																-	· · · · · · · · · · · · · · · · · · ·	-
			1		- 1	-	1				1												1			1			,	-
Infrastructure - Inspection Visual Inspection		1	1	1				1			1	1		1	1		-			1						1		1	,	+
Inspection		1	1	1	1	-	1				1	1			1		1	1		1			1					1		+
Visual Inspection Ultrasonic - Manual		1	1	1	1	-	1	1		1		1		1		1		1					1			1	-	1	/	+
Ultrasonic - Manual Ultrasonic - Train based		1	1	-	-	-	1					1						1		1						1		1	, , , , , , , , , , , , , , , , , , ,	-
Ottrasoric - Train based Eddy current inspection - Train based			1		1	1	1				1	1						1		1			1							
- Track geometry - train based				-																									, · · · · · · · · · · · · · · · · · · ·	-
Dynamic track behaviour - train based																													, · · · · · · · · · · · · · · · · · · ·	-
Dynamic track behaviour - train based Noise monitoring																													, , ,	-
Notve monitoring								-																				1	, , , , , , , , , , , , , , , , , , ,	-
- Preventive/condition based maintenance				-																									· · ·	
Rol Choose				-																									, ,	-
Rol Transaca				-																						-			· · · ·	-
Rail Change Rail Transpose Grinding Lubrication				-				-																					· · · · ·	-
Q Lubrication				-																									· · · ·	-
Fish Plate lubrication																													· · · ·	-
IBJ replacement																														
- Re-sleeper																													, · · · · · · · · · · · · · · · · · · ·	
- Replace sleeper pads and insulators																														
- Noise abatement																														
- Re-fastening systems																														
0																													, , , , , , , , , , , , , , , , , , , ,	
- Corrective maintenance																													, , , , , , , , , , , , , , , , , , , ,	
Rail Change - defects		1	1	1	1		1		1		1	1		1	1		1									1	1			1
Weld change - defects																														
Rail adjustment																														
Ballast reprofile			1		1		1				1	1					1									1				1
Wet bed removal												1																		
Tactical reballast																														
Plain line tamping						1																								
Stoneblowing							1																							
Geometry manual																														
replacement of pads and fasteners																														
			1																											
- Renewals			1				1																							
-Rail, sleeper and Ballast renewal			1																											
Sleeper and ballast renewal		1	1											-		1							1							-
Tactical resleeper			1								l																			
Ballast cleaning			1				1																							
			1				1																							
- Off Track maintenance			1				1																							
Drainage			-													1														
Fencing			1				1																							
Embankments			1																											
Civil structures (flyovers, underpass)		1	1											-		1							1							-
Vegetation			1				1																							

Innovation - ballasted track with vehicle and wagon innor	ovations																													
				Transport a	ind logistics						Construction an	nd maintenance				Oper	ation		Data					Emission	n factors				Di	- Onto
	Reference unit		Vehicle chara	acteristics		Pro	duction			Machinery characteristics				Production		Produ	ction	Dependencies				Climate change en	missions (kg/unit)			Air pollution en	sissions (kg/unit)		Source of data	Quality of data source and
LCA block	(e.g. km, m ¹ , tonne, train,								Production							Energy		(eg relationship between frequency of	Source of data	Quality of data source and where				CO ₂ e				NMVOC	eg carbon reporting	
	wagon, terminal)	Transport mode	Load capacity	Fuel consumption	Energy consumption	Distance travelled	Activity time	Equipment	(e.g. tonnes/h, m3/h,	Power	Fuel consumption	Energy consumption Ou	uantity (e.e.	Unit	Working time	(Direct use of energy in task.	Utilisation rate (%)	task upon boundary conditions such as	eg carbon reporting statements,	possible accuracy of data (upper and	002	CH	N ₂ O	1x CD2 34x CH4	50 ₂	NO,	PM ₁₀	Non-methane Volatile	statements, model, expert	t data (upper and lower
			(tonnes)	(e.gl/100 km)	(e.g kWh)	(Km)	(Hours)		km/h)	(kW, hp)	(e.g l/100 km)	(e.g kWh) Qu	(e.g.	ş. tannes, km)	(hours)	processing)		load (MGT), traffic type, curve etc)	model, expert estimate	lower limits)	Carbon dioxide	Methane	Nitrous Oxide	34x CH ₄ 288x N-O	Sulphur dioxide	Nitrogen oxides	Particulate matter	Organic Compounds	estimate	limits)
ferret ment																								2310 10,0						
- Project preparation																										-				-
- Vehicles/Wagons																														-
Vehicle modifications																														
New vehicles																														
art																														
- Infrastructure upgrades																														
- Signalling system (for longer trains)																														-
- Signal position and junction layouts																										-				
E						-																				-				-
 Other infrastructure changes to accommodate longer tra- ture 	trains																													
 Infrastructure upgrades to gauge envelope 																														
 Electrification of non-electrified infrastructure 																														
- Upgrade of track and structures to carry greater load																														
82																														
Disposal Decommission/removal works																														
Decommission/removal works Disposal costs/recycled value																														
- Disposal costs/recycled value - Facilities	1				1	1	1					1							1	1				1	1	1				1
					1		1												1											1
Operation activities (non-maintenance)												1																		
Operation activities (non-maintenance) - Traction energy - (emission savings per tonne of freight)	4)																													
- Personnel - transport							1																							
- Facilities	1																													
					+	-	+													1				I						4
Maintenance activities - see RAMS template - impact of y Rolling stock - Inspection	greater loading, improved acceleration	on and braking on existing maitenan	nce activities																											
hereafting																										-				-
Preventive/condition based maintenance																														-
- Corrective maintenance																														
 Rolling stock refurbishment 																														
Infrastructure - Inspection Visual Inspection																														
- 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																														-
Kall Transpose						-																								
- Rail Change - Rail Transpose - Grinding - Lubrication						-																								-
m Fish Plate lubrication																														-
- IBJ replacement					1	1	1					1												1	1	1				
C Re-sleeper																														
- Replace sleeper pads and insulators																														
- Noise abatement	1																													
- Re-fastening systems	-	-			+	1	+												1	1				I		1				+
- Corrective maintenance	-	I			1	1	1												1	1			-	1	1	1				4
Corrective maintenance Rail Change - defects	-			-	1	1	1					1							1	1				I	1	1				1
Weld change - defects	1						1											1	1	1					1	1				1
Rail adjustment					1	1	1					1							1	1				1	1	1				
Ballast reprofile																														
Wet bed removal					1		1																							
Tactical reballast					1																									
Plain line tamping							1																			-				
Stoneblowing Geometry manual					1	1	1	l				1							1	1	l			I		1				1
Geometry manual replacement of pads and fasteners	1				1	1	1												1	1				1	1	1				+
	1			-	1	1	1					1							1	1				I	1	1				1
- Renewals					1		1												1											1
-Rail, sleeper and Ballast renewal	1						1													1										1
Sleeper and ballast renewal																														
Tactical resleeper																														
Ballast cleaning																														
							1												1											
- Off Track maintenance																			1											
Drainage																			1	1										
Fencing	1						1												1	1										+
Embankments	-				+	1	+												1	1				I		1				-
Civil structures (flyovers, underpass) Vegetation	-				1	1	1												1	1			-	1	1	1				4
vegetation							1													1										

