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

SUSTRAIL

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EXECUTIVE SUMMARY

This Deliverable describes the Business Case being developed within the SUSTRAIL research project, presents methodology and interim findings, and gives guidance to partners for the next phase of the project.

The main purpose of this element of the SUSTRAIL research (Work Package WP5) is:

1. *to make the Business Case* for the proposed vehicle and track innovations;
2. *to make recommendations for whole-system implementation*, including phasing-in of novel technologies and strategies for the equitable redistribution of whole-system savings.

WP5 also acts as an *iterative filter*, providing feedback to the engineering development work throughout the project from an economic perspective. To date, the steps have been:

- prioritisation of the duty requirements for the SUSTRAIL vehicle and track system (D2.5);
- selection of a set of vehicle innovations to include in the 'freight vehicle of the future' (WP3); and
- selection of innovations to include in the definition of 'sustainable track' (WP4) – this step is currently underway.

The final steps will be:

- refinement of the SUSTRAIL vehicle and track system definitions (WP3&4), including a preferred package of innovations – in the case of the vehicle two alternative packages are planned, one an 'Improved Conventional' vehicle and the other a more ambitious 'Futuristic' vehicle;
- analysis in greater detail of the costs and benefits of the chosen packages, including: (i) Life-Cycle Costing (LCC) and (ii) Reliability, Availability, Maintainability and Safety (RAMS) analysis (Task 5.1); the user and environmental benefits (Task 5.2); track access charges, which can play a key role in allocating the whole-system savings between infrastructure managers and freight operators in particular (Task 5.3); recommendations for technical implementation and phasing-in of the innovations (Task 5.4); and a synthesis of the Business Case.

The outputs will be brought together in the following framework:

Item	Analysis outputs
1.	Description of the innovation
2.	Rationale for the innovation
3.	LCC and RAMS analysis – main findings
4.	Cost-benefit analysis (CBA): • financial case for industry stakeholders (NPV, IRR) • socio-economic case (NPV, BCR, IRR)
5.	Impact on rail market share, CO_2 and other emissions
6.	Technical implementation and phasing – recommendations

Table ES1: Business Case outputs

Examples of the Description and Rationale were developed for the current set of vehicle innovations (see Appendix 1).

An initial assessment of the selected vehicle innovations has been carried out from an LCC and RAMS perspective (Chapter 2). This analysis is preliminary and on a high level, relying on judgements made by the WP3 team about key variables on a 0-10 scale. It provides a useful stepping stone in developing the methodology. In the next phase of the study, LCCs (€) will be estimated alongside key indicators of reliability, availability, maintainability and safety (see Section 9.1.2) This information will be transferred to the CBA, where it forms a large portion of the key inputs.

Downstream from the LCC and RAMS analysis is the analysis of user and environmental benefits (see Chapter 3, and 6-8 for case study examples). The main analytical tool here is a freight demand model which allows for scaling up from changes in the generalised costs of rail freight movement, to a prediction of future rail freight mode share, and monetised benefits (€) to freight users, from: reliability gains; increased average speed; reduced costs of freight service; savings in CO_2 emissions; and potentially other environmental benefits. This relies on the LCC analysis to estimate the cost changes to the IMs and freight operating companies. It also relies on guidance from the research on Track Access Charges (TACs) (Chapter 4) for the allocation of benefits between industry parties and end users. An average figure of 35% cost variability is recommended for TACs looking forward.

Interim findings are provided for the UK case study (Chapter 6). For the purpose of developing the analysis tools, a set of starting assumptions was made about the impacts of the SUSTRAIL vehicle innovations, including: a 5% reduction in TACs following a reduction in dynamic forces and in track damage; a 10% improvement in reliability measured by train delay per tonne-km; a 7.5% reduction in journey time related costs; a 20% reduction in fuel cost for a given load; a reduction in wagon maintenance and non-fuel operating costs of 10%; and a reduction in emissions factors for rail by 20% matching the reduction in fuel consumption.

These assumed changes would lead to, amongst other outputs:

- a net benefit of €533million to End Users (Present Value over 30 years, at 2015 prices and values, 3.3% social discount rate), made up of a reliability benefit, an average journey time benefit and a benefit from lower rail freight pricing;
- a net benefit of €306million (Present Value) from reduced CO_2 emissions across freight transport as a whole – this would rise to €665million if the UK official values (central estimate) were used in place of the IMPACT central values [3];
- a 2.5%-3.5% increase in overall rail freight usage (of tonne-km), rising to a 13% increase in the 'Food, drink and agriculture' segment; and
- a 14% reduction in local and regional air pollutant emissions from rail.

A wider range of cost and benefit items will be calculated for the final Business Case in the next phase of the project, leading to both the financial and socio-economic results indicated in Table ES1 above. The scope of the CBA is shown in Table 9.3. Appendix 3 covers the CBA framework and parameters.

The analysis approach and data availability for the other two case studies is also covered in this deliverable (Chapters 7&8). The Bulgarian case study will address a corridor with a very high proportion of international, containerised transit traffic and high existing rail share. Like the UK case study, demand forecasting will be carried out, with the assistance of a set of previous analyses relating to the same network. However, the starting point for Bulgarian rail freight is a relatively high level of TACs (section 4.1). The Spanish case study looks at a corridor of growing strategic importance in linking the Iberian peninsula with France and the central EU, where there are also substantial opportunities to take market share from road for inland transport from the container ports at Algeciras, Valencia and Barcelona, at which a

large proportion of the traffic is to/from the Atlantic area. Current demand and trend data exist, and there is good data on container freight costs, energy consumption and emissions, which will provide a starting point for projecting future demands using elasticity based methods analogous to those used in the UK case study.

Another key element of the business case is the assessment of Technical Implementation and Phasing (Chapter 5). A literature review is being prepared, which addresses the state of the art in relation to human factors issues and operational issues arising from the integration of novel vehicles and track systems into the existing railway. Consultation with stakeholders is being used to probe these issues more deeply; a second round of consultation will take place once the innovations are fully defined, in late 2013/early 2014. Research is also ongoing into the wider body of experience of integration of new technologies for track and vehicles. The outputs of this work will include:

- the projected time profile for introduction of the new vehicle into the European fleet over the period from 2015 onwards (potential % share of UIC Class R/S vehicles, by year, indicating any expected variation by country/area/market segment, and resulting % share of freight benefitting, by tonne-km in market segments above);
- the projected time profile for introduction of the track innovations on the European mixed-traffic network from 2015 onwards (% of network covered, by year, indicating any expected variation by country/area/market segment, and resulting % share of freight benefitting, by tonne-km in market segments above);
- the findings on optimal phasing from Task 5.4 on which these profiles are based;
- anticipated barriers to implementation;
- actions required to overcome the barriers to implementation, and the indicative timing and cost/revenue/performance implications of these actions, which needs to be incorporated into the CBA.

Finally, the deliverable notes that in the next phase of the research, the vehicle innovations will be integrated into the Improved Conventional Vehicle (‘Demonstrator 1’, which will be a physical demonstrator) and the Futuristic Vehicle (Demonstrator 2, by simulation). The track innovations will also be combined into a package. The impact of the Business case will depend on exactly which scenarios are being compared (Table ES2). However, the key tests we anticipate will be (vi) versus (i), and (v) versus (i), the other combinations providing supporting information about the added value of each component.

Scenarios	Baseline vehicle (Y25)	Improved ‘Conventional’ Vehicle	Futuristic Vehicle
Baseline Track	i	ii	iii
Improved Track	iv	v	vi

Table ES2: Business Case scenarios

1. INTRODUCTION

1.1 Purpose of SUSTRAIL Work Package 5

The SUSTRAIL project aims to contribute to the development of the rail freight system, and to support rail in regaining market share from road transport. The focus of the research is on a combined improvement in both freight vehicles and track, including track-train interaction. The outcomes are expected to include higher running speeds, reduced track damage, higher reliability and increased performance of the rail freight system as a whole, with reduced costs and enhanced profitability for its stakeholders.

Within SUSTRAIL, the purpose of Work Package 5 (WP5) is:

1. *to make the Business Case* for the proposed vehicle and track innovations;
2. *to make recommendations for whole-system implementation*, including phasing-in of novel technologies and strategies for the equitable redistribution of whole-system savings.

This work package (WP5) also acts as an *iterative filter*, providing feedback to the engineering development work in the project from an economic perspective (Figure 1.1). The first two steps shown have been completed; the third – selection of track innovations – is in progress; and the final step is due to commence following submission of this deliverable.

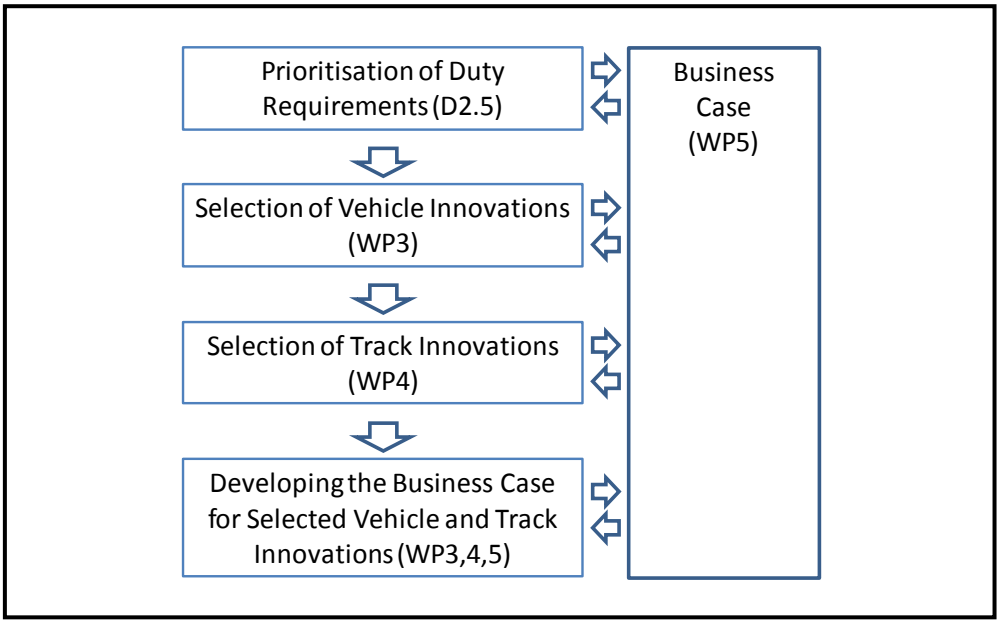


Figure 1.1: Role of WP5 as an iterative filter

Section 1.2 below sets out the approach to the Business Case in WP5, and describes how the business case framework has been used to support prioritisation work in the project as a whole to date. Section 1.3 looks forward to the development of the Business Case for the final SUSTRAIL innovations, including the methods and data to be used, and the interactions between Work Packages 3,4 and 5.

1.2 Research contributing to the Business Case

1.2.1 The Business Case framework

Central to the SUSTRAIL Business Case is the *impact on stakeholders in the industry*, including the infrastructure managers (IMs), freight and passenger operators, and the end users whose freight is being moved. It needs to be demonstrated that for these stakeholders the benefits of the SUSTRAIL innovations outweigh the costs (see Table 1.1).

	Groups			
	IMs	**Train Operators**	**End Users**	**3rd Parties**
Impacts	- changes in costs and revenues	Freight Operators - changes in costs and revenues Passenger Operators - changes in costs and revenues	- changes in costs and benefits	Environmental Externalities - CO_2 & noise Government - grant or subsidy requirements

Table 1.1: Business Case impact table – top level

Therefore the Business Case will include a cost-benefit analysis comprising:

- financial analysis of the impact on IMs, train operators, end users and government, in terms of net present value (NPV) and internal rate of return (IRR) – further details follow in this deliverable; and
- a socio-economic cost-benefit analysis covering all parties, in terms of NPV, IRR and benefit:cost ratio (BCR).

More widely, the SUSTRAIL research is expected to contribute to a *more sustainable European freight sector*. This increase in sustainability is to be achieved through both:

(i) attracting freight market share towards rail from less sustainable modes (road in particular) by "designing the freight vehicle-track system for higher delivered tonnage with improved availability at reduced cost" (Description of Work, p1); and

(ii) increasing the sustainability of rail freight itself, both in economic and environmental terms – for example by reducing CO_2 emissions or noise per tonne-km (Description of Work, p1,33).

SUSTRAIL will assess how the proposed changes in the vehicle-track system will impact initially on costs and system performance, and finally on these wider goals of rail market share and sustainability (Figure 1.2). These wider impacts will be integrated into the cost-benefit analysis as far as is technically feasible.

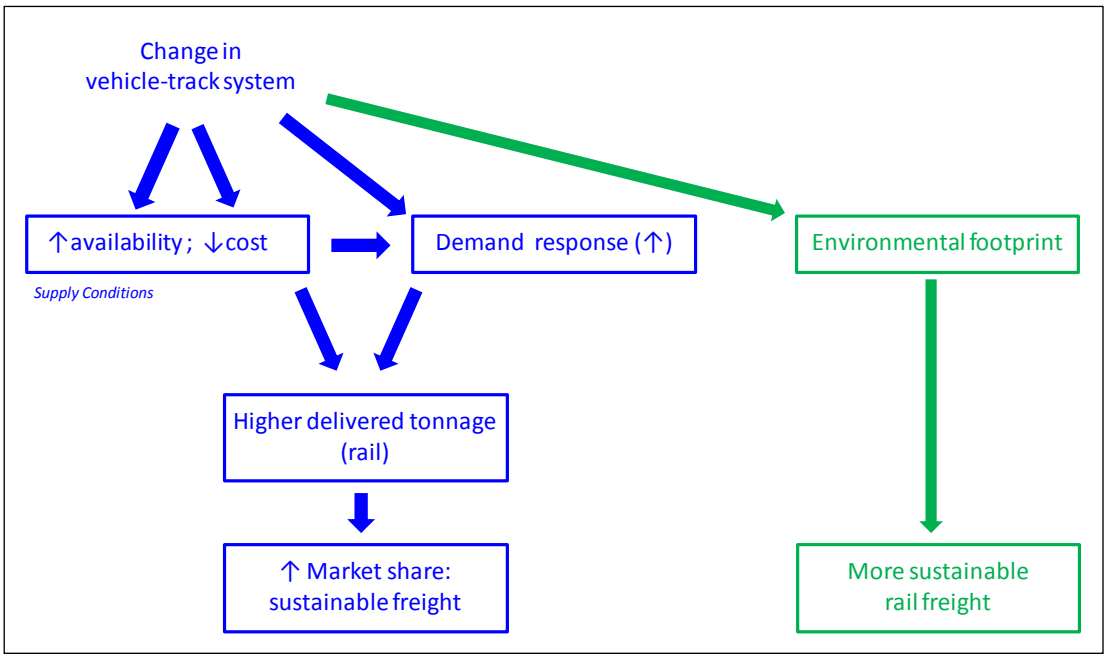


Figure 1.2: Impact pathways from the SUSTRAIL innovations to sustainability goals

The changes in costs will be estimated using Life Cycle Costing (LCC) analysis for both the IMs and train operators, and the impacts on whole-system performance will be measured using Reliability, Availability, Maintainability and Safety (RAMS) analysis (see Chapter 2).

Implications for user and environmental benefits will be estimated in three case studies, based in the UK, Spain and Bulgaria. An overview of the methodology for these benefits is given in Chapter 3. This work includes demand analysis for the purpose of estimating:

- the value of the change in the vehicle-track system to end users;
- their expected demand response to the rail freight system improvement;
- the implications for market shares.

These user and environmental benefits are reliant on the outputs from LCC and RAMS analysis, and also on assumptions about track access charges between the IM and the train operators. There is a distinct Task (5.3) dedicated to understanding the potential for differentiated access charges reflecting the relative damage cost of different vehicle-types (see Chapter 4). In the Business Case, track access charges will influence the flow of revenue from train operators to the IM, and hence the distribution of whole-system savings.

Moreover, as noted in Section 1.1, the Business Case is also concerned with *implementation* of the vehicle and track innovations proposed by the project. IMs and train operators have a wide range of technologies in use at any time, and the innovations need to be compatible with these to ensure that the operation of the railway system remains integrated. Therefore there is a research Task (5.4) focusing on: interfacing the innovations with existing track forms and vehicles, human factors and operational aspects.

In summary, therefore, the outputs of the Business Case for the selected SUSTRAIL innovations will comprise the following items (Table 1.2).

Item	Analysis outputs
1.	Description of the innovation
2.	Rationale for the innovation
3.	LCC and RAMS analysis – main findings
4.	Cost-benefit analysis: • financial case for industry stakeholders (NPV, IRR) • socio-economic case (NPV, BCR, IRR) • impacts on rail market share
5.	Impact on rail market share, CO_2 and other emissions
6.	Technical implementation and phasing – recommendations

Table 1.2: Business Case outputs

1.2.2 Prioritisation of duty requirements

An important step in the first year of SUSTRAIL was the definition of duty requirements. These include: essential duty requirements which must be met by the innovative freight wagon and track – for example, a large number of TSIs and standards applicable to railways which are expected to remain fixed; and also duty requirements for improvement, which specify changes above and beyond the essential duty requirements which will allow rail freight to become more sustainable and gain market share (D2.5 [39]).

A large number of ideas for new duty requirements were considered. In order to prioritise among the suggested new duty requirements, they were assessed against a set of criteria derived from the Business Case framework[1]. The prioritisation exercise made use of the available information at this stage of the project, including operators' and IMs' inputs, as well as the evidence from the SUSTRAIL research (Tasks 2.1 to 2.5.3), and the findings of a workshop focusing on this topic, held on 12 July 2012 in Sofia, Bulgaria.

Emerging from the prioritisation was the set of new duty requirements shown in Table 1.3. These were rated High/Medium/Low priority, with the implication that: High priority items would be pursued most urgently, using the majority of the resources; Medium and Low items would be given less priority, however even the Low items have potential – their Low priority reflects greater risks (in terms of technical viability) and/or smaller apparent rewards.

These duty requirements are about determining what the SUSTRAIL improvements should be, in terms of the parameters targeted, the direction of change, and – particularly where research evidence exists – the magnitude of the target.

[1] The criteria were: availability; cost; service quality; and environmental footprint; plus technical viability. Technical viability referred to the operators', IM's and research team's judgement about whether the duty requirements are: (i) capable of being addressed by the project with 3 years' intensive research; and (ii) implementable by the industry.

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

Table 1.3: Duty requirements for improvement, by priority level

1.2.3 Selection of vehicle innovations

At the next stage of SUSTRAIL, the research team began to translate these requirements for improvement into a set of proposed technologies and engineering solutions to incorporate in the SUSTRAIL vehicle.

Again, the options were assessed using a set of criteria derived from the Business Case framework, this time augmented with greater detail where the engineering research team felt able to give it: for example, specific attention was given to production costs and availability for mass production, and the criteria were given numerical weights based on the research team's judgement about the importance of each item in the overall case. Decisions were reached about the inclusion/exclusion of each innovation, taking into account this assessment, at the WP3 workshop on 6 December 2012 in Genova, Italy.

Note that these innovations are packaged into two improved vehicles: (i) labelled the Conventional vehicle, or 'Demonstrator 1', including 17 of the 39 technical innovations considered; (ii) labelled the Futuristic vehicle, or 'Demonstrator 2' including 30 of the 39 technical innovations considered. These vehicles will be compared with a typical current UIC Class R/S flat container wagon with Y25 bogies, for Business Case purposes.

'Demonstrator 1' will be built into a real vehicle for testing, whilst 'Demonstrator 2' with more advanced/futuristic technology will be subject to computer-based modelling.

WP3 "THE FREIGHT TRAIN OF THE FUTURE" - Assessment of Potential Technology Innovations												
FOCUS AREA	INNOVATION	Compliance with Duty Requirements (as set out in D2.5)	Technological Benefit	Production Costs	Availability for Mass Production	Reliability	Maintainability	Sustainability (Energy consumption, damage)	Weighted Priority Index	INCLUSION IN SUSTRAIL VEHICLE?		Notes
										Conventional	Futuristic	
Weight		0.05	0.1	0.1	0.15	0.25	0.175	0.175	1			
RUNNING GEAR (3.1)	Modified Y25 primary springs	7.9	6.3	6.3	9.0	7.4	7.1	7.3	7.40	Yes	Yes	
	Rubber springs	7.1	5.9	4.6	7.3	6.3	4.9	6.9	6.14	No	No	
	Double tenoir dampers	7.4	5.7	5.0	8.8	6.7	6.7	6.8	6.78	Yes	Yes	
	Wedge dampers	5.3	4.2	6.1	8.2	6.0	5.8	5.8	6.06	No	Yes	
	Hydraulic dampers	7.2	7.7	3.9	8.0	5.3	5.0	6.6	6.07	No	Yes	
	High resistance damping material	5.9	5.0	5.3	6.5	6.3	6.5	6.8	6.18	Yes	Yes	STP
	HALL bushes	7.6	7.3	4.0	6.9	5.5	5.5	7.1	6.12	No	No	
	Pusher springs	6.8	4.8	5.6	7.3	5.8	5.9	6.0	6.00	No	No	
	Steering linkages	8.1	8.1	3.6	6.8	6.0	5.0	8.3	6.42	No	Yes	
	Centre pivot stiffness	6.1	4.9	4.8	6.6	6.5	5.8	6.5	6.03	No	Yes	
	Axle coating	7.6	7.2	5.8	7.1	7.9	6.7	7.4	7.19	Yes	Yes	
	Novel wheel steel	7.0	6.5	5.5	7.3	7.6	7.5	7.4	7.14	Yes	Yes	
	Novel wheel shape	6.6	5.5	5.7	7.0	7.5	7.5	7.2	6.97	Yes	Yes	
	Resilient wheels	5.5	4.9	3.0	4.6	3.6	4.1	5.2	4.29	No	No	
TRACTION AND BRAKING (3.2)	Disk brakes	7.4	7.4	3.3	7.0	6.6	5.3	6.5	6.21	Yes	Yes	in comparison include
	Electronic distributor	7.0	6.2	3.8	6.3	6.0	4.8	6.7	5.81	Yes	Yes	
	Independently rotating wheels	4.8	4.3	2.4	3.6	3.8	3.2	3.6	3.58	No	Yes	to be considered GTU
	Use of friction modifier at wheel	7.0	6.7	4.4	5.4	5.9	4.7	6.7	5.74	No	Yes	
	Brake pad with friction modifier	7.7	7.1	5.3	5.6	6.4	6.0	7.0	6.35	No	No	
	Traction motor "Induction"	7.5	7.5	4.0	7.5	6.0	6.0	7.5	6.51	Yes	No	
	Traction motor "Permanent Magnet"	8.0	7.7	3.0	7.0	6.7	6.0	8.3	6.69	No	Yes	
	Power electronic drive "Multi level topology M2C"									No	Yes	
	Power electronic drive "Silicon Carbide SiC"									No	Yes	
	Energy storage "Batteries"	5.0	4.0	3.5	7.5	5.0	5.0	5.0	5.13	Yes	Yes	not in demonstrator
	Energy storage "Ultra capacitors"	6.5	4.0	3.0	6.0	5.5	7.0	6.5	5.66	Yes	Yes	not in demonstrator
	Medium frequency transformer for AC-grid									No	Yes	
BODY AND BOGIE STRUCTURES (3.3)	Lightweight bogie based on novel materials	8.3	8.0	3.7	4.8	5.2	5.3	7.1	5.78	No	Yes	
	Lightweight bogie based on hybrid solution	8.2	8.3	4.2	4.9	5.5	5.0	7.7	5.99	No	Yes	
	lightweight bogie based on shape and components	8.3	7.9	5.3	5.9	6.9	7.2	7.3	6.89	Yes	Yes	
	Composite bogies	8.4	7.4	2.7	3.2	4.6	4.2	6.6	4.94	No	No	
	Aerodynamic fairings	7.1	6.3	5.2	6.4	6.6	5.4	6.6	6.22	No	Yes	
	Light weight body based on novel steels	8.9	8.2	5.1	5.7	6.4	6.2	7.4	6.61	Yes	Yes	
	Light weight body based on aluminium alloys	8.6	8.0	4.2	5.5	6.1	6.2	7.1	6.33	No	No	
	Light weight body based on Composite materials	8.6	8.2	3.8	3.8	4.5	4.6	7.0	5.36	Yes	Yes	some components only
CONDITION MONITORING (3.4)	Axle monitoring through acoustic emission	7.9	8.0	4.3	4.6	5.9	6.3	7.6	6.21	No	Yes	
	Axle monitoring through vibration analysis	8.3	8.1	5.8	6.3	6.7	6.9	8.2	7.07	Yes	Yes	demonstration through external
	Energy harvesting	8.1	8.1	5.0	6.0	6.1	6.3	7.8	6.61	Yes	Yes	
	Machine vision technology for monitoring wheels	6.7	6.4	4.3	4.6	5.2	4.8	5.8	5.25	No	No	wayside
	Thermal sensors to monitor axle boxes	7.6	7.2	5.0	5.4	5.9	4.9	6.3	5.85	Yes	Yes	KES

Table 1.4: Innovations for inclusion in the SUSTRAIL vehicles: (i) Conventional; & (ii) Futuristic

1.2.4 Selection of track innovations

WP4 is close to a prioritisation of the track innovations. The method adopted is: to assemble and review existing research, including the INNOTRACK priorities and Network Rail prioritisation work, and to develop a SUSTRAIL FMEA (Failure Modes and Effects Analysis). This work to date has produced an interim set of 27 potential track innovations, in the five categories listed below; the next step will be to finalise a shortlist or package of priorities with SUSTRAIL partners – the ranking is likely to be based on judgement, taking into account the potential impact on the Risk Priority Index from the FMEA and the broad order of cost of the innovation.

