Capacity for Rail

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

Compendium and evaluation of RAMS, LCC and migration tools, and methods and sources of data

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Deliverable 52.1

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Lead contractor for this deliverable:

- USFD

Project coordinator

- UIC

Contributors

- DB
- IST
- COMSA

Executive Summary

The aim of this document is to provide background on the current technology assessment methodologies and tools used in other rail related EU framework projects and by the wider industry. It matches these existing assessment methodologies to the Capacity4Rail aims of an *affordable, automated, resilient and high capacity railwa*y and the definitions of these terms defined in WP5.1.1. This document also highlights areas of concern with the assessment of low technology readiness level innovations to mature technologies and the issue of bias.

Following a workshop organised as part of D5.1.1 with representatives from all of the sub-projects this deliverable will be revised to reflect any changes to the definitions and roadmaps resulting from that exercise as well as clarity innovations being developed within the project and the assessment needs for each sub-project relative to the roadmap targets. This revised deliverable will then serve as a reference document for the following tasks developing the assessment methodology within workpackage 5.2.

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Abbreviations and acronyms

Abbreviation / Acronym	Description
CAPEX	Capital Expenditure
CBA	Cost Benefit Analysis
CMS	Carbon Management System
CO_{2e}	Carbon dioxide equivalent (measure of greenhouse potential)
EIA	Environmental Impact Assessment
FMEA	Failure Mode and Effects Analysis
FP6	EU Framework 6 research programme
FP7	EU Framework 7 research programme
GRIP	Guide to Rail Investment Process
HAZOP	Hazard And Operability Study
IRR	Internal Rate of Return
KPI	Key Performance Indicator
LCA	Life Cycle Analysis
LCAT	Life Cycle Assessment Tool
LCC	Life cycle cost
LCCA	Life cycle cost analysis
MART	Mean active repair time
MDT	Mean down time
MFA	Material Flow Analysis
MTBCF	Mean time between critical failures
MTBF	Mean time between failures for corrective maintenance
MTBM	Mean time between maintenance for preventative maintenance
MTBSAF	Mean time between service affecting failure
MTTM	Mean time to maintain
MTTR	Mean time to repair
NPV	Net Present Value
OPEX	Operational Expenditure
PPM	Passenger performance measure
RAMS	Reliability, Availability, Maintainability and Safety
SE	Stakeholders/Effects
SEA	Strategic Environmental Analysis
SFA	Substance Flow Analysis
SME	Small Medium Enterprises
SP	Sub-project
TRL	Technology Readiness Level

1. Background

The Capacity4Rail project has the principle aim to develop the solutions and roadmaps *"to obtain an affordable, adaptable, automated, resilient and high capacity railway for 2020,2030 and 2050"*."SP5 - System assessment and migration to 2030/2050" has the tasks of producing a vision and roadmap for the future railway as well as assessing the developments and innovations from the other subprojects; SP1, SP2, SP3 and SP4. To fully assess the progress of the project towards these goals, the vision and the methods of assessment will be interlinked, with the assessment methodologies being selected to assess that progress is aligned to the roadmap. It is not expected that the innovations within the Capacity4Rail project will fully meet the full extent of all of the targets set out in the roadmap, but it must demonstrate that is making progress towards them.

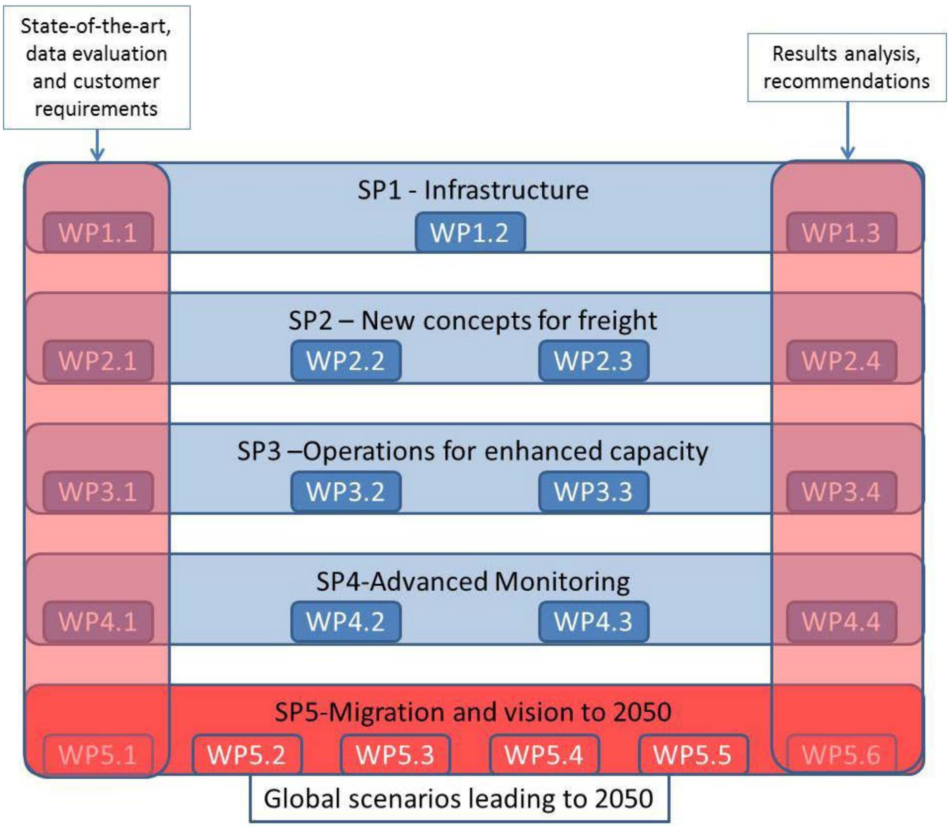

FIGURE 1*STRUCTURE OF THE CAPACITY4RAIL PROJECT*

WP5.2 has the task to identify the assessment methodologies, data and develop the tools required to carry out the evaluations of the technologies which begins with this task, T5.2.1. The purpose of this deliverable is to report the assessment methodologies used in other railway EU projects and by different organisations, gather the background state of the art for assessment methodology and relate each assessment measure to the roadmap goals.

Therefore this deliverable, which has the aim of reviewing suitable assessment methodologies and tools, is partly structured around the same definitions and themes as defined in D5.1.1 – "Railway Road Map – paving the way to an affordable, resilient, automated, and adaptable railway".

2. Objectives

This deliverable has the purpose to provide a basis to the deliverables in WP5.2, WP5.4, WP5.5 and WP5.6 which will deliver the assessment tools to be used in the project, the assessment of the innovations from the other sub-projects and the demonstrations and the final guidelines. By studying a selection of rail related EU projects and other methodologies, this task aims to understand how the assessment methodologies used relate to the goals of the project and identify the sources of data which can be used within the project, this is expected to provide the options for the assessment from which the most relevant can be selected and refined. Figure 2 illustrates how this deliverable fits within the wider work of the Capacity4Rail project and in particular within SP5.

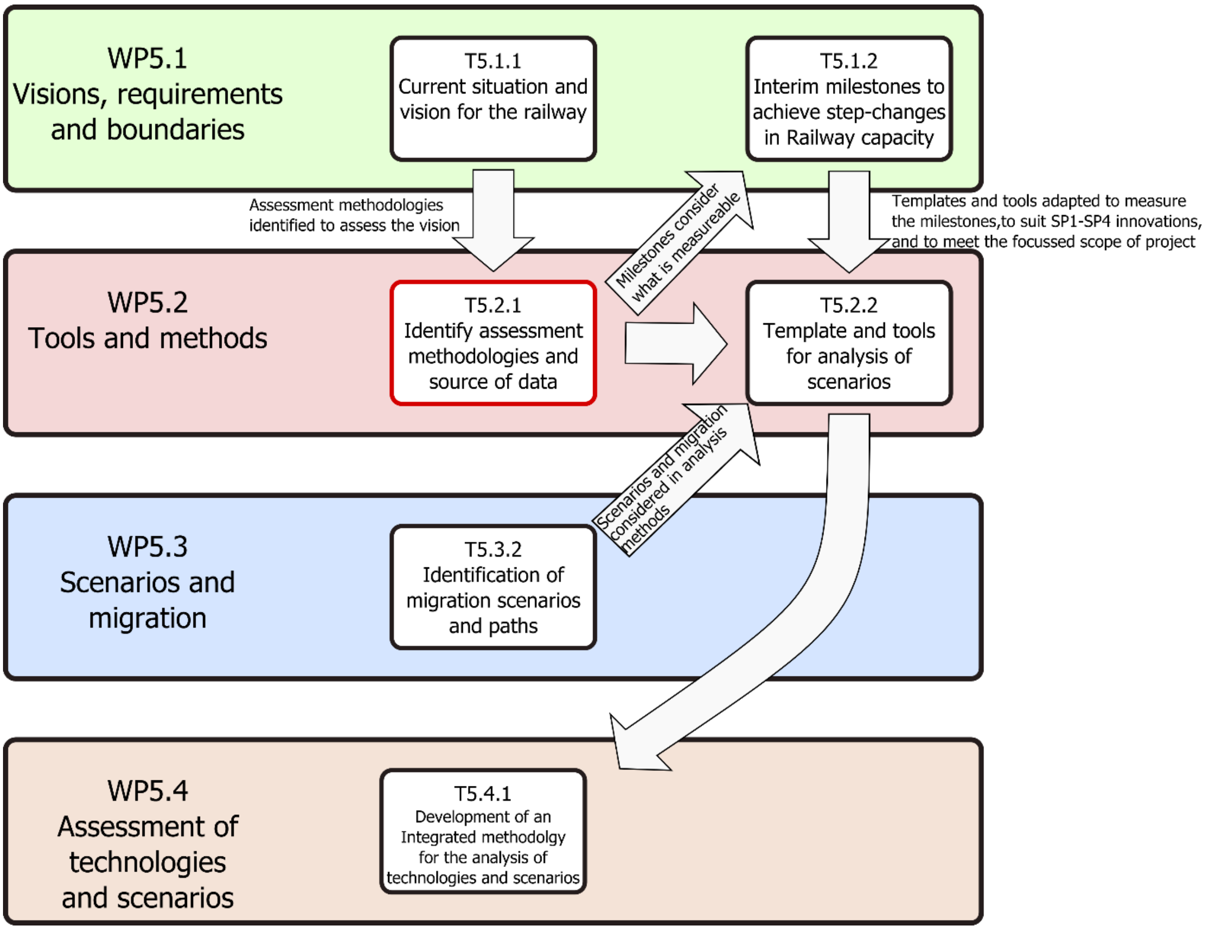

FIGURE 2– *FIT OF TASK T5.2.1 WITHIN THE CONTEXT OF OTHER SP5 TASKS AND WORK PACKAGES*

The assessment method used for the innovations will be highly dependent upon the scenarios and the principle aim of the particular innovation. Therefore, this document will be further extended as the innovations from the other work packages become better defined and which targets on the roadmap they aim to address. A workshop organized as part of WP5.1, to be held in May 2014 will provide much of this input.