			Capacit					C4R Capacity for Rail	R											
Capacity4Rail Technology	Evaluation temp	late - LCA																		
Sub-project:	SP2																			
Innovation:	Innovations in Freight	Operation - wagon shunting	, intelligence for vehic	es in terminals, termina	al operation															
The life cycle analysis will start with a product breakdown shows an example product breakdown structure	structure and will consider all of	he life cycle stages through to disp	oosal. The figure on the right																	
	estment >> Oper	tion & Maintenance	Disposal																	
			Life cycle phases																	
Scenario and boundard conditions for assess	ment																			
Baseline case - existing terminal technology and existing	vehicles																			
Component	Sub Component	Description of component/sub component	Baseline noise performance (within scenario - dB(A))	Key components (contribution to noise)		Value	Unit [MGT, years]	Refer	Unit [km, each,]	Type of material (e.g. steel, concrete, copper,)	Quantity	Unit (e.g. t, kg, m ³ ,)	CO2 Carbon dioxide	Climate chang CH ₄ Methane	emissions (kg) N ₂ O Nitrous Oxide	CO2e 1x CO2 34x CH4 298x N2O	SO ₂ Sulphur dioxide	NO _x NUtrogen oxides	Sliution emissions (kg) PM ₁₀ Particulate matter	NMVOC Non-methane Volatile Organic Compounds
			-		-															
			-		ning															
					factu															
			-		anut															
			-		ia i															
			-		later											-				
			-		2															
Innovation - Optimised sensor, communication and data s	trategy																			
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	ence unit Unit	Type of material (e.g. steel, concrete, copper,)	Materials Quantity	Unit (e.g. t, kg, m ³ ,)	CO ₂ Carbon dioxide	Material climate d CH ₄ Methane	ange emissions (kg) N ₂ O Nitrous Oxide	CO2e 1x CO2 34x CH4 298x N-O	SO ₂ Sulphur dioxide	NO _x NO _x Nitrogen oxides	h <mark>r pollution emissions (kg)</mark> PM ₁₀ Particulate matter	NMVOC Non-methane Volatile Organie Compounds
			-																	
			-		rin 8															
			-		facturing															
			-		anufacturing															
					ial manufacturing															
					faterial manufacturing															
					Material manufacturing															
					Material manufacturing															
Cast antegories and Life Cycle Phases Realing case - scring series it following and setting wildes - so CA	88				Material manufacturing															
Baseline case - existing terminal technology and existing vehicles - no CAI	aranza unit	value descritation	rrangeor and logistics		Material manufacturing		en planstarida	Eas and maintenance	Pedark		Operation	byenderick	Drus Social dire	Quilty of data source and when		Clearle plane enteriologi (2/2)	Ad Caucar	Actory Ar publica		CCT S
Baseline case - existing terminal technology and existing vehicles - no CAI		Velicit care statist List departing Dannel	Foregoes and Expetities motion Energy consumption Energy consumption	Produktor Ottana tavaliad (coi)	Mittae Mittae Mittae Mittae Mittae Mittae Mittae Mittae	Periodicition (5.6. Section Tribute	And Construction	Example consumption (c = 400)	Quantity Use Control of Control o	woting time (Court) [D	Organization Construction Co	(eg relationship between frequ	Orsa snov a store of data register appet clinita store of the store of data	Quality of data source and shin positive accuracy of data (page)	e Cop	Control Superstanding July	ng Catalog P Catalog	Attris Solutions Attristics Solutions Marganetations Marg	minor (Kync) Priodate marker Priodate marker Description	Source of data Source of data source Source of data source Source of sources Source of sources Sources Source of sources Sources Sources Source of sources Sources Sources Sources Source of sources Sourc
Baseline case - existing terminal technology and existing vehicles - no CAI	aranza unit	Velicit course statistic Lead capacity Ford come	Fareport and Exploits	Productors Octanos travelide (fice) (fice)	Ny time Equipment	Pedadion (6.6, Lorany), Thin, Longh, J	And Continued Co	So and multicenses	Quantity UKE (r.g. turns c.	wotig tim (Court)	Overalise Terry grand, presenting	(eg relationship between frequ	ency di	Guality of data source and sub- positive accuracy of data (source lower limits)	e Coparate	Conto Surger entation 32/5 Millians Notes	ng Caluer	Actors Argenbulan	Particular mater Cogeni Compound Cogeni Compound	Saves of data is classes of data data is classes is classes of data data is classes initial initi

Baseline case - existing terminal technology and existing	vehicles - no CAPEX																1											
	Reference unit		Vehicle chan		and logistics	Prod	duction		Machinery characteristics	Construction a	and maintenance		Production		Operation Production	Dependencies	Data			Climate charge e	missions (kg/unit)	Emiss	ion factors	Air pollution err	nissions (kg/unit)		Source of data	Quality of data source and
LCA block	(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 (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 (%)	(eg relationship between frequency or task upon boundary conditions such as load (MGT), traffic type, curve etc)	of eg carbon reporting statements, model, expert estimate	Quality of data source and where possible accuracy of data (upper and lower limits)	co, Carbon dioxide	CH ₄ Methane	N ₂ O Nitrous Oxide	CO2e 1x CD3 34x CH4 298x N2O	SO ₂ Sulphur dioxide	NO <u>.</u> Nitrogen axides	PM ₁₀ Particulate matter	NMVOC Non-methane Volatile Organic Compounds		where possible accuracy of t data (upper and lower limits)
Operation activities (non-maintenance) Traction energy - (emission savings pertonne of freight)	0																											
🛱 🎗 - Personnel - transport					-	-																-						-
Facilities - Loading and unloading energy																												
- Loading and unloading energy																												
•	1 1				_	-			_		-						-	-								44		4
Innovation - freight terminal innovations in wagon shunt	ting, intelligent vehicles, terminal open	ation																										
				Transport a	and logistics					Construction a	and maintenance				Operation		Data				·	Emiss	ion factors				Da	Data
	Reference unit		Vehicle chan	acteristics		Prod	duction		Machinery characteristics				Production		Production	Dependencies				Climate charge e	missions (kg/unit)			Air pollution err	nissions (kg/unit)		Source of data	Quality of data source and
LCA block	(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 (e.g. tornes/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, Utilisation rate (%) processing)	(eg relationship between frequency or task upon boundary conditions such as load (MGT), traffic type, curve etc)	of eg carbon reporting statements, model, expert estimate	Quality of data source and where possible accuracy of data (upper and lower limits)	co _a Carbon dioxide	CH ₆ Methane	N ₂ O Nitrous Oxide	CO2e 1x CD1 34x CH4 298x N2O	SO 3 Sulphur dioxide	NO <u>.</u> Nitrogen oxides	PM ₁₀ Particulate matter	NMVOC Non-methane Volatile Organic Compounds		t data (upper and lower limits)
c Investment																										_		
Vehicles/Wagons Wagon modifications and shunting vehicles																												-
- Shunting whicles						-																-				+ +		
2 2																												
문 중 - Infrastructure upgrades																												
と 当 - Upgrade of terminal layout																												
- Loading and unloading equipment									_																			
 Operation activities (non-maintenance) 																										++		
- Traction energy - (emission savings pertonne of freight)	0											1														1		
불 홈 - Personnel - transport																										_		
0 C - Facilities						1	1		_			1											-			4		4
- Loading and unloading energy						1	1					1	1										-			+		