The 27 proposed innovations are in the following categories – further details can be found in Section 5.2:

(i) Automated inspection;
(ii) Materials;
(iii) Track stiffness;
(iv) Rail joints, pads and ballast;
(v) Maintenance.

1.3 Scope of this Deliverable

Looking ahead to the development of the Business Case for the selected vehicle and track innovations, this deliverable seeks to demonstrate that methods are in place where necessary for the Business Case, and that data is either available or plans are in place to fill data gaps. The deliverable also reports on interim results where available.

Finally, but importantly, the deliverable provides guidance to WP3&4 on what is needed to develop the Business Case for the final innovations, including:

- what data/modelling outputs/information is needed and when;
- feedback WP3&4 can expect from WP5.

Chapters of the Deliverable cover Tasks 5.1-5.5 (Ch 2-5 & 9), and initial work on the three Case Studies (UK – Ch 6; Bulgaria – Ch 7; and Spain – Ch 8). A summary of guidance to WP3&4 is in Ch 10.

2. LIFE CYCLE COSTING AND RELIABILITY, AVAILABILITY, MAINTAINABILITY AND SAFETY ANALYSIS

2.1 Introduction

This chapter describes the initial assessment of the proposed WP3 innovations. The innovations are assessed from a life cycle cost (LCC) perspective and from a reliability, availability and maintainability (RAM) perspective. Current available data of the innovations is not including information about safety (S) or maintenance supportability (S) related issues. Therefore these parameters have to be address in a more detailed analysis when more information is available.

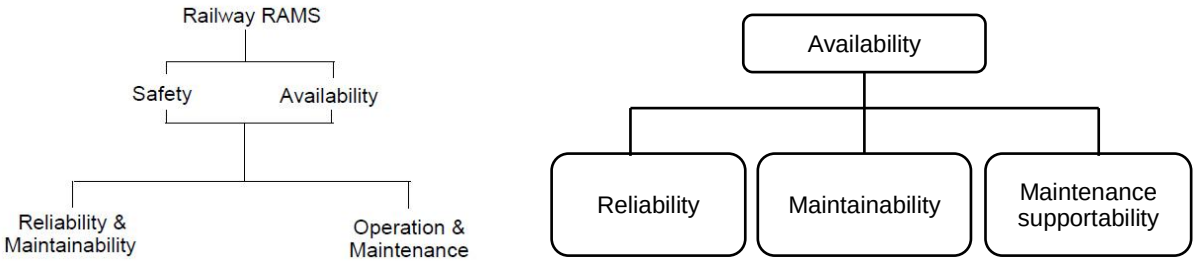


Figure 2.1: Railway RAMS and conventional RAMS

RAMS is a technical methodology to assess a product/system performability in all phases of its life length to deliver a system/product that is reliable, with minimal requirements to operate and maintain, easy to support, being safe without getting any negative environmental impact. By using RAMS in an early stage of a product /system implementation, huge cost savings can be done e.g. by avoiding unnecessarily high operation and maintenance costs and also avoiding safety and health cost. It is particularly important to take perform RAMS analysis and to do a maintenance impact statement in the investment phase.

According to [40] RAMS means Reliability, Availability, Maintainability and Safety. Reliability is defined as the probability that an item can perform a required function under given conditions for a given time interval, measured in terms of e.g. function probability, failure rate, mean time to failure (MTTF) or mean time between failure (MTBF).

Availability is defined as the ability of a product to be in a state to perform a required function under given conditions at a given instant of time or over a given time interval assuming that the required external sources are provided. Maintainability is defined as the probability that a given active maintenance action, for an item under given conditions of use can be carried out within a stated time interval when the maintenance is performed under stated conditions and using stated procedures and resources and is measured in terms of e.g. mean time between maintenance (MTBM), mean time to maintain (MTTM) or mean time to repair (MTTR).

Due to the fact that "Safety" is an important factor in the railway world, S in RAMS has been converted from maintenance Supportability Maintenance (maintenance logistics) to Safety. According to [41] Maintenance supportability is defined as the ability of a maintenance organization to have the correct maintenance support at the necessary place to perform the required maintenance activity when required Safety is defined in [40] as state of a technical system freedom from unacceptable risk of harm and measured as e.g. hazard rate, mean time between hazard system failures (MTBHSF) or numbers of accidents. In Figure 2.1 (left figure) the inter relationships between elements of the railway RAMS and the industrial RAMS standard.

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

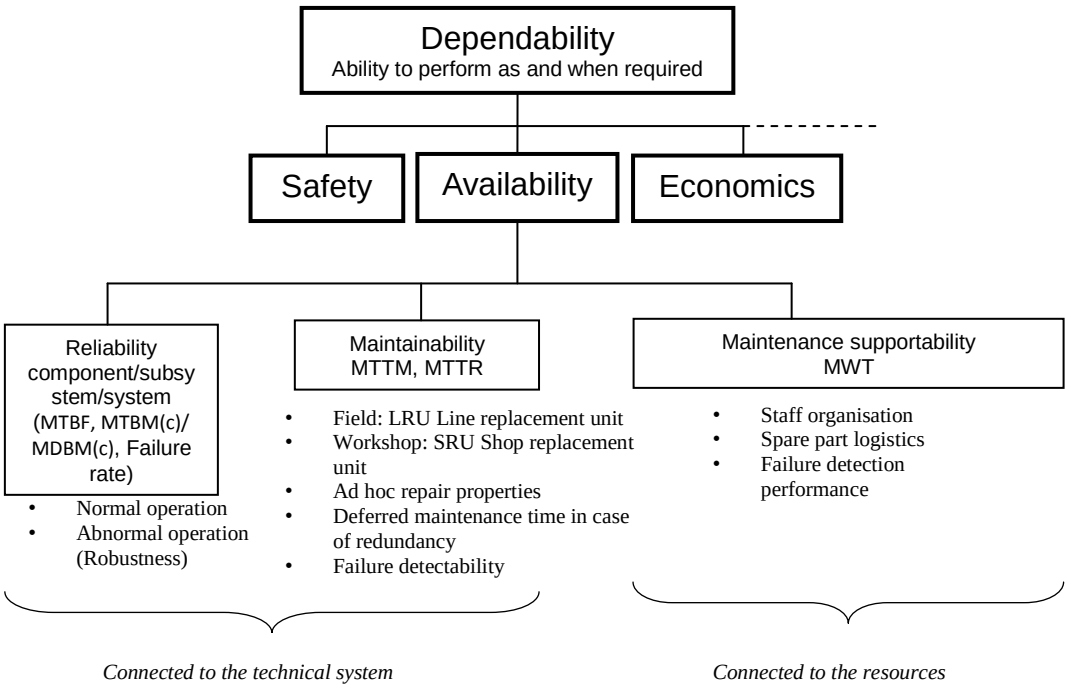


Figure 2.2: The figure describes the relations between dependability, safety, availability and economics according to [2]

2.2 LCC Life Cycle Cost

Life cycle cost analysis (LCCA) at different levels or for different options provide basic decision support in the form of [42]:

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

LCCA enables an approach because it includes all costs at all relevant stages, including the technical behaviour of the product described by RAMS. An LCC calculation is based on a Product Breakdown Structure (PBS) and a Cost Breakdown Structure (CBS). PBS is used to find parts/components that will be affected by an implemented change in the structure. e.g. a rail replacement, see Figure 2.3 left figure. The WP4 innovations have to be mapped onto a common PBS in order to perform a holistic analysis of the system. In the example: in addition to the rail fastenings the joints also have to be replaced. In the CBS the replaced components are marked in red and they will affect the investment, installation and corrective maintenance costs. In the example, the investment cost of the rail, joints and fasteners will be added together with the installation cost and new rail will reduce the cost for corrective maintenance.

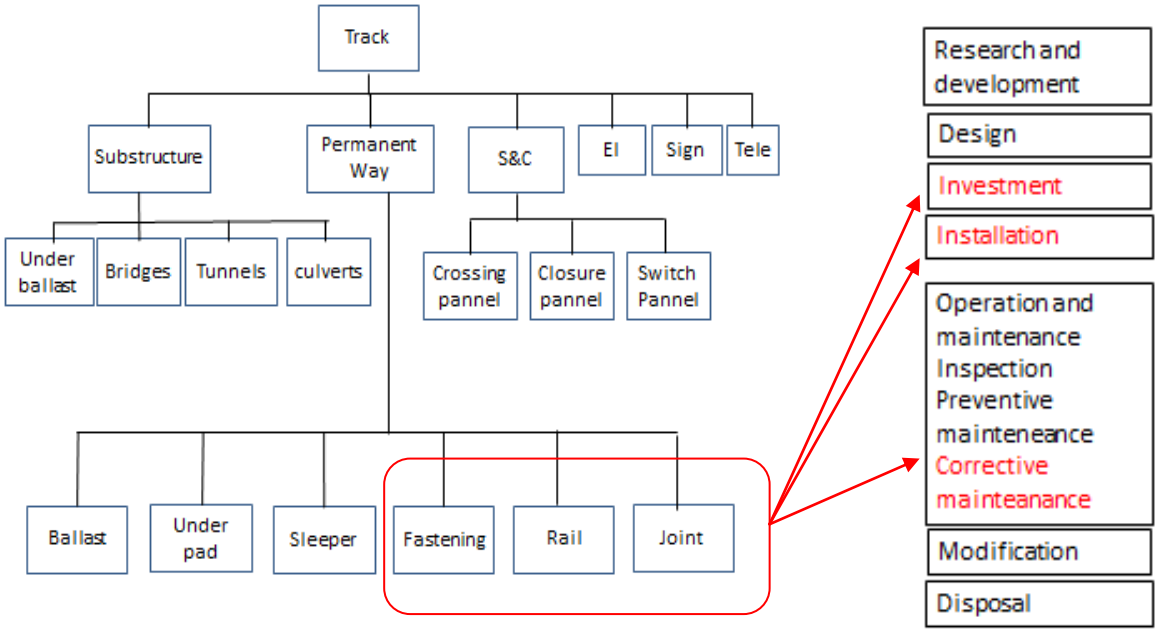


Figure 2.3: Product Breakdown Structure (PBS) for infrastructure and Cost Breakdown Structure

What complicates the use of LCC is that the actual cost of the operation and maintenance phase is usually unknown and standard costs might have to be used. In a similar way the WP3 innovations have to be mapped onto a PBS for wagons and locos. The PBS of the infrastructure and the rolling stock will should be joined to analyse the relationships between the two systems. In Figure 2.4 a preliminary attempt to present the PBS for Wagons and locos are presented, e.g. a new steering link will cause the wagon to run more smoothly and thereby reduce the MTBF for the wheels and axles. A known PBS and CBS will facilitate the analysis of the difference between different options/innovations and how they will affect the RAMS parameters and LCC of the whole system/product.

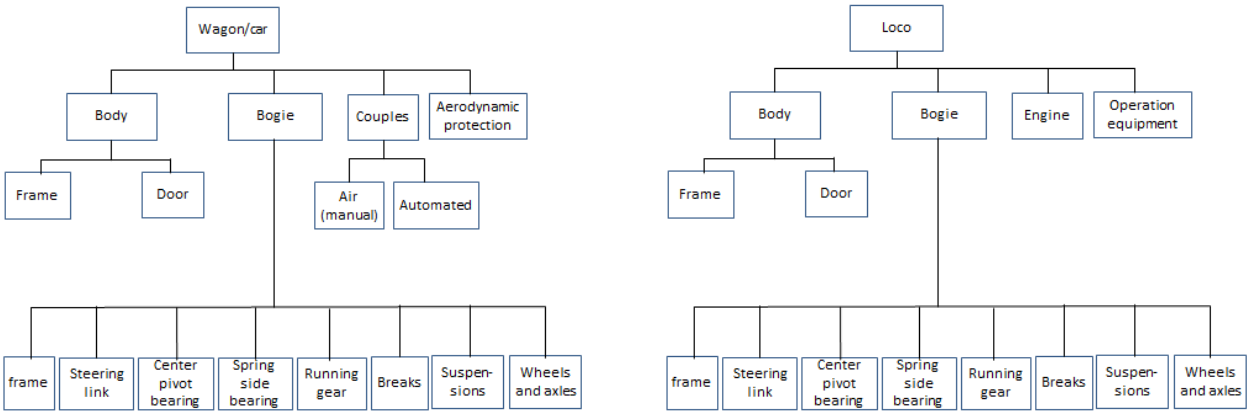


Figure 2.4: Product Breakdown Structure for wagons and locos

2.3 Goals

The goal of task 5.1 is to assess the innovations and options developed and proposed in WP3 and WP4 from a RAMS and LCC perspective.

2.4 Methodology

For the initial assessment a data input form was developed which addressed different aspects related to RAMS and LCC. The input form was reduced in size and complexity to fit the data available in the design teams. Together with the answers from the reduced input form, information from an assessment matrix created by WP3 and telephone conference meetings an initial assessment of availability and cost vs. duty requirement has been performed. Due to the different time schedule of the work performed in WP4 no assessment of the WP4 innovations are presented in this report.

2.5 Data gathered

Descriptions of the following WP3 innovations have been communicated to WP5.1, and can be found in the Appendix 1.

1. Tuned primary suspension
2. Energy harvesting
3. Axle temperature monitoring
4. Axle monitoring through vibration measurements
5. Inter-axle linkages
6. Battery
7. Induction motor
8. Ultra capacitor

2.6 Availability analysis

One of the main purposes with a RAMS analysis is to calculate the availability of a defined required function. The availability is a measure of the combined effect of reliability, maintainability and maintenance supportability. The required function could be a combination of functions, or a total combination of functions of an item which are considered necessary to provide a given service [41]. In railway applications the S in the RAMS abbreviation stands for safety while in industrial applications the S stands for maintenance supportability which is the ability of a maintenance organization to have the correct maintenance support at the necessary place to perform the required maintenance activity when required. The maintenance supportability is not explicitly expressed in the Railway standard [40] but it is included in the concept of maintenance. However to analyses the total availability or effects of non-availability the total downtime is of interest. There are three types of availabilities [43]; inherent availability, achieved availability and operational availability. Each of the measures describes different aspect of the availability.

2.6.1 Inherent availability (A_I)

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

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

where MTBF is the mean time between failure which is equal to the up time of the system. In the inherent availability downtime due to preventive maintenance or any other intentionally

generated downtime is considered as uptime. MTTR is the mean time to repair and it only considers the actual repair time for corrective maintenance.

2.6.2 Achieved availability (A_a)

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

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

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

2.6.3 Operational availability (A_o)

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

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

2.7 System reliability

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

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

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

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

2.7.1 Prioritised WP3 innovations

Within the framework of WP3 the innovations has been assessed by the involved partners creating an assessment matrix. The innovation has been assessed by nine different partners with respect to the following parameters,

- Compliance with Duty Requirements (as set out in D2.5)
- Technological Benefit
- Production Costs
- Availability for Mass Production
- Reliability
- Maintainability
- Sustainability (Energy consumption, damage)

where each parameter could be judge according to a scale from 0-10, Ten being the value representing the best and zero the worst. By using the weighted average of these assessments WP3 presented a list of prioritized innovations (Table 1.4). The innovations were also classified if they could be included in a conventional wagon or in a futuristic version. For the initial LCC and RAMS assessment of the WP3 innovations, the prioritised innovations of the conventional wagon are considered in Table 2.1. Each parameter was assigned a weighting factor depending on their estimated importance relative each other.

			Requirements (as set out in D2.5)	Technological Benefit	Production Costs	Availability for Mass Production	Reliability	Maintainability	Sustainability (Energy consumption, damage)
Weight			0 0,05	0,1	0,1	0,15	0,25	0,18	0,175
	Nr	INNOVATION							
RUNNING GEAR (3.1)	1	Modified Y25 primary springs	7,9	6,3	6,3	9,0	7,4	7,1	7,3
	2	Double lenoir dampers	7,4	5,7	5,0	8,8	6,7	6,7	6,8
	3	High resistance damping material	5,9	5,0	5,3	6,5	6,3	6,5	6,8
	4	Axle coating	7,6	7,2	5,8	7,1	7,9	6,7	7,4
	5	Novel wheel steel	7,0	6,5	5,5	7,3	7,6	7,5	7,4
	6	Novel wheel shape	6,6	5,5	5,7	7,0	7,5	7,5	7,2
TRACTION AND BRAKING (3.2)	7	Disk brakes	7,4	7,4	3,3	7,0	6,6	5,3	6,5
	8	Electronic distributor	7,0	6,2	3,8	6,3	6,0	4,8	6,7
	9	Traction motor "Induction"	7,5	7,5	4,0	7,5	6,0	6,0	7,5
	10	Energy storage "Batteries"	5,0	4,0	3,5	7,5	5,0	5,0	5,0
	11	Energy storage "Ultra capacitors"	6,5	4,0	3,0	6,0	5,5	7,0	6,5
BODY AND BOGIE STRUCTURES (3.3)	12	Lightweight bogie based on shape and components	8,3	7,9	5,3	5,9	6,9	7,2	7,3
	13	Light weight body based on novel steels	8,9	8,2	5,1	5,7	6,4	6,2	7,4
	14	Light weight body based on 15 Composite materials	8,6	8,2	3,8	3,8	4,5	4,6	7,0
CONDITION MONITORING (3.4)	15	Axle monitoring through vibration analysis	8,3	8,1	5,8	6,3	6,7	6,9	8,2
	16	Energy harvesting	8,1	8,1	5,0	6,0	6,1	6,3	7,8
	17	Thermal sensors to monitor axle boxes	7,6	7,2	5,0	5,4	5,9	4,9	6,3

Table 2.1: Weighted average of the partners' assessment of each innovation with respect to each parameter

2.7.2 Estimation of the WP3 innovation impact on availability

In order to calculate the inherent availability the MTBF and the MTTR is required. This information is however not available for the innovations. An estimation of the reliability and maintainability is however present in the table which is related to needed MTBF and MTTR. Based on the estimated reliability and maintainability in Table 2.1, an estimation of the effect that each innovation will generate on the inherent availability is performed. In the estimation process the MTBF is assumed to be proportional to the reliability *R*

$MTBF = R.$

Therefore the MTBF is assigned the value of the reliability estimation. The MTTR is assumed to be the opposite to maintainability and the estimate value (M).

$MTTR = 10 - M$

The MTTR is therefore assigned the value $10 - M$ meaning that when the maintainability estimation increases the MTTR decreases and vice versa. By using these assumptions an estimated inherent availability $\hat{A}_I$ can be calculated by using the relation

$$\hat{\hat{A}}_I = \frac{R}{R+(10-M)}$$

The estimated inherent availability is a measure based on the estimation of reliability and maintainability. The proportions between the estimated reliability and the maintainability is not reflecting the true proportion which governs the value of the inherent availability. The estimated inherent availability is only valid in a relative sense between the population of the innovations which was subjected to the assessment with the assessment scale of 0-10. The weighting factors presented in the assessment table of the WP3 innovation in is not used in the inherent availability estimation. In Table 2.2 and in Figure 2.5 the resulting estimation of the inherent non-availability is presented.

Sorted innovations according to Ai	1-Ai	Ai	WP3 index
6 Novel wheel shape	2,45	7,55	6,97
5 Novel wheel steel	2,50	7,50	7,14
1 Modified Y25 primary springs	2,80	7,20	7,40
12 Lightweight bogie based on shape and components	2,87	7,13	6,89
4 Axle coating	2,93	7,07	7,19
15 Axle monitoring through vibration analysis	3,18	6,82	7,07
2 Double lenoir dampers	3,33	6,67	6,78
11 Energy storage "Ultra capacitors"	3,53	6,47	5,66
3 High resistance damping material	3,59	6,41	6,18
13 Light weight body based on novel steels	3,73	6,27	6,61
16 Energy harvesting	3,75	6,25	6,61
9 Traction motor "Induction"	4,00	6,00	6,51
7 Disk brakes	4,16	5,84	6,21
8 Electronic distributor	4,63	5,37	5,81
17 Thermal sensors to monitor axle boxes	4,65	5,35	5,85
10 Energy storage "Batteries"	5,00	5,00	5,13
14 Light weight body based on Composite materials	5,45	4,55	5,36

Table 2.2: Sorted innovations according to the inherent availability estimation Ai

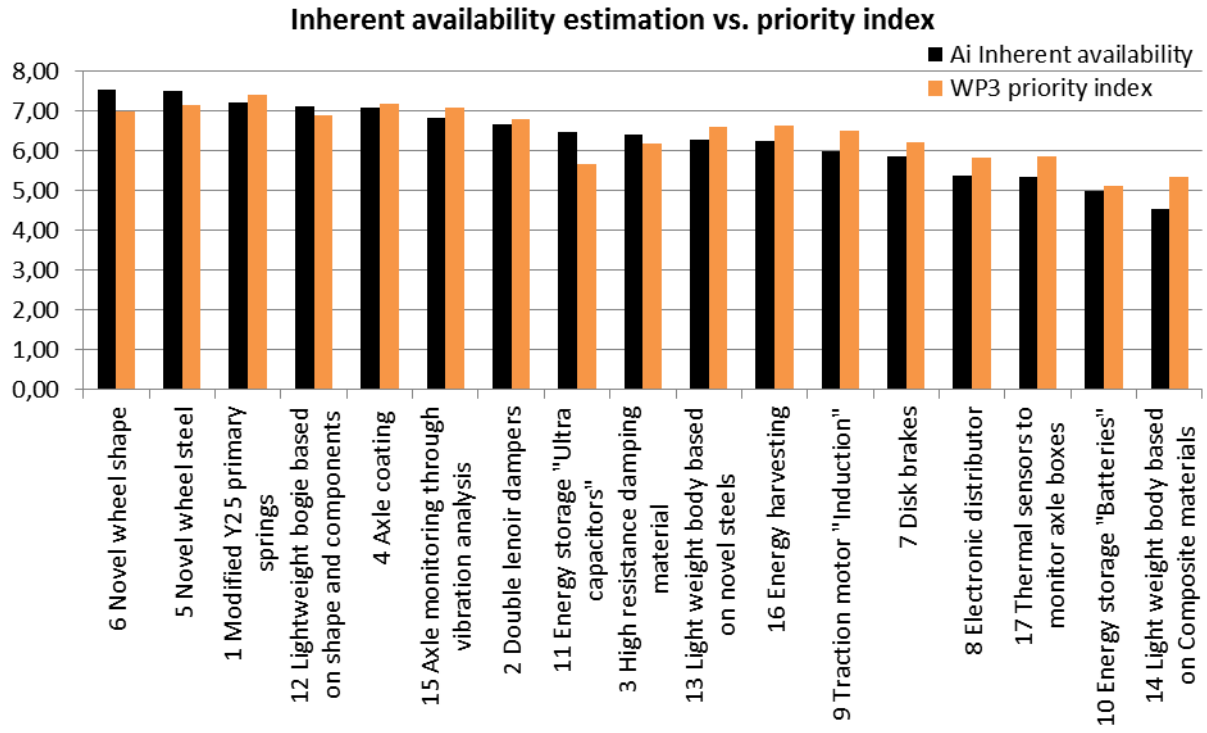


Figure 2.5: Inherent availability estimation vs. priority index of the WP3 innovation

2.7.3 Down time cost analysis

To analyse how the failure frequency and the maintainability effects the cost and the maintenance plan a scatter plot of the number of failures vs. MTTR can be used. A relative value of the MTTR was estimated in the previous section and the number of failures for a certain time interval could be estimated in similar way. A high score in the reliability assessment would result in a low score in the number of failures. Therefore the number of failures could be expressed as

$$nr_{failure} = 10 - R$$

By plotting the number of failures on a logged y-axis and the MTTR on a logged x-axis an estimation of the costs associated with a innovation and its reliability and maintainability can be visualised. Innovations that are plotted along lines -45° tilted from the y axis will generate the same amount of costs. In the following four figures the scatterplots can be seen for each WP1-3 group. In Figure 2.6 a combined plot of the groups can be seen.