3. Document structure

This task identifies relevant tools and methodologies which represent the current state of the art for the evaluation of the innovations and technologies developed within SP1-4 of CAPACITY4RAIL. Each tool has been assessed on its appropriateness for evaluating the innovations against the objectives set in the roadmaps defined within Task5.1.1. This task builds upon the methodologies developed within the past EU framework projects and includes environmental costing, socio-economic factors, and a probabilistic approach to uncertainty; and applies these to targets set within the roadmaps.

This document is structured as below:

Literature review

1. Past and current EU framework projects and the assessment criteria developed
2. Other documents and assessment methods from other industries
3. Technology readiness levels and risk

Application of methodologies to Capacity4Rail objectives defined within the roadmap

1. Affordable
2. Adaptable
3. Resilient
4. Automated
5. High-Capacity

Conclusions and next steps

4. Aims of past and current EU framework projects and the assessment criteria used

This chapter briefly describes the aims and objectives of past and present, EU framework projects and the relevant assessment methodologies used within that project.

4.1 MARATHON

Project objectives

The MARATHON FP7 project had the objective to provide a solution for operating longer, heavier and faster trains. This will then reduce rail freight operating costs, improve the system capacity and productivity, innovate and modernise the service for customers. The project studied the application of available wireless communication technology and management tools.

Technology assessment methodologies

As part of this project a market study was carried out to determine the current needs for capacity and to provide the basis of the business case and the definition of a market business model against which the innovations were assessed. Innovations were also tested for effectiveness towards the target of capacity reduction, assessed for technical feasibility and reliability. The technical assessment has been carried out against sets of operational cases, including use of the communication equipment in normal and degraded modes. Whilst a number of business scenarios were used to evaluate the business case against, including the simulation of train circulation, freight traffic simulations and sustainability aspects.

4.2 InnoTrack

Project objectives

INNOTRACK was an FP6 project which had the principle objective to reduce maintenance and infrastructure costs by 30%, by the application and development of innovative infrastructure technology and optimising maintenance and inspection. As a result the project was structured so that SP1- Key cost drivers and SP6 – LCC and RAM ran across and fed into all of the technical work packages.

Technology assessment methodologies

SP1 identified the maintenance activities and interventions which formed the largest parts of the maintenance budgets of the railway infrastructure managers involved in the project. This work also identified and created a common cost structure for railway renewals and maintenance, based partly on Network Rail's Infrastructure Cost Model, which formed the basis of life cycle costing work.

SP6 developed the methodology for LCC and RAMS to be used throughout the project and assessed the life cycle costs for the innovations developed and demonstrated throughout the project and the methodology has been developed into a guideline (D6.5.4 GL – Guidance for LCC and RAMS). As part of the project a study of the LCC and RAMS tools used by different EU infrastructure managers was carried out and the different tools assessed for capability, data was also gathered regarding the RAMS data collected by each infrastructure manager. The guideline covers all aspects of life cycle cost analysis, from the initial framing the boundaries of the analysis, application of discounted cash flow / net present value, sensitivity analysis and Monte Carlo probabilistic approaches. The guideline also defines key performance indicators for RAMS and the integration of social cost benefit analysis into the life cycle analysis, this was based on the ProRail methodology and costs for interruptions and delays. The guideline also introduces generic analytical methods for analysing risk and reliability, these included:

- Root Cause Analysis
- Failure Mode and Effects Analysis
- Risk Priority Number
- Fault Tree Analysis
- Event Tree Analysis
- Hazard and Operability Study
- Preliminary Hazard Analysis
- Delphi Technique

Also as part of INNOTRACK an FMEA analysis of the Balfour Beatty Embedded Slab Track was carried out and a balanced scorecard method of assessment, where a number of different financial and non-financial factors were scored and then weighting factors applied to each, the sum of these factors for the embedded slab track and for the base case of ballasted track could then be compared.

A life cycle analysis of carbon was also carried out to compare the embedded slab track to ballasted track. This analysis was based on a bottom up approach of using a product breakdown structure to identify the material and quantities used, as well as maintenance recorded and predicted maintenance activities, with the ICE database to predict the embedded carbon and the carbon involved in maintenance for both the embedded slab track and the base case.

Tools and data

D-LCC was the software tool used to carry out the life cycle analysis

Cost and reliability was provided mainly from each individual infrastructure manager for cost and maintenance frequency for the base cases and the innovation work packages provided material and reliability data for the innovations.

Carbon data from University of Bath ICE (Inventory of Carbon and Energy) database.

4.3 ON-TIME

Project objectives

ON-TIME is an FP7 project with the aim to provide a step change in railway capacity by reducing delays and improving traffic fluidity.

Technology assessment methodologies

ON-TIME deliverable D1.2 – A framework for developing an objective function for evaluating work package solutions (Cost function), provides the basis for the assessment. Key terms of Transport Volume, Journey Time, Connectivity, Punctuality, Resilience, Passenger Comfort, Energy and Resource Usage are defined and functions provided for each term, these can be scaled by using weighting factors and summed to produce an overall objective function against which the innovations will be assessed. For each ON-TIME workpackage the functions relevant to that work have been identified as well as the relevant constraints. Use of tools such as the Graffica HERMES simulator will be used to simulate the operation to a given timetable with or without delay scenarios artificially induced.

4.4 AUTOMAIN

Project objectives

The AUTOMAIN project is focused on increasing the capacity of the rail network by reducing the required possession time for maintenance. The project aims to introduce the adoption of widespread automation in order to improve the Reliability, Availability, Maintainability and Safety (RAMS) of railway infrastructure equipment and systems, reducing possession times up to 40%. Besides increasing automation of maintenance activities, new inspection and monitoring techniques, better maintenance strategies (best-practice, lean approach, better planning, etc.) along with modular infrastructure design are studied.

Technology assessment methodologies

The primary objective of AUTOMAIN was to reduce by 40% the possession time required for maintenance. In order to measure the results and progress due to the developments in AUTOMAIN, several KPIs are defined for each subproject. This measurement always consists of:

- A measurement of the actual performance situation, either by actual measurements or by estimation of the actual numbers.
- Quantification of the effect of the improvements achieved by measuring, by estimating or by using the results of the demonstrator
- Calculating an overall effect for the objective, basically using one of the two following formula:

Equation 1 $$\textit{Improvement} = \frac{\textit{actual possession time} - \textit{new possession time}}{\textit{actual possession time}} \cdot 100\%$$

Or

Equation 2 $$\textit{Improvement} = \left(1 - \frac{\textit{new possession time}}{\textit{actual possession time}}\right) \cdot 100\%$$

AUTOMAIN project has five key innovations and five different operating concepts (maximised availability, availability on demand; 24/7: maintain between services and 24/7 maintenance-free). This can be seen in the figure below:

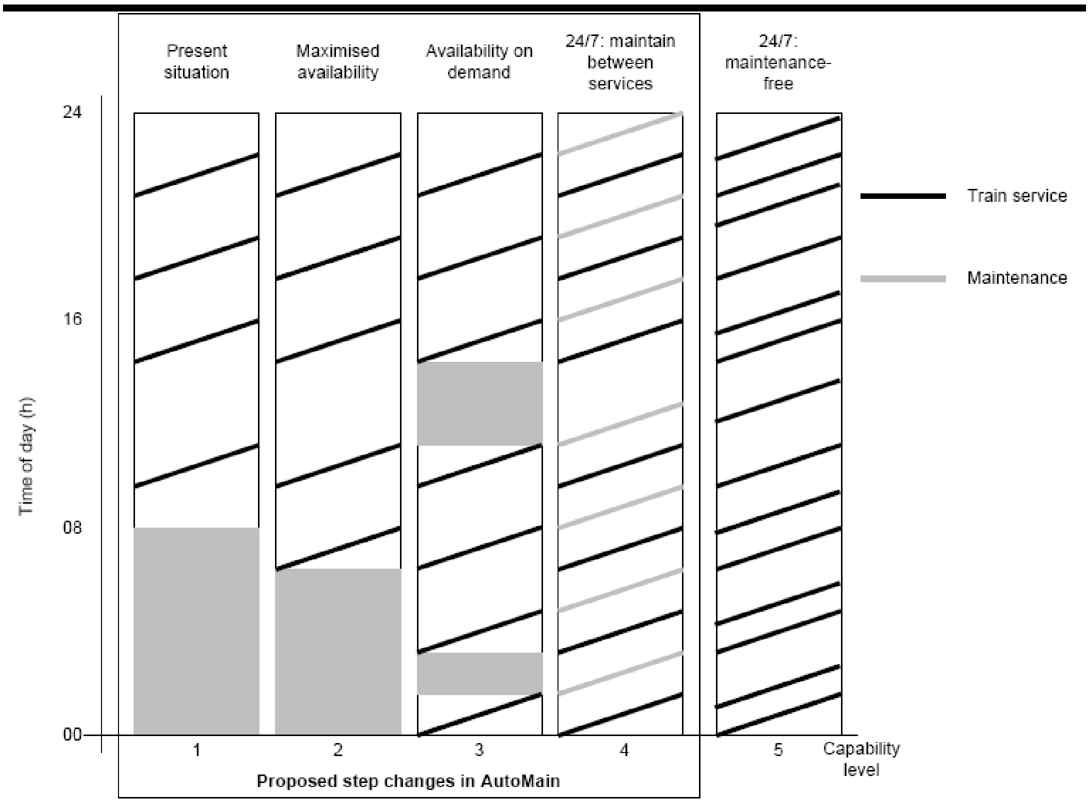

FIGURE 3 –AUTOMAIN CONCEPTS FOR REDUCING THE IMPACT OF MAINTENANCE ON CAPACITY

Each of the five key innovations has an appropriate framework by which they can be evaluated. This evaluation framework is composed of a set of criteria:

- The contribution it has towards the appropriate proposed step change operating scenarios considered in AUTOMAIN project (maximise availability, availability on demand;24/7 maintain between services and 24/7: maintenance-free).

- The capability requirements
- The contribution towards the high level objectives of the project
- Measure of increased train paths.

Furthermore, for each demonstrator it has been indicated what part of the solution has to be demonstrated and how. For the planning and scheduling tool, more specific requirements have been defined.