		C4	R				C4R Capacity for Roll																						
Capacity4Rail Technology Evaluation template - LCA		Capacity																											
iub-project:	SP3																												
nnovation:	Optimised strategies to manage major disturban	ces																											
hows an example product breakdown structure	nuture and will consider all of the life cycle stages through to d																												
icenario and boundard conditions for assessme	ent																												
																													-
ost categories and Life Cycle Phases																													
aseline case - existing strategies LCA block	Reference unit (e.g. km, m ¹ , torne, train, wagon, terminal) Transport mode	Vob/decision Load capacity (tonnes)	Transport an steristics Fuel consumption (e.g.l/200 km)	Energy consumption (e.g.kWh)	Distance travelled (Km)	Activity time (Hours)	Equipment	Production (e.g. tannes/h, m3/h, km/h)	Mitchinery characteristics Power (kW, hp)	Construction = Fuel consumption (e.g.l/100 km)	Energy consumption (e.g.kWh)	Quantity	Decoloceitea Unit (e.g. tonnes, km)	Working time (hours) (Di	Opters Produc Energy irect use of energy in task, processing)	ction	Dependencies (eg relationship between frequency of tak upon boundary conditions such as load (MST), 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 ₃ Carbon dioxide	Climite charge o CH _a Methane	nitsions (ks/unit) N ₂ O Nitrous Oxide	CO_e 1x CO_ 34x CN4 298x N-O	SO ₃ Sulphur dioxide	NO_ NO_ Nitrogen axides	ssions (131/unit) PM ₅₃ Particulate matter	NMVOC Non-methane Volatile Organic Compounds	Source of data	Quality of data source an where possible accuracy of data (upper and lower limits)
Ageration activities (non-maintenance) Traction energy - (emission savings per tonne of freight)																													-
nnovation - new strategies																													-
LCA block	Reference unit (e.g. km, m ¹ , torne, train, wagon, terminal) Transport mode	Vob/decision Load capacity (tonnes)	Transport an steristics Fuel consumption (e.g.l/200 km)	Energy consumption (e.g.kWh)	Distance travelled (Km)	Activity time (Hours)	Equipment	Production (e.g. tannes/h, m3/h, km/h)	Mitchinery characteristics Power (kW, hp)	Construction = Fuel consumption (e.g.l/100 km)	Energy consumption (e.g.kWh)	Quantity	Decoloceitea Unit (e.g. tonnes, km)	Working time (hours) (Di	Opters Produc Energy irect use of energy in task, processing)	ction	Dependencies (eg relationship between frequency of tak upon boundary conditions such as load (MST), 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 ₃ Carbon dioxide	Climite charge o CH _a Methane	nitsions (ks/unit) N ₂ O Nitrous Oxide	CO ₃ e 1x CO ₃ 24x CN ₄ 298x N ₂ O	SO ₃ Sulphur dioxide	NO_ NO_ Nitrogen axides	ssions (131/unit) PM ₅₃ 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)
Regration activities (non-maintenance) Traction energy - (emission savings per tonne of freight)																													

			Capacit					C4R Capacity for Rail									
Capacity4Rail Technology Evaluation template - LCA			Capacit	ry tor kall													
Sub-project:	SP4																
Innovation:	New concepts and tech	nologies for advanced mon	itoring in embankment	ts, bridges, different tra	ck types, switches etc												
The life cycle analysis will start with a product breakdown s shows an example product breakdown structure	structure and will consider all of the	ne life cycle stages through to disp	oosal. The figure on the right														
R&D >> Inves	stment Dperat	ion & Maintenance	Disposal	>													
			Life cycle phases														
		1															
Scenario and boundard conditions for assessment - Scenario should include extreme weather events	e																
Baseline case - current sensor technology			N	oiro			fespan	Refere	co unit		Materials			Climate chang	e 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 ₂ O Nitrous Oxide	CO2e 1x CO2 34x CH4 298x N2O	Sulpl
					- D0												
			-		r. L												
			-		manufacturing												
					anu												
			-		- <u>-</u>												
			-		Material												
					E E												
			-														
Innovation - Optimised sensor, communication and data str	trategy			oise			fespan	Refere			Materials			Mahadal alfareta a	nange emissions (kg)		
Component	Sub Component	Description of component/sub component		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 ₂ O Nitrous Oxide	CO2e 1x CO2 34x CH4 298x N2O	Sulpl
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	Air point	ition emissions (kg)	
SO ₂ Sulphur dioxide	NO _x Nitrogen oxides	PM ₁₀ Particulate matter	NMVOC Non-methane Volatile Organic Compounds
SO2 Sulphur dioxide	NO _x Nitrogen oxides		Non-methane Volatile Organic
SO2 Sulphur dioxide	NO ₄ Nitrogen oxides		Non-methane Volatile Organic
SO2 Sulphur dioxide	NO, Nitrogen oxides		Non-methane Volatile Organic
SO2 Sulphur dioxide	NO, Nitrogen oxides		Non-methane Volatile Organic
SO2 Sulphur dioxide	NQ, Nitrogen oxides		Non-methane Volatile Organic
SO2 Sulphur dioxide	NQ, Nitrogen axides		Non-methane Volatile Organic
SO2 Sulphur dioxide	NQ, Nitrogen oxides		Non-methane Volatile Organic
SO2 Sulphur dioxide	NQ, Nitrogen oxides		Non-methane Volatile Organic
SD, Sulphur dloxide	NQ, Nitrogen axides		Non-methane Volatile Organic
SD, Sulphur dloxide	NQ, Nitrogen axides		Non-methane Volatile Organic
SQ, Sulphur dloxide	Nitrogen audes	Particulate matter	Non-methane Volatile Organic
Sulphur dioxide	Nitrogen oxides	Particulate matter	Non-methane Volatile Organic Compounds
SO, Sulphur dloxide	Nitrogen audes	Particulate matter	Non-methane Volatile Organic
Sulphur dioxide	Nitrogen oxides	Particulate matter	Non-methane Volatile Organic Compounds
Sulphur dioxide	Nitrogen oxides	Particulate matter	Non-methane Volatile Organic Compounds
Sulphur dioxide	Nitrogen oxides	Particulate matter	Non-methane Volatile Organic Compounds
Sulphur dioxide	Nitrogen oxides	Particulate matter	Non-methane Volatile Organic Compounds
Sulphur dioxide	Nitrogen oxides	Particulate matter	Non-methane Volatile Organic Compounds
Sulphur dioxide	Nitrogen oxides	Particulate matter	Non-methane Volatile Organic Compounds
Sulphur dioxide	Nitrogen oxides	Particulate matter	Non-methane Volatile Organic Compounds
Sulphur dioxide	Nitrogen oxides	Particulate matter	Non-methane Volatile Organic Compounds
Sulphur dioxide	Nitrogen oxides	Particulate matter	Non-methane Volatile Organic Compounds