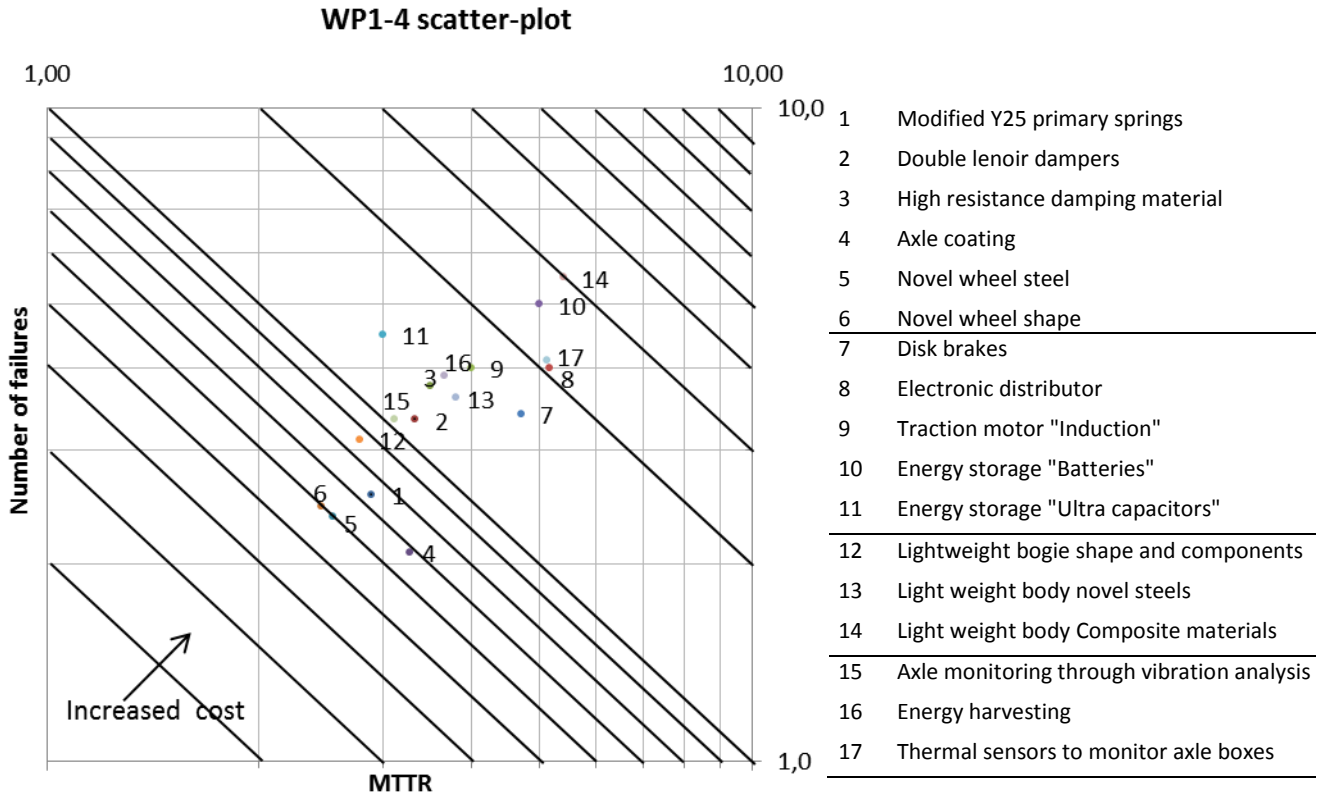


Figure 2.6: Number of failure and MTTR scatter plot of WP3.1-4 innovations

Note again that these are preliminary, illustrative findings only, and that the performance of each innovation will be assessed in the next phase of the research.

2.8 LCC estimation

The purpose with the LCC Life cycle cost analysis is to examine all cost elements for each component and for each life cycle phase and compare it with the expected gain, normally expressed in monetary terms recalculated to a present value resulting in a net present value (NPV). The NPV for the LCC phases R&D, Operation, Maintenance and Disposal could be expressed as

$$NPV = -RDC + \sum_{n=1}^{N} [(G - OC - MC) * FY(N, q, r_{no})] + DC * FS(N, q, r_{no})$$

where RDC is the research and development cost and production cost or investment cost. G is the expected yearly gain, OC is the yearly cost of operation, MC is the yearly cost of maintenance. FY is a factor for recalculating the yearly amounts to a present value and FS is a factor for calculating the residual value back to a present value from the end of the year N (life length of the system). The two factors are both functions of the asset life length (N), inflation rate (q) and the nominal interest rate (r_{no}). DC is the disposal cost or residual value which is multiplied by the factor FS for recalculating it to a present value. FS is a function of the. As an initial approach to estimate the LCC, the parameters in the assessment matrix of the WP3 innovations are used with the following relationships.

- $RDC = \frac{1}{2} \cdot [Production\ Cost + (10 - \text{Availability for Mass Production})]$
- $G = Gain$: Compliance with Duty Requirements
- $OC = (10 - \text{Sustainability (Energy consumption, damage)})$
- $MC = (10 - Inherent\ avaialbility \cdot 10)$
- $DC = Not\ includd\ in\ the\ analysis$

Note! The estimated maintenance cost MC is considered related to the non-availability and it's scaled by 10 to represent the non-availability in the region 0-10 comparable with the other estimates. The Sustainability is expressed in terms of energy consumption which is related to operation costs and damage which is related to an increased maintenance cost. The damage should be removed from this assessment.

The yearly present value factor FY and the factor FS for calculating the residual present value is calculated using the following equation

$$FY(N, q, r_{no}) = \frac{(1 + r_r)^N - 1}{r_r(1 + r_r)^N}$$

$$FY(N, q, r_{no}) = \frac{1}{(1 + r_r)^N}$$

where

$r_r = \frac{(1+r_{no})}{(1+q)} - 1$.

In the estimated LCC calculation the following values for the interest rate, inflation and life length where assumed.

$$\begin{cases} r_{no} = 6\% \\ q = 2\% \\ N = 30\ Years \end{cases}$$

The LCC estimation of the WP3 innovations is plotted in the following four figures for each group WP3-1 to WP4. Figure 2.7 shows a combined plot of all selected innovations of WP3.

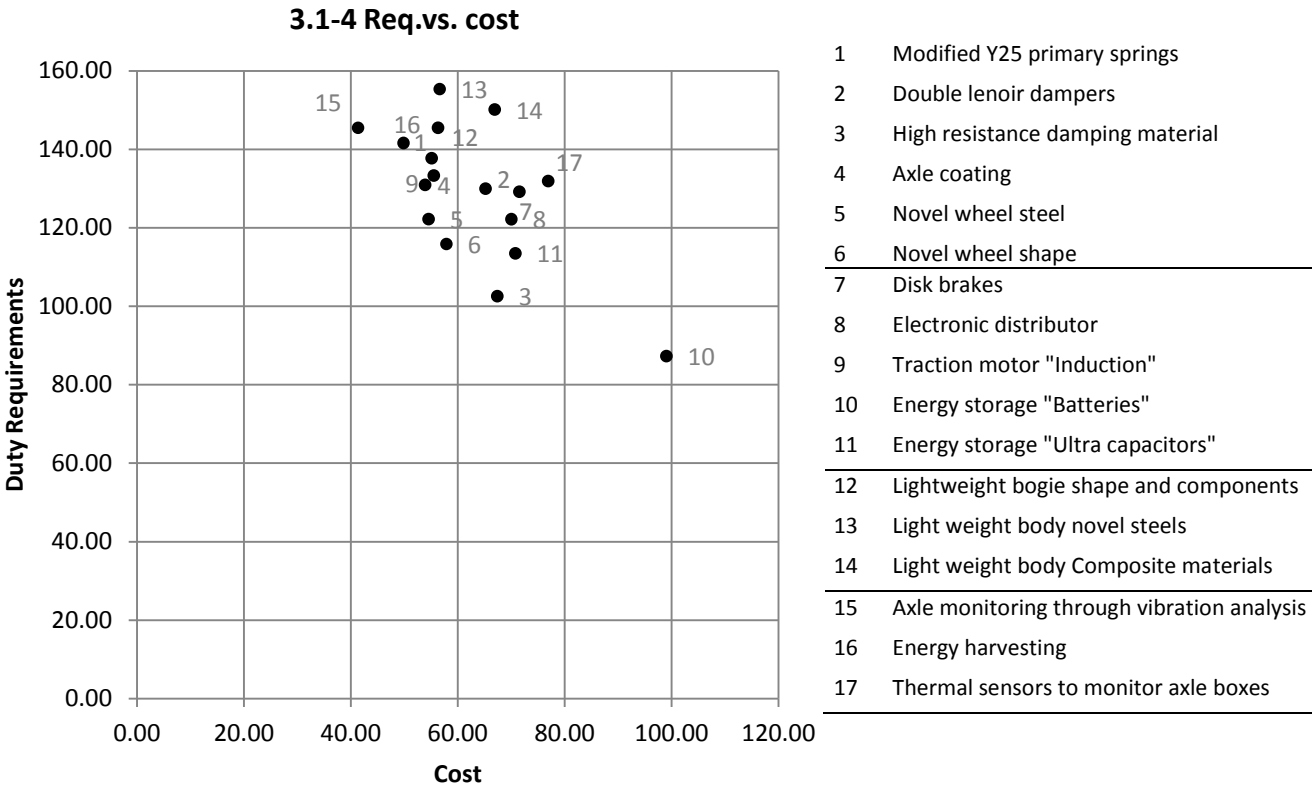


Figure 2.7: Duty requirement vs. cost for WP3.1-4

By plotting the duty requirement vs. the cost, see Figure 2.8, an estimate of the benefit per cost could be illustrated.

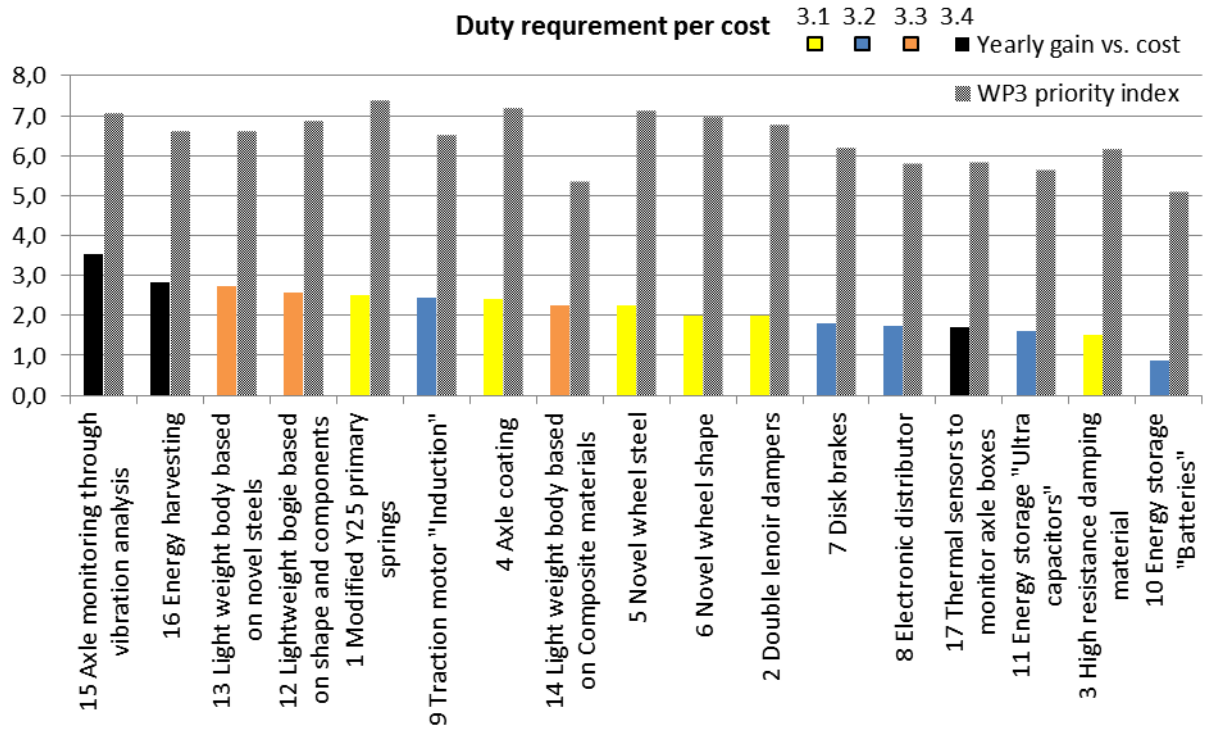


Figure 2.8: The yearly gain vs. the yearly cost is plotted in a deciding order from left to right together with the priority index of theWP3 assessment matrix

2.9 Conclusions

Based on the assessment data for the innovations/options found in WP3 a preliminary RAMS and LCC analysis of the innovations has been conducted in three steps, estimation of the impact on availability, down time cost analysis and LCC estimation. The estimations in the analysis are on a rather high level e.g. assuming that MTBF is equal to with the estimated value of reliability, and might be questioned concerning those innovations/options that will be sorted out because of low availability and/or high costs.

- **WP3 Assessment matrix:** The Sustainability is expressed in terms of energy consumption which is related to operation costs and damage which is related to an increased maintenance cost. The damage should be removed from this assessment and only be reflected by a changing operational condition which would affect the reliability parameter. Additional assessment parameters should also be added like How the innovation will affect the:
    a. Inspectability
    b. Corrective and preventive maintainability
    c. Inspection intervals
    d. Maintenance strategies
    e. Maintenance supportability
    f. Safety
    g. Etc.

- **Availability assessment.** The estimated effect on the inherent availability follows in principle the weighted priority index of the WP3 assessment matrix. A more detailed study of the availability should include measures of real values of MTBF and MTTR. It should also include, not only the downtime due to corrective maintenance, it should include the downtime due to preventive maintenance and logistic delays.

- **Down time cost analysis.** By examining the plot in Figure 1 in Appendix 2 for the WP3.1 innovations the high resistance damping material (nr3) is associated with the largest estimated impact on the down time cost. It has a higher estimated number of failures and a repair times compared to the other innovations. The novel steel and shape innovations (nr5&6) has the lowest estimated impact on the down time cost due to failures. For WP3.2 the Energy storage battery (nr10) is associated with the highest costs and the disc brake (nr7) and the energy storage (ultra-capacitors) (nr11). For WP3.4 the composite body (nr14) has a higher associated cost compared to the innovation dealing with a light weight body based on shape and components which has the lowest cost due to failure driven down time in this group.

- **LCC analysis:** Scatterplots of the requirement and the estimated cost can be seen in the 5 figures before Figure 2.8 for all innovations and for each WP3 group. From the scatterplots the innovations which generates the highest complains to the duty requirement vs. cost can be identified. This analysis can also be done in Figure 2.8 where the requirement/cost is plotted. When examining Figure 2.8 and the first six innovations, related to WP3.1 (Running gear), the modified spring (nr1) resulted in a larger gain/cost compared to (nr3) high resistant damping material. For WP3.2 Traction and braking the induction motor (nr9) generates a larger gain compared to (nr10) Battery. For WP3.3 the light weight body based on steel (nr13) resulted in a higher benefit score compared to the light weight body based on composite material

than (nr14). When analysing WP3.4 condition monitoring the vibration measurement system (nr15) showed a higher value compared to the thermal sensor system for the axel-box (nr17). When comparing the yearly gain/cost, which is sorted in Figure 2.8 with a deciding order from left to right, with the WP3 priority index one can conclude that the correlation is smaller compared to the inherent availability vs. WP3 priority index plot in Figure 2.5.

- By analysing Figure 2.8 the following innovations where listed as number one for each group.
  - ✓ WP3.1 Modified Y25 primary springs
  - ✓ WP3.2 Traction motor "Induction"
  - ✓ WP3.3 Light weight body novel steels
  - ✓ WP3.4 Axle monitoring through vibration analysis

- It is difficult to estimate a LCC value by only using estimated relative values of the parameters presented in the WP3 assessment matrix. If the model and the data input could be refined and tuned by using real values and relations between the different cost elements and LCC phases a better assessment could be made.

NOTE! It is important to note that differences in the assessment could be due to inaccuracies in the input data or inaccurate assumptions in the model. Results based on relative assessment measures should always be analysed in more detail before the decision stage.

3. USER AND ENVIRONMENTAL BENEFITS: OVERVIEW OF METHODS

3.1 Introduction

The scope of the work is to provide the following elements of the Business Case:

- freight benefits of improved freight vehicles and track, in terms of: improved reliability; increased availability of services; increased speed and quality; reduced cost of service;
- passenger benefits in terms of the value of increased path capacity;
- CO_2 impact;
- noise impact if measurable;
- any other relevant environmental impacts.

The first of these will require an analysis of freight demand in each of the case studies, with the ability to represent the freight flows in the reference case and with the improved vehicles & track in place. The second will require a passenger service model (and is the subject of Task 5.2.3). The third, fourth and fifth will require estimates of emissions rates from freight vehicles and track (including life cycle emissions), and methods to estimate the associated damage costs – we plan to follow HEATCO practice [1].

3.2 Treatment of reliability inputs from RAMS

3.2.1 Background

In Task 5.2, there will be an analysis of future freight demand, with and without the SUSTRAIL innovations in place. This will be driven by changes in the cost, quality and availability of freight services[2], and the predicted changes in cost, quality and availability will be drawn from the LCC and RAMS modelling in Task 5.1.

One element of quality that is particularly important for freight users is reliability, and this affects their valuation of the freight service and their mode choice between road and rail (e.g.[35]). Table 3.1 summarises the most important quality factors based on a review of UK studies.

[2] as described in D2.5 [39]

Attribute	Ranking
Reliability	1
Scheduled transit time	2
Flexibility (in departure time)	3
Control/tracking	4
Security	5
Ease of (un)loading	6
Environment	7
Damage	8
Equipment availability	9

Source: [36] quoted in [35]

Table 3.1: Important freight transport quality attributes

In demand analysis, the influence of reliability on demand is represented by a *value of reliability* in one form or another (different forms are considered below). In SUSTRAIL we need to link that to the prediction of reliability coming from the RAMS model.

This section develops the approach to reliability that we plan to take in Task 5.2, for the UK case study and for the methodological recommendations for the other case studies. Covered here are:

- definition of reliability for demand modelling purposes;
- how this would link to the RAMS model in Task 5.1;
- form of the demand model;
- evidence on key parameters;
- data requirements;
- links to next steps within the project.

3.2.2 Definition of Reliability in Task 5.2

In the Business Case, we need to define reliability in a way which reflects freight users' requirements from the rail freight system. Their demand for rail freight is what will drive revenues and user benefits – hence profitability and the socio-economic case for investment[3].

The research evidence indicates that freight users are sensitive to:

- unexpected delay time – when a shipment arrives late at its destination, compared with the schedule, for any reason;

[3] note: vehicle reliability may also affect the cost of freight operations – not only service quality. For example, wagon unreliability may require an operator to reduce the length of a wagon rake (train) at short notice - leading to inability to ship the full desired quantity on occasions, *or* to use of road transport for the residual, at higher cost, or to pay leasing costs for larger wagon fleets than would be necessary if wagons were more reliable. Wagon unrealiability will also, obviously, influence wagon maintenance costs. Hence reliability can impact on Life Cycle Cost of the freight system, not only Reliability, Availability, Maintainability and Safety.

- schedule delay – where freight operators extend the schedule, inserting additional journey time in order to reduce the probability of unexpected delay.

In order to measure unexpected delay time and schedule delay, it is necessary to have measures of[4]:

- scheduled journey time (base), $\hat{J}_0$
- actual journey time, J_0
- scheduled journey time (after rescheduling), $\hat{J}_R$

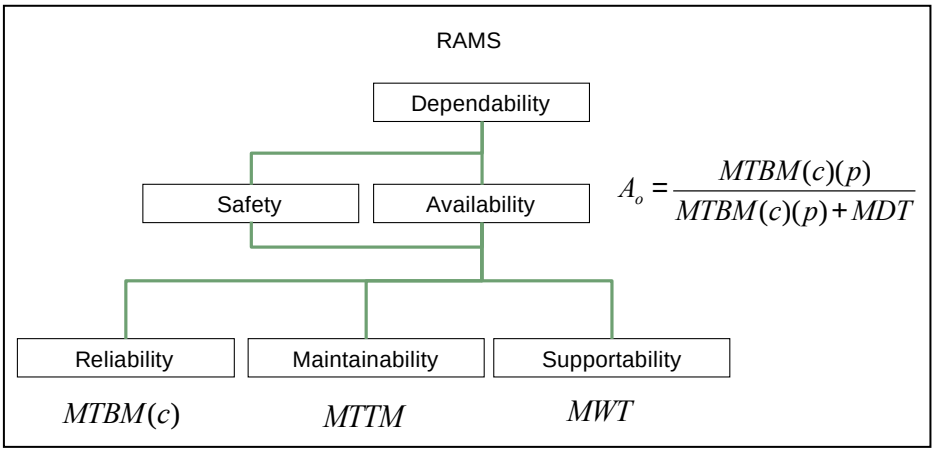
Hence unexpected delay time $DT = J_0 - \hat{J}_R$ and schedule delay $SD = \hat{J}_R - \hat{J}_0$.