4.5 SUSTRAIL

Project objectives

SUSTRAIL is a Seventh Framework funded project with the aim of making railways infrastructure more resilient to freight traffic and rolling stock which is less damaging to the track. SUSTRAIL aims to allow the freight market to increase position and market share by improving Sustainability, Competitiveness, and Availability of European railway networks due to an integrated approach.

Technology assessment methodologies

The assessment methodologies adopted in the SUSTRAIL project includes a typical bottom up engineering approach and a top down statistical approach for modelling costs. The bottom up engineering approach is similar to that used in the INNOTRACK project, using life cycle costing by building up a cost breakdown structure for the different stages in the product's life and determining the maintenance requirements based on either historical data, or models for damage and wear and the cost of the required interventions. Engineering modelling and experimental wear data will also feed in to the RAMS analysis and form the basis of the KPIs for RAMS.

The LCC and RAMS will as far as possible adhere to the EN 50126-1:1999 standard "Railway applications – The specification and demonstration of Reliability, Availability, Maintainability and Safety (RAMS)". This standard entails that RAMS assessment operates at various distinct levels:

- System level (locomotive, wagon)
- Sub-system level (e.g., bogie, braking system, bodywork, engine, etc.)
- Component level (frame, wheels, springs, etc.)

The top down approach uses statistical data to determine a cost model based on actual historical, this is more accurate as a base model, but it can be difficult to determine the detail and the causes of the costs. It is also problematic in applying innovations to such models.

4.6 SMARTRAIL

Project objectives

The SMARTRAIL project brings together experts in the areas of highway and railway infrastructure research, SME's and railway authorities who are responsible for the safety of national infrastructure, The goal of the project is to reduce replacement costs, delay and provide environmentally friendly maintenance solutions for ageing infrastructure networks. This will be achieved through the development of state of the art methods to analyse and monitor the existing infrastructure and make realistic scientific assessments of safety. These engineering assessments of current state will be used to design remediation strategies to prolong the life of existing infrastructure in a cost-effective manner with minimal environmental impact.

The SMARTRAIL vision is to provide a framework for infrastructure operators to ensure the safe, reliable and efficient operation of ageing European railway networks. This will be achieved through a holistic approach which will consider input from state of the art inspection, assessment and remediation techniques and use this data to consider "what if" scenarios using whole life cycle cost models. These models will allow the infrastructure operators to make rational decisions on the best use of limited funding which will be committed to the long-term maintenance of the rail infrastructure networks.

Technology assessment methodologies

SMARTRAIL aims to develop new models/tools for LCA and LCC in order to assess different railway infrastructure rehabilitation techniques from an economical and environmental point of view. From the LCA and LCC models developed, a multi-decision tool will be created to compare different rehabilitation techniques.

For the development of the LCA, both EN ISO 14040 and EN ISO 14044 have been used as reference documents. In the case of LCC, ISO 15686-5 has been considered.

Both LCA and LCC accounts for the construction, maintenance and rehabilitation of track stages during a period of 60 years. The track components considered in the analysis are: rail, rail pads, sleepers, ballast and geosynthetics. This can be seen in the figure below:

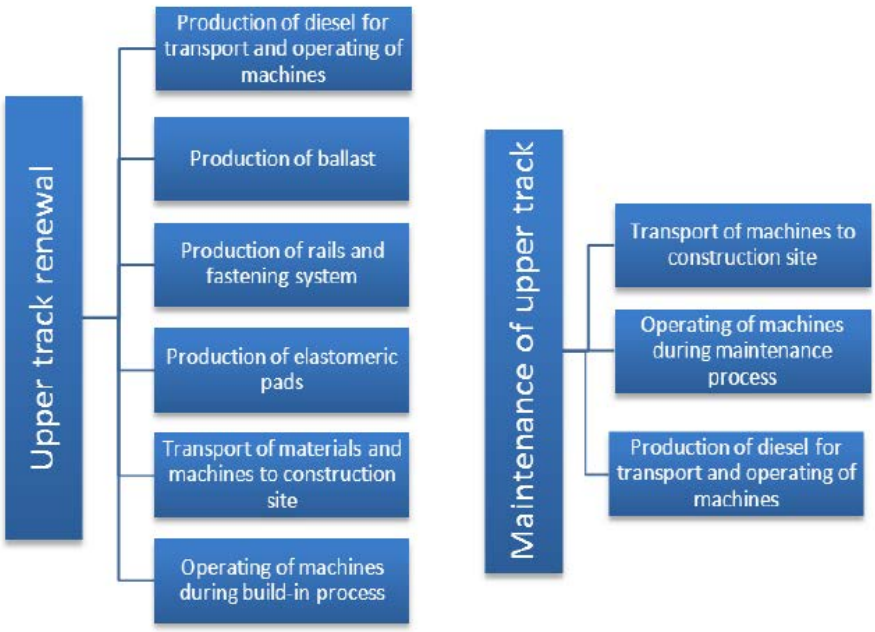

FIGURE 4 – SMARTRAIL BREAKDOWN OF TRACK COMPONEMENT

As source of information for data required for LCA, Gabi software has been used. It considers extraction of materials to construction, and then maintenance and rehabilitation works for 60 years.

Both LCC and LCA have been used to assess the effect of including geosynthetics during track rehabilitations in two case studies: open track and transition zone between embankment and bridge. To do this assessment, the expected lifespan –time between renewals- of materials (rails, sleepers, etc.) and the frequency of maintenance activities have been estimated.

Life time (in years)	No.1 Variant (without geotextile)	No.2 Variant (with geotextile)	No.3 Variant (with geotextile)	No.4 Variant (with geotextile)
Ballast	25	35	35	38
Sleepers	20	20	25	30
Rails and fastening system	30	30	33	45
Elastomeric pads	30	30	30	45
Geocomposite	/	35	35	38
Number of maintenances	**No.1 Variant (without geotextile)**	**No.2 Variant (with geotextile)**	**No.3 Variant (with geotextile)**	**No.4 Variant (with geotextile)**
Ballast tamping	45	30	30	25
Ballast stabilizing	45	30	30	25
Rail milling	15	15	15	10

FIGURE 5 – SMARTRAIL EXPECTED LIFE SPAN OF COMPONENTS

The two main parameters of the LCA are energy consumption and gas emissions (CO2), and they are expressed by Goblal Warming Potencial index considering 100 years (GWP 100). The LCA results can be displayed by construction or maintenance/renewal, and by type of material/action. Some examples for open track are shown below:

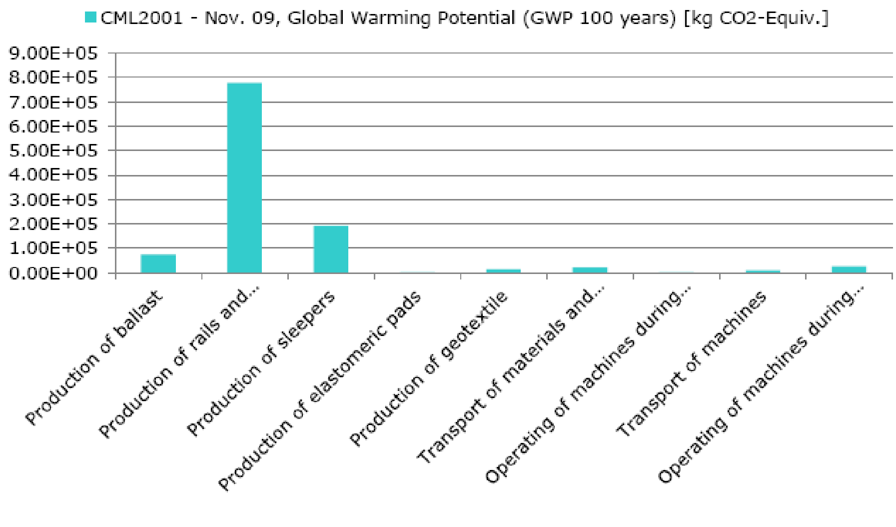

FIGURE 6 – EXAMPLES OF OPEN TRACK LCA RESULTS

4.7 InfraGuider

Project objectives

InfraGuider was an FP7 coordinated action project to provide a European answer to the environmental challenges, specifically the management of climate change, hazardous substances and resources.

The project aimed to carry this by developing consensus at a European level for:

- the current state of environmental performance within the railway sector, and to highlight the criticalities to become effective and practical for the internal Environmental Management system implemented by railway companies and suppliers;
- the infrastructure functional subsystems and interfaces from the environment point of view;
- the balance of goods in terms of material flow, environmental performance indicators EPIs and relevant ranking.

Technology assessment methodologies

The main methodologies used for the assessment of environmental impact of hazardous materials were Material Flow Analysis (MFA) and Substance Flow Analysis (SFA) with the analysis based on the international standard ISO 14001 gives guidance to organisations on the structure and content of environmental management systems.

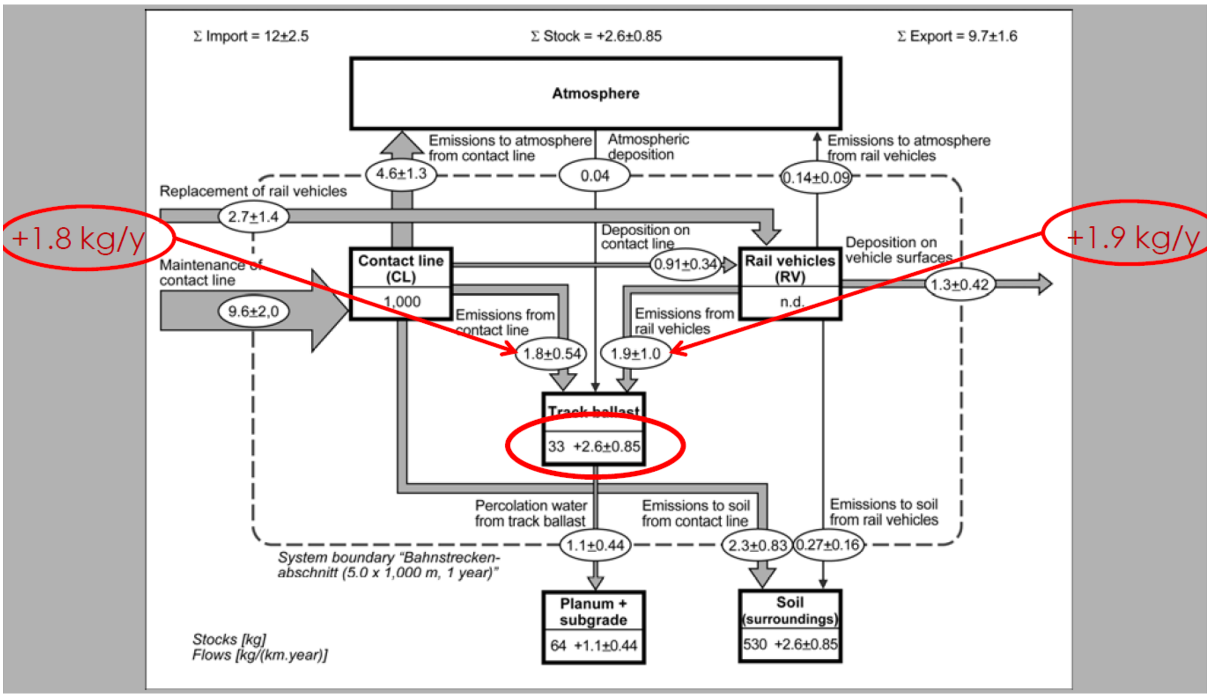

Figure 7 - Example Material Flow Analysis for copper use in rail transport.