Baseline case - Track design - with current sensor technology																														
LCA block	Reference unit (e.g. km, m ¹ , tonne, train, wagon, terminal)	Transport mode	Vehida cherre Load capacity (tonnes)	Transport and I teristics Fuel consumption (e.g.1/200 km)	Energy consumption (e.g.kWh)	Distance travelled (Km)	Activity time (Hours)	Equipment	Production (e.g. tonnes/h, m3/h, km/h)	Methiony characteristics Power (kW, hp)	Construction at Fuel consumption (e.g.l/100 km)	nd maintenance Energy consumption (e.g.kWh)	Quantity	Unit (e.g. tonnes, km)	Working time (hours)		ation Utilton , 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	Central to christer or CH ₄ Methane	Nicous (27/031) Nicous Oxide	CO2e 1x CO2 34x CH4 298x NoO	son factors SO ₂ Sulphur dioxide	Alt poliution en NO, Nitrogen oxides	PM ₁₀ PM10 Particulate matter	NMVOC Non-methane Volatile Organic Compounds	Source of data eg carbon reporting statements, model, expert estimate	Quality of data sou where possible acc data (upper and
Analasia Analasia Herestenen de Industrian L'exectence de Industrian de Josephilie de Industria de Josephilie de Industria Herestenic de Industria Herestenic de Industria Herestenic de Industria Seconda de Industria Seconda de Industria Herestenic de Industria Seconda de Industria Herestenic de Industria Seconda de Industr									Amp 11							processing		tona (mar), carrie type, carve etc.						298x Nr.O				organic compositor	estimate	
Installation Installation of sensor technology and associated cabling																													1	
and communication infrastructure																														-
Testing and commissioning Inspection/quality control																													1	f
Disposal																													I	
Decommission/removal works Disposal costs/recycled value																													1	-
Operation artivities (non-maintenance)																														
- Traction energy - Personnel - transport																													1	
Facilities Data processing/data analysis																													1	-
Maintenance activities (see RAMS temolate) Senior - Corrective maintenance of sensor - Papair of sensor damaged due to flying ballast, ice, moisture, fatigue, brigh acceleration forces,																													!	
Sensor Corrective maintenance of sensor																													1	
Repair of sensors damaged due to flying ballast, ice, mnistrue fatieue high arrelevation forces																														
Other maintenance of sensor engineent																														1
- Battery replacement																													1	1
Other maintenance of sensor equipment Battery replacement Sensor position and realignment Data retrieval																													!	1
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Visual Inspection Ultrasoric - Manual																								1	1				t'	1
- Ultrasonic - Train based							1					1				1	1		1					1	1				1 1	1
Track geometry - train based																	1												1 1	1
Slab monitoring for cracks and movement																									1				<u>ا</u>	-
Prove monofilig																	1												1	1
Normer environmente																													1	1
- Grinding																	1												1 '	1
Lubrication Fish Plate lubrication																													'	1
IBJ replacement Re-sleeper																														1
Replace sleeper pads and insulators Noise abatement																														1
Inguine regress path and instatemes																														1
Rail Change - defects Weld change - defects																														1
Rail adjustment Ballast reprofile																														1
Wet bed removal Tactical reballast																														1
Plain line tamping Stoneblowing																														1
Geometry manual replacement of pads and fasteners																													1	f
Re-fastening systems																														<u> </u>
- Off Track maintenance Drainage																													-	1
Fencing Civil structures (flyovers, underpass)																													1	f
Vegetation																													1	f
Switch - Inspection of switch																									-					(
Visual Inspection Ultrasonic - Manual																														f
Ultrasonic - Train based Eddy current inspection - Train based																														
Track geometry - train based Dynamic track behaviour - train based																													1	1
Noise monitoring Train based high speed image capture inspection																													1	(
Preventive/condition based maintenance of switch																														<u> </u>
S&C adjustment Lubrication																													1	
Grinding Tighten/adjust stretcher bars																													1	
Adjust drive																													1	1
Corrective maintenance of switch Half set replacement																													1	1
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Replace bearers S&C tactical reballast						-																							1	-
S&C tamping Manual S&C geometry correction																													1	
Repair/replace switch motor and drive mechanisms Repair/replace locking mechanisms																													1	-
Repair electrical/signalling/interlocking failures																	1												'	-
Bridges - Inspection of bridge																			-					1	1				f′	-
Visual Inspection Bridge monitoring of measurement																								1	1				t'	1
Other bridge inspection																								1	1				1	1
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reinforment, spray concrete etc																													'	1
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- Visual inspection																	1												1	1
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- Embankment stabilisation Geotextiles																													<u> </u> '	1
Concrete pries																													¹	1
- Renewals Rail, sleeper and Ballast renewal																														1
Steeper and balliast renewal Tactical resleeper																													1	1
Ballast cleaning																													1	1
- Renewals of switch S&C renewal																													1	1
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Innovation - Optimised sensor, communication and data	a strategy			Transport a	and logistics						Construction a	nd maintenance				Operat	tion		Data					Emissio	n factors				0	Data
LCA block	Reference unit		Vehicle chara	acteristics		Pro	duction		Resolution	Machinery characteristics				Production		Operat Product	tion	Dependencies (eg relationship between frequency of	Source of data	Quality of data source and where		Climate charge er	nissions (kg/unit)	CO ₂ e		Air pollution er	missions (kg/unit)	NUMBER OF	Source of data	Quality of data source and where possible accuracy of data (upper and lower limits)
	(e.g. km, m ¹ , tonne, train, wagon, terminal)	Transport mode	Load capacity (tonnes)	Fuel consumption (e.g1/100 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 Worki (e.g. tonnes, km) (ht	urs) (Direct us	Energy use of energy in task, processing)	Utilisation rate (%)	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 an lower limits)	i CO ₂ Carbon dioxide	CH ₆ Methane	N ₂ O Nitrous Oxide	CO20 1× CO2 34× CH4 298x N2O	50 ₂ Sulphur dioxide	NO, Nitrogen axides	PM ₃₀ Particulate matter	NMVOC Non-methane Volatile Organic Compounds	statements, model, expert	data (upper and lower
Investment									xm/n)						,	processing		ioad (MiGL), tramic type, curve etc)						298x N ₂ O		-		Organic compounds	estimate	timits)
Project preparation Investment and installation																														
 Installation of sensor technology and associated cabling and communication infrastructure 	ng																													
Heredowst																														
0 Inspection/quality control																														
- Decommission/removal works																														
Disposal costs/necycled value																														
- 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, mo																														
Corrective maintenance or sensor Repair of sensors damaged due to flying ballast, ice, mo	noisture, fatigue, high acceleration	n forces,																												
- Other maintenance of sensor equipment																														
Other maintenance of sensor equipment Battery replacement Sensor position and realignment Data retrieval																														
Data retrieval																														
- Inspection of track																														
Visual Inspection Ultrasonic - Manual																														
Eddy current inspection - Train based			1		1		1						1								-	1								
Dynamic track behaviour - train based Slah monitoring for cracks and monitoring			1										1																	1
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sall change Rail Transpose			1																											
Lubrication			1																											
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Re-sleeper Replace sleeper pads and insulators																														
Noise abatement																														
- Corrective track maintenance Rail Change - defects																														
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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 (Hydwers, underpass) - Vegetation																														
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- Visual Inspection																														
- Ultrasonic - Manual - Ultrasonic - Train based																														
Dynamic track behaviour - train based Noise monitoring																														
bef faktning option: Constraints of the second se																														
 - Preventive/condition based maintenance of switch - S&C adjustment 																														
Grinding Tables (adjust stretcher hour							1						1												1					
Adjust drive						1	1																		1					
Corrective maintenance of switch Held for treatment			1										1																	
Crossing replacement Crossing replacement Crossing weld renair							1																							
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Repair/replace switch motor and drive mechanisms Repair/replace locking mechanisms							1																		1					
Repair electrical/signalling/interlocking failures							1						1												1					
Bridges - Inspection of bridge - Visual Inspection - Bridge monitoring eg optical monitoring of movement - Other bridge inspection						1	1						1												1					
- Visual Inspection						1	1																		1					
priope monitoring og optical monitoring of movement Other bridge inspection	11						1																							
Pradictive/condition based maintenance Bridge strengthening - og fibre reinforment, steel reinforment, spray concrete etc							1																							
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- Emparisment stabilisation Geotextiles						1	1						1																	
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- Renewals Rail, sleeper and Ballast renewal																														
Sleeper and ballast renewal Tactical resleeper																														
Ballast cleaning							1																							
- Renewals of switch S&C renewal							1																							
- Renewals of bridge platform																														
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Appendix 4 - RAMS Templates

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							Capacity	for Rail				
Capacity4Rail Technology Eva	luation templa	te - RAN	IS data									
Sub-project:	SP1											
Innovation:	New Concepts	based on modu	ular slab track - sla	b track evaluate	ed against ballast	ed track						
Maintenance and inspection tasks												
Maintenance/ inspection task	New task required for innovation? Y/N				time Maintain)		maintenance task unable for and m spped limits on ne	nfrastructure during (time infrastructure in. number of lines, eighbouring lines etc	time infrastructure labour, number of lines, logistic costs, han		Sources of data used - statistical data, models. Detail assumption where possible uncertainty limits or distributions for frequenc maintain. If data changes based on traffic type, MGT, track curvat Please detail how this will change and reference any models (eg fatigue models etc) which could be used for sensitivity an	
			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	ge)											
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 Stakeholders due to innovation? Y/N	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		number of per costs, hand	t of parts, cost of labour, sons required, logistic dling, cost of track availability	Sources of data used - statistical data, models. Detail assumption where possible uncertainty limits or distributions for frequen maintain. If data changes based on traffic type, MGT, track curva Please detail how this will change and reference any models (fatigue models etc) which could be used for sensitivity a	
		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											
	New task required Stakeholders for innovation? Y/N 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 assumption where possible uncertainty limits or distributions for frequenc maintain. If data changes based on traffic type, MGT, track curvat Please detail how this will change and reference any models (g	
Renewal/replacement task						mints on neighbouring mes etc		unavanasinty			uld 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 l	be considered										
Describe how the frequency of failure/injury and impact differ between	en the baseline case innovation for each fa	ilure mode considered	. An FMEA and risk asse	ssment process sh	ould be carried out be	ore completing thi	s table				
	New failure Stakeholders mode/hazard due impacted	Frequency/likel	ihood of failure/injury	Impact o	of failure/injury						
	to innovation? Y/N										
Failure mode/injury type		Baseline case		Baseline case							
Flooding of track		baseline case	Innovation	baseline case	Innovation	-					
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	n			1							
Track worker injury/fatality - fall from height				1							
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							Capacity	for Rail				
Capacity4Rail Technology Evalua	tion template	e - RAMS	data									
Sub-project:	SP1											
Innovation:	New Concepts	based on modu	ılar slab track - ini	novative slab tr	ack evaluated again	nst existing slab	track					
Maintenance and inspection tasks												
Maintenance/inspection task	New task required for innovation? Y/N		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		labour, number of persons required, logistic costs, handling, cost of track		Sources of data used - statistical data, models. Detail assumptions made where possible uncertainty limits or distributions for frequency and t maintain. If data changes based on traffic type, MGT, track curvature, ca Please detail how this will change and reference any models (eg wear 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												