When dealing with data on journey time across large numbers of trips, it is useful to have metrics which describe the distribution of journey times, and in this case we might describe the distribution of J_0 in terms of:

- mean journey time, $\bar{J}_0$
- spread, or standard deviation, σ_{J_0}

3.2.3 Links to the RAMS model (Task 5.1)

The structure and methodology for the RAMS model described by LTU includes a wide range of possible indicators, covering: dependability; safety; availability; reliability; maintainability; and supportability.



Source: [37]

Figure 3.1: RAMS model proposed structure

In order to value the freight user benefits of the SUSTRAIL innovations in Task 5.2, we need input data on the change in overall reliability of freight service from Task 5.1. As defined in the previous section, we are particularly interested in: any change in overall journey time leading to a later arrival at destination; and in extreme cases non-provision of the freight service.

[4] note that the use of subscript 0 is to indicate the Do-Minimum scenario, without the SUSTRAIL innovations. The subscript 1 will indicate the Do-Something scenario, with the SUSTRAIL innovations in place.

For example, suppose the SUSTRAIL innovations lead to:

- reduced frequency of preventive track maintenance (increased MTBM);
- reduced frequency of track faults leading to reduction in temporary speed restrictions (increased MTBF and MTBM(c));
- reduced frequency of faults on vehicle wheelsets (MTBF)

... the RAMS analysis will combine these to provide reliability/availability/dependability impact for the system as a whole. The question is: what is the best indicator or indicators to transfer from RAMS to the user benefit analysis in Task 5.2?

3.2.4 Form of the demand model

The demand model will use changes in *generalised cost*, combined with *generalised cost elasticities* to predict the influence of service quality on rail freight demand over time. This will allow for variation from an exogenous time trend, based on SUSTRAIL-specific factors.

Generalised user cost, G, for freight can be written

$$G = C + v_a J_a + v_b J_b + ... + v_x X$$

where C is the money cost of freight service (in €);

v_a is the value of freight journey time component a, for example a is scheduled journey time;

v_b is the value of freight journey time component b, for example b is delay time compared with the schedule; and

v_x is the value of any other service quality component X, for example v_X may be a cancellation penalty and X the probability of cancellation.

Generalised cost elasticities are defined

$$Elas(T,G) = (\partial T / \partial G)(G / T)$$

where T is a measure of demand, such as tonnes or tonne-km;

∂ indicates a small change.

Essentially, the demand function uses the generalised cost change due to the SUSTRAIL innovation, and the generalised cost elasticity, to predict the new demand

$$T_1 = T_0\left(1 + \left(\frac{\partial G}{G_0} \cdot Elas(T,G)\right)\right)$$

This is a simplification of the model structure likely to be used, but highlights the need for data on journey time components and service availability/cancellation.

3.2.5 Evidence on key parameters

Key parameters in the user benefit assessment in Task 5.2 will be marginal values of delay time, which would be applied to any changes in delay as a result of the SUSTRAIL innovations, and generalised cost elasticities. Tables 2 and 3 show research-based values that are likely to be useful in the SUSTRAIL case studies. The values in Table 3.2 need to be

updated to 2015 prices and values and converted to €. The elasticities in Table 3.3 need to be checked for transferability.

Commodity group	Value (£/minute/tonne)
Food, drink and agriculture	0.013
Coal and coke	0.005
Petroleum	0.010
Ores and metals	0.004
Construction	0.006
Chemicals	0.010
Others	0.013

Source: [23]; Note: 2003/4 values

Table 3.2: Values of delay time

Reasons for the differences in values of delay appear to include lower inventories/quick response/just-in-time production and perishability in some sectors.

Commodity group	Elasticity
Food Products	-1.4990
Lumber, Wood, and Wood Products	-1.2816
Chemicals	-1.0534
Primary and Fabricated Metal Products	-0.9084
Rubber and Plastic Products	-1.2348
Stone,Clay and Glass Products	-0.9558
Electrical Machinery	-1.1644

Source: [21]

Table 3.3: Generalised cost elasticities

3.2.6 Data requirements

It is clear that Task 5.2 needs an overall measure of rail freight reliability, using the types of variables defined in section 3.2.2, extended to include the probability of complete non-availability/cancellation of freight service. We can narrow the data requirement by focusing on containerised traffic[5]. In Table 3.2, for example, we expect the relevant categories to be 'Food, drink and agriculture' and 'Others'.

[5] or more widely on certain types of traffic for which the wagons used are the wagon types being developed in SUSTRAIL (UIC Class R&S)

Bilateral discussion between Tasks 5.1 and 5.2 have agreed it will be possible for 5.1 to provide 5.2 with a top level reliability measure of the type discussed here. For the UK case study specifically, the LEFT model requires 'average late time (mins) at destination for freight trains' (see Chapter 6).

We also anticipate some averaging and/or use of a 'representative trip' on particular route/train types, since the RAMS model cannot model every single combination of route and train type on the network.

From a freight user point of view, the following breakdowns are of interest – but they may or may not always be available:

- by commodity group – e.g. see Table 3.2;
- by distance – this plays an important role in the LEFT model to be used in the UK case study and is of particular interest – demands are calculated by distance bands, and the evidence indicates that many values and parameters vary by distance on rail.

From a modelling viewpoint we also expect some differences in reliability, availability, maintainability and safety impacts due to these factors:

- by line standard – e.g. typical mixed passenger/freight line; typical freight only line (single/double track);
- with freight trains operating at max speed 140kph (UK), OR 120kph or lower (UK) for modelled years – e.g. 2015 and 2030.

Again, there are likely to be limits to the disaggregation that can be provided in the RAMS data.

3.3 Treatment of other user benefits

3.3.1 Journey time

Increased speed is a stated goal of SUSTRAIL, and a high priority duty requirement is to achieve a modest increase in maximum freight operating speeds, e.g. from 120 to 140km/h in the UK case study; and from 100 to 120km/h in the Spanish and Bulgarian cases (Table 1.4).

The analysis of user benefits from reduced freight journey times will follow the same framework as for reliability above, i.e. a generalised cost formulation, combining values of freight time savings with the change in freight time, all within a consumer surplus change measure, the 'rule of a half':

$$\Delta CS_{it} = 0.5\left(G_{it}^{0} - G_{it}^{1}\right)\left(T_{it}^{0} + T_{it}^{1}\right)$$

where

i signifies a particular market segment, such as Food, drink and agriculture;

0 and *1* superscripts signify the baseline and the 'with SUSTRAIL innovations' scenario respectively, in year *t*.

Values of freight travel time are country-specific, although it is advisable to check for plausibility against the European values presented in HEATCO [1] and IMPACT [3].

We expect to rely on the IMs represented in SUSTRAIL for data on the average speed implications of a change in maximum speed, since stopping patterns and interactions with other traffic are likely to be affected, and the relationship with average is therefore complex.

3.3.2 Freight service charges

When the cost of rail freight service to the end user decreases, this also creates user benefits, and again the generalised cost function in 3.2.4 and the 'rule of a half' benefit measure in 3.3.1 may be used to make the calculation.

It is worth noting that the sources of a reduction in freight user charges may lie in:

- reduced fuel or non-fuel operating costs to the Freight operator – for example if the SUSTRAIL vehicle has a lower energy requirement to achieve the same performance;
- reduced track access charges by the IM – potentially reflecting reduced infrastructure costs, although note that <100% of track costs are covered (or are ideally covered) by variable charges – for example if the SUSTRAIL vehicle reduces track damage, then this should feed through in reduced variable track access charges, although not in the same proportion (see Chapter 4);
- reduced vehicle maintenance expenses.

The cost changes above are all essential components of the life-cycle cost of the vehicle-track system as a whole, and the LCC analysis (Task 5.1) is key to their calculation. Meanwhile, the track access charges and charges to the end user give rise to revenues for the recipient, and these financial flows also need to be taken into account in the CBA framework (Chapter 9).

3.4 Passenger capacity benefits

These relate to the UK case study only in SUSTRAIL. This analysis was planned in order to represent impacts arising on the more congested mixed passenger/freight networks in the EU.

As well as freight user and environmental benefits, there may be infrastructure path capacity benefits from freight trains running closer to line speed. Thus paths maybe freed up for either further freight or passenger services. Valuing specific paths is a very involved task since it depends on the exact mix of services and passengers using the route and the precise capacity constraints on the route. As such we do not propose to undertake capacity assessment for all of the case study routes. We will undertake one case study for valuing freight paths. It is hoped that the results from this case study can be used to inform the likely value of capacity savings in other case study routes.

The aim of this work is identifying an appropriate rail scarcity charge which would make freight and passenger operators pay for their use of rail capacity in line with the opportunity cost of the use of these slots.

Charging for scarce capacity would require estimation of the opportunity cost of a slot. The most attractive solution to this problem in theory is to 'auction' scarce slots.

Currently within UK, operators are not charged for the use of scarce capacity and this leads to an excess demand for slots. A more efficient use of resources would be with slots allocated to operators based on their willingness to pay, subject to an appropriate subsidy regime internalizing other externalities. Our work sets out an approach that could be used in future studies.

The appropriate scarcity charge is added to the access charge for operators of these slots. After the imposition of the optimal charge, and the addition of a subsidy regime to internalize other externalities, the operator with the highest willingness to pay will be the only one, in the short-run, who can afford to use the slots. In this way, the imposition of charging has the same effect as the outcome of an auction (again with the appropriate subsidy regime in place). If the

allocation of slots was undertaken by the regulatory authority, based on the same appraisal as ours, then again, the outcome would be the same as from the charge. Thus the choice between the three approaches is ultimately a matter of practicality and administration costs, rather than of theoretical correctness.

For the case study analysis, we have focused on a section of the West Coast Main Line north of Lancaster up to Glasgow for a number of reasons:

- It is an important and heavily utilized part of Britain's rail network where scarce capacity is a problem
- On the West Coast Main Line there is a degree of competition for slots on the network between operators with overlapping franchises and freight operators.
- This stretch of the route is a single line in each direction, with slower freight mixing with fast passenger services, ie Glasgow <> London, Glasgow <> Manchester Airport and Birmingham <> Glasgow. Currently there are 3 passenger trains per hour and around 27 freight trains per day in each direction. The demand for freight on this stretch of line is growing (most of it containerised traffic), with forecasts of 36 per day in 2019. There are upgrades currently in progress to accommodate this demand, introducing more passing loops. Some freight speeds are also constrained by not using electrified locomotive stock. By 2019 it is planned to accommodate 36 freight trains per day, up to 48 per day in 2030.
- Passenger operators would like a fourth path per hour and a more regular interval timetable. If freight could be speeded up there is clearly potential for a fourth path and considerable benefits from this freed up capacity, which can be modelled using PRAISE[6].

In order to undertake this analysis the intention is to use the PRAISE rail forecasting mode ([32]). PRAISE forecasts rail demand between Origin destination pairs on a network as well as for individual services and ticket type, taking account of fares, journey times, desired departure times and overcrowding. It is very useful for looking at issues concerning capacity as well as competition between different operators.

There are four stages to the calibration of the demand model.

- Estimation of the generalized cost of travel for each return service and ticket combination.
- Calibrating ticket specific constants to ensure that the base market shares can be replicated.
- Setting the sensitivity of the model to replicate known elasticities of demand.
- The final stage iterates to adjust for overcrowding on trains.

An upper level of the model scales overall changes in rail demand following service level changes based on generalized journey time elasticities as estimated in the standard British rail demand forecasting model.

The cost model employs a cost accounting approach incorporating costs that are related to operating hours, costs that are related to train kilometres and fixed costs.

PRAISE yields results for changes in consumer surplus, operating profits, modal switch values and vehicle kilometres, which can be used in conjunction with external cost valuations to undertake an appraisal.

Data requirements for this work include the following:

[6] The number and overall day/night spread of freight paths is assumed fixed for the purposes of this analysis.

- Demand information for each OD pair on the network will be taken from passenger loadings based on the National Rail Traffic Survey.
- Costs will be based on average costs per train km from previous work.
- Generalised Journey Time Elasticities will be taken from Passenger Demand Forecasting Handbook (PDFH), based on Revealed and Stated Preference research.
- Values of time and adjustment time will also be taken from the PDFH, based on Revealed and Stated Preference research. The value of time used was a weighted average of business, leisure and commute time values.
- The model uses 'departure time profiles' (as used in the MOIRA model) to generate desired departure times for each simulated individual.
- Crowding Penalty valuations are taken from the PDFH and are in pence per crowded minute of journey, varying by route, and degree of crowding.

Data acquisition is in hand (with DfT and Network Rail), a suitable case study area has been identified, and discussions have been held to confirm the proposed methodology.

3.5 Environmental benefits

The main categories of environmental benefits to be measured and taken into account are:

- CO_2 impacts;
- noise impacts;
- various regional and local air pollutants such as CO, NOx, SO_2 and particulates (PM_{10}).

Emissions models tend to be country specific, since the vehicle fleet, driving conditions, and the pattern of residential development around rail lines vary widely. For CO_2, the aim is to measure the change in emissions in each year of the appraisal period (see Chapter 9) due to the SUSTRAIL innovations versus a Baseline scenario. This calculation reflects the fact that is does not matter where the pollutant is released, the impact (via climate change) is global. Methodology is well established, and for example the UK has a spreadsheet tool capable of estimating the CO_2 emissions impact of many realistic policy options [33]. By contrast, there is no standard method for quantifying the impacts of noise or air pollution across the EU, although advice is available in the IMPACT study [3] and once national methods exist in a few EU countries. Suitable values for these pollutants are available from HEATCO [1] and from the EU 'IMPACT' study [3].

Generic safety values are available from the same sources (HEATCO and IMPACT) if required – i.e. if Task 5.1 predicts any impact on safety from the SUSTRAIL innovations. The specific marginal value of reduced derailments is available from [31].

4. TRACK ACCESS CHARGES

A key economic variable at the interface between train operators and infrastructure managers is the charges that are paid by the operators to access the infrastructure. If these are properly aligned to the damage caused to the infrastructure by a particular vehicle and the network capacity that it consumes then access charges can provide a strong incentive for operators to use rolling stock which minimises whole system.

The SUSTRAIL project includes a task which seeks to enhance understanding of the variability of track damage cost (measured by the remedial work of maintenance and renewal activity expenditure by the infrastructure manager) to the usage by vehicles.

The output of the task will be Deliverable 5.3 due at the close of August 2014. As such this section primarily discusses the data and methods that will be used in subsequent analysis. Further the understanding of existing access charge regimes is used directly in this deliverable as a means of allocating changes in costs and benefits between freight operators and infrastructure managers.

The structure of this section is as follows. 4.1 provides brief background on existing access charge regimes in the EU and in the three case study countries. 4.2 then outlines the interactions between the access charge research stream and the wider Business Case assessment for the purpose of allocating costs and benefits between operators and infrastructure managers. 4.3 sets out the progress made on the three streams of SUSTRAIL research on access charges.

4.1 Existing access charge regimes and implications for the interim Business Case

For each case study country we outline the key features of the access charging system. Figure 4.1 also presents a comparison as to the level of freight access charges across a number of European countries. As can be seen Spain (SP) generally has lower access charges for a given weight of train, while Great Britain (UK) has roughly average charges and Bulgaria (BG) has relatively high charges.

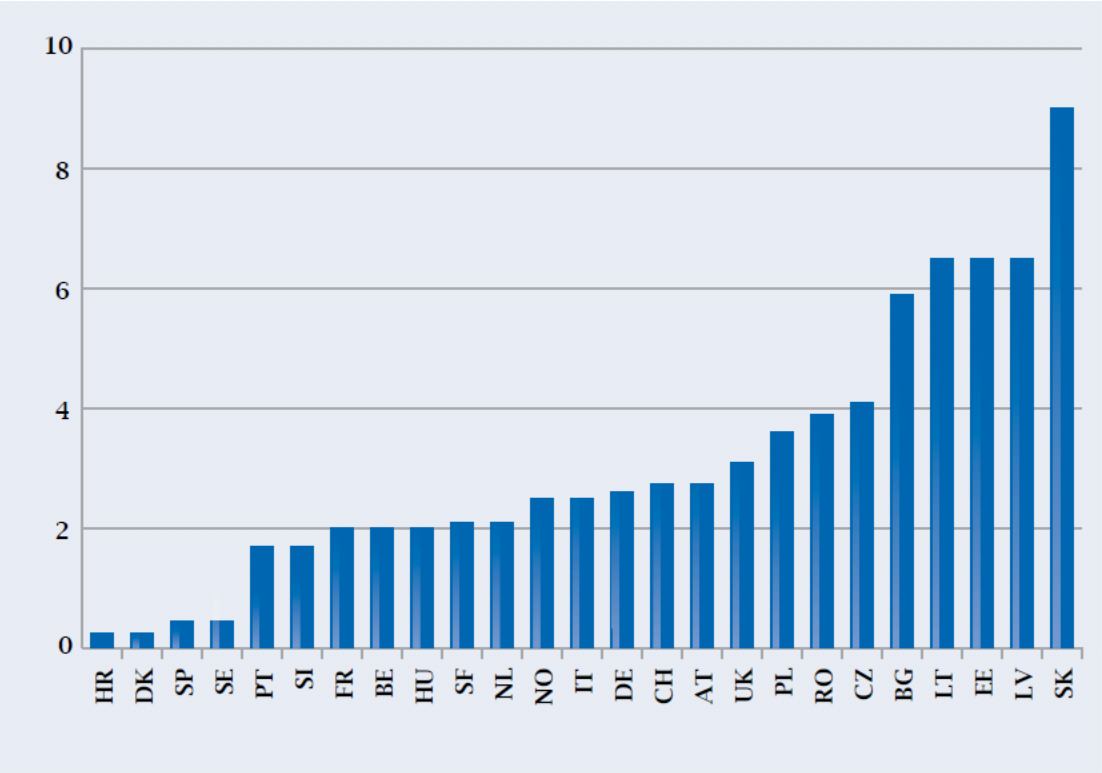


Figure 4.1: Access Charges for a typical 960 Gross Tonne Freight Train (Euros/Train-Km) in 2008

Source: [24]

Bulgaria

Source: [25] and [24]

- Charges comprise three core elements: A path reservation fee, a fee per train-km and a fee per gross tonne-km
- Charges are different for freight and passenger trains
- Freight charges: € 0.65/train path plus € 1.9/train-km plus € 0.0020/gross ton-km in 2003
- From 2007, freight charges were reduced by 10%
- Overall 65% of infrastructure costs are recovered from levying access charges on both passenger and freight traffic in 2003

Great Britain

Source: [25] and [24] and Network Rail

- The principle of freight access charges is to recover the additional wear and tear costs associated with the infrastructure from running the freight service
- This is different to (franchised) passenger traffic which also pay a contribution to fixed charges
- Charges are levied per vehicle-km. However each vehicle has a different charge rate depending on its characteristics and how these influence infrastructure damage
- Damage determined by relative vertical forces applied by vehicles
- This factor is now being extended to take account of the propensity of the bogie to cause lateral rolling contact fatigue damage. Vehicles are divided between 7 different bands, according to bogie type, which affects the level of charging.

- Approximately 10% of maintenance and renewal expenditures are recovered through (variable) track access charges [26].

Spain

Source: [27] and [24]

- Freight charges different to passenger charges
- Charges comprise of a reservation charge per train path and then a train-km charge
- Charges differ by time of day

In addition to surveying the actual charges imposed by infrastructure managers, we have also surveyed the literature on best evidence on actual variability of infrastructure costs to train usage. This is important since it provides high level evidence as to what proportion of infrastructure cost can be thought of as 'in scope' for change following vehicle improvements.

The CATRIN project [28] was the last EU project to bring together research from a variety of case studies to produce findings which can be generalized. It produced a set of recommendations relating to the extent to which infrastructure costs vary with traffic. For maintenance and renewals costs it was recommended that 35% be used in the absence of other evidence.

4.2 Implications for D5.5

Given the strategic nature of the current assessment, it is recommended that the interim cost benefit analysis utilises the best evidence value of 35% cost variability. As a worked example consider a vehicle improvement that reduces vehicle track damage by 10%. This should reduce maintenance and renewals cost by 3.5% since only 35% are damage related. As the vehicle-track modelling in WP3/4 progresses, then we can substitute this assumption for better context specific information.

4.3 Methodology for developing the SUTRAIL access charge research

There are three distinct sub-tasks under this heading. These are:

4.3.1 Sub-Task 5.3.1 – Statistical analysis of engineering simulation outputs

The aim of this work is to try and add to the state of the art in understanding how different damage types affect maintenance and renewals cost. In particular it is well known that some damage actually reduces the effects of other damage (for example the presence of heavy freight trains reduces the need for rail grinding to address the effects of rolling contact fatigue from high speed passenger trains). Thus while engineering models are very accurate in predicting each damage type, it is often not feasible to model explicitly the interactions in all scenarios. The aspiration of this work is to use statistical analysis to relate cost to measures of different damage types for a number of track sections. This should provide a useful summary equation as to how cost relates to the damage mix which can be applied to other track sections. This is difficult to produce from engineering model alone.

We have identified a number of track sections in Sweden and are seeking data from the infrastructure manager. We have agreement from the infrastructure manager to provide data. We have chosen to explore data possibilities with Sweden given our good contacts there and the fact that we know that the cost data is sufficiently disaggregate to allow such analysis.

Once data has been obtained we will begin engineering simulation model runs to generate the data for statistical analysis.

4.3.2 Sub-Task 5.3.2 – Using the econometric approach to undertake a series of country specific case studies aimed at better understanding the variability of cost with respect to traffic

Here we have particular emphasis on understanding renewals costs. Given the complex relationship between traffic and renewals (long asset lives; cyclical nature of renewals), new research is needed. We have several new datasets for use in this task.

Switzerland – We have data on 120 track sections from 2003-2012. This is a very rich panel dataset which allows us to look at a variety of interesting issues. First we have traffic data for 7 traffic types including 2 freight train types (long distance and other freight trains). This should help us provide more econometric evidence regarding difference in cost by type of trains. Secondly the length of time we have the data over (10 years) should help us get a better handle on renewals cost variability (this is more challenging than maintenance cost given that we have that renewals cost depends on cumulative traffic).

Great Britain – We have maintenance and renewals costs for relatively aggregate zones comprising the GB network (between 6 and 10 zones depending on the year) from 1995 to 2010. The length of this panel will hopefully allow for a better investigation of renewals and maintenance cost interactions.

Sweden – We have data on renewals costs at track section level and, importantly, we are developing a measure of cumulative tonnage usage for each track section (as opposed to in year tonnage usage). This new data is a real innovation and should help us model renewals expenditure in a much more theoretically consistent manner than simply relating current expenditure to current traffic levels.

4.3.3 Sub-Task 5.3.3 – Research into the effectiveness of differentiated access charge in influencing market behaviour.

The aim is to understand what impact (or not) different access charge regimes already in place within Europe have had on the behaviour of various industry players and how changes to these regimes, particularly in respect of differentiation by vehicle, would influence future behaviour. We will review the experiences in the market of introducing differentiated access charges (such as in Britain and Austria) through desk reviews and interviews with key industry members. We are also undertaking a similar (desk) review for New Member States.

5. TECHNICAL IMPLEMENTATION AND PHASING

5.1 Introduction

This task (5.4) will analyse the impact on the case study routes of implementing the proposed technology from WP3 (vehicle) and 4 (Track).

Task 5.4.1: Considers track technologies and issues that arise from their implementation.

Task 5.4.2 : Considers vehicle technologies and the issues that arise for their implementation.

Task 5.4.3 : Considers training, new skill requirements and the opportunities for automation.

Task 5.4.4 : Considers the impact on freight operations of the optimised train and other identified innovations.