4.8 MAINLINE

Project objectives

MAINLINE project aims at developing methods and tools that will contribute to a more cost efficient and effective improvement of European railway infrastructure based on whole life considerations. The outputs of the project will help Infrastructure Managers to better decide whether replacing or extending the life of its assets, and the most suitable method to be employed. According to these, the project addresses the following topics:

- Apply new technologies to extend the life of elderly infrastructure
- Improve degradation and structural models to develop more realistic life cycle cost and safety models
- Investigate new construction methods for the replacement of obsolete infrastructure
- Investigate monitoring techniques to complement or replace existing examination techniques
- Develop management tools to assess whole life environmental and economic impact.

Technology assessment methodologies

MAINLINE project's main objective is to help IMs to compare different maintenance and replacement strategies for track and infrastructure based on life cycle evaluation, and for that purpose a Life Cycle Assessment Tool (LCAT) is being developed.

The life cycle evaluation quantifies not only direct economic costs, but also indirect costs like availability costs and environmental impact costs. Moreover, the LCAT takes into account target safety levels in the optimization process. An exhaustive review of the existing literature on LCC has been carried in MAINLINE, analysing existing codes/standards, guidelines, research projects and several software packages for LCC analysis. Deliverable 5.4 presents the conclusions of this extensive review of literature and emphasises the points in common and the main differences found between them.

The LCAT that is being developed in MAINLINE covers bridges, tunnels, track, cuttings and retaining walls. The LCAT addresses the asset condition and corresponding planning of future interventions by considering (a) maintenance and replacement strategies of the assets, (b) lifetime performance of the asset tools for the considered assets and (c) condition indicators from measurements.

The overall structure of the LCAT follows the structure shown in the following figure. The LCA results (that are mainly related to CO2 and waste) are converted to monetary values and then considered in the LCC analysis.

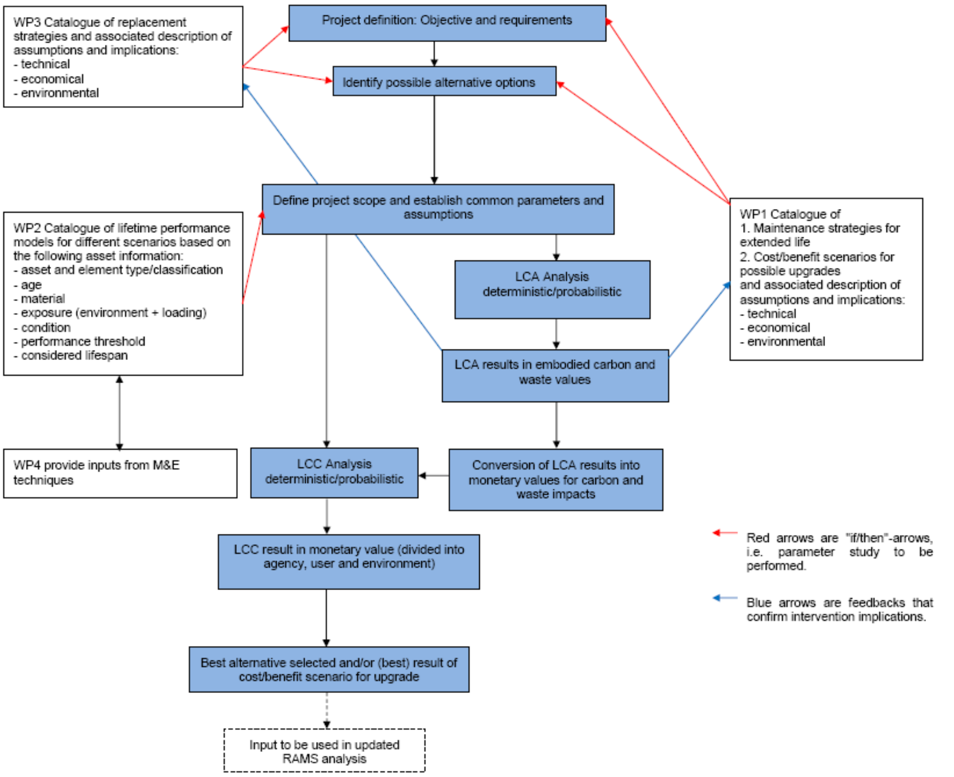

FIGURE 8–MAINLINE LCAT STRUCTURE

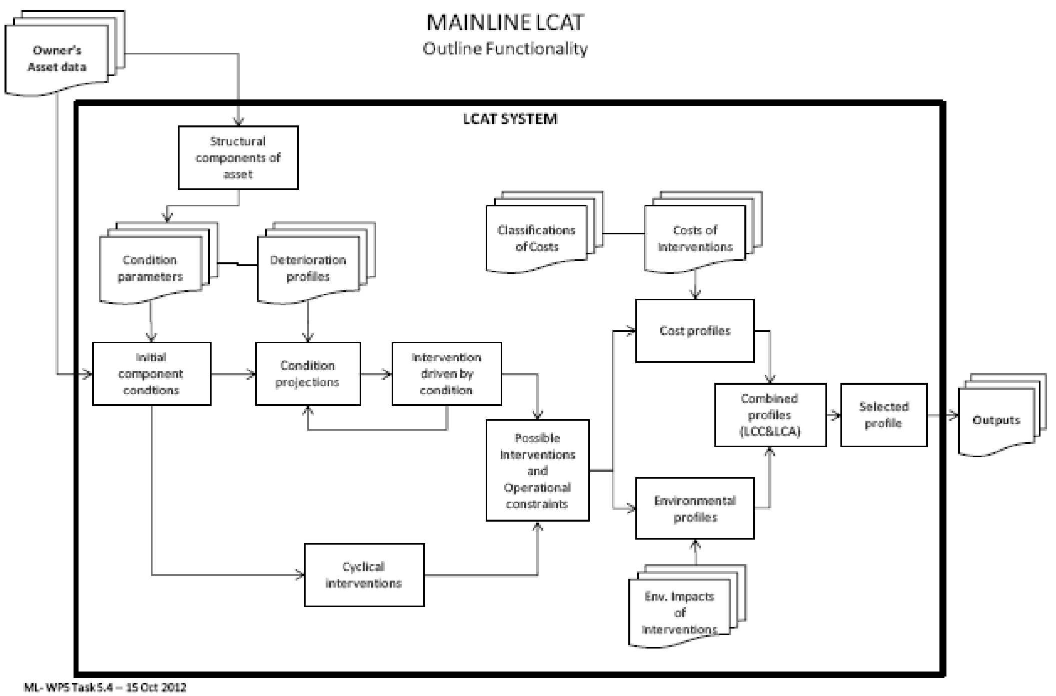

Figure 30 - Schematic illustration of the proposed functionality for the LCAT.

FIGURE 9 – PROPOSED FUNCTIONALITY OF MAINLINE LCAT TOOL

4.9 ARRIVAL

Project objectives

ARRIVAL (Algorithms for Robust and online Railway optimization: Improving the Validity and reliAbility of Large scale systems) is a Specific Targeted Research Project funded by the FET (Future and Emerging Technologies) Unit of the European Commission (EC) — priority IST (Information Society Technologies) — within the 6th Framework Programme of EC. The main goal of ARRIVAL was to develop foundational algorithmic research in order to provide fundamental efficiency and quality improvements for robust online planning systems.

Technology assessment methodologies

In this project the algorithms themselves were assessed rather than the impact that they had on the railway system and capacity. The algorithms were tested and assessed based on their robustness and computational time for given scenarios.

4.10 D-Rail

Project objectives

D-Rail is an FP7 project focused on the identifying the root causes of freight traffic derailments. One of the key issues that this project will address is the culmination of independent minor faults which combine to cause a derailment. The project also aims to address the future demands on the rail freight system. The project will assess monitoring systems, look at alarm levels and vehicle identification technologies and develop a deployment plan based on RAMS and LCC analyses and field testing on VUZ's test track in the Czech Republic.

The objectives of the project are:

- Reduce the occurrences of freight train derailments within Europe by between 8 - 12%
- Through understanding and mitigation provide derailment related cost reductions of 10 – 20%
- Improve the competitiveness of freight operation against other transport modes

Technology assessment methodologies

- Simulation and analysis to identify and evaluate the key contributory factors associated with derailment including combined causal effects for the freight vehicle and track system
- RAMS analysis including Risk analysis, risk assessment
- Cost-Benefit Analysis (CBA), LCC analysis
- The use of a certain tool/techniques for conducting risk analysis has been not yet decided

Data sources

The principal sources of data and databases used for D-Rail are:

- European statistics database EUROSTAT
- European safety database ERADIS
- DNV (Det Norske Veritas) 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

5. Other documents and assessment methods

5.1 RAILPAG

RAILPAG (Railway Project Appraisal Guidelines) was a European research project which put forward a common framework for the appraisal of railway projects. RAILPAG was built based on a similar harmonization exercise carried under TINA (Transport Infrastructure Needs Assessment) European research project for transport projects in general.

RAILPAG guidelines were derived from the combination of several methodologies to support the assessment of different railway projects, namely the CBA (Cost Benefit Analysis) and an analysis of impacts through EIA (Environmental Impact Assessment). Those methods would build several scenarios and assess them, providing different demand forecasts and defining project alternatives, leading ultimately to the definition of an overall Stakeholders/Effects (SE) matrices.

For a comprehensive definition of an overall Stakeholders/Effects (SE) approach, an initial step mainly consisted of identifying the different stakeholders involved in the projects. This step focused in understanding and defining the multiple partners interacting in the planning process, from a set of institutions, companies and individuals. In the railway infrastructure context, several agents/stakeholders should be identified, namely the Public Administrations and Infrastructure Owners, the Infrastructure Managers or Railway Undertakers, the Regulator, the Transport Service Operators, the users as well as the non-users, and other potential stakeholders (landowners, constructions companies, industrial partners and manufacturers, etc).