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Failure													
	New failure mode	Stakeholders	Frequency of failure	, Mean time between	Time to repair (MTR Mean time to		Unavailability of i	nfrastructure during	Repair cost (cost c	of parts, cost of labour,	Sources of data used - statistical data	, models. Detail assumptions ma	
	due to innovation?	impacted	failure,	Weibull	Re	Repair)		repair task (time infrastructure unable		ons required, logistic	where possible uncertainty limits o	r distributions for frequency an	
	Y/N						for and min. num	nber of lines, spped	costs, handl	ing, cost of track	maintain. If data changes based on tra	ffic type, MGT, track curvature,	
								bouring lines etc	unav	ailability	Please detail how this will change and reference any models (eg		
Failure mode (eg from FMEA)										-	fatigue models etc) which cou	ld be used for sensitivity analysi	
			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													
	New task required		Frequency of	f renewal task	Time to re	new/replace		nfrastructure during		cost of parts, cost of	Sources of data used - statistical data		
	for innovation? Y/N	impacted						infrastructure unable		of persons required,	where possible uncertainty limits o		
								nber of lines, speed		andling, cost of track	maintain. If data changes based on tra		
							limits on neighbouring lines etc		unav	ailability	Please detail how this will change an		
Renewal/replacement task												d be used for sensitivity analysi	
			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 co													
Describe how the frequency of failure/injury and impact differ between the							completing this table						
	New failure	Stakeholders	Frequency/likeliho	ood of failure/injury	Impact of f	failure/injury							
	mode/hazard due	impacted											
	to innovation? Y/N												
Failure mode/injury type													
			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		1											
Teal													
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		1											
Track worker injury/fatality - fall from height		1											
	1	1	1	1	1	1	1						

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Capacity4Rail Technology Evalu	iation temi	nlate - R <i>l</i>	steh 2M4				Cupucii					
Sub-project:	SP1											
Innovation:	New track desi	gns and specif	ications for very h	igh speed lines	(if innovation sla	b track)						
Maintenance and inspection tasks												
Maintenance/inspection task	New task required for innovation? Y/N		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 where possible uncertainty limits or distributions for frequency and ti maintain. If data changes based on traffic type, MGT, track curvature, can Please detail how this will change and reference any models (eg wear 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												
	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		where possible uncertainty limits or distributions for frequency maintain. If data changes based on traffic type, MGT, track curvatur Please detail how this will change and reference any models (eg	
Failure mode (eg from FMEA)						L .		1				Id 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		Frequency of renewal task		Time to r	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		cost of parts, cost of of persons required, indling, cost of track ailability	Sources of data used - statistical data, models. Detail assumption: where possible uncertainty limits or distributions for frequency maintain. If data changes based on traffic type, MGT, track curvatu Please detail how this will change and reference any models (eg fatigue models etc) which could be used for sensitivity ana	
			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 mu												
Describe how the frequency of failure/injury and impact differ bet							t before completing t	this table				
	New failure mode/hazard due to innovation? Y/N	Stakeholders impacted	Frequency/likelil	nood of failure/injury	Impact o	f failure/injury						
Failure mode/injury type			Baseline case	1	Baseline case	I	-					
Flooding of track			baseline case	Innovation	baseline case	Innovation						
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	ation											
Track worker injury/fatality - fall from height												



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							Capacity	for Rail				
Course it ADail To shuse loop. F				_								
Capacity4Rail Technology E	valuation tel	mplate -	RAIVIS data	a								
Sub-project:	SP1											
Innovation:	New track desig	gns and specifi	cations for very h	igh speed lines (if innovation bal	lasted track)						
Maintenance and inspection tasks												
	New task required		Freque	ncy of task		/inspect (MTM Mean		nfrastructure during		cost of parts, cost of		models. Detail assumptions made and
	for innovation? Y/N	impacted			time	Maintain)		(time infrastructure		f persons required,		distributions for frequency and time
								in. number of lines,		dling, cost of track		fic type, MGT, track curvature, cant etc.
							spped limits on ne	ighbouring lines etc	unava	ilability		d reference any models (eg wear rate,
Maintenance/inspection task								I		h		d be used for sensitivity analysis.
1			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										ļ		

Failure													
	New failure mode due to innovation? Y/N	Stakeholders impacted		ıre, Mean time betwee re, Weibull		r (MTR Mean time to Repair)	repair task (time for and min. nu	f infrastructure during infrastructure unable mber of lines, spped ghbouring lines etc	number of perso costs, handl	f parts, cost of labour ons required, logistic ing, cost of track ailability	where possible uncertainty limits or distributions for frequency and time maintain. If data changes based on traffic type, MGT, track curvature, cant et Please detail how this will change and reference any models (eg wear rate		
Failure mode (eg from FMEA)											fatigue models etc) which could be used for sensitivity analysis.		
Plan dia amin'ny sola			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 - wheel prome/roning stock failure													
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		Frequenc	y 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 where possible uncertainty limits or distributions for frequency and tir maintain. If data changes based on traffic type, MGT, track curvature, can Please detail how this will change and reference any models (eg wear 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			Busenne euse		busenne euse	intertation	Dasenne dase		busenne tuse				
Rail, sleeper and Ballast renewal													
Sleeper and ballast renewal													
Tactical resleeper													
Ballast cleaning													
												-	
Safety impacts - for safety critical failures - the impact on safet	w must be considered												
Describe how the frequency of failure/injury and impact differ		case innovation f	or each failure mode	considered. An FMEA ar	d risk assessment	process should be carri	ied out before comp	leting this table					
	New failure	Stakeholders		ihood of failure/injury		of failure/injury							
	mode/hazard due to innovation? Y/N	impacted											
Failure mode/injury type				1		1	_						
			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													
Teach marker initial (fabric) at the distribution													
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 o	Poration					_							
Track worker injury/fatality - manual lifting/machine or tool o Track worker injury/fatality - fall from height	peration	1											
nack worker njury/ratanty - ran nom neight													
		1		1	1	1	1						

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Capacity4Rail Technology Evalua	tion template - RAI	MS data										
Sub-project:	SP1											
Innovation:	New concepts f	for Switches a	nd Crossings base	ed on failure mo	odes analysis							
Maintenance and inspection tasks												
	New task required	Stakeholders	Frequ	ency of task	Time to mainta	in/inspect (MTM Mean	Unavailability of	of infrastructure during	Maintenance cos	st (cost of parts, cost of	Sources of data used - sta	atistical data, models. Detail assur
	for innovation? Y/N	impacted			tim	e Maintain)		sk (time infrastructure		r of persons required,		ainty limits or distributions for free
								min. number of lines,		andling, cost of track		based on traffic type, MGT, track o
							spped limits on	neighbouring lines etc	una	vailability		vill change and reference any mod
Maintenance/ inspection task) which could be used for sensitiv
			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					-	· · · · · · · · · · · · · · · · · · ·						
	New failure mode due to innovation? Y/N	Stakeholders impacted	Frequency of failure, Mean time between T failure, Weibull				Unavailability of infrastructure during repair task (time infrastructure unable for and min. number of lines, spped limits on neighbouring lines etc		number of perso costs, handl	of parts, cost of labour, ons required, logistic ing, cost of track railability	r, Sources of data used - statistical data, models. Detail assu where possible uncertainty limits or distributions for fr maintain. If data changes based on traffic type, MGT, trad Please detail how this will change and reference any mo fatigue models etc) which could be used for sensit	
Failure mode (eg from FMEA)			Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation	fatigue models etc) which co Baseline case	Innovation
Flooding			Daseille Case	mnovation	Dasenne case	movation	Dasenne case	mnovation	Dasenne case	mnovation		IIIIovation
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												
	New failure mode	Stakeholders	Frequency	of renewal task	Time to	renew/replace		f infrastructure during		cost of parts, cost of	Sources of data used - statistical da	•
	due to innovation? Y/N	Impacted						e infrastructure unable Imber of lines, speed		of persons required, andling, cost of track	where possible uncertainty limits maintain. If data changes based on t	
	T/IN							ghbouring lines etc		-		
Renewal/replacement task								gibbouring intes etc	unavailability		Please detail how this will change and reference any models etc) which could be used for sensiti	
			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 of							g this table					
	New failure mode/hazard due	Stakeholders impacted	Frequency/likelih	nood of failure/injury	Impact o	of failure/injury						
	to innovation? Y/N	impacted										
Failure mode/injury type												
			Baseline case	Innovation	Baseline case	Innovation						
Flooding												
Signalling/electrical failures												
Signalling/electrical failures Ice, ballast or other object between switch and stock rail preventing switch locking												
 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 												
 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 												
 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 												
 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 												
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 Perailment due to switch rail wear Track worker injury/fatality - crushed by train												
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												
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												
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												