It must be noted that there are opportunities to implement either a track or vehicle technology or combine both together. The approach taken will be dependent upon business case, but a higher resilient track running a less damaging vehicle should offer a greater benefit than the sum of the two technologies considered separately.

5.2 Novel rail technologies, interface and track stiffness knowledge and issues

The following innovations (of varying levels of technical maturity) are to be considered within SUSTRAIL. Some of these innovations are currently being trialled and therefore more accurate information has been available, others are still in early stages of development. Implementation issues have been considered, particularly staff training, compatibility with existing infrastructure, maintenance and adherence to standards. All of the innovations have been grouped together into the following themes.

Automated Inspection – These technologies generally allow more asset information to be processed than previous methods or provide a greater certainty of installed condition. Once these processes are validated and proved to be robust they generally require less judgement / intervention by the workforce, whilst providing monitoring of standard adherence and specifications. Inspection techniques generally have no issues regarding compatibility with existing infrastructure, but new or old infrastructure components need to be validated to ensure that all problems can be detected or else other inspection techniques would still be required and this would severely impact the business case of the new inspection process.

1. Plain Line Pattern Recognition – This project is currently under trial on the NR West Coast Main Line and will offer cost savings and safety improvement from the reduced need to have manual track patrols, therefore freeing up resource to either save or use on maintenance activity. The system currently being trialled by NR can cover up to 800km of track in one shift and uses a bank of seven cameras fitted under the train take high resolution photographs every 0.8mm, at speeds of up to 200kph. In addition to these, four laser cameras record the profile of the track every 20mm. Inputs from geometry measurement systems to provide valuable information about the track while it's under load and it also includes an automated ballast shoulder measurement system to support hot weather preparation. Captured data is automatically processed to identify any broken, missing, misaligned or damaged track components and in third

rail areas, thermal imaging cameras look for loose connections. Every fault is given a precise GPS location stamp.

2. RCF and crack detection – Projects are underway for improved ultrasonic testing for managenese crossings via a Synthetic Aperture Focusing Technique and for High Speed Alternating Current Field Measurement system to detect RCF and cracks in plain line from a test train, both projects due to complete concept proving by the end of 2013.

3. RCF and crack detection via Eddy Current and Ultrasonic testing - Move towards greater use of train based inspection techniques to reduce the risk from putting staff on track to carry out testing / inspections. The train based Ultrasonic Test Unit is a fleet of 4 vehicles that cover primary routes every 8 weeks, secondry routes every 16-24 weeks and rural routes annually. They are equiped for crack detection, rail profile and wear monitoring, geometry monitoring and ground probing radar. Sperry Railpix captures high definition video images at locations where a suspected defect is detected.

4. Use of handheld technology to make defect location easier and improve the accuracy of data being captured on the track to automatically populate defect management and work planning systems. System rolled out from late 2012.

5. Use of longitudinal, guided wave ultrasonics for the inspection of rails in level crossings to reduce the need to lift and remove surface systems to inspect the rail. Also being evaluated for use in S&C to detect the presence of transverse defects in the head, web and foot of switch blades which can be difficult to test using conventional contact ultrasonic techniques. Trial under development on NR LNE region.

Materials – New materials require thorough validation against performance, safety and life cycle requirements. This can sometimes lead to revised technical standards. New materials have to be clearly identified so that any particular installation, inspection or maintenance processes can be observed and appropriate training given to the workforce. Compatibility with existing infrastructure can be an issue, which needs careful management to ensure any interfaces are maintained to the designed intent.

6. Premium Rail Steels – These have been trialled in a number of high wear/RCF sites to increase rail life based upon the use of predictive tools such as Track-Ex. The premium steel rail cost is higher than standard materials by around 15%, but trials over 24 months have indicated whole life benefits from reduced grinding and inspection frequency and extended life leading to reduced replacement cycles. Trials are also under way using Premium Rail Steel for S&C full depth switch rail, the project is due to report late 2013.

7. Use of novel materials – Plastic sleepers are under development by a number of suppliers and will be subject to an NR procurement tender later in 2013. Potential applications will include standard sleepers and S&C bearers. The unit cost of plastic / composites over wood types is higher (potentially double the cost), but this may be offsett by increased life span, claimed to be circa 50 years, resulting in overall whole cost savings from reduced installation frequency.

8. Rail anti-corrosion coatings – e.g. for Dawlish Sea Wall and Severn Tunnel to improve rail life. Trials underway with zinc based and resin based systems, but there are problems ensuring the coating is not damaged by rail handling etc.

9. Investigate alternative materials for crossings and other rail components – Proposals to develop hardened manganese steel alloy machined crossings in place of cast manganese parts for cost and life benefits and explosive depth hardened crossings. Trials including small welded sections underway in 8 NR locations, results due by 2015. Trials for full machined crossings to be developed.

Track Stiffness – Transitions of track stiffness is probably more important than the actual stiffness achieved. As techniques to model and monitor track stiffness are to be developed and may drive new standards. Compatibility is not an issue as techniques to manage track stiffness are well understood and will be added to as new techniques emerge. Perhaps the greatest impact will affect the workforce in understanding what needs to be done and when to maintain the required performance.

10. Dynamic measurement of variations in track stiffness to identify locations with abrupt changes in loaded deflection that give rise to high track dynamic forces. This will allow improved transition design guidelines to be devloped and allow timely maintenance to be undertaken based upon detection of deterioration. A project has been funded to develop a system to measure overall track stiffness rather than just ballast / formation stiffness from a rail vehicle running at speed via Technology Strategy Board 'Accelerating Innovation in Rail' programme. This project is due to complete late 2013.

11. A project has just been funded (May 2013) to fit falling weight deflectometer (FWD) equipment to a road / rail vehicle to increase productivity of track stiffness measurements, both in plain line and S&C, in the railway environment (RSSB / URS). Existing road vehicle mounted equipment created major access problems on the trackbed.

12. Improved structural support for track via the development of standards for the design of transition zones, use of piling techniques and ground penetrating radar in conjunction with track stiffness data. Guidance document developed for NR roll out by the end of 2013.

13. Modelling S&C system using flexible track models to optimise the track support system for S&C to include the assessment of equalised support conditions for S&C (i.e. varied across the panel to account for the greater seated area of bearers, and thus stiffness).

Rail Joints, Pads and Ballast – These components should ideally be compatible with existing infrastructure to enable a simple implementation as required by new track laying or maintenance activities. Training and standards should not present many difficulties once the techniques and products are developed.

14. Structural assessment of S&C system at a component level (i.e. from rail surface to bearer). Realistic inputs will come from other work streams identified below.

15. Under sleeper / Under bearer pads – claimed to have the potential to extend ballast life up to 2 or 3 times the current level. NR is to undertake some trials of 4x ¼ mile sections of track for a 2 year trial starting in about 6-12months time.

16. Techniques to determine the effectiveness of rail pad / fastening systems by monitoring rail roll to better understand component condition and prioiritise maintenance replacement increasing asset life. Standard practice is to monitor this statically via an applied load. NR has trialled a dynamic train system but results have been influenced by variable lateral forces, cant deficiency and track curvature. Data being reviewed prior to further development.

17. Reduction in squats achieved through the development of rail grinding techniques. On-going development to optimise rapid material removal techniques to reduce maintenance time.

18. Review and optimisation of rail pad design and performance to enable a range of components to be used to optimise track stiffness for specific locations. Pad for life required to avoid rail foot failures from pitting , corrosion and increased dynamic forces. This tends to be an issue on high tonnage plain line, when the rail is not replaced as frequently as on curves. Improved pads available which can last the life of the rail, but automated pad replacement equipment would be benefitial for existing pad installations.

19. Ballast life – Core research underway with the University of Southampton to develop ballast behaviour models to understand loading and ballast migration due to complete in 2015.

20. Assessment of dynamic track forces using a load measuring wheelset, particularly at discontinuities in the running surface (i.e. rail joints and crossings). Review current standards and assess P2 calculation for cast crossing design loads and refine management of dip angles giving rise to high dynamic loads and increased occurrence of failure at higher risk rail ends / joints. Trial to commence September 2013.

Maintenance – These technologies improve maintenance activities in terms of planning, access and output. Compatibility, training and standards are not considered to be an issue for the implementation of these techniques.

21. High output plant e.g. ballast cleaners, track relaying trains are in service but limited by plant reliability, planning and track access issues.

22. Reliability Centred Maintenance (Risk Based Maintenance)- This aims to maintain a reliable track via fewer inspections, but fixing failing infrastructure sooner. NR RCM trials to be held from April to June 13. Need to understand clear performance targets and be able accurately define failure modes and times to failure from first identification of faults.

23. Linear Asset Display system LADS to enable engineers to use the latest information about a particular section of track through accurate locational alignment overlaid on an accurate geospatial map of the network / assets. Allow multiple data sources to be overlaid to understand deterioration rates in addition to absolute values to identify and better prioritise maintenance activities. Understand effectiveness of work carried out.

Identify root cause of failures rather than treating the symptoms. Achieve effective long lasting repairs. Link different data streams together to allow better understanding of the root cause of faults i.e. rail defect at geometry fault with GPR poor formation conditions and excessive deflection. Fix formation rather than just replace rail and leave the same underlying problems untreated.

24. Further development and use by NR Routes of the Track-Ex predictive tool. New modules to be introduced in 2013 to include new rail materials, aid maintenance planning and track design - e.g. determination of the impacts of new fleets / increased traffic over specific routes, optimisation of cant for curves and transitions to reduce RCF.

25. Determine dynamic impact forces resulting from wheel-rail contact transitions (i.e. varying longitudinal rail profiles) and wheel transfer zones (i.e. wing rail to crossing nose) for inclusion into maintenance and design models (e.g.Track-ex). Trials underway based upon installation tolerances, including relative component heights and resilient components.

26. Improved possession planning and maximising effiency of track access opportunities – e.g. AutoMain initiatives.

27. Improved S&C performance – e.g. HPSS and other points operating equipment (POE) systems reliability, automated measurement of switch blades / weld repairs, Modular delivery/installation of S&C panels.

5.3 Novel vehicle technologies and interface issues arising

There are 39 vehicle technologies being considered in WP3 (see Table 1.3). With two target vehicle types:-

- The ‘Conventional Vehicle’ with a target running speed of 120kmh, incorporating 17 SUSTRAIL project innovations
- The ‘Futuristic Vehicle’ with a target running speed of 140kmh, incorporating 30 SUSTRAIL project innovations.

As with the track technologies in Task 5.4.1, implementation issues have been considered, particularly staff training, compatibility with existing infrastructure and vehicles, maintenance and adherence to standards. All of the innovations have been grouped together into the four following themes.

5.3.1 Suspension and Running Gear

Consideration is given to suspension spring and damper types, axle coatings and wheel materials, wheel shape, steering and centre pivot stiffness.

These innovations must be compatible to the existing infrastructure and could be implemented onto existing vehicle types. Standards and vehicle maintenace would not be adversely affected, but staff training would have to include new components and validation techniques to ensure the vehicles are maintained to their design specification.

5.3.2 Traction and Braking

Consideration is given to disc brakes, electronic braking distribution, independent wheel rotation, friction modifiers, traction drives, energy storage and transformers.

Standards could be affected by the implementation of new braking and energy systems, particularily in terms of safety verification. Likewise staff training would need to be implemented to ensure safety and reliability in service. Compatibilty may become an issue if vehicle types are mixed with other rolling stock in the same train and with other trains on the route due to variations in braking performance etc.

5.3.3 Body and Bogie Structures

Consideration is given to bogie weight reduction, bogie shape / aerodynamics and light weight vehicle bodies.

There could be implications for the suspension design if bodies are made substainlly lighter due to the greater variation in vehicle weight from empty to loaded, particularly if the weight saving of the body is given to increased carrying capability. Also revised aerodynamics would require validation for compatibility with structures (tunnels etc), passengers and track workers on platrforms and trackside. This may drive changes to standards. Training and maintenance requirements are unlikely to be substaintally impacted.

5.3.4 Condition Monitoring

Cosideration is given to axle and wheel monitoring via accoustics and vibration, energy harvesting and thermal sensors to monitor axle boxes.

Vehicle monitoring may be achieved on the vehicle or trackside, with advantages and disadvantages to both options. Which ever approach is accepted there needs to be consideration of compatibility with other vehicles to ensure all trains on a given route are protected. Development and training will be required to be able to respond to the monitoring to detect and then address wheel and axle faults.

5.4 Human factor issues, operational issues and stakeholder consultation

One objective of the SUSTRAIL project is to address phasing issues of the innovations designed, in order to give answers to the important question about the acceptance of rail innovations, i.e. if and under which conditions will the industry buy into the proposals coming forward from the project.

The analysis of phasing issues of SUSTRAIL innovations is built through the definition of a business model and the assessment of impacts. One particular aspect includes the identification and the assessment of human factor issues, such as :

- the impacts of SUSTRAIL innovations on human aspects of the rail freight operations, (maintenance, inspection and other train handover activities);
- key barriers for implementation of the designed innovations that may be brought by human factors during the phasing of the introduction of innovations.

Hence the human factor analysis addresses to two main goals:

1. Assessing how human factors and workforce skills are influencing the implementation (phasing) of innovative solutions in the railway system, and identifying key barriers to implementation brought by human factors;
2. Assessing how innovations influence the need for human activities, e.g.
    a. Training
    b. New workforce skills
    c. Recruitment

As concerns the first goal of the analysis, results expected are qualitative, based on literature review and experts opinion.

The second goal implies a more articulated analysis, which main outcome is the assessment of the need for changes in human factors brought by SUSTRAIL innovations, responding to specific objectives e.g., :

- Assessing where and when training has to change and/or new training is needed
- Assessing which operations are most affected by changes in human factors: maintenance (also representing largest working force), inspections, monitoring
- Evaluating the impact of SUSTRAIL innovations on drivers
- Assessing social impact of SUSTRAIL innovations, as an input to Cost-Benefit analysis to be performed as a general impact assessment framework of the business case;
- Proposing a framework to update and renew human factors aspects, to keep the human factors and workforce skills correlated with the progress and implementation of innovations

Operational aspects of the freight train of the future require specific attention since higher speed, longer train length and different wheel-rail forces have significant impact on freight train operations. Changes in operations affect human factors aspects such as driver behaviour and handling need. Such aspects have to be included in the impact analysis, with indications of the human resource differentials between ex-ante and ex-post scenarios, based on the availability of relevant operation times at cross borders and terminals within the business cases, and having as outcome the impact on freight train operations of the optimised freight train of the future including:

- access/egress to/from terminals
- cross border operations (coupling/decoupling of locomotives, train handover)
- other operations.

This subsection assesses the human factor and operational issues arising from the implementation of the innovations to be developed in WP 3 and 4. The assessment is an iterative progress and will therefore be updated during the project period in the course of the development of the innovations.

This section provides an initial assessment of major human factor and operational issues, starting with a literature review of past and ongoing research projects, and with the outcome of a preliminary survey made among stakeholders of the rail sector including national IMs and railway associations.

The list of innovations to be assessed was given in the previous two sections, concerning "Novel rail technologies, interface and track stiffness knowledge and issues" and "Novel vehicle technologies and interface issues arising" respectively.

Whilst the technical and operational specifications are still under definition in WP3 and WP4, experts have considered aspects of SUSTRAIL technological innovations in order to give opinion on general and specific aspects related to human factors.

5.4.1 Literature review

The literature review focuses on European research projects dealing with human and operational issues arising from the implementation of innovations in the rail sector. Furthermore, literature covering topics regarding rail operations, maintenance and inspections has been identified as well in order to underpin the analysis presented in subsections 5.3 and 5.4.

The literature review led to the conclusion that past rail innovation projects did not focus on the analysis of human factor and operational issues. However, some useful analysis has been undertaken within the INNOTRACK project[7]. Because SUSTRAIL innovations developed in WP 4 build on INNOTRACK solutions, their considerations regarding human factor issues are relevant to our analysis. In particular, INNOTRACK identified the areas where training for operational staff is required as well as the preferred medium to be employed (provision of guidelines, technical visits, etc.). INNOTRACK Deliverable 7.2.2 summarises the results and states that track staff training activities are required for technical innovations in the areas of "track support", "switches and crossings" and "rail and welding". Within the third category, a higher level of training needs is identified for "guidance on the use of different rail grades", while the implementation of the other solutions are supposed to require lower level of training.

A methodology to analyse human factor issues due to the implementation of rail innovation has been developed in HUSARE[8] project [29]. To our knowledge there has been no research project undertaken on European level to further develop the proposed methodology. The HUSARE methodology could apply to SUSTRAIL in order to analyse human factor and operational issues. Whilst the methodology is originally developed to analyse human factors of cross-border operations, the document recommends its application to a single infrastructure and by doing so, the analysis may be driven by the comparison of two situations, such as before and after the introduction of new technologies[9]. The HUSARE methodology is a four-step approach that starts with the identification of specific scenarios reflecting a task or a set of task which are required to be performed during train operation or maintenance activities. The second step comprises (1) a narrative description of each scenario, (2) a hierarchical task analysis that provides detailed information about the task steps and the task agents involved in the scenario, (3) a collection of relevant data about rules, procedures, technical systems, and working practices, and (4) data on competence issues that influence the task agents performance. Steps (2) and (3) needs to be carried out for the situations before and after the introduction of track and vehicle innovations. This is necessary for the third step that requires their comparison in terms of differing rules, procedures, working practices etc. and the expected human factor issues. The fourth step aims to predict and analyse the possible human errors or failures that may occur within the scenario.

[7] INNOTRACK was a three-year project (2006-2009), funded by the European Commission's 6th framework programme, that brought together the major stakeholders in the rail sector to develop innovative solutions in the areas of track substructure, rails and welds, and switches and crossings with the goal of a 30% reduction in life cycle costs.

[8] HUSARE was a two-years project (1998-2000), funded within the 4th framework programme. In particular, it was focused on developing a common methodology to identify and manage human factor issues arising from trans-European rail operations in order to increase their safety, efficiency, and reliability ([29 p. 12).

[9] [29], p. 44.

The literature review comprises a set of further research projects and official documents that may underpin the analysis of SUSTRAIL required within subtasks 5.4.3 and 5.4.4. To this regard we identified literature to collect information within the areas of rail operations, maintenance, and human factors. The selection of the literature was focused on contributions published after 2000 with few exemptions for projects of particular interest for SUSTRAIL. Projects have been identified from various sources, among them were of particular importance a list of 717 rail research project published by SKILLRAIL and two transport research directories, i.e. the Transport Research & Innovation Portal (www.transport-research.info) and the RSSB Human Factors Library (http://www.rssbhumanfactorslibrary.co.uk/membership/login.aspx).

Relevant studies for the category covering relevant topics on rail operations include TREND (Towards new Rail freight quality and concepts in the European Network in respect to market), 2TRAIN (TRAINing of TRAIN Drivers in safety relevant issues with validated and integrated computer-based technology, 2006-2009), SKILLRAIL (Education and Training Actions for high skilled job opportunities in the railway sector 2009-2011), and other projects listed in the following table. In particular, SKILLRAIL emphasizes the future need of training due to "technological developments affecting the professional requirements related to the operation of trains and networks as well as the maintenance of rolling stock and infrastructures". The third column "relevant information/topics for SUSTRAIL" contains information that may be exploited for the specific analysis of human and operational factor issues within SUSTRAIL tasks 5.4.3 and 5.4.4 to be undertaken in the course of the project. If the results of the project are not considered as relevant for these tasks, it is indicated in the same column with "n.a.".

Name of the project	Summary of the project	Relevant information/topics for SUSTRAIL	Employment category addressed by the project
2TRAIN - TRAINing of TRAIN Drivers in safety relevant issues with validated and integrated computer-based technology (2006-2009)	It developed European best-practice guidelines for an Efficient, safety enhancing, and cost-effective use of modern technologies for driver training and for the ongoing competence and performance assessment.	List and description of operational scenarios to be handled by train drivers (D 2.4.1); discussion of human factor issues for train drivers and adequate response through training (focused on safety-critical situations) (D1.2.1); details about existing training contents and technologies used in different European countries (Spain/UK included, but only passenger for UK) (Benchmarking Report).	Train driving (human factor issues and training)
ACEM-RAIL - Automated and cost effective maintenance for railway (2011-2013)	The project focuses on the track. The final goal is to reduce costs, time and resources required for maintenance activities and increase the availability of the infrastructure. The project includes both conventional and high speed lines.	State-of-art of maintenance in Railway (D 1.1); railway inspection and monitoring techniques – analysis of different approaches (D 1.2).	Maintenance and inspection
AUTOMAIN - Augmented Usage of Track by Optimisation of Maintenance, Allocation and Inspection of Railway Networks (2011-2014)	The aim of the AUTOMAIN project is to generate additional capacity of freight paths on the existing network by improving the efficiency of track maintenance to reduce the amount of time the railway is closed to traffic. This will be achieved through the development of innovative technologies and procedures in a number of areas for freight traffic .	Investigation of existing practices in rail maintenance, including Network Rail practices (D 1.1); analysis of current working practices in relation to tamping for Network Rail (D 2.2).	Maintenance
EC-DG TREN Impact assessment study on amendments to the rail access legislation in the framework of the recast of the 1st railway package (2008-2009)	Annex E: Methodology and results of the assessment of impacts on employment and safety).	List of railway employment categories; list of activities involved in cross-border operations.	Operations
EUDD*plus* - European Driver´s Desk Advanced Concept Implementation (2006-2010)	The objective of the project EUDD*plus* was to enhance a Europe wide standardisation and harmonisation of a locomotive driver's desk functional arrangement and layout, including the testing and verification of the ergonomic advantages, sub system performance and the potential economic benefits (LCC).	n.a.	Train driver

EXTRA - Thematic synthesis of transport research results. Paper 8 of 10: Human factors (2001)	Objective was to provide a structured guide to the findings and policy implications of research relating to human factors carried out in the Transport RTD Programme between 1994 and 1998.	Cluster of projects regarding "technology acceptance" that covers all modes and deals primarily with the implementation of new technologies into the transport sector.	Human factors
HUSARE - Human factors analysis techniques for cross-border rail operation (1998-2000)	Development of a common methodology to identify and manage human factor issues arising from (trans-European) rail operations in order to increase safety, efficiency, and reliability.	HUSARE Methodology may be (partially) applied to SUSTRAIL.	Train driving (human factor issues focused on cross-border operations)
INNOTRACK - Innovative track systems (2006-2009)	INNOTRACK has developed a multitude of innovative solutions in the areas of track substructure, rails & welds, and switches & crossings with the objective to reduce the life cycle cost of track maintenance by 30%.	Report on training needs and plan for training programmes for accompanying the implementation of INNOTRACK solutions (D 7.2.2). Maintenance cost categories analysis for European IMs (2006 data for Network Rail and Adif, see Annex U); identification of a set of principal European maintenance cost categories; results of INNOTRACK workshops of Infrastructure Maintenance Engineers: identification and priorisation of most common European track maintenance problems (Annex B + L Adif, Annex H + R NetworkRail) (D 1.4.6).	Maintenance
Mainline - MAINtenance, renewaL and Improvement of rail transport iNfrastructure to reduce Economic and environmental impacts (2011-2014)	The project is aimed to adress the implications of rail traffic increase in terms of a higher rate of deterioration of elderly rail assets and the need for shorter line closures for maintenance or renewal interventions.	Current monitoring and examination practices, including Network Rail practices (D 4.1).	Inspection
Rail training 2020 - Training needs and offers in the European railway area the next 10 - 15 years (2007)	Identification of training needs for rail staff due to legal, technological, demographic and market changes that the railways need to deal with in the coming years.	n.a.	Operations, maintenance and inspection (training)
SAFEDMI - Safe Driver Machine Interface (DMI) for ERTMS Automatic Train Control (2006-2008)	The aim is to design and develop a ERTMS-compliant safe (at least SIL2) Driver-Machine interface with safe wireless communication interfaces for configuration, safe wireless and firmware downloading and diagnostic purposes to respond to the increasing safety level needs in the Automatic Train Control systems of high-speed rail lines.	n.a.	Train driving