Besides the analysis of the institutional framework and socio-economic context of the project under analysis, another important step consisted of the multimodal transport planning exercise. This step would inevitably lead to a comprehensive spatial plan of transportation infrastructure systems. Generally, an initial screening process to reduce the number of candidate projects is followed within a macroeconomic appraisal context, including macroeconomic and demographic forecasts, technological and innovations aspects, regulatory constraints and other relevant information. Then, a definition of feasible alternatives is pursued, identifying capacity constraints and bottlenecks and incorporating latent demand and a Strategic Environmental Analysis (SEA). Furthermore, a more detailed analysis is conducted by assessing the environmental, social and cohesion aspects of each alternative, quantifying the several externalities (reduced energy consumptions, lower emissions of pollutant gases and CO_2, less land occupations, etc). This assessment is generally conducted through general equilibrium models, in which the redistribution of benefits is spatially distributed and from the perspective of each stakeholder. Finally, this multimodal transport planning exercise is concluded with a systemic and holistic view, exploring the integration of the transport system with other modes, as well as the interoperability aspects, and including some network effects.

A very important aspect within this step of assessment of different alternatives is the definition of a reference case/scenario. This reference case/scenario should be based on a 'do-minimum' alternative, complying with the same demand levels, i.e. supplying similar capacity to the transport system. A useful example of this idea is the assessment of a high speed line project versus a track doubling project.

Regarding traffic forecasting necessary to estimate the project cash flows, the multimodal approach should again be included with a typical demand choice models mimicking the overall transport modal choice. These transport demand models should focus on the competing modes, as well as on the traffic generated or induced and, as far as possible, include different value of time for each user. Demand models will typically depend on fares, travel times, quality of service, etc. Therefore, a detailed sensitivity analysis of the users to different pricing policies is mandatory and should be integrated in a dynamic way in the financial analysis of the different alternatives.

The financial analysis necessary for the assessment of different alternatives is crucial to define the different cost components from a Life-Cycle Cost (LCC) perspective, including for example, the financial investment costs (renewals), the financial infrastructure maintenance and operating costs, the vehicle operating costs met by the operators. In order to be integrated in the Stakeholders/Effects approach (SE matrices), the financial analysis should be assessed from an agent-based approach, i.e. taking into account the agent incurring those costs or benefitting from those revenues. Regarding the revenues for instance, they should be included for the infrastructure manager or railway undertaking and for the service operators, similarly to what happens to the taxes for new generated traffic. These revenues would necessarily depend on a rail pricing policy, which must define the financial transfers between agents and possibly some subsidies within transparent criteria.

In terms of the Cost-Benefit Analysis (CBA), typical ratios should be computed for each alternative project, e.g. the IRR (Internal Rate of Return), the NPV (Net Present Value) and the CBR (Cost Benefit Ratio). These calculations should include as investment costs: the planning costs (design costs), the land and property costs (expropriation and compensation), construction costs (site preparation, infrastructure, superstructure and supervision of works) and rolling stock costs (trains). Regarding the benefits to users and operators, they should include generally the time and money savings through the assessment of a generalized cost (overall 'disutility' of travelling between a particular origin and destination) involving time given up, money expenditure and other criteria such as discomfort, etc. Moreover, the willingness to pay should be estimated so that one can quantify the change in the consumer surplus provided by the new alternative. The volume of travel by mode and trip category for each O-D pair, assessed before within the multimodal transport demand modelling, is used to make projections for the base year and for future years; as well as the change in the generalized costs of travel by mode and trip category for each O-D pair. Besides, the gains to the transport service providers or 'producer surplus' due to a change in the supply curve should also be assessed. Other benefits related to variations in investment, operating and maintenance costs should also be included, and when possible these benefits should distinguish the type of traffic: existing traffic and diverted traffic (new rail users diverted from other modes) and the generated traffic (new users who were not travelling). Other potential benefits, relative to safety improvements, should be added through the assessment of the changes in accident rates for different modes and project alternatives, detailing if possible, the beneficial changes per accident and per severity degree. Safety aspects may also by quantified using the values derived from the associated insurances. Note that vehicle operating costs as a user benefit should also be included, whereas regarding externalities, and namely the environmental impacts, these impacts should be mitigated and their associated mitigating measures should be included as a cost.

Finally, RAILPAG also put forward particular aspects relevant to railway projects, such as guidelines for direct measurements of capacity based on experimental data, i.e. in terms of capacity and bottlenecks, for single track and double track depending on length of blocks, in maximum number of trains per day. These standard capacity measures are controversial as there is not a consensus between researchers and practitioners on the quantification of rail track capacity, because it depends on many aspects (e.g. types of traffic, heterogeneity, usage over the day and maintenance needs, as well as timing, etc). Regarding the delay component, RAILPAG also discusses the need to assess through micro-simulation the percentage of trains delayed more than 5 minutes for passenger trains, and more than 30 minutes for freight trains. Finally, RAILPAG addresses also the calculation of the residual value and considerations on the project life/horizon, as well as on the discount rate to affect the cash flows.

The Annexes contained in RAILPAG are an excellent starting point regarding any necessary information for a comprehensive assessment within the CBA methodology. For instance, information regarding external costs relative to accidents, noise, air pollution, climate change, nature and landscape, up-/down-stream and urban effects, is detailed for each travel mode and for passenger and freight. Moreover, guidelines for useful life considerations for railway components are described, detailing namely a range for the lifespan of track superstructure components, as well as tunnels, bridges and access facilities and stations, and rolling stocks. These values are only a guideline and should be properly justified depending on the alternative project under analysis.

The different case studies, some analysed in great detail, are also a relevant source of material and exemplification of the RAILPAG methodology. Cases studies focused on line upgrading and line renewal, or bottleneck removal or other more specific cases have been analysed within RAILPAG research project and provide through spreadsheets an important source for practitioners and researchers.

5.2 Network Rail GRIP (Guide to Rail Investment Process)

GRIP is a Network Rail gated process for investment scheme divided into eight stages and at the end of each stage a gateway test of the proposals is set, and a decision as to whether further development work on the project is made. The level of details of the scheme and assessment increase with each stage as does the maturity of the project proposal.

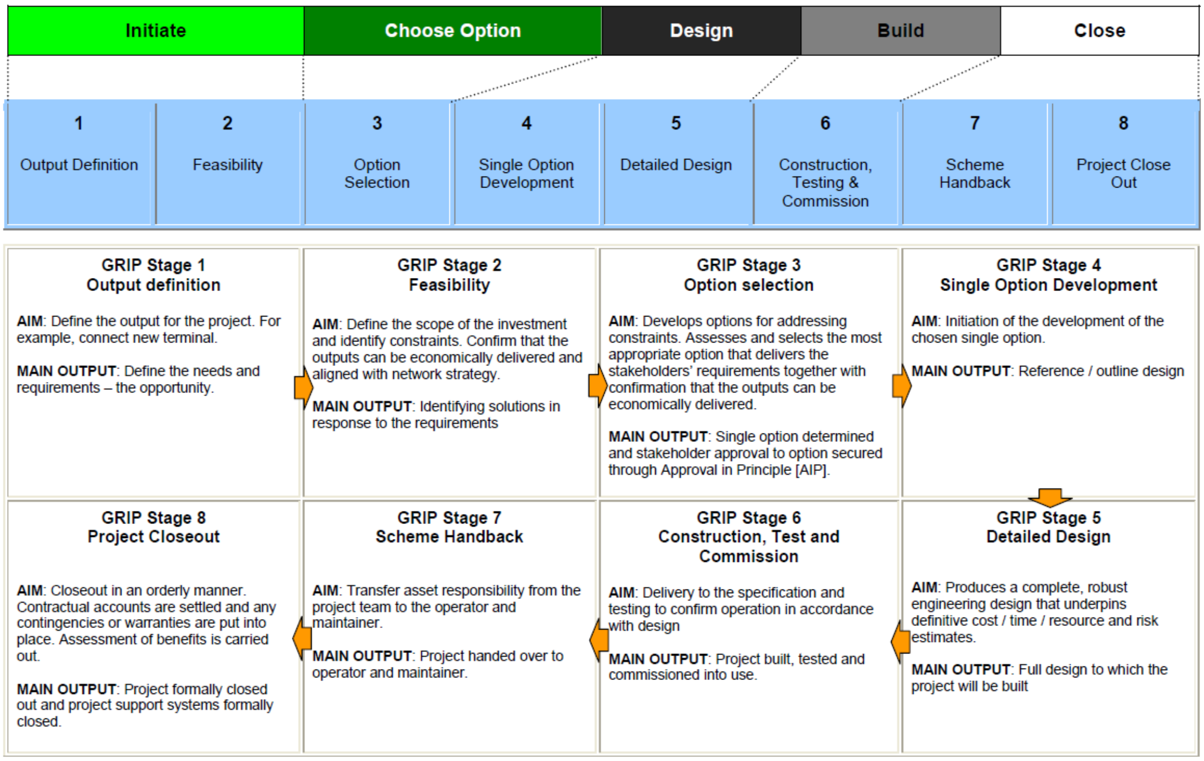

Figure 10 - Network Rail GRIP process

5.3 UK Government Green Book – Appraisal and Evaluation in Central Government

The Green Book is guidance provided by the UK Government Treasury to support the evaluation and delivery of public funded projects and has the aim that now public policy, programme or project is adopted without first answering:

- Are there better ways to achieve this objective?
- Are there better uses for these resources?

It also aims to enable the user to identify other possible approaches which may achieve similar results.

The Green Book methodology encourages that where feasible monetary values are established for all costs benefits of the scheme in order to perform a comparable assessment of the costs and benefits of the relevant options.

Cost benefit analysis should be carried out rather than cost-effectiveness analysis where:

Cost-benefit analysis – analysis which quantifies in monetary terms as many of the costs and benefits of a proposal as feasible, including items for which the market does not provide a satisfactory measure of economic value. In the case of no market data being available costs should be based on “willingness to pay” for a benefit, or in the case of a costs “expected compensation”.

Cost-effectiveness analysis – analysis which compares the costs of alternative ways of producing the same or similar outputs.