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for frequency and time
track curvature, cant etc.
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ensitivity analysis.

ail assumptions made and s for frequency and time T, track curvature, cant etc. ny models (eg wear rate, sensitivity analysis.

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Capacity4Rail Technology Evaluation	on template - RAMS data										
Sub-project:	SP1										
Innovation:	New designs for switches resil	ent to extreme	weather condit	tions							
Maintenance and inspection tasks											
•	New task required Stakeholders	Frequ	ency of task	Time to maintain	/inspect (MTM Mear	unavailability o	of infrastructure during	Maintenance cost	t (cost of parts, cost of	Sources of data used - statistical da	ta, models. Detail assumptions made and
	for innovation? Y/N impacted			time	Maintain)	maintenance ta	sk (time infrastructure	labour, number	of persons required,	where possible uncertainty limit	s or distributions for frequency and time
						unable for and	min. number of lines,	logistic costs, ha	andling, cost of track	maintain. If data changes based on	traffic type, MGT, track curvature, cant etc.
						spped limits on	neighbouring lines etc	unav	ailability		and reference any models (eg wear rate,
Maintenance/inspection task					-		-				ould 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											
<u></u>											

Failure												
Failure mode (eg from FMEA)	New failure mode due to innovation? Y/N	Stakeholders impacted		Frequency of failure, Mean time between Tir failure, Weibull		r (MTR Mean time to Repair)	repair task (time for and min. nu	Unavailability of infrastructure during repair task (time infrastructure unable for and min. number of lines, spped limits on neighbouring lines etc		of parts, cost of labour, ons required, logistic ling, cost of track vailability	Sources of data used - statistical data, models. Detail assump where possible uncertainty limits or distributions for frequ maintain. If data changes based on traffic type, MGT, track cu Please detail how this will change and reference any model fatigue models etc) which could be used for sensitivit	
Failure mode (eg from FIVIEA)			Baseline case	tanavation	Baseline case	In a constinue	Deceline rece	turn evention.	Baseline case		· ·	
et a subsec			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												
Stretcher bar failure Derailment due to switch rail wear												
Derainment due to switch fail wear												
Renewal/replacement tasks												
Renewal/replacement task	New task required for innovation? Y/N		Frequency of renewal task		Time to	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		cost of parts, cost of of persons required, andling, cost of track vailability	Sources of data used - statistical data, models. Detail assumpti where possible uncertainty limits or distributions for freque maintain. If data changes based on traffic type, MGT, track curv Please detail how this will change and reference any models fatigue models etc) which could be used for sensitivity.	
Renewal/replacement task			Baseline case	Baseline case Innovation Baseli		Innovation	Baseline case Innovation		Baseline case Innovation		Baseline case	Innovation
- Renewals			basenne tabe		buseline tuse		Dusenne tuse		basenne tase			
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 of							g this table					
Failure mode/injury type	New failure mode/hazard due to innovation? Y/N	Stakeholders impacted	Frequency/likel	ihood of failure/injury	Impact o	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			1									
Stretcher bar failure Derailment due to switch rail wear												
Derailment due to switch rail wear												
Derailment due to switch rail wear Track worker injury/fatality - crushed by train												
Derailment due to switch rail wear Track worker injury/fatality - crushed by train Track worker injury/fatality - injured by train												
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												
Derailment due to switch rail wear Track worker injury/fatality - crushed by train Track worker injury/fatality - injured by train												

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Capacity4Rail Technology Evaluation template	- RAMS da	ta					Capacity					
Sub-project:	SP1											
Innovation:	Optimised S&C	concor stratogi										_
Maintenance and inspection tasks	optimised S&C	sensor strategi	C 3									
Maintenance and inspection tasks	New task required for innovation? Y/N			cy of task	time N	/inspect (MTM Mean Maintain)	maintenance task unable for and mi spped limits on ne	nfrastructure during (time infrastructure n. number of lines, ighbouring lines etc	labour, number logistic costs, ha unav	(cost of parts, cost of of persons required, indling, cost of track ailability	Sources of data used - statistical data where possible uncertainty limits (maintain. If data changes based on tra Please detail how this will change a fatigue models etc) which cou	or distribu affic type, and refere
			Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovat
- 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												
Train based man speed image capture inspection Preventative/condition based maintenance of switch												
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/leprace rocking mechanisms												
hepan creation, signaling/interiorking fanares												
		1	1	1	1	1	I	I	I		1	

els. Detail assumptions made ibutions for frequency and ti pe, MGT, track curvature, car erence any models (eg wear l	me 1t etc.
used for sensitivity analysis.	ale,
vation	
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Failure												
Failure mode (eg from FMEA)	New failure mode due to innovation? Y/N	Stakeholders impacted		ıre, Mean time between re, Weibull		(MTR Mean time to Repair)	repair task (time for and min. nu	f infrastructure during infrastructure unable mber of lines, spped ghbouring lines etc	number of per costs, hand	of parts, cost of labour, cons required, logistic lling, cost of track vailability	Sources of data used - statist where possible uncertainty maintain. If data changes base Please detail how this will c fatigue models etc) wi	limits or distribut ed on traffic type, hange and referen
			Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovati
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												
	New task required for innovation? Y/N		Frequency	y of renewal task	Time to	renew/replace	renewal task (tim for and min. nu	f infrastructure during e infrastructure unable mber of lines, speed ghbouring lines etc	labour, numbe logistic costs, l	cost of parts, cost of r of persons required, nandling, cost of track vailability	Sources of data used - statist where possible uncertainty maintain. If data changes base Please detail how this will c	/ limits or distribut ed on traffic type, P hange and referen
Renewal/replacement task											fatigue models etc) w	
			Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovati
- 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 of safety must be considered	n for each failure mode	considered An EM	EA and rick accord	nt process should be ca	ried out before co	mploting this table						
		considered. An Fivi	LA anu nok assessine			inpleting this table	-					
		Stakeholders	Frequency/likeli	hood of failure/iniury	Impact o	f failure/iniury						
	New failure mode/hazard due	Stakeholders impacted	Frequency/likeli	ihood of failure/injury	Impact o	f failure/injury						
	New failure		Frequency/likeli	ihood of failure/injury	Impact o	f failure/injury						
Failure mode/injury type	New failure mode/hazard due											
Failure mode/injury type	New failure mode/hazard due		Frequency/likeli Baseline case	ihood of failure/injury	Impact o Baseline case	f failure/injury						
Failure mode/injury type Cost of unavailability due to sensor failure	New failure mode/hazard due											
Failure mode/injury type Cost of unavailability due to sensor failure Repair of sensors damaged due to flying ballast, ice, moisture, fatigue, high acceleration forces,	New failure mode/hazard due											
Failure mode/injury type Cost of unavailability due to sensor failure Repair of sensors damaged due to flying ballast, ice, moisture, fatigue, high acceleration forces, Flooding	New failure mode/hazard due											
Failure mode/injury type 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	New failure mode/hazard due											
Failure mode/injury type 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	New failure mode/hazard due											
Failure mode/injury type 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	New failure mode/hazard due											
Failure mode/injury type 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	New failure mode/hazard due											
Failure mode/injury type 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	New failure mode/hazard due											
Failure mode/injury type 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	New failure mode/hazard due											
Failure mode/injury type 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	New failure mode/hazard due											
Failure mode/injury type 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	New failure mode/hazard due											
Failure mode/injury type 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 Loe, 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 Stretcher bar failure Derailment due to switch rail wear Track worker injury/fatality - crushed by train Track worker injury/fatality - slips, trips and falls	New failure mode/hazard due											
Failure mode/injury type 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	New failure mode/hazard due											