SAIL - Semi Trailers in Advance Intermodal Logistics (2000-2002)	It intended to improve the intermodal transportation of semi-trailers in Europe. This project intends to increase the percentage of semi-trailers of transported by rail. The optimisation potential will be identified with a special emphasis on the interfaces of the system's elements. The worked out solutions will be practically demonstrated and evaluated on a relevant typical route in Europe.	Description of terminal operations (Final Report)	Terminal operations
SKILLRAIL - Education and Training Actions for high skilled job opportunities in the railway sector (2009-2011)	SKILLRAIL aimed to foster a better match between the human resources needs to make railways more competitive and the offer of skills coming out of the different research institutes. One of the output was the design and launching of a sustainable framework, i.e. the EURAIL "European University of Railway", for creation, dissemination and transfer of knowledge within the railway sector.	It emphasizes the future needs of training due to "technological developments affecting the professional requirements related to the operation of trains and networks as well as the maintenance of rolling stock and infrastructures" (see Skillrail brochure, 2011); list of 717 rail research projects (D 1.3).	n.a.
SUSTRAIL Deliverable 2.3 (2012)	This deliverable is mainly oriented to the specification of track performance required, and infrastructure managers' (IMs) needs; it includes the work of the task 2.3: Track design requirements for reduced maintenance.	Track design requirements for reduced maintenance; IMs track duty requirements: data about current maintenance strategy of the three routes in Bulgaria, Spain, and UK; examinations and monitoring or prevention operations; maintenance operations; renewal operations (D 2.3).	Maintenance (practices)
Training and staff requirements for railway staff in cross-border operations (Atkins et al., 2002)	The report is the result of a study that was sponsored by the Directorate General for Energy and Transport of the European Commission with the aim of supporting a number of policy initiatives in the second railway package.	The study investigated selection criteria, training system, etc. for rail staff involved in cross-border operations for 20 European countries (including Spain).	Cross-border operations (qualifications and training)
TREND - Towards new Rail freight quality and concepts in the European Network in respect to market (2005-2006)	The objective was to elaborate a series of specific actions that addresses the general framework proposed by the European Commission's White Paper focused on strengthening the rail freight sector.	Comprehensive data collection of two European rail corridors affecting Bulgaria and Spain (e.g. overview of activities and processing times for cross-border operations at specific sites) (Deliverable Work Package B2).	Cross-border operations

WORKFRET - Working Cultures in the Face of Intermodal Freight Transport Systems (1997-1998)	The main objectives were to analyse existing working cultures and organisational/ managerial structures characteristics in European freight transport systems, examine implications of the integration of new technologies, new logistics and production systems, apply technology assessment tools and suggest policy measures to establish desirable, effective and efficient anthropocentric systems in the freight transport sector.	An identification of new technologies (these consists mainly of New Information and Communication Technologies) and new logistics and production systems under introduction in freight transport systems as well as a comprehensive assessment of their impacts on working cultures.	Operations (human factors)

Table 5.1: Human factor issues / operational issues literature review summary

5.4.2 Preliminary survey of stakeholders

This section provides the outcomes of interviews undertaken with major stakeholders of the railway sector. The interviews were carried out on the telephone with one exception where the inputs were delivered via e-mail.

The main purpose of the interviews was to gather input for an initial analysis of human factors and phasing issues of SUSTRAIL innovations. In particular, it was aimed to collect qualitative assessments from experts who have insights to different areas such as maintenance and inspection activities of tracks and vehicles, railway operations, or rail human factor issues. Another purpose of the interviews was to refine the methodology of the assessment by improving the questionnaire. In fact, on the basis of the initial assessment of human factors and operational issues, a more specific analysis will be undertaken for the Business Case (task 5.5), whilst applying the refined methodology.

The following organisations contributed to the SUSTRAIL human factor and phasing issues analysis for tasks 5.4.3 and 5.4.4:

- Network Rail (NR)
- National Railway Infrastructure Company Bulgaria (NRIC)
- Societatea Comerciala de Intretinere si reparatii vagone de calatori CFR-SIRV Brasov SA (SIRV)
- Union des industries ferroviaires europeennes (UNIFE)

It has to be remarked that some experts found themselves not in the position to express a definite judgement, due to the still provisional definition of SUSTRAIL innovations. The current state of development of SUSTRAIL innovations was judged by some experts as insufficient to provide an analysis of human factors and operational issues. Thus, the outcome of the survey might be improved at a future stage during the project, when all components of SUSTRAIL innovations will made clear and are available to a wider panel of stakeholders. In any case, the information collected were still sufficient to form an initial analysis of human factors and operational issues.

The interviews consisted of 11 questions that are stated in the following in sequence. Subsequently to each question, a table illustrates the inputs provided by each of the representative of the organisations involved.

1. Maintenance: provide a list of the maintenance tasks that could be affected by the implementation of SUSTRAIL innovations and specify changes in terms of frequency, automation and costs.

	Terms of change		
Maintenance tasks identified (track)	**Frequency**	**Automation**	**Costs**
Rail replacement (NR, NRIC)	Decreased (NR, NRIC)	Unchanged (NRIC)	Decreased (NRIC)
Ballast screening (cleaning) (NRIC)	Decreased (NRIC)	Unchanged (NRIC)	Decreased (NRIC)
Tamping (NRIC, UNIFE)	Decreased (NRIC, UNIFE)	Unchanged (NRIC)	Decreased (NRIC)
Grinding (UNIFE)	Decreased (UNIFE)		Decreased due to lower frequency (UNIFE)
Switches and crossings repair (NRIC)	Decreased (NRIC)	Increased (NRIC)	Decreased (NRIC)
Stress neutralization of continued welded track (NRIC)	Unchanged (NRIC)	Increased (NRIC)	Decreased (NRIC)
Sleepers and fastenings repairs and replacement (NRIC)	Decreased (NRIC)	Unchanged (NRIC)	Decreased (NRIC)
Vehicle maintenance activities			
Maintenance costs			Decreased , e.g. maintenance of wheels (see additional notes) (SIRV)

Additional notes

Regarding maintenance of wagons, activities may be affected by SUSTRAIL innovations, but according to the current state of development of SUSTRAIL innovations, the change is difficult to state precisely by SIRV. It will become clear when the manufacturers of the components provide the “minimum conditions for maintenance activities” for each innovation. Also, initially the innovations will only be inspected by SIRV, but maintained by the manufacturer. SIRV expects a decrease in mechanical maintenance work and an increase in electronical work, e.g. by employing the equipment for checking electronic parts.

2. Inspectability: How will the innovations affect the possibility to perform safety and functional inspections?

Identified terms of changes (track inspections)	**SUSTRAIL innovations (overall)**	**Premium rail**	**Rail track recognition**	**Track stiffness monitoring**
Quality and automation	Increased (NRIC, NR)		Increased (see note below) (UNIFE)	Increased (NR)
Frequency	Increased (NRIC), unchanged (NR)	Decreased (NR)	Decreased (NR)	Increased (NR)
Manual labour	Decreased (NRIC)		Decreased (see additional notes) (UNIFE)	Decreased (NR)
Costs per inspection	Decreased (in case the costs of manual labour are high) (NRIC); decreased (NR)			Decreased (see additional notes) (NR)
Terms of changes (vehicle inspections)				
Time per inspection (SIRV)	decreased by 30% (rough estimation) (SIRV)			
Personnel need (SIRV)	Decreased (SIRV)			

Additional notes:

Currently, track stiffness is difficult to measure and very costly, hence it is done rarely. This task will benefit from automation, thus decrease costs and, consequently, increase the optimal frequency in doing it. The higher costs due to the increase in activities in transition management are compensated by cost reductions in other areas. In particular, an increase in frequency implicates better monitoring of the changes in track stiffness. This allows an improvement in maintenance scheduling and reduces maintenance related costs (NR)

Rail track recognition: the use of sensors improves information about the current state of the track. Currently, inspections are made by humans walking along the track and it is a complex task to observe the state of the track and to make judgements about the need of doing maintenance activities. The use of a sensor is more reliable to identify issues. (UNIFE)

3. Accessibility: what has to be done to gain access to the part?

	SUSTRAIL innovations (overall)	**Premium rail**	**Rail track recognition**	**Track stiffness monitoring**
Effects on accessibility	Decreasing number of fasting elements and their unification (NRIC)	no change (NR)	Reduced accessibility (NR)	Reduced accessibility (NR)

Additional notes

Rail track recognition and track stiffness monitoring: currently, activities are carried out manually on-track side. Implementing the SUSTRAIL innovations implicates that activities are carried out on vehicles and hence accessibility to the parts is reduced.

4. Ergonomics: do innovations have impacts on working conditions of maintenance agents who have to work with these innovations (e.g. working positions, vibrating tools, hot/cold surfaces, dangerous locations)? In your opinion, are new working conditions improved or deteriorated?

Effects on working conditions identified (track)	**SUSTRAIL innovations (overall)**	**Premium rail**	**Rail track recognition**	**Track stiffness monitoring**
Overall effect (NR)	Improved working conditions (NRIC)	No change (NR)	Improved working conditions (NR)	Improved working conditions (NR)
Heavy manual labour	Decreased (NRIC)			
Working positions, vibrating tools, hot/cold conditions and dangerous locations	Decreased by increasing of machinery in track works (NRIC)			

5. Will these innovations set any new demands on the handling of maintenance (and inspection) tools and machinery? (Y/N) Which of them in particular?

SUSTRAIL innovations (overall)	Track: Yes (NR, NRIC, UNIFE) Vehicle: Yes (see note below) (SIRV)
Premium rail	No change (NR); new grinding machine is needed or old one needs to be adapted to take into account the stronger and harder rail to be worked (UNIFE).
Rail track recognition	Reduction in handling of maintenance (NR)
Track stiffness monitoring	Reduction in handling of maintenance (NR)
New fastenings	Require new tools and machinery and also new handling (NRIC)
New measurement technologies and measured parameters	Require new tools and machinery (NRIC)
Use of Linear Asset Display System (LADS)	Require implementation of new GPS and interface system on track maintenance and inspection machinery (NRIC)

Additional notes

Regarding vehicle maintenance activities, it is not expected to need handling new tools. New equipment might become necessary, for example new test stands for brakes (SIRV).

6. To support the introduction of innovations, are there new features of the task agents' skill set required and if so, for which task agents will be training required? Will these innovations require any change in maintenance personnel training?

	SUSTRAIL innovations (overall)	**Premium Rail**	**Rail track recognition**	**Track stiffness monitoring**
Qualification of agents	Decrease in need of agents with low level of education and adaptability (NRIC)	No change (NR)		
Skill set	Increase in engineer and technical skills, work with computer and digital systems and tools (NRIC).	No change (NR)	Need of skill set to use software that elaborates data from the track sensor innovation. Need for understanding and interpreting these data to organise the maintenance team (UNIFE)	
Training	Specific personnel training to work with new technologies, tools and machinery (NRIC)	No change (NR)	Yes (see cell above) (UNIFE)	
Maintenance tasks	Working with new elements (fastenings, switch elements); work with Linear Asset Display system (LADS) (NRIC)			
Inspection tasks (NRIC)	Need to use new devices, technologies elements (e.g. fastenings, switch elements) (NRIC)			
Effects (vehicle)				
Skill sets	Yes (see additional notes) (SIRV)			
Training	Yes (see additional notes) (SIRV)			

Additional notes

Regarding maintenance activities of wagons, it is expected that innovations require new skill sets. One example is the innovation of a solar battery on the wagon that implies that maintenance workers for sure will need to have new skill sets in order to undertake the maintenance tasks required. In addition, new skill sets might be required to commit to UIC safety regulations after implementing the new components. There will be also a need to handle equipment to check electronic parts what requires in turn qualified personnel. Also, the new distribution system of the brakes will be electronic and this in turn needs specialised workers as well. To bridge the gaps in the skill set required, training is probably needed. (SIRV)

7. Maintenance strategy:

a) Describe the degree to which the maintenance tasks of the innovations can fit into current maintenance schedules or if new activities have to be planed? If so, describe the amount of this change (hours, costs)?

Change in maintenance schedule identified	**SUSTRAIL innovations (overall)**
Frequency	Decreased for rail replacement, ballast screening (cleaning), tamping, switches and crossings repair (NRIC); maintenance activities decrease (UNIFE).
Overall maintenance costs	Decreased (NRIC, UNIFE)
New planning required	Yes (because of decreasing frequency, see above) (NRIC)

b) How will the innovations affect the inspection/monitoring procedures?

Effects on from implementing SUSTRAIL innovations (overall)	**Description of effect**
Increased automation (NRIC, NR)	Increased automation leads to higher productivity and objectivity. Thus, the frequency of the inspections may be increased (NRIC). Improvement of productivity of track inspections: one person can inspect 8 km manually per shift, while the use of a machine allows to inspect 100 km per shift (NR). Frequency of track walking inspections decrease (track walking inspections in critical areas will always be maintained) (UNIFE).
Cost benefits (NRIC)	Increasing productivity and objectivity will allow to make more measurements and analysis for the same amount of costs (NRIC).
Type of maintenance	Use of sensors for track and vehicle wheels allows to monitor continuously the ”health status” of the parts and hence implicates a change of the strategy from reactive maintenance to predictive maintenance (UNIFE).

8. Safety: Does the implementation of innovations lead to positive or negative effects on occupational or social safety and if so, please describe the expected impacts.

Category of occupational or social safety identified (track)	**SUSTRAIL innovations (overall)**	**Premium rail**	**Rail track recognition**	**Track stiffness monitoring**
Train accidents (NRIC)	Decreased (NRIC).		Safety increases e.g. because the use of a sensor and software is more reliable than manual inspections (walking along the track) (UNIFE).	
Train delays (NRIC)	Decreased (NRIC)			
Safety and health conditions at track maintenance works (NRIC, NR)	Improved (NRIC, UNIFE, see additional note)	Increased due to decreased frequency of maintenance and inspection activities (NR)	Improved, because people are not working anymore on the track, but in the vehicle (NR).	
Operational speed and capacity (NRIC)	Decreased (NRIC)			
Category of occupational or social safety identified (vehicle)				
Maintenance and inspections workers safety	Increased (SIRV)			

Additional notes

There will be a lower risk of accidents for workers walking on the tracks because the SUSTRAIL innovations decrease the length of the track that needs to be inspected and because workers might be more productive and hence less workers are needed to do the inspection. The risk for workers walking along the track lies in the fact that inspection works usually are done during the night when traffic volumes are lower and the line they are walking on closed, but on the other line the traffic is still going on.

9. Human factors: Are the innovations improving and/or reducing the problems associated with human interaction? This includes improvements that reduce maintenance related risks, costs, improve productivity and safety.

Changes related to human factors identified	**SUSTRAIL innovations (overall)**	**Premium rail**	**Rail track recognition**	**Track stiffness monitoring**
Maintenance related risks (NRIC)	Improved (NRIC)	No change (NR)		
Maintenance costs (NRIC)	Decreased (NRIC)			
Productivity and safety (NRIC, NR)	Improved (NRIC)		Improved system performance (see additional notes) (NR)	

Additional notes

Whilst the decision for an eventual intervention is currently taken on the basis of judges from the workers undertaking the inspections, they will be taken based on the data monitored by the vehicle and processed by software systems that finally provides recommendations based on the data measured. (NR)

10. Phasing issues: specify the technical barriers to implementation with respect to existing infrastructures (e.g. interfaces of existing technologies and innovations with electric system feasible) and processes and the general effects related to the phasing of innovations. Specify if there are financial barriers.

Category of phasing issue identified (track)	**SUSTRAIL innovations (overall)**	**Premium rail**	**Rail track recognition**	**Track stiffness monitoring**
Qualification of maintenance staff (NRIC)	Problems related to the need to use new inspection tools and machinery with electronic and digital systems (NRIC)	No issues (NR)		
Other issues (NRIC)	Necessity of interface connections for data transfer between new inspection tools and machinery and existing maintenance machinery (NRIC)			
Costs (NRIC, UNIFE)	Costs of innovations in earthworks and switches have longer term of proposal return (NRIC). LCC of new components will be lower, but initial costs are higher than classical products. There is a need to communicate the lower LCC to IMs. However, IM managers usually think short-term (2-3 years), whilst SUSTRAIL innovations might only become profitable after 7-10 years time (UNIFE).			
Social conflicts (NRIC)	Innovations will cause decreasing need of low qualified staff which may lead to social conflicts (NRIC).			
Environment (NRIC)	Problems with recycling novel railway materials (e.g. plastic sleepers) (NRIC).			
Uncertainty about benefits (NR)			It is still necessary to refine data about the innovations' performance (NR).	
Category of phasing issue (vehicle)				
Costs (SIRV)	Initial investment costs to introduce innovations are in general always a barrier for implementation. It will depend on the costs of materials for the new bogie (SIRV).			
Relation to existing components and technical barriers	According to the current state of development, no technical phasing issues are expected. For when development of innovations will be more advanced, it will be more likely to provide a better assessment on this issue. However, it is expected that eventual technical barriers can be overcome through a collaboration between SIRV and the designers of the components.			

11. Operations

a) Provide a list of tasks related to operations (e.g. train driving, shunting, cross-border operations, freight handling, access/egress to terminals etc.) that are likely affected by the introduction of track and vehicle innovations.

Tasks identified	**SUSTRAIL *track* innovations (overall)**	**Premium rail**	**Rail track recognition**	**Track stiffness monitoring**
Manual inspections (NR)		No effects (NR)	Manual inspections will be automated (NR)	
Operations (NRIC)	Time schedule, speed, traffic capacity (NRIC)			

b) Which tasks might likely benefit from the implementation of innovations (e.g. reduction in operation times for crossing borders and terminals)?

Identified tasks	**SUSTRAIL innovations (overall)**
Operations (NRIC)	Increased operational speed, increased traffic capacity, decreased traffic breaks due to maintenance works, decrease of necessary maintenance materials for maintenance (rails, sleepers, ballast, fastenings), decrease of maintenance work processes (NRIC).

c) Are there new features of the task agents' skill set required and if so, for which task agents is likely to be training required to assist the introduction of innovations? (Refer to Question 6 regarding the new features of the skill set required for inspections and maintenance agents)

Tasks affected	**SUSTRAIL innovations (overall)**
Manufacturing (NRIC)	Welding, cutting and drilling of rail and switches of novel steels (NRIC)

In summary, the outcome of the interviews gives useful provisional insights on the impacts of SUSTRAIL innovations on human factors. In particular, the stakeholders interviewed agreed that the effort in maintenance and inspections will decrease, however, they are not able to quantify or to assess the magnitude. This is due to a still provisional specification of SUSTRAIL innovations. They will therefore be asked to provide their opinion at a later stage again, as well as additional stakeholders, when the specifications of the innovations will be defined in details.

The results of the interviews – although provisional – reflect the expectation in a decrease in track and vehicle maintenance and inspection efforts. In fact, these two areas are expected to benefit most from SUSTRAIL innovations terms of a decrease in human factor related costs. Regarding track maintenance activities, cost decreases are expected for several tasks due to a decrease in the frequency and an increase in automation. Regarding inspections, a cost decrease per single inspection is expected and a notable increase in the quality of inspections, in terms of the ability to identify failures in the track, such that maintenance activities can be

optimised and the risks of train accidents decreased. In general, manual work tasks are expected to decrease due to the implementation of SUSTRAIL innovations, in particular the need of walking along tracks. For several track and vehicle inspection and maintenance tasks, the experts expect a change in demand for the handling of machinery and skill sets required – such as an increase in engineer and technical skills and skills to work with computer and digital systems – and hence it necessitates training activities to accompany the introduction of SUSTRAIL innovations.

One major objective of the interviews was also to identify barriers for introducing SUSTRAIL innovations. The experts were able to provide some useful insights on this regard, such as the concern of higher initial investment costs compared to conventional components, the lack of specific skills of workers to deal with the innovations, technical phasing issues such as the necessity of interface connections for data transfer between new inspection tools and machinery and existing maintenance machinery, and environmental problems, e.g. due to recycling of novel railway materials.

6. ANALYSIS FOR THE UK CASE STUDY

6.1 Introduction

The objective of this work is to demonstrate the direct impacts of SUSTRAIL vehicle and track improvements on the freight market using the LEFT strategic freight demand forecasting model, and furthermore to examine the impact on emissions of CO_2 and other key pollutants.

The LEeds Freight Transport model (LEFT) was developed in the course of the ITeLS project [13] and the Rail Research UK (RRUK) [9] programme. Very few other functioning freight models are available. Those that are attempt to predict geographic flows of freight, hoping to match mean flows observed moving in a base year, an extremely difficult task which gives insufficient attention to the real 'drivers' of freight traffic. Earlier work with TRANSTOOLS, a European wide network freight model, was unsuccessful as there was no functioning endogenous mode split in the model. LEFT runs very quickly yet incorporates virtually all current knowledge regarding the effects of (policy and other) changes on the quantum of freight traffic, split by mode and commodity groups. The latest version of LEFT4 used here was developed as part of the EPSRC funded Green Logistics project with further enhancements made during the course of the current project.

6.2 LEFT model architecture

The starting point in the LEFT model is to use GB road and rail freight data to construct matrices for freight tonnes. Disaggregation of these data within LEFT4 is by the following dimensions:

i) The base data is split over the 7 commodity groups consistent with the categories provided in the Department for Transport's Continuing Survey of Road Goods Transport (CSRGT) data [5]:

A. Food, Drink and Agricultural Products
B. Coal, Coke and related items
C. Petroleum and Petroleum Products
D. Metals and Ores
E. Aggregates and Construction
F. Chemicals and Fertilisers
G. Others.

For the purposes of our analysis in SUSTRAIL, we will focus on Food, Drink and Agricultural Products and Others only, as these are the commodity categories which feature containerised goods and as such are the only commodities affected by the proposed vehicle improvements. The remaining commodities (B-F) are grouped together as 'Bulks' for the purposes of presentation. Note that containerised traffic represented 24% of total rail tonne kms in 2006, and in LEFT4 this is projected to rise to 30% and 40% in 2015 and 2030 respectively.

ii) The base data by commodity is split over 9 (road) distance bands, again consistent with those used by the CSRGT data. For a movement involving rail as the trunk haul, the rail distance is taken as equal to the road door to door distance. When road collection and delivery is involved, the total distance for such a rail based movement is that much greater.

iii) The base total market is split for each commodity and distance band according to whether traffic is favourable for rail operations, referred to as train-friendly (TF), or train-unfriendly (TU). For Bulks, TF traffic is that traffic we deem suitable for trainload movement from origin to destination. For Non-bulks (Food etc, and Miscellaneous), TF traffic is that to which we have assigned the need for collection and delivery (at most) at one end.

There are therefore 2*7*9 = 126 cells. Financial costs (expressed in £ per tonne) of road and rail movements for each vehicle type in each cell are a function of distance, speeds, driver costs, fuel costs, loading and backload factors, vehicle (or train) capacity and vehicle type, guided by freight industry cost data and described in detail in [9]. For rail there are additional components of cost associated with access charges, any marshalling and lifting costs and any associated road collection or delivery legs.