The Green Books sets out the following stages in the appraisal process

1. Justifying the action – what is the need being address and is it work the cost, this should include negative consequences of the action as well as the results of not intervening.
2. Setting the objectives –define the desired outcomes and objectives of an intervention
3. Option appraisal –this should also consider the ‘do minimum’ option and:
- Identify the costs for each option and the value of these
- Identify the benefits for each option and value of these
- Adjust valued costs and benefits for:
    - Distributional impacts (effects of proposals on different sections of society)
    - Relative price movements
- Costs should be adjusted based on timing by discounting to their present values.
- Consider a base case against which it is possible to demonstrate risk and optimism, evaluate impact of changes to key variables and assessment against different future scenarios
- Unvalued impacts should be considered using weighting and scoring techniques
- Create decision guidelines which may include constraints such as a budget ceiling, maximum cashflow and available funding and funding methods
4. Developing and implementing a solution - from the option appraisal stage decision criteria and judgement should be used to select the best option which is then refined into a solution.
5. Evaluation – after implementation an evaluation should be carried out to assess the change based on historical data and ensure lessons are learnt

The Green Book also discusses “Optimism Bias” where project appraisers tend to be overly optimistic, and consequently adjustment should be made for this bias and allowing for sufficient contingency, which could be based on expert judgement or from data of past projects comparing estimated costs at different stages in the project to the final project cost.

Assessment of risk must also be considered, decision trees and sensitivity analysis should be applied, and scenarios can be used investigate at different potential future scenarios and how that may affect the appraisal. Monte Carlo analysis can also be applied to evaluate uncertainty and risk, however, it must be cautiously applied especially when risks may not be independent of one another.

Unvalued costs and benefits are most commonly assessed using weighting and scoring (multi-criteria analysis),though this is susceptible to bias.

5.4 Transport For Scotland's Carbon Management System

Transport for Scotlands 2008-2011 Corporate Plan stated that "We are committed to ensuring, at every level, at every stage, in every project, that [carbon] mitigation and adaptation considerations are embedded in our decision making processes. Throughout this Plan period we will develop, pilot and implement a range of new procedures and tools to help us systematically manage our carbon footprint." And Climate Change Act (Scotland) 2009 mandated a reduction of greenhouse emission by 80 by 2050, this led transport for Scotland to develop bespoke tools to quantify operational and project greenhouse gas emissions, as a Carbon Management System CMS, with the aim of using the tools to record carbon footprint (calculating the operational and project carbon footprint) and optimisation, minimising carbon by providing a design decision support tool.

As such the Transport for Scotland CMS considers it's carbon calculations divided up as operational carbon, which is generally accrued from the annual accounts of the transport operators; and project carbon which is calculated for each individual project as a bottom up approach.

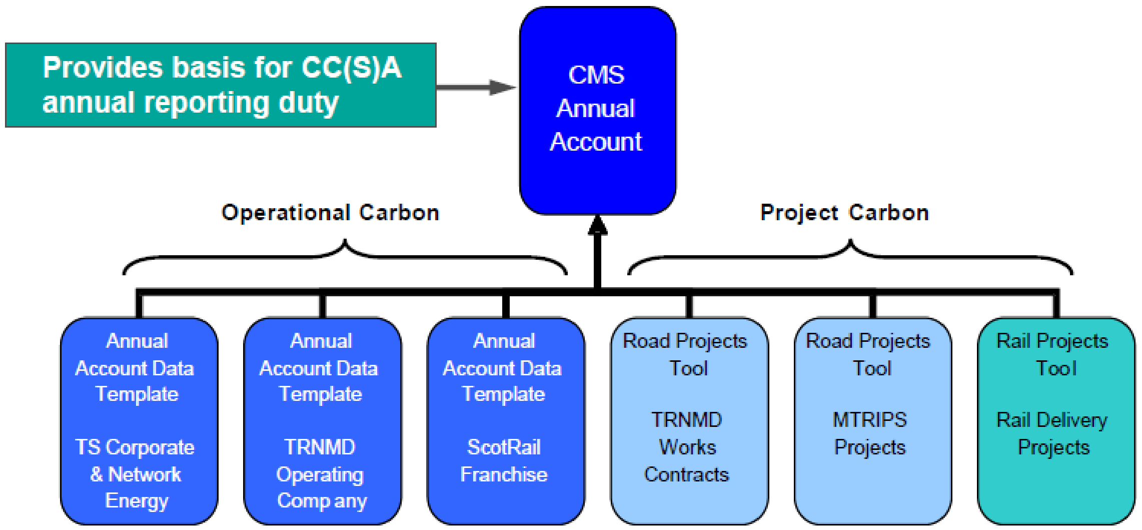

Figure 11 – Source of data in Transport For Scotlands carbon management system

The project carbon is calculated from an inventory of materials used in the project, with raw material and manufacturing/process carbon supplied from the manufacturer, construction carbon is calculated from bills of materials and operational carbon from modelled emissions based on likely maintenance cycles and energy consumption. The model is reviewed annually against data from University of Bath Inventory of Carbon Emissions (ICE) Database and Defra Emission Factors and Guidance data which is used to update the data within the Transport for Scotland's CMS data tables.

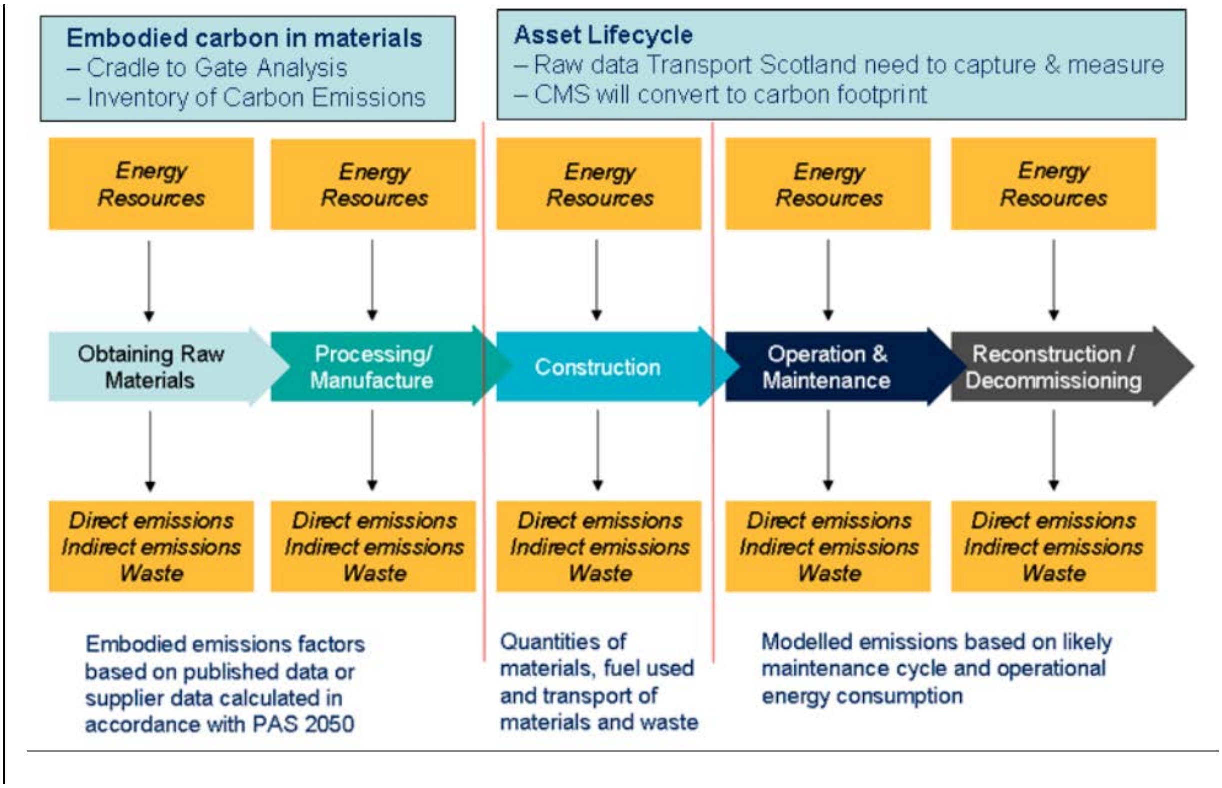

Figure 12 – Data sources for project assessment component of Transport For Scotland's CMS

5.5 RSSB Project T913 Whole Life Carbon Footprint of the Rail Industry

The aim of the RSSB project was to identify the dominant sources of railway carbon emissions across the whole life carbon footprint and to identify external factors which benefit the rail industry in the future eg. More energy efficient production of steel and concrete and lower carbon electricity generation in the grid. The project aimed also to observe what could be achieved through internal factors such as improving track life and produce recommendations for improving the accuracy and coverage of carbon estimates in the future.

This project used a top down methodology of dividing the GB rail industry into distinct portions that could then be assessed and modelled in isolation and then combined to represent the entire industry's footprint. Data was collected from each portion and reported in carbon dioxide equivalents ($CO_{2\,e}$) and normalised for each reporting unit. The project also developed a process for defining the study's boundaries and assessment of the quality of the data used to generate the carbon footprint assessment.

Methodology builds on recognised greenhouse gas accounting principles in particular the Greenhouse Gas Protocol (WBCSD 2004) and PAS 2050 developed by BSI. Include direct and indirect emissions and as far as possible account for all Kyoto Protocol Greenhouse gases, reported as tonnes of carbon dioxide equivalents (tCO2e).

This report, T913, carefully considers the scope of the calculation and defines a criteria for exclusion of data in order to simplify the calculation. Exclusions were defined based on:

- Materiality – are the emissions material enough to be relevant (at how small a level of detail should be considered), this study considered anything likely to exceed 5% of total GB rail industry
- Consequentiality – are the emissions the sole consequence of the operating rail services? Or would they have happened anyway?
- Ability to influence – can the GB rail industry influence the emissions directly through their own policies and actions?
- Stakeholder interest – are the activities or project generating the emissions of high stakeholder interest? Are they symbolic or highly visible to the travelling public or decision makers?

This report created definitions of data quality which were used to express the quality of the final report. Data quality was defined as:

- High – estimates of consumption were available in physical units
- Medium – estimates of consumption available in physical units from a sample, but needed to be extrapolated or modelled to expand estimate to whole rail industry
- Low – no physical data was available so estimates were derived by secondary measures, eg maintenance of structures based on financial investment.
- Data gap – acknowledged gaps in the data where no physical or financial data were available, eg disposal of life expired materials.

The report also considered the need for normalisation of its reporting. For example if passenger numbers increase, it may require more rolling stock to run and hence a greater fuel consumption pushing up the total carbon footprint of the rail industry, however, the kgCO_{2e} per passenger km or kg CO_{2e} per freight tonne km may have reduced. But concluded that reduction in accuracy and loss of resonance of the data determined that at present it did not make sense to normalise the total carbon footprint result into aggregated functional units, but it did make sense to study the normalised data for subsystems to provide the correct metrics to be applied by train operators (CO_{2e} per passenger km and CO_{2e} per freight tonne km) and Network Rail (CO_{2e} per track km).