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							Capaci	ty for Rail				
Capacity4Rail Technology Evalu	ation template -	RAMS d	lata									
Sub-project:	SP2											
Innovation:	Innovations in T	rains/Wagons	- optimised lengtl	n, speed, perfe	ormance, central/a	automatic couple	r, EP/electronio	c braking, electifica	ation, automatio	on, weight		
Maintenance and inspection tasks												
Maintenance/ inspection task	New task required for innovation? Y/N		Freque	ncy of task		n/inspect (MTM Mean Maintain)	maintenance ta unable for and	of infrastructure during sk (time infrastructure min. number of lines, neighbouring lines etc	labour, number logistic costs, ha	(cost of parts, cost of of persons required, Indling, cost of track ailability	where possible uncertainty limi maintain. If data changes based or Please detail how this will chang	ata, models. Detail assumptions made and ts or distributions for frequency and time traffic type, MGT, track curvature, cant etc. e and reference any models (eg wear rate, 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							1					
Vegetation										-		
				1	ļ						I	

	New failure mode due to innovation? Y/N	Stakeholders impacted		ıre, Mean time betweeı re, Weibull		r (MTR Mean time to Repair)	repair task (time for and min. nu	f infrastructure during infrastructure unable mber of lines, spped ghbouring lines etc	number of perso costs, hand	of parts, cost of labour, ons required, logistic ing, cost of track railability	where possible uncertainty l maintain. If data changes based Please detail how this will cha	al data, models. Detail assumptions mad imits or distributions for frequency and i on traffic type, MGT, track curvature, ca inge and reference any models (eg wear ch could be used for sensitivity analysis.
Failure mode (eg from FMEA)			Develine rece	In a sustion	Decelling sees	1	Deceline and	to a section	Decelling sees	1		
Track			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												
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												
	New task required	Stakeholders	Frequency	of renewal task	Time to	renew/replace	Unavailability o	f infrastructure during	Renewal cost (cost of parts, cost of	Sources of data used - statistic	al data, models. Detail assumptions mad
	for innovation? Y/N						renewal task (tim for and min. nu	e infrastructure unable mber of lines, speed ghbouring lines etc	labour, number logistic costs, h	of persons required, andling, cost of track vailability	where possible uncertainty l maintain. If data changes based Please detail how this will cha	imits or distributions for frequency and on traffic type, MGT, track curvature, ca inge and reference any models (eg wear
Renewal/replacement task												ch 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 cons	idered											
Safety impacts - for safety critical failures - the impact on safety must be cons Describe how the frequency of failure/injury and impact differ between the		for each failure m	ode considered. An FN	/IEA and risk assessmen	t process should be	e carried out before co	mpleting this table					
Describe how the frequency of failure/injury and impact differ between the		for each failure m Stakeholders impacted		/IEA and risk assessmen ihood of failure/injury		e carried out before co f failure/injury	mpleting this table					
	baseline case innovation New failure mode/hazard due	Stakeholders					mpleting this table					
Describe how the frequency of failure/injury and impact differ between the	baseline case innovation New failure mode/hazard due	Stakeholders	Frequency/likeli	ihood of failure/injury	Impact o	f failure/injury	mpleting this table					
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Describe how the frequency of failure/injury and impact differ between the l Failure mode/injury type Track Flooding of track Rail defect identified - clamp and/or speed limits applied Derailment/delays - Rail break	baseline case innovation New failure mode/hazard due	Stakeholders	Frequency/likeli	ihood of failure/injury	Impact o	f failure/injury	mpleting this table					
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Sub-project:	SP2											
Innovation:	Innovations in F	reight Operatio	on - wagon shuntir	ng, intelligence f	for vehicles in ter	minals, termina	l operation					
Failure	New failure mode	Stakeholders	Frequency of failure,	Mean time betwee	n Time to repair (I	MTR Mean time to	Unavailability of ir	nfrastructure during	Repair cost (cost of	parts, cost of labour,	Sources of data used - statistical data,	models. Detail assumptions made and
	due to innovation?	impacted	failure,			pair)		frastructure unable	number of person	ns required, logistic	where possible uncertainty limits or	distributions for frequency and time
	Y/N							ber of lines, spped bouring lines etc		ng, cost of track ailability	maintain. If data changes based on training and the second	fic type, MGT, track curvature, cant etc d reference any models (eg wear rate,
Failure mode (eg from FMEA)							initis on neight	bouring intes etc	unava	inability		d 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 limit	s applied											
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Derailment/delays - hitting object./animal on tra	ack											
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Stretcher bar failure												
Derailment due to switch rail wear												
Crossing failure Rolling stock												
Traction power failure												
Other rolling stock failures												
Operational/signalling												
	error											
Train collision - Signal passed at danager - driver		lure										
Train collision - Signal passed at danager - driver Train collision - Signalling failure/S&C/traffic ma Failure of innovative shunting system		lure										
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Train collision - Signal passed at danager - driver Train collision - Signalling failure/S&C/traffic ma Failure of innovative shunting system		lure										
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Train collision - Signal passed at danager - driver Train collision - Signalling failure/S&C/traffic ma Failure of innovative shunting system Laoding and unloading Failure of loading and unloading mechinary Safety impacts - for safety critical failures - the in	nagement system fai pact on safety must d impact differ betwee New failure	be considered een the baseline cas Stakeholders	e innovation for each f			k assessment process ailure/injury	should be carried ou	t before completing	this table			
Train collision - Signal passed at danager - driver Train collision - Signalling failure/S&C/traffic ma Failure of innovative shunting system Laoding and unloading Failure of loading and unloading mechinary Safety impacts - for safety critical failures - the in Describe how the frequency of failure/injury and	nagement system fai pact on safety must d impact differ betwe New failure mode/hazard due	be considered					should be carried ou	t before completing	this table			
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Capacity4Rail Technology Evaluation te	molato - F	tch 2MAS	_									
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Sub-project:	SP3											
Innovation:	Optimal strate	gies to manage	major disturbance	S								
	•		-									
Failure	N. 6.1	Challed and the second	F						D			
	New failure mode due to innovation?			Mean time between Weibull		MTR Mean time to epair)		frastructure during	Repair cost (cost of	parts, cost of labour, is required, logistic	Sources of data used - statistical data where possible uncertainty limits o	
	Y/N	Impacteu	ianure,	weibun	ne ne	epan)		ber of lines, spped		ig, cost of track	maintain. If data changes based on tra	
	.,							bouring lines etc		ilability	Please detail how this will change an	
Failure mode (eg from FMEA)				1		1				1	fatigue models etc) which cou	
Track			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												
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												
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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 Failure mode/injury type Track Flooding of track Rail defect identified - clamp and/or speed limits applied Derailment/delays - Rail break Derailment/delays - track alignment fault Derailment/delays - Intack lignment fault Derailment/delays - hitting object/animal on track Earthwork failure SkC Flooding Signalling/electrical failures Ice, ballast or other object between switch and stock rail preventing switch locking Daray to rive from flying ballast, ice failing from vehicles Stretcher bar failure Derailment due to switch rail wear Crossing failure Rolling stock Traction power failure	New failure mode/hazard due	Stakeholders impacted	Frequency/likeliho	od of failure/injury	Impact of f	failure/injury	ing this table					
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 baseling Failure mode/injury type Track Flooding of track Rail defect identified - clamp and/or speed limits applied Derailment/delays - Rail break Derailment/delays - track alignment fault 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 Robling stock Traction power failure Derailment due to switch rail wear Crossing failure Robling stock Traction power failures Operational/signalling Traction power failures Ope	New failure mode/hazard due	Stakeholders impacted	Frequency/likeliho	od of failure/injury	Impact of f	failure/injury	ing this table					
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 Failure mode/injury type Track Flooding of track Rail defect identified - clamp and/or speed limits applied Derailment/delays - Nail break Derailment/delays - Vancel alignment fault Derailment/delays - Nakel profile/rolling stock failure Derailment/delays - hitting object./animal on track Earthwork failure 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 Corossing failure Derailment due to Switch rail wear Corossing failure Operational/signalling	New failure mode/hazard due	Stakeholders impacted	Frequency/likeliho	od of failure/injury	Impact of f	failure/injury	ing this table					
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 Failure mode/injury type Track Flooding of track Rail defect identified - damp and/or speed limits applied Derailment/delays - Rail break Derailment/delays - Iandslide Derailment/delays - Iandslide Derailment/delays - Iandslide Derailment/delays - hitting object./animal on track Earthwork failure Signalling/electrical failures Ice, ballast or other object between switch and stock rail preventing switch locking Damage to switch drive from flying ballast, ice failing from vehicles Stretcher bar failure Derailment due to switch rail wear Crossing failure Rolling stock Traction power failure Derailment due to switch rail wear Crossing failure Operational/signalling Traction power failures Operational/signalling Traction power fai	New failure mode/hazard due	Stakeholders impacted	Frequency/likeliho	od of failure/injury	Impact of f	failure/injury	ing this table					
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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 Failure mode/injury type Track Flooding of track Rail defect identified - damp and/or speed limits applied Derailment/delays - Rail break Derailment/delays - Iandslide Derailment/delays - Iandslide Derailment/delays - Iandslide Derailment/delays - hitting object./animal on track Earthwork failure Signalling/electrical failures Ice, ballast or other object between switch and stock rail preventing switch locking Damage to switch drive from flying ballast, ice failing from vehicles Stretcher bar failure Derailment due to switch rail wear Crossing failure Rolling stock Traction power failure Derailment due to switch rail wear Crossing failure Operational/signalling Traction power failures Operational/signalling Traction power fai	New failure mode/hazard due	Stakeholders impacted	Frequency/likeliho	od of failure/injury	Impact of f	failure/injury	ing this table					
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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 Failure mode/injury type Track Flooding of track Rail defect identified - clamp and/or speed limits applied Derailment/delays - Rail break Derailment/delays - track alignment fault Derailment/delays - Inacklide Derailment/delays - Shitting 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 Derailment due to switch rail wear Crossing failure <td>New failure mode/hazard due</td> <td>Stakeholders impacted</td> <td>Frequency/likeliho</td> <td>od of failure/injury</td> <td>Impact of f</td> <td>failure/injury</td> <td>ing this table</td> <td></td> <td></td> <td></td> <td></td> <td></td>	New failure mode/hazard due	Stakeholders impacted	Frequency/likeliho	od of failure/injury	Impact of f	failure/injury	ing this table					