The modelling is based on generalised costs (GC) which, in addition to the financial cost of road and rail transport, include other monetised non-financial attributes such as time and delay costs as well as a mode specific constant. This latter is a penalty (expressed as a percentage of the road costs) for using rail as opposed to road, implemented by adding to rail cost. The values of time and delays are used based on interviews reported in [11] to yield commodity specific valuations of delay time per tonne and shown in Table 6.1 below. These figures were applied to each commodity specific values of delay time taken from these interviews to yield average commodity specific delay costs.

Table 6.1: Values of time and reliability

	Value of reliability (p/min/tonne)	Value of time (p/min/tonne)
Food, Drink, Ag	1.3	2.5
Coal & Coke	0.5	0.9
Petroleum	1.0	1.3
Ores & Metals	0.4	0.8
Construction	0.6	0.8
Chemicals	1.0	1.3
Others	1.3	2.5

To illustrate the sophistication of the cost calculations an example of the generalised cost components for rail is shown in Table 6.2 below.

Table 6.2: Generalised Cost Breakdown for Rail Vehicles (Other, 0-25km)

Distance band 1:0-25km					
Split no.	1	2	3	4	5
Split proportion	0.6	0.2	0	0.1	0.1
Loco type	AI	AI	AI	GC	GC
loco weight	126	126	126	126	126
Wagon type	FEA	FLA	IFA2	IPA2	IWA
COSTS PER TONNE (£)					
loco access cost per tonne	0.01	0.01	0.01	0.01	0.01
Wagon access per tonne	0.14	0.04	0.09	0.03	0.07
Fixed traction cost per tonne	1.54	1.22	1.57	1.71	0.88
Variable traction cost per tonne	0.03	0.02	0.03	0.03	0.02
Wagon cost per tonne	3.40	1.91	2.86	0.37	1.40
RAIL COST PER TONNE (FULL LOAD)	5.15	3.23	4.59	2.18	2.40
loco access cost per tonne	0.01	0.01	0.01	0.01	0.01
Wagon access per tonne	0.02	0.01	0.02	0.02	0.01
Fixed traction cost per tonne	1.54	1.22	1.57	1.71	0.88
Variable traction cost per tonne	0.03	0.02	0.03	0.03	0.02
Wagon cost per tonne	3.40	1.91	2.86	0.37	1.40
RAIL COST PER TONNE (EMPTY LOAD)	5.03	3.20	4.52	2.17	2.34
ROAD TRANSIT COST	7.31	7.31	7.31	0.00	0.00
LIFTING COST	1.25	1.43	1.25	0.00	0.00
TOTAL FINANCIAL COST	15.02	12.80	14.32	2.75	3.01
rail journey time cost per tonne	3.70	3.70	3.70	1.20	3.70
rail delay cost per tonne	1.00	1.00	1.00	1.00	1.00
road journey time cost per tonne	0.14	0.14	0.14	0.00	0.00
road delay cost per tonne	0.50	0.50	0.50	0.00	0.00
Final additive rail penalty	1.11	1.11	1.11	0.54	0.60
TOTAL GENERALISED COST	21.5	19.2	20.8	5.5	8.3

LEFT generates outputs in the form of:

- Mode shares, tonnes and tonne-km by commodity/distance band
- Vehicle kms by vehicle type which are linked to an emissions model to generate changes in CO_2; SO_2; NO_X; CO; PM_{10}

In each of the 126 cells, mode split is determined by a multinomial logit (MNL) choice based on generalised costs from up to 13 (8 road and 5 rail) vehicle types. The problem that the MNL model has with similarity between alternatives is accounted for by the use of a similarity table [i]. This table also allows us to direct traffic towards particular vehicle types (e.g. smaller vehicles for shorter distance traffic).

Due to the risk of aggregation bias we applied the mode split separately with road Generalised cost perturbed in turn by -10%, -5%, 0, +5%, +10%.

6.3 Data

Road Tonnes and Tonne-kms

Base data on road tonnes and tonne-kms disaggregated by commodity and distance band were kindly made available to us by the UK Department for Transport (DfT). However, in recent years a discrepancy has arisen between two sets of DfT official figures for GB freight vehicle kilometres, one from manual and automated counting (National Road Traffic Survey, reported in [8]) and one from the questionnaire based Continuing Survey of Road Goods Transport (CSRGT), reported in [5]. The CSRGT forms the UK's return to Eurostat, which along with

the other EU member states, can be found at http://epp.eurostat.ec.europa.eu/portal/page/portal/transport/data/database. We have chosen to take a figure somewhere in-between, with the implication that the CSRGT figures have been seriously under-reporting in recent years and adjusted the data appropriately. This process involves scaling one source of DfT data, which gives the distance band and commodity grouping breakdown, to another source of DfT data, which directly observes the lorries moving. We also make specific allowance for the failure of the first source to include foreign registered vehicles, and for miscoding of other large vehicles (eg. Buses) as trucks in the second source.

Rail Tonnes and Tonne-kms

Detailed official county-to-county rail data for GB rail 'tonnes' in 2006 for calibration of the base year was kindly supplied to us by MDS Transmodal. Tonne-kms are derived by multiplying tonnes by the mid-point of the distance band. Table 6.3 shows how this base rail traffic for 2006 is distributed across distance bands.

Table 6.3: Distribution of 2006 base Rail Tonne-kms by distance band

		Distance band mid-point (km)									
Tkms (Mn)	Commodities	12.5	37.5	75	125	175	250	350	450	550	Total
	Food, Drink, Ag	0	1	6	25	26	65	35	62	69	289
	Others	0	0	132	66	218	603	990	1,613	3,079	6,702

Forecasting for future years

Road and rail time series data aggregated by commodity were used for econometric forecasting of future traffic, as described in [17]. In that study, six econometric time series models were applied to modelling and forecasting the road plus rail freight demand in GB, based on annual time series data for the period 1974-2006. The models each used a set of dummies and the Index of Industrial Production (2003=100) for each commodity group *k* (a proxy for the economic activity in that sector) as explanatory variables. Based on its relative forecasting accuracy over the longer time horizon the partial adjustment (PA) model formulation was chosen as the basis for the forecasts used here (with an assumed GDP growth rate of 0% following recent experience). The PA model brings the dynamic partial adjustment process into the traditional regression model through the inclusion of a lagged dependent term.

Our purpose is to create a "do nothing" base for the years 2015 and 2030 to illustrate the effect of various scenarios with the sorts of traffic levels then expected (split into our 126 cells for both modes). The results of these forecasts are shown in

Table 6.4 below.

Table 6.4: Future and base year 'do nothing' forecasts.

	Road (Bn Tkms)			Rail (Bn Tkms)			Rail % Share		
	2006	2015	2030	2006	2015	2030	2006	2015	2030
Food , Drink, Ag	56.4	72.4	108.9	0.3	0.4	0.6	0.5	0.5	0.5
Coal & Coke	1.5	1.5	1.7	8.6	9.0	9.8	85.2	85.5	85.2
Petroleum	6.5	6.7	7.2	1.5	1.6	1.7	19.1	18.9	19.1
Ores & Metals	7.6	7.2	6.5	2.3	2.1	1.9	23.0	22.8	23.0
Construction	34.2	39.4	49.9	2.7	3.2	4.2	7.3	7.5	7.8
Chemicals	8.6	8.7	8.8	0.3	0.3	0.3	3.8	3.7	3.8
Others	73.1	100.9	172.1	6.2	9.0	16.0	7.9	8.2	8.5

6.4 Calibration

Once we have a model that produces initial outputs, we must adjust its parameters to replicate the 126 mode split figures in the base data by choosing model parameters that are plausible, behave well and satisfy various test.. The aim is to reproduce these probabilities to at least 3 decimal places, ie. our model will (almost) exactly reproduce the observed base shares of road and rail in the 126 cells.

Additionally, we have data for vehicle-kilometres for each of our lorry types. We only have data at the national level, ie. summed over all commodities and distance bands etc. There is therefore limited scope in using this data at the detailed calibration stage, but we can bear in mind how the outturn is looking relative to the observed vehicle-kilometres data, and adjust accordingly until the model gives an adequately close estimate.

Calibration proceeds by:

(i) altering the lambda parameter (λ) which governs the sensitivity of demand to differences in GC between different vehicle types;

(ii) altering the % of traffic deemed 'suitable' to each vehicle type;

(iii) altering the similarity matrix that relates the generalised cost 'pointed' vehicle type to that of all other vehicle types;

(iv) altering the generalised cost figures for the rail wagon types, which we know to be poorly estimated due to specificity of use and lumpiness of traffic flows.

During the detailed calibration process, attention is also paid to the modelled Composite Cost of the pair of lowest (Generalised) cost Road and Rail alternatives, expressed as a ratio to the lowest of these two. Our criterion is that the Composite Cost to lowest cost ratio should lie in the range (0.950, 0.999). In particular, this constrains the lambda value parameter, used in the Vehicle type split Model.

6.5 Freight transport elasticities

Freight generalised cost elasticities are fundamental to the LEFT4 model, determining the new market size as generalised cost changes. By elasticities we here mean demand elasticities with respect to some element of cost.

In the development of LEFT4, the procedure for deriving elasticities was as follows. Elasticities both for Tonnes and for Tonne-kilometres with respect to generalised cost are imported separately for each of the 7 commodity groups, split by TF and TU (i.e. 28 elasticity values in all). These values were chosen from a consideration of the literature, which reports many elasticities, mostly now catalogued by the Bureau of Transport Economics (BTE).

The LEFT4 model without market size effects (i.e. with that routine switched out) is then run with 10% changes in generalised cost in order to derive mode-split only GC elasticities and cross-elasticities. We were then guided by the method of Taplin ([18]; [19]; [20]), which explored relativities between the various elasticities and part elasticities that are consistent with economic theory.

We have been particularly influenced by the work of [4], cross checking against other sources as indicated earlier.

Lastly, after entering our estimates into the model, we tested simple policies designed to reveal the effective elasticities being applied, and felt the changes to be slightly too large. Consequently the entered elasticity figures were scaled down by a factor of 0.88. This took account of the findings of [14], in which they estimated a meta model on Revealed Preference data that gave an average price elasticity of approximately -0.66.

The resultant own-GC elasticities for rail are shown in Table 6.5 below.

Table 6.5: Rail Generalised Cost Elasticities

	Tonnes	*Tkms*
Food , Drink, Ag	11.5	10.1
Others	3.4	2.6

At first glance these appear high but are driven by the fact that these commodities have low rail market share so are inherently more sensitive for rail.

6.6 Emissions Modelling

In Great Britain past atmospheric emissions and greenhouse gases are reported annually by the National Environmental Technology Centre (NETCEN), the operating division of AEA Technology, in its National Atmospheric Emissions Inventory (NAEI) on behalf of the Department for Environment, Food and Rural Affairs (DEFRA). NETCEN provides the official emission estimates for the public sector in the UK.

The following is a list showing the air pollutants and greenhouse gases considered here

- Carbon dioxide (CO_2)
- Carbon monoxide (CO)

- Nitrogen oxides (NO_x)
- Particulates (PM_{10})
- Sulphur dioxide (SO_2)

Road emissions

Emissions can be estimated with a distance-based approach by multiplying vehicle travel data (vehicle kilometres) with emission factors relating to travel distance (e.g. grammes/km). Alternatively, the fuel-based approach combines the fuel consumption as an expression of the vehicle activity with emission factors expressed as mass per unit of fuel used. Both approaches take into consideration various types and sizes of vehicles in the UK fleet, grouped by the vehicle categories of European emission standards which were in force by the year 2006.

Emissions of CO_2 are calculated from the carbon content per tonne of fuel, and SO_2 is estimated from the sulphur content in the fuel. The calculation of CO_2 and SO_2 from fuel consumed was carried out by multiplying the fuel consumption per distance unit by the total travel distance and the appropriate fuel specific emission factor.

Full detail of these calculations is provided in [12].

Rail Emissions

Emissions from the rail transport industry are a combination of both direct and indirect emissions. Direct emissions are primarily produced as a chemical by-product of the combustion of fuel oil (gas oil). Other sources include emissions from stationary sources. Indirect emissions are associated with the railway industry's use of electricity, including for traction. In this application only direct emissions from moving freight were taken into account. Electric traction accounts for only a small proportion of GB rail freight movements.

As with road freight transport CO_2 and SO_2 for rail were calculated on the basis of fuel consumption. Whilst general theory says that there is not a direct relationship between fuel consumption and emissions of NO_x, CO and $PM_{10,}$ in order to apply the distance-based approach it would be necessary to have more detailed information about the fleet. Therefore it was also decided to also use fuel-based emission factors for the calculation of NO_x, CO and PM_{10} from rail freight transport, obtained from ([30], Table A38).

Table 6.6 summarises the variables which are suggested for calculating rail emissions in our framework.

Table 6.6: Input and output variables for estimating GB rail freight emissions

Input variables	Train-km for base year
	Fuel consumption (in kg/km)
	Total fuel consumption for GB rail freight (in millon tonnes)
	Emission factors for freight train in tonnes/kilo-tonne (t/kt) of diesel fuel SO_2: 2.8 CO_2: 314 NO_x: 17.5 CO: 4.90 PM_{10}: 0.22
Output variables	Emissions for SO_2, CO_2, NO_x, CO and PM_{10}, in kt

(Based on: [30], Table A38)

6.7 Scenario to be investigated

Scenarios are implemented in LEFT through changes in generalised cost components such as speed, reliability and track access charges. The model adjusts mode share accordingly and uses known tonne and tonne-km elasticities to change market size as described below.

The procedure is as follows. First, we remove from the Road matrices those Tonnes that are deemed to be required to carry out the collection and delivery (C&D) functions of the Rail matrices. The degree of C&D activity is exactly specified by our TF/TU definitions, for Bulks and Non-bulks separately (based on our own judgement and best information to hand). We then use the market size elasticities applied to base data (by mode, commodity and distance band) for both Tonnes and Tonne-kilometres. The next step is to sum figures by mode, and reassign the resulting totals over distance bands so as to obtain the forecast Tonne-kilometres figures from the forecast Tonnes figures (effectively using the implicit average length of haul to determine the new spread over distance bands). We then split this traffic by vehicle type. The final step is to compute the new road C&D trips associated with the forecast rail movements, and add them back in.

We implement the SUSTRAIL vehicle improvements in the following way

1. We assume the improvements in bogie design will result in a reduction of 4% in track access charges (TAC), with an additional 1% reduction from optimising vertical track stiffness, for a total of 5% reduction in TACs. This is equivalent to a 14.3% reduction in track damage, assuming that the average 35% variability of maintenance and renewal costs given in Section 4.2 is reflected in future TACs.
2. We assume a corresponding improvement in reliability, measured by 10% reduction in train delay per tonne-km
3. We assume a journey time improvement increases the maximum operating speed from 120 to 140kph. Given a limited share of journey is spent at that speed we take half of the max potential saving, giving a 7.5% reduction in journey time related costs.
4. We assume increased vehicle efficiency resulting in a 20% reduction in fuel cost for a given load
5. We assume reduction in wagon maintenance and non-fuel operating costs of 10%.
6. We assume the CO2 impact of the innovations is a reduction in emissions factors for rail by 20%.

Table 6.7 shows the commodity related vehicle types which are affected by our improvements.

Table 6.7: Rail Wagon types used in the modelling

Commodity Group	*TOPS Wagon Type Code*	*Load Share % (TF)*	*Load Share % (TU)*	*Description*	*Affected by innovations? (Y/N)*
Food, Drink, Ag	FEA	20	20	Twin flat wagon.	Y
Food, Drink, Ag	IWA	70	70	Hopper Wagon	N
Food, Drink, Ag	OTA	10	10	Timber Wagon	N
Others	FEA	60	40	Intermodal flat wagon.	Y
Others	FLA	20	15	Lowliner' Bogie container wagon	Y
Others	IFA2	0	0	Intermodal flat wagon.	Y
Others	IPA2	10	5	Car Transporter Wagon	Y
Others	IWA	10	40	Hopper Wagon	N

As can be seen from the table, only 10% of Rail related Food, Drink and Agriculture base traffic are affected by these innovations (although there will be some switching to this wagon type in the scenario), so the effect on this commodity group is very constrained.

All of these cost changes are indicative at this stage. All these five items are easily adjustable via LEFT, so this allows our initial runs to be re-specified.

6.8 Interim Results

In LEFT the bogies affected by these improvements will only be in the Food, Drink and Agriculture and the Others category (which includes final manufactured goods). Given the range of the vehicle types modelled in LEFT, these will only apply partially to these commodities in accordance to the proportion of total commodity traffic carried by rail in the affected vehicle types.

These resultant generalised cost changes yield the following changes in tonne-kms shown in Table 6.8.

Table 6.8: Effect of SUSTRAIL improvements on tonne-kms

2015	*Road*			*Rail*			*TOTAL*		
	BASE	SCEN	%Change	BASE	SCEN	%Change	BASE	SCEN	%Change
Food , Drink, Ag	72.4	72.3	-0.06	0.4	0.4	12.96	72.7	72.7	0.01
Others	100.9	100.3	-0.61	9.0	9.7	7.42	109.9	110.0	0.05
Bulks	63.5	63.5	0.00	17.6	17.6	0.00	81.1	81.1	0.00
TOTALS	**236.8**	**236.2**	**-0.28**	**26.9**	**27.6**	**2.65**	**263.7**	**263.8**	**0.02**
2030	Road			Rail			TOTAL		
	BASE	SCEN	%Change	BASE	SCEN	%Change	BASE	SCEN	%Change
Food , Drink, Ag	108.9	108.8	-0.06	0.6	0.6	12.70	109.5	109.5	0.01
Others	172.1	171.0	-0.63	16.0	17.1	7.36	188.1	188.1	0.05
Bulks	74.0	74.0	0.00	19.4	19.4	0.00	93.4	93.4	0.00
TOTALS	**355.0**	**353.9**	**-0.33**	**35.9**	**37.1**	**3.48**	**390.9**	**391.0**	**0.02**

These results show the predicted effects if each scenario had been introduced in 2006 and carried forward to our future years. No attempt is being made here to predict the future, merely the effect of each of the three policies if applied in 2006.

Table 6.9 shows that Food, Drink and Agriculture traffic rises by almost 13% but from an extremely small base. The impact on Others is much larger in absolute terms, but amounts to just over 7% increase in rail traffic. The results show that the impacts on overall market size of freight traffic are minimal (0.02%) and the extra rail traffic is primarily abstracted from road.

Table 6.9: Effect of SUSTRAIL improvements on Rail Generalised Cost and Consumer Surplus

	GC (£ per tonne)			*Tonnes*			*Change in CS (£)*
2015	BASE	SCEN	%Change	BASE	SCEN	%Change	
Food , Drink, Ag	36.4	36.0	-1.3	1,235,199	1,436,995	16.3	624,911
Others	34.7	33.8	-2.5	23,198,348	25,608,257	10.4	21,221,429
Total							**21,846,341**
2030							
Food , Drink, Ag	36.4	36.0	-1.3	1,935,198	2,236,525	15.6	975,587
Others	34.7	33.8	-2.5	40,862,109	45,054,821	10.3	37,357,240
Total							**38,332,827**

Table 6.10: Decomposition of SUSTRAIL improvements on Rail Generalised Cost

	Distance band mid pt = 37.5km					*Distance band mid pt = 550km*				
Commodity	Food, Drink, Ag	Others				Food, Drink, Ag	Others			
Wagon type	FEA	FEA	FLA	IFA2	IPA2	FEA	FEA	FLA	IFA2	IPA2
GC BASE (£ per tonne)	27.6	22.4	19.8	21.6	6.9	68.0	47.0	36.3	44.0	28.0
GC SCEN (£ per tonne)	26.6	21.8	19.4	21.1	6.6	64.7	45.0	35.0	42.2	26.6
£ per tonne savings										
TAC	0.03	0.02	0.01	0.02	0.01	0.42	0.35	0.13	0.24	0.11
Reliability	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Vehicle and speed efficiency	0.12	0.06	0.05	0.06	0.07	1.69	0.89	0.70	0.90	0.98
Wagon maintenance	0.68	0.43	0.24	0.36	0.06	1.07	0.67	0.38	0.57	0.18
Total change in GC	**0.92**	**0.61**	**0.40**	**0.54**	**0.24**	**3.28**	**2.01**	**1.31**	**1.81**	**1.38**
% Change in GC	**3.4**	**2.7**	**2.0**	**2.5**	**3.4**	**4.8**	**4.3**	**3.6**	**4.1**	**4.9**

Table 6.9 shows the effects of the improvements on generalised costs and, through application of the rule of a half, the resultant increase in consumer surplus in 2015 and 2030, which is over £38 million (over €45 million) by 2030. The generalised costs are averages, volume weighted (by tonnes) across the distance bands for TF and TU. The effects of the cost changes appear small but they are diluted by some vehicles in the commodity categories that are not affected as shown in

Table 6.7. Note there are no changes to Road GC and the Rail cost base does not change over time.

Table 6.10 illustrates how the different improvements affect generalised cost. Here we have taken some example costings for the affected wagon types for the two commodities in the dominant rail friendly category for short distance traffic and long distance traffic. This shows how the impact of the improvements is largely driven by the savings in wagon maintenance for short distance traffic. For longer distance traffic the figures show that, for both commodities, vehicle and speed efficiency savings make up over 50% of the GC savings. The increasing importance of the vehicle and speed efficiency savings with distance is shown by larger absolute and percentage changes in GC in the longer distance band.

Table 6.11 shows the effects on lorry and locomotive vehicle-kilometres and the emissions of CO_2, SO_2 , NO_x , CO and PM_{10} taken over all commodities (so percentage changes are small). Results are given first for Road, then Rail and Total for 2015 and 2030. There is no total shown for vehicle-kilometres since adding lorries to rail locomotives is not helpful.

For Rail, all emissions are taken as proportional to loco kilometres, and so the percentage changes are equal for all emissions. Diesel and electric traction are included in the calculations. For Road, a more nuanced approach is adopted, and consequently the percentages do differ. The important figures, though, are those shown for Total, where reductions in one mode are netted off against increases for the other mode. The Base column shows that Road emissions massively dominate those from Rail in all cases. Interestingly the small modal shift to rail is generating slight increases (0.5% and below) in SO_2, CO and PM_{10}.

Table 6.11: Changes in Vehicle kms and total emissions

		Base	*Scenario*	*%change*
2015				
Road	Vkms (bill)	32992	32930	-0.2
	CO2 (ktonnes)	28793	28736	-0.2
	SO2 (ktonnes)	7.33	7.32	-0.2
	NOx (ktonnes)	167.93	167.58	-0.2
	CO (ktonnes)	35.06	34.99	-0.2
	PM10 (ktonnes)	3.32	3.31	-0.2
Rail	Vkms (bill)	58	62	5.8
	CO2 (ktonnes)	975	825	-15.3
	SO2 (ktonnes)	0.90	0.76	-15.3
	NOx (ktonnes)	5.43	4.60	-15.3
	CO (ktonnes)	2.76	2.34	-15.3
	PM10 (ktonnes)	0.34	0.29	-15.3
Total	Vkms (bill)			
	CO2 (ktonnes)	29768	29561	-0.7
	SO2 (ktonnes)	8.23	8.08	-1.9
	NOx (ktonnes)	173.36	172.17	-0.7
	CO (ktonnes)	37.83	37.32	-1.3
	PM10 (ktonnes)	3.66	3.60	-1.6
2030				
Road	Vkms (bill)	47955	47847	-0.2
	CO2 (ktonnes)	42238	42138	-0.2
	SO2 (ktonnes)	10.75	10.73	-0.2
	NOx (ktonnes)	245.78	245.15	-0.3
	CO (ktonnes)	51.49	51.36	-0.3
	PM10 (ktonnes)	4.87	4.85	-0.3
Rail	Vkms (bill)	84	90	7.1
	CO2 (ktonnes)	1399	1199	-14.3
	SO2 (ktonnes)	1.29	1.11	-14.3
	NOx (ktonnes)	7.79	6.68	-14.3
	CO (ktonnes)	3.96	3.40	-14.3
	PM10 (ktonnes)	0.49	0.42	-14.3
Total	CO2 (ktonnes)	43638	43337	-0.7
	SO2 (ktonnes)	12.05	11.84	-1.7
	NOx (ktonnes)	253.57	251.83	-0.7
	CO (ktonnes)	55.46	54.75	-1.3
	PM10 (ktonnes)	5.36	5.27	-1.5

7. ANALYSIS FOR THE BULGARIAN CASE STUDY

7.1 Introduction and main objectives

The main objectives of this analysis are to assess the financial and economic efficiency and benefits for each entity involved in the transport process and the society as a whole. The analysis is made using the proposed rolling stock improved and of a new type and with changing the market share of rail freight in transportation of containers.