5.6 TRANS-TOOLS

TRANS-TOOLS ("TOOLS for TRansport Forecasting ANd Scenario testing") is a European transport network model that has been developed in collaborative projects funded by the European

Commission Joint Research Centre's Institute for Prospective Technological Studies (IPTS) and DG TREN.

TRANS-TOOLS is a strategic tool for assisting in predicting the outcome of long term behaviour of main transport corridors, TRANS-TOOLS consists of a high level economic model, a trade and freight based model, a passenger demand model and a multimodal assignment model. The combination of these models allows for the impact of economic and trade changes, changes to household income, car ownership and transport supply to be modelled, identifying the changes in loads on the transport system, the shift between transport modes and identify regions where potential bottlenecks in the transport system may develop.

5.7 TREMOVE

TREMOVE is another policy assessment model used to study the effects of different transport and environment policies on the emissions of the transport sector. The model estimates the transport demand, modal shifts, vehicle stock renewal and scrapage decisions as well as the emissions of air pollutants and the welfare level, for policies as road pricing, public transport pricing, emission standards, subsidies for cleaner cars etc. The model covers passenger and freight transport in 31 countries and covers the period 1995-2030.

The first version of the TREMOVE model was developed in 1997-1998 by K.U.Leuven and DRI as an analytical underpinning for the second European Auto-Oil programme.

Since 2002, Transport & Mobility Leuven has further developing the model for DG ENV. TREMOVE was recently used for the evaluation of the new emission standard proposal (EURO standards), and several other policy evaluations, as road pricing, NOx abatement of maritime ships, and CO_2 policies. This first version included 9 countries until 2020.

Recent projects (f.e. TREMOVE SCP-CAR) contain the impact of environmental taxation and a scrappage subsidies on transport emissions and economy. TREMOVE was extended with a new module that covers the material flows (production and waste) of road transport. The most recent version TREMOVE v3.1 is available at the JRC of the European Commission.

5.8 EMMOSS

EMMOS - Emission model for shipping and rail was also developed by Transport & Mobility Leuven and is able to calculate emissions from rail, inland shipping and maritime shipping for Flanders.

EMMOSS was developed for the VMM to determine emissions caused by railway, inland waterways and seagoing vessels, for transport of people as well as goods on Flemish territory. For seagoing vessels this concerns not only emissions at sea but also in harbour emissions (caused by ships manoeuvring or at berth). The emissions of ships in ports have a substantial share in total emissions of maritime transport for Flanders, with important harbours like Ghent, Antwerp and Zeebrugge. The model is used to make a yearly inventory of emissions and to simulate scenarios, taking into account the technological evolutions within the different transport modes.

6. Technology readiness levels (TRL)

Technology readiness levels were initially developed to evaluate technology at NASA in the 1970's and 1980s to provide a common set of definitions for the maturity of evolving technologies within the organization. Since this time TRL has become ubiquitous, although there are different variations in the definitions as they have been tailored to specific technology types, the original NASA TRLs had just 7 levels in 1989, however, the use 9 levels of technology readiness is now accepted as standard.

The EU H2020 programme defines TRL levels with the following definitions:

- TRL 1 – basic principles observed
- TRL 2 – technology concept formulated
- TRL 3 – experimental proof of concept
- TRL 4 – technology validated in lab
- TRL 5 – technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies)
- TRL 6 – technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies)
- TRL 7 – system prototype demonstration in operational environment
- TRL 8 – system complete and qualified
- TRL 9 – actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies; or in space)

TRL levels define the maturity of a particular technology and therefore the risk level of that technology becoming successful, with technology at the low TRLshaving the most risk and the high TRLs levels the least. Conversely complexity of the system increases with TRL, so at a low TRL perhaps a single component is tested, but as the TRL increases it will be integrated into a system creating greater complexity and increasing the numbers of potential failure modes. Development costs also increase with TRL, and these costs should be considered when comparing a low TRL innovation with a mature technology as well as the associated risk of success.

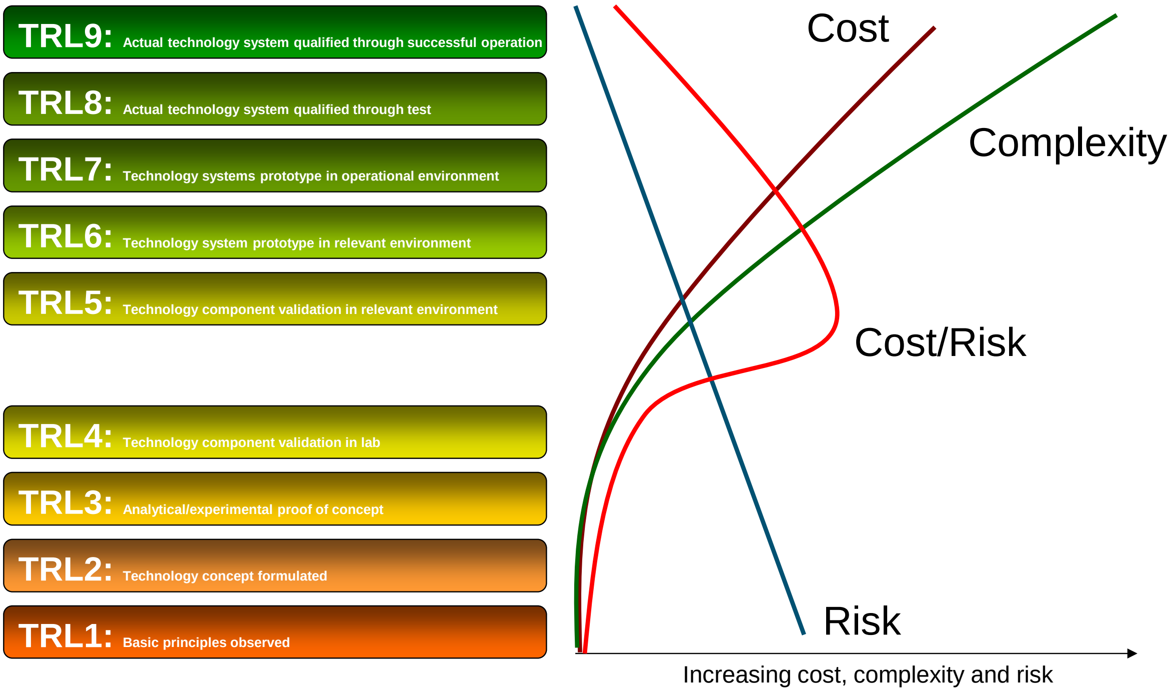

FIGURE 13 - DIAGRAM OF TRL LEVEL VS RISK AND COST OF DEVELOPMENT TO NEXT STAGE.

There are a number of TRL assessment tools that exist, either as flow charts or as software tools, which guide the user through a series of questions to determine the appropriate TRL for their particular innovation or technology.

7. Optimism in cost benefit analysis and risk analysis

The UK Government Green Book, describes briefly the issue of optimism in carrying out cost benefit in large capital schemes, where the issues of costs exceeding initial calculations can be quite common. And although some of this optimism may be due to a bias in the assessor to particular technologies there is also the problem of unknown costs and risks. This can also be a problem in assessing a new innovation against an incumbent technology for which detailed cost and failure data are available.

Firstly if we consider costs and failure mechanism, these can broadly be categorized as known knowns, known unknowns and unknown unknowns. For example a new technology may have a clearly known failure mode, such as wear and through laboratory testing or modelling the failure rate can be defined, and with enough data a failure distribution can be generated. Known unknowns are potential failure mechanisms which are known that they could occur in a final product, but there is no data available on the rate of occurrence, in which case an estimate or expert judgment may be required. Thirdly there will be unknown unknowns, these are failures which are unexpected and were not planned or envisaged. Similarly there will be known known costs, known unknown costs and unknown unknowns, and the proportion of these will change at the different technology readiness levels and as a new technology is incorporated into a system the complexity will increase and so will the number failure mechanisms and previously unconsidered costs.

This will lead to a bias towards a new technology in any cost benefit analysis when compared to an existing technology, purely because for the mature technology more of the costs and failure mechanisms are known.

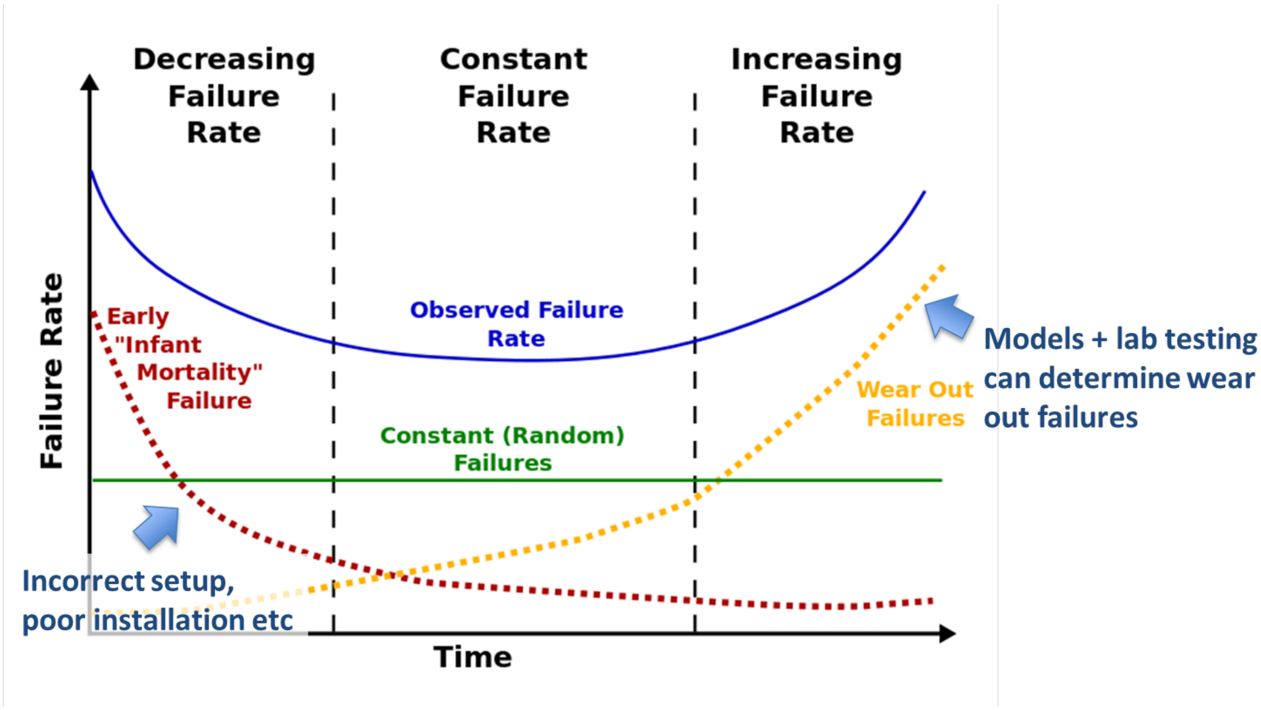

FIGURE 14 – FAILURE RATES OVER TIME (ACCORDING TO THE BATHTUBE CURVE)

Although methods such as fault tree analysis, FMEA, HAZOP and breakdown structures can help to identify risks and potential failure modes, and help to identify the unknown unknowns, they will never be complete, especially at the lower TRLs. Therefore, to fairly compare a high TRL product with a low one a factor for this difference in risk and costs should be considered, this can be done with experience or with data from similar projects and a comparison between the cost estimation at different stages in a project or product development compared to the final cost.