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Capacity4Rail Technology Evaluation template	- RAMS da	ta					Cupucity					
Sub-project:	SP4											
Innovation:	New concepts a	and technologi	es for advanced mor	nitoring in emba	nkments, bridge	s, different track	k types, switches	s etc				
Maintenance and inspection tasks		Charlos had a second	-								6	data Batallara andreada a d
	New task required for innovation? Y/N	Stakeholders impacted	Frequenc	y of task	Time to maintain/in time M	nspect (MTM Mean aintain)	maintenance task (unable for and min	frastructure during time infrastructure n. number of lines, ighbouring lines etc	labour, number of logistic costs, han	cost of parts, cost of persons required, dling, cost of track lability	where possible uncertainty limits o maintain. If data changes based on tra Please detail how this will change a	, models. Detail assumptions made and r distributions for frequency and time ffic type, MGT, track curvature, cant etc. nd reference any models (eg wear rate,
Maintenance/inspection task			Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation	fatigue models etc) which cou Baseline case	d be used for sensitivity analysis. 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	-											
Rain transpose												
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 tamping												
Manual S&C geometry correction												
Repair/replace switch motor and drive mechanisms Repair/replace locking 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	New failure mode Stakeholders	Frequency of failur	e, Mean time betweer	n Time to repair	(MTR Mean time to	Unavailability of	infrastructure during	Repair cost (cost	of parts, cost of labour,	Sources of data used - statistical dat	ta, models. [
	due to innovation? impacted Y/N	failure	e, Weibull	1	Repair)	for and min. nur	nfrastructure unable nber of lines, spped hbouring lines etc	costs, hand	ons required, logistic ling, cost of track /ailability	where possible uncertainty limits maintain. If data changes based on tr Please detail how this will change a	traffic type, N and reference
Failure mode (eg from FMEA)		Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation	fatigue models etc) which con Baseline case	ould be used f
Track		buschine cuse		baseline case		buschine cusc	initovation	buschine cuse	innovation		liniovacio
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										l	
S&C										l	
Flooding										l	
Signalling/electrical failures										l	
Ice, ballast or other object between switch and stock rail preventing switch locking										l	
Damage to switch drive from flying ballast, ice falling from vehicles										l	
Stretcher bar failure										l	
Derailment due to switch rail wear										l	
Crossing failure										l	
Bridge failures										l	
Road vehicle collision with bridge					_					l	_
Bridge scour due to flooding										l	
Corrosion failure					_					l	_
Masonary deterioration				-				1		l	
Embankment failures										l	
Landslide										l	
										Į	
Renewal/replacement tasks	No. 1 and an end that a balance										
	New task required Stakeholders for innovation? Y/N impacted	Frequency	of renewal task	Time to	renew/replace	renewal task (time for and min. nur	infrastructure during infrastructure unable nber of lines, speed hbouring lines etc	labour, number logistic costs, h	cost of parts, cost of of persons required, andling, cost of track vailability	Sources of data used - statistical dat where possible uncertainty limits maintain. If data changes based on tr Please detail how this will change a	s or distributio traffic type, M
Renewal/replacement task							-1			fatigue models etc) which co	uld be used f
		Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovation	Baseline case	Innovatio
- Renewals										l	
Rail, sleeper and Ballast renewal											
Sleeper and ballast renewal										l	
Tactical resleeper										l	
Ballast cleaning										l	
- Renewals of switch										l	
S&C renewal										l	
- 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 inn	ovation for each failure mode considered. An EN	AFA and risk assessmen	at process should be c	arried out before co	moleting this table						
	New failure Stakeholders mode/hazard due impacted to innovation? Y/N		nood of failure/injury		f failure/injury						
Failure mode/injury type		1				1					
			- <u>-</u> .		- <u>.</u>						
		Baseline case	Innovation	Baseline case	Innovation						
Track		Baseline case	Innovation	Baseline case	Innovation						
Flooding of track		Baseline case	Innovation	Baseline case	Innovation						
Flooding of track Rail defect identified - clamp and/or speed limits applied		Baseline case	Innovation	Baseline case	Innovation						
Flooding of track Rail defect identified - clamp and/or speed limits applied Derailment/delays - Rail break		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		Baseline case		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		Baseline case		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		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		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		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 S&C		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 S&C Flooding		Baseline case	Innovation	Baseline case	Innovation						
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Flooding of track Rail defect identified - clamp and/or speed limits applied Derailment/delays - Rail break Derailment/delays - track alignment fault Derailment/delays - landslide 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		Baseline case	Innovation	Baseline case	Innovation						
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Flooding of track Rail defect identified - clamp and/or speed limits applied Derailment/delays - Rail break Derailment/delays - track alignment fault Derailment/delays - under 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		Baseline case	Innovation	Baseline case	Innovation						
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distributions for frequency and time
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