	Examples
Known knowns	Detailed historical failure data for existing technology Detailed historical cost data
Known unknowns	Known failure modes, but no data on rates of occurrence Low quality cost data Future trends for climate change Future passenger demographics Future demand for rail transport
Unknown unknowns	Unexpected system interactions causing failure Unexpected installation costs and failure modes due to setup

TABLE 1 - EXAMPLES OF KNOWN KNOWNS, KNOW UNKNOWNS AND UNKNOWN UNKNOWNS.

The quality of the data used in assessments should be analysed and the uncertainty related to this quality considered within the assessment. RSSB T913 defined data quality as:

- High – estimates of consumption were available in physical units
- Medium – estimates of consumption available in physical units from a sample, but needed to be extrapolated or modelled to expand estimate to whole rail industry
- Low – no physical data was available so estimates were derived by secondary measures, eg maintenance of structures based on financial investment.
- Data gap – acknowledged gaps in the data where no physical or financial data were available, eg disposal of life expired materials.

8. Normalisation

The issue of appropriate normalisation of results was mentioned in the RSSB report T913 specifically related to whether CO_{2e}should be normalised against for example passenger km or freight tonne km. The use of normalisation in assessment, like in the RSSB report, needs to be considered on a case by case basis to determine the relevance of the normalisation to the aims of the assessment.

Where all factors in the assessment can be translated into costs there is no need for normalisation, as the non-financial benefits will implicitly be contained in the cost-benefit analysis. However, where it is not possible consider all costs and benefits financially then normalisation should be considered, for example if a particular innovation aims to improve capacity and it is not possible to consider capacity in terms of a financial benefit, then it may be beneficial to consider whole life cycle costs, carbon dioxide equivalents etc normalised to non-financial KPIs for capacity.

9. Application of assessment methodologies to D5.1.1 roadmap

This section describes the application of the assessment methods to the roadmap and definitions developed in D5.1.1.

		Affordable			Adaptable			Resilient			Automated			High-Capacity		
Project/Method/Models		Economic	Environmental	Safety	Interoperability	Service demands	Climate change	Extreme weather	Accessibility	Infrastructure failure						
EU Projects	MARATHON	x		x						x		x				
	INNOTRACK	x	x	x						x						
	ON-TIME					x									x	
	AUTOMAIN					x				x		x			x	
	SUSTRAIL	x				x				x					x	
	SMARTRAIL	x	x													
	InfraGuider		x													
	MAINLINE	x	x													
	ARRIVAL									x					x	
	D-RAIL	x		x												
Other methodologies	RailPag	x	x	x	x	x	x	x	x	x		x			x	
	Network Rail GRIP process	x	x	x	x	x	x	x	x	x		x			x	
	RSSB		x													
	Transport for Scotland carbon assessment tool		x													
Models	TRANSTOOLS 2.5	x				x										
	TREMOVE	x	x			x										
	EMMOS		x													

TABLE 2 - RELEVANCE OF THE REVIEWED PROJECTS AND ASSESSMENT METHODS TO THE CAPACITY4RAIL ROADMAP TARGETS

9.1 Affordable

Definition:

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.*

This has been divided in the roadmap into economic aspects, environmental aspects and safety, which are discussed below.

Economic Aspects

Were possible all costs and benefits should be evaluated as financial costs and benefits. 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 its CO_{2e}emissions by x number of tonnes and is allocating y m€ to achieve this target, this gives a cost for tonnes of CO_{2e}emissions which can be used on top of the material, operational and fuel prices.

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 and tasks identified and budgeted throughout the product lifecycle and then adjusted for to a NPV. The economic aspects should be reported as a Life Cycle Cost (includes on direct costs), Life Cycle Cost

Benefit Analysis (includes indirect costs and benefits), CAPEX and OPEX. To properly study the affordability it is necessary to look at all of these figures as in many cases the actual affordability of work can depend more on the access to cash and political will, this can occasionally make high CAPEX and low OPEX projects more appealing, where governments can boast of high investment in a nation's infrastructure. This can be counter to the results of a LCCA which will often favour reduced upfront costs in favour of higher on-going costs due to the impact of discounting to net present values. Cash flow is also another important metric which should reported from the LCCA as affordability can also depend upon where costs fall within a company's funding cycle.

Dealing with uncertainty in LCC

Life Cycle Costing (LCC) methodologies and tools have usually included some analysis associated with uncertainty considerations. Typically, several sources of uncertainty associated with railway projects raise in the LCC analysis, i.e. the main inputs are typically unknown and are predicted based on sensitivity analysis or any statistical method. In case that not all the necessary parameters are well known and even uncertainties are part for future cash flows, these uncertainties have to be estimated at the beginning of the analysis. There are different kinds of uncertainties like

- not well known values of parameters due to missing data for existing systems,
- uncertain values of parameters by reason of missing experiences for new components or systems or
- parameters like life time of components, failure rates or maintenance intervals are not constant but described by probability density functions (PDF) (see also Figure 2)

For the first two cases of not well known values of parameters a sensitivity analysis helps to identify the impact of the uncertainty and to focus on further analysis. The idea is to vary the input parameters for the LCC analysis and to evaluate the impact on the result and to the input respectively. If the failure rate is described by a PDF (Probability Density Function) the maintenance activities and hence the related costs could also be specified by the PDF. If the model contains more than one uncertain parameter that is described by a PDF a Monte-Carlo-Simulation is a good method to predict the probability of the results. Monte Carlo simulation methods are standard approaches used to assess the uncertainty associated with an output (e.g. NPV, IRR, CBR) given the uncertainty associated with the inputs. This uncertainty associated with inputs is usually quantified using probability distributions. Moreover, the correlations associated with different uncertain inputs should also be assessed so that the Monte Carlo simulation can include such considerations. Typical statistical software (e. g. Palisade, @Risk) has standard probability distributions included and add-ins are used with Excel spreadsheets to run Monte Carlo simulation. Some specific LCC software also can provide the possibility to run Monte Carlo simulation (e.g. D-LCC).

The assessment of the uncertainty associated with inputs is usually conducted through the statistical analysis of comprehensive databases, running Goodness-of-fit tests for several inputs or using other methods based on expert judgment techniques, in case there is no available data.

Another important innovation that has been followed in recent years was the application of the Bayesian models (or hierarchical Bayesian models) in railway infrastructure to estimate degradation processes and the associated maintenance and renewal actions. Bayesian models have been developed in many areas of applied sciences. Bayesian models diverge from classical statistical models because they treat parameters as a random variable, meaning that they can be modelled through a prior distribution, which is then combined with the traditional model likelihood so that the posterior distribution of the parameters can be derived. In a way, there is a learning mechanism: an initial prior combined with the traditional likelihood leads to an updated posterior, which can then be used as a prior for the next time period. Therefore, the great advantage of Bayesian models over other classical models is mainly the learning mechanism and the fact that it can combine several sources of data, from databases to expert judgements.

Measures of economic impact

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

Sources of cost data

- Infrastructure manager cost data
- 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

Potential tools

- D-LCC
- MAINLINE LCAT tool
- Excel with @Risk
- WinBUGS
- Palisade

Environmental

Environmental aspects can consider:

- Carbon dioxide equivalent greenhouse gas emissions
- Ozone depleting gas emissions
- Release of other materials into the environment toxic to
- Waste disposal

As most of the current strategies and the roadmap in D5.1.1 refer mainly to greenhouse emissions, it will be the impact on greenhouse effect which will be assessed within the Capacity4Rail project. The methodology for assessing the impact of the greenhouse gas emissions is a similar method 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.

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.

Measures of environmental impact

- Total life cycle CO_{2e} – Carbon dioxide equivalents
- Financial value equivalent to greenhouse emissions

- CO_{2e} /passenger km, CO_{2e} /freight tonne km

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

Potential tools

- Gabi LCA Software
- MAINLINE LCAT tool

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.

Measures of the impact of safety

- Risk factors from risk assessment, fault tree analysis, FMEA, HAZOP

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

9.2 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, some of 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 technologies should developed should be interoperable as a given, 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 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 risk 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

Tools for LCCA and LCA with different scenarios applied

9.3 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

EXTREME WEATHER

Extreme scenarios such as hurricanes, flooding and landslides in the RAMS analysis as discussed in Section 9.2. 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.

9.4 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.

9.5 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. It is possible to create a financial cost function for capacity, for example using the reduction in possession time function from AUTOMAIN, it is possible to create a 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.

10. Conclusions and next steps

The evaluation framework for the Capacity4Rail project will need to be tailored around the particular innovations and scenarios developed within the project and the evaluation need will become clearer after the first workshop held in May 2014, where the roadmap and the contribution of the innovations towards the roadmap goals will be clarified.

With regard to the assessment methodology, this should as closely as possible follow the guidance set out within the RAILPAG and UK Green Book, where a cost analysis is carried out first and foremost and as many parameters as possible are monetised and a life cycle cost benefit analysis is carried out. In the cases where it is not possible to monetise parameters then an approach such the RAILPAG SE (Stakeholder Effects) matrix or a balanced scorecard (weighted parameters) method is used. Caution should also be employed when comparing mature technologies against low TRL innovations and allowances should be made to counter the impacts of bias, it is also important when considering whole life analysis to consider external trends such as the inevitable decarbonisation of power from the grid.

Whilst this deliverable identifies many methods which may be applied to the assessment of the Capacity4Rail innovations, to create a balanced assessment the methods must be tailored to the availability and quality of the data from each individual sub-project and build on methods and models which will be developed within these workpackages.