It will be emphasized on the specificity and the factors influencing on the implementation of the new type of wagons under the Bulgarian conditions.

7.2 Methodology

The approach that will be applied in implementation of the financial and economic analysis is incremental.

Two versions will be compared: a version without putting into operation and using the new rolling stock and a version with putting into operation and using the new type of rolling stock. With traffic forecasting, the available forecasts made under technical assistance projects funded by the EU for the railway sections of the railway line Kalotina - Sofia - Plovdiv - Svilengrad and related to various research and analyses will be used. These forecasts will be adjusted taking into account the effects of the economic crisis.

Certain investments (financial and economic), costs (financial and economic), revenues and benefits based on traffic forecasts and the analysis of LCC and RAMS will be also analyzed.

The evaluation of the effectiveness and benefits will be made for the rail infrastructure manager, railway operators, end users of the transport service and the society as a whole.

The financial analysis will be made for the railway infrastructure manager, rail carriers and end customers, and the economic analysis is for all participants in the transport process that benefit from commissioning of new wagons and society as a whole. This will be the reason of putting into operation and using the proposed new types of wagons.

Railway carriers are the ones to make the necessary investments for putting the new wagons into operation and attract new customers. So, their role is very important and it is necessary to analyze the conditions, under which they would do that (increasing market share, cost reduction, using grants for implementation of investments and achieving greater efficiency and profit). With using grants, it is necessary to determine the amount of grant, so that the financial indicators of the own share of investments in new wagons (defined as a difference between the investment and grant) are positive.

The risk analysis for financial and economic analyses will be made using the Monte Carlo method.

7.3 Traffic Forecasts

A number of traffic types will be examined and forecasted:

7.3.1 Container traffic carried by rail (transit, import and export).

This traffic is international and 100% rail; it depends on factors that are external to the country. When forecasting it, statistical data from Eurostat and the National Statistical

Institute will be considered. The future and upcoming changes in the rail, road and intermodal infrastructure of neighboring countries (the Marmara tunnel, railway projects in Serbia, the new bridge between Vidin and Calafat) will be taken into account as well.

The forecasts will use: regression analysis, elasticity coefficients and expert assumptions and estimates.

7.3.2 Container traffic generated from river and sea container terminals (import, export and transit)

At the moment this traffic is generated in the ports of Varna and Burgas and is entirely transported by road. It can be distributed between road and rail, if in Bulgaria there is relevant intermodal infrastructure and if railways offer better conditions of transportation. Currently there is no such intermodal infrastructure built but there are strategies and projects to build it in the period 2014 – 2020. The only intermodal terminal in Bulgaria currently operating is the one built in Yana. The Thessaloniki port traffic to and from the country and the ports of Varna and Burgas will be considered as well.

Data and forecasts made within the following projects will be used:

- SAPS Study. The special assistance for project sustainability (SAPS) on Burgas port expansion project, Interim Report, October 2010, Japan international cooperation agency (JICA), consulting team: Padeco Co., Ltd.of Japan.
- Sofia Intermodal Freight Terminal, Financial & Economic Analysis – Draft Final Report, Ministry of Transport, January 2008.
- The special assistance for project formation (SAPROF) for new container terminals development project at the ports Varna and Burgas, Republic of Bulgaria, Final Report, Summary, November 2007. SAPROF time for Japan Bank for International Cooperation (JBIC); Pacific Consultants International (PCI), Tokyo, Japan; The Overseas Coastal Area Development Institute of Japan (OCDI)
- Project "Technical Assistance for the development of Burgas railway junction" funded by the European Union EVROTRANSPROEKT 2010.

The forecasts will use: regression analysis, elasticity coefficients and expert assumptions and estimates.

7.3.3 Domestic container traffic

There is no such traffic in Bulgaria. The possibility to containerize certain groups of cargoes after the construction of the intermodal and logistics infrastructure will be assessed and then the market shares of rail and road transport, both before and after putting the new types of wagons into operation will be determined.

The forecasts will use: regression analysis, elasticity coefficients, gravitation models, logit models to determine market shares and expert assumptions and estimates.

7.3.4 Container traffic by rail depending on the type of technology used

7.3.4.1 Rail container shipments

This type of traffic is implemented by trains where part of wagons are flat and loaded with containers. Containers are transported by rail carriers through the system of direct freight

trains (unspecialized trains). This type of technology is used when the container flow is insufficient to form specialized container trains (block trains).

7.3.4.2 Transportation of containers by specialized container trains (block trains or system of trains with constant composition in the intermodal rail network)

This type of traffic is implemented with the existing intermodal and logistics networks and sufficient power of container flows.

This type of traffic will be forecasted on the basis of forecasts of container traffic carried by rail of type 1, 2 and 3 and the estimated development of the intermodal infrastructure and network of intermodal terminals.

7.3.5 Container rail traffic by new wagons

This traffic depends on two factors:

- Life cycle of the flat wagons existing and used in the transport process for conveyance of containers. This factor is very important with old wagon fleet for transportation of containers.
- Level of reduction of costs and benefits of using the new railway wagons for the railway operators and end users respectively.

7.3.6 Kalotina - Sofia - Plovdiv - Svilengrad

Container traffic of type 1, 2, 3, 4 and 5 transported along railway line Kalotina - Sofia - Plovdiv - Svilengrad and final forecasts of rail traffic for transportation of containers with the new wagons.

7.4 Basic steps to forecast different container and rail traffic

1. Forecasting the performance of network of intermodal terminals and its maximum capacity. This will be important for forecasting container traffic and forecasting the rail traffic associated with transportation of containers using the new type of wagons, respectively. For that purpose strategic documents and projects related to it will be used.

2. Forecasting the renewal of wagon fleet of flat wagons for transportation of containers with wagon of the new type.

3. Forecasting the major possible container rail assignments that can be implemented in the existing and estimated intermodal network.

4. Forecasting the technologies used for transportation of containers by rail: wagon shipments through a system of direct freight trains and shipments by block trains or specialized container trains.

5. Positioning the railway line within the future intermodal networks. Determination of the sections where wagons with containers and container trains could run along.

6. Forecasting the future containerization in Bulgaria based on forecasts of goods suitable for containerization and forecasts of domestic rail container transport based on that.

7. Final forecasts of container transportation by rail with the new wagons.

7.5 Infrastructure charges

7.5.1 Comparative analysis

To compare the factors influencing on determination of the infrastructure charges, reference documents of infrastructure and annexes to them in Hungary, Poland, Czech Republic, Slovakia, Romania and Bulgaria have been analyzed.
In all countries surveyed there is no dependency on the hourly interval. Only in the Republic of Bulgaria with the current state of charging there is no classification of lines and trains by categories. In all other countries there is a distinction depending on whether the train is passenger or freight (even on the train category).

Regarding the costs of using electrical power and equipment for traction current supply, they are paid separately only in Bulgaria and on private infrastructure GYSEV Zrt in Hungary.

7.5.2 Specific features for Bulgaria

With determining the charge for using railway infrastructure, which is public property, it is only the amount of costs incurred directly as a result of the train service performed that are taken into account. Two types of charges are provided:

- charge for running along the railway infrastructure, which does not depend on the type of trains and is the same for all tracks of the railway infrastructure;
- charge for requested and unused capacity.

7.5.3 Procedure for changing the levels of infrastructure charges

Every year, by 30 June, NRIC State Company provides the RA Executive Agency with information on the actual costs for ongoing maintenance of the railway infrastructure during the previous year and determines the necessary level of the amount of infrastructure charges for the next year.

The necessary level of charges can include also allowances/bonuses, compensations and/or discounts arising from the implementation of infrastructure projects, traffic and the requirements of the transport market, differentiated for parts of the railway infrastructure, which will are publicly announces.

The validity period of this tariff is one year. The change of the amount of infrastructure charges is publicly announced three months before its entry into force.

7.5.4 Change of the charges related to putting the new type of wagons into operation

In connection with putting the new type of wagons into operation, it is possible to involve discounts in infrastructure charges for certain parts of the rail infrastructure, which is publicly announced.

7.6 Investments

The investments determined in this project for the new types of wagons will be used. When these investments are used for an economic analysis, they must be corrected and transformed into economic investments by establishing an appropriate correction coefficient. For this purpose "BULGARIA - General Guidelines" will be used.

If grants are used, their size and the level of own contribution to investments of the rail carrier will be determined, so that the indices of financial performance ban indicate acceptability and effectiveness of the own contribution to investments.

7.7 Costs

The costs of rail carriers and end users interested in the current project are connected with the maintenance and operation of wagons: standard flat wagons operating at the present moment and wagons of the new type, the costs of train delays in regard to the approved schedule, the costs of energy for using old wagons and wagons of new type and costs of infrastructure charges. These costs will be determined on the basis of the assumed methods for LCC and RAMS.

The reduction of the infrastructure manager's costs is connected with the improved wagons-track interaction and the maintenance and operation of the track due to corresponding improvements. These costs will be determined on the basis of the accepted methods for LCC and RAMS.

When these costs are used for the economic analysis, they must be corrected and converted into economic costs by determining an appropriate correction coefficient. "BULGARIA - General Guidelines for Cost Benefit Analysis for projects to be supported by the Cohesion Fund and the European Regional Development Fund in 2007-2013" will be used.

7.8 Revenues

The revenues related to the project concern the revenues of infrastructure charges for a rail carrier. These revenues will be determined based on the agreed reductions of infrastructure charges in connection with the use of wagons of the new type.

7.9 Benefits

To determine economic benefits, "BULGARIA - General Guidelines for Cost Benefit Analysis for projects to be supported by the Cohesion Fund and the European Regional Development Fund in 2007-2013" will be used.

7.10 Conclusion

The benefit of putting wagons of the new type into operation will be found after traffic forecasting and performing financial and economic analyses and sensitivity and risk analysis.

8. ANALYSIS FOR THE SPANISH CASE STUDY

The analysis of the rail freight transport in Spain is discussed in this section by analyzing the different facts that mark the current situation and the future.

Regarding the organization of the content for the Spanish case, in the next sections will be presented the focussed Spanish scenario, data sources, the cost analysis and the CO_2 emissions study, and an example of data application.

8.1 Scenario Description.

Spain has a natural strategic location for its geography, where the ports of Algeciras and Valencia have a special position in the transoceanic traffic and in the flow between the countries of the Mediterranean area towards the Atlantic area. The Spanish port activity, according to the Ministry of Public Works and AEFP (Private Railway Companies Association), has increased, and, if we only consider the transport of containers, Spanish ports in 2011 moved 13.3 Million TEUs, of which 6.31 million TEUs were transferred to ground transport (only 10% to rail transport).

The Spanish situation in rail freight presents a significant loss of market share. Thus, according to sources of the Ministry of Public Works, and to year 2008 data, in Spain 1474 billion of metric tonnes are moved in the country, of which only 31 million of metric tonnes are transported by railways. According to Eurostat, in 2010 the Spanish railway market share was 4,2% of the total metric tonnes, when the European Union average was 14,9%, and that of neighboring countries was between 12 to 22%.

However, this situation must also consider the existence of natural flows in the Spanish transport that have not historically been linked with railway and port infrastructures. Spain is a country where the main difficulty of rail freight is to present an unbalanced traffic between origins and destinations. To this must be added a technical and administrative difficulty in the border crossing derived from the difference in gauge (UIC 1435 mm and 1668 mm Iberic gauge). There are bilateral agreements between the operators in both sides of the border, solved in a clearly way in passenger traffic: there are standards and policies already in use, and it is possible to operate with variable gauge rolling stock. For the freight traffic the only possibility is to transfer the load at the border to another train, or to road transport.

Since one of the requirements of this document is the cost analysis, it is important to emphasize that the available data represent the Spanish situation under some hypothesis done by researchers, since it is impossible to know the private agreements and company rates in the freight transport. Nevertheless, the available data are sufficiently revealing as to highlight a relevant cost analysis according to the requirements, and to its integration into the LEFT model used in SUSTRAIL.

Finally, the Spanish infrastructure development (both railway and port) is an advantage for the European railway corridors for freight traffic. So, for the SUSTRAIL project, the Mediterranean corridor was chosen for a set of key questions:

- It is a corridor that supports mixed traffic passengers/goods on a line with Iberian gauge designed for high performance and allowing the passenger traffic up to 200 km/h.
- The Mediterranean corridor gives the connection with the ports of Algeciras, Valencia and Barcelona, and the transition with France.

- The national action plan is oriented to the modification of the facilities to support mixed traffic (passengers and freight) in a track with three rails for traffic circulation in UIC and Iberian gauge.

The Mediterranean Corridor represents a strategic line in the Spanish network. Actually is the centre of attraction for the development of new business. In April 2013, SNCF invested in the corridor with a participation of 25% in the Spanish private company COMSA Rail Transport, while Renfe and DB Shenker Rail AG signed an agreement with the aim of enhancing the market share of the freight transport.

8.2 Data Sources

The data analysis is performed using the available data published by the Spanish Railway Observatory (OFE, Observatorio del Ferrocarril en España), in which it is presented the state of the activities and developments in the Spanish railways. Actually the most recent data correspond to the year 2011 statistics.

The Spanish Railway Observatory, which produces reports since 2007, collects and compiles accurate and impartial information on a set of indicators that reflect the situation of the railway sector. It integrates all areas related to railway and infrastructure, passenger and freight traffic. It also includes economic and sustainability data.

The work done by the R&D department of the Spanish Railway Foundation try to homogenize the national and international statistical information, and provides information on the current demand and trends. Thus, the indicators compiled by the OFE are easily interpretable, not redundant and comparable with international indicators in use.

The information is collected in collaboration with the infrastructure managers and the operators involved in the railroad: ADIF, RENFE, Feve, Euskotren, Ferrocarrils de la Generalitat Catalunya, Ferrocarrils de la Generalitat Valenciana, Coto Minero Cantabrico, Activa Rail, Transfesa, Comsa Rail Transport, Logitren, Acciona Rail and Tracción Rail. Other sources that have been used are National Ports, INE (National Statistics Institute), Ministerio de Fomento (Ministry of Development), BBVA Foundation and UIC.

Regarding the freight sector the report considers:

- Evolution of rail infrastructure dedicated to freight traffic: length of lines, usage, fees and costs.
- Methodology for determining operating costs associated with the transport of goods by rail.
- Simulation of costs for "train type" of goods representing the commonly circulating in Spain, and volume load and traction mode.
- Opening the market for rail freight transport: network, operators in the General Interest Railway Network (RFIG), railway companies and authorized applicants.
- Transport of goods by rail: Main indicators, tonnes carried and tonne-kilometres produced, prices, incomes, supply, use, transport by type of goods, traffic flows, international traffic, railport traffic.
- Economic and sustainability data: turnover, investment, infrastructures, employment, market share, consumption and emissions.

8.3 Cost data identification

Prices in rail freight are, in most cases, free and fixed in transport contracts concluded between the customers and the operators. For this reason the pricing on these contracts are not public information.

Anyway an example of prices can be given using the data of the Spanish operator *Renfe Mercancias.* In the case of multi-client intermodal train, for which Renfe defined routes and conditions, the multi-client intermodal rate is fixed (Tarifa multimodal Multicliente). This rate is applied to all users of the network, differentiated according to whether they are loaded or empty containers, and the dimension of these (feet). An approach to the evaluation of the prices can be shown by analyzing the average income per ton.km and the average price per ton.

According to the OFE report, the average price for the Spanish operator *Renfe Mercancias*, is shown in Table 8.1.

Table 8.1. Average price per tonne and incomes. Renfe mercancias.Year 2011.

	Average price per ton (€/ton)	**Income (eurocent/ton.km)**
Multiproduct (including bulk)	10.92	3.63
Metals	13.64	2.56
Automotive	23.26	4.94
Intermodal	13.93	2.6
Average	11.99	2.75

The prices for the transportation of loaded and empty containers are presented in Table 8.2 and in Table 8.3.

Table 8.2. Average price for the transportation of loaded containers. Renfe Mercancias. 2011.

Containers (feet)	**Price (c€/km)**
20’	0.33
30’	0.36
40’	0.39
50’	0.46

Table 8.3. Average price for the transportation of empty containers. Renfe Mercancias. 2011.

Containers (feet)	**Price (c€/km)**
20’	0.26
30’	0.29
40’	0.32
50’	0.37

In order to have an idea of the costs of a railway company, the OFE report offers an evaluation of data related to costs, emissions and consumption.

This evaluation is done per kind of goods:

- Metal products
- Construction and mining
- Petrochemical
- Agriculture
- Automotive
- Manufactured
- Intermodal.

For every good, three kinds of tables are offered:

- Train characteristics.
- Operating costs.
- Consumption and emissions.

In order to have a harmonized view of the data, in the OFE report the analysis is done presenting the data split in 4 scenarios:

- Electric traction
  - Smooth profile
  - Mountainous profile
- Diesel traction
  - Smooth profile
  - Mountainous profile.

For the comparison of data, the rolling stocks used are the same in each couple of scenarios. For the electric traction it is used the Renfe 253 locomotive and for the diesel traction the Renfe 335 locomotive.

Same hypothesis is done for the profile, since for the smooth profile it is considered the line León-Valladolid and for the Mountainous profile, the line Gijón-Leon.

8.4 Costs analysis

There are several factors included in the costs evaluation. Anyway, all costs are related to:

- Costs attributable to a service;
- Indirect cost attributable to a service.

In order to quantify the different cost, these can be organized in 5 groups:

- Rolling stocks
- Platforms/wagon
- Operation
- Canons
- Other costs.

For each group of costs, some hypotheses have been assumed by the OFE researchers.

1) **Rolling stocks:**
   - The maximum of the train is 450 meters.
   - Annual journey of the locomotives (electric or diesel): 100.000 km.
   - Annual hours of operation of the locomotives: 1811.
   - Annual journey of a wagon: 40.000 km.
   - Annual usage of a wagon: 727 hours.
   - Energy costs based on the 2011 ADIF Network Declaration.
   - The railway operator is the owner of the rolling stocks and the wagons:
     - Financing 100% of the acquisition;
     - Financing time: 10 years.
     - Interest (TAE): 3.50%.
     - Euribor 1 year: 1.495%.
     - Diferential: 2%.
   - Cost of a locomotive: fixed euros +euro/kW+euros per tonne of the locomotive (en million euros):
     - Price Diesel: 1+0004*(power)+0.0833*(mass);
     - Price Electric: 1.666+0.0002083*(power)+0.012962*(mass);
   - Amortization of the locomotive: 25 years.
   - Residual value of the locomotive: 10%.
   - Cost of a wagon: fixed euros +euro/axle of the wagon+euro per tonne of tare (in million euros):
     Price: 0.021+0.01*(axle)+0.016*(tare);
   - Amortization of the wagon: 25 years.
   - Residual value of the wagon: 0%.
   - The maintenance costs of the locomotive are proportional to the cost: 4 % for electric and 7% for diesel.
   - The maintenance cost for the wagons is proportional to the acquisition cost: 3%.
   - Management costs based on the 2011 ADIF Network Declaration.
   - Other cost for the traction: 3% on the investment in the locomotive.
   - Other fixed costs for the rolling stocks: 3% on the investment in the rolling stocks.

2) **Infrastructure**
   - Infrastructure manager fees based on the 2011 ADIF Network Declaration:
     - Circulation fees related to the value of km.tren used.
     - Fees for path booking depending of the hour of the day.
   - Additional costs in terminals:
     - Fees based on the 2011 ADIF Network Declaration.
     - Access to terminals.
     - Dispatch from terminal.
     - Operations in terminals.

3) **Personnel costs**
   - Social insurance for each employed is 29,90% of the salary.
   - The driver has an average age of 30 years.
   - Additional personnel expenses (food and lodging): 80 €/day.
   - Working personnel year: 240 days.

In general the cost for the personnel is the one shown in

Table 8.4.

Table 8.4. Personnel costs.

Average cost for personnel. Values in Euros	
Annual salary	42.000
Bonus	6.000
Compensation for excess hours	5.000
Social insurance	18.000
Training and physical examination	6.000
Food and lodging. 240 days at 80 €/day.	19.200
Total	**96.200**

8.5 Emissions analysis

According to the study developed by the OFE, the model for calculating the energy consumption is based on the energy balance of the train:

Energy entering the train = Energy leaving the train + Losses

The entering energy, E_n, is the sum of:

- Energy required for overcoming the aerodynamic drag in straight and in curve.
- Energy consumed by the auxiliary services.
- Energy loss due to the traction performance and in auxiliary services.
- Energy dissipated braking.

In the case of electric trains with regenerative braking, the energy generated while braking, whether used to supply equipment or returned to the catenary or to the power network, must be subtracted.

Having calculated the net energy consumption, the traction energy consumption, $E_{traction}$, at the entrance of the substation is obtained multiplying the net energy by the coefficient C_{rail} representing the losses in the railway network and depending on the electrification voltage.

For diesel traction the coefficient C_{rail} is 1.

$$E_{traction} = E_n \cdot C_{rail} \quad (1)$$

The energy consumption at the substation, $C_{network}$, is obtained multiplying the traction energy consumption by the coefficient $C_{network}$ representing the losses in the public network for transmission and distribution of the energy:

$$E_{substation} = E_{traction} \cdot C_{network} \quad (2)$$

The CO_2 emissions are calculated at the substation level (or at the entrance of the vehicle if the traction is Diesel) multiplying the energy in kWh, or the consumed litres, by the emitted CO_2 grams for kWh or for litres, $C_{emission}$:

$$E_{CO_2} = E_{substation} \cdot C_{emission} \quad (3)$$

8.6 Results

With the hypothesis of the section 8.4 the OFE report presents an analysis of the cost for the freight operation and the evaluation of the consumption and emission. The analysis done presents a big data dispersion in the cost evaluation considering the different scenarios and the kind of goods. These costs vary between 1.93 c€/(net tonn.km) to 13.31 c€/(net ton.km) (Table 8.5).

Even if the diesel locomotive has a higher load capacity, the freight trains pulled by electric locomotive has lower costs due to lower tractive maintenance costs and lower consumptions.

Table 8.5. Cost in c€/net ton.km. Source OFE.

	Electric		Diesel	
	Smooth profile	**Mountainous profile**	**Smooth profile**	**Mountainous profile**
Metal products	1.93	2.54	2.33	2.84
Construction and mining	2.36	2.99	2.92	3.40
Petrochemical	1.93	2.50	2.35	2.90
Agriculture	2.64	3.24	3.20	3.75
Automotive	11.03	10.99	13.35	13.31
Manufactured	2.70	3.27	3.40	3.73
Intermodal	3.17	3.40	3.76	3.82

The dispersion in CO2 emission is even higher than the dispersion in costs considering the different scenarios and kind of goods. The values vary between 5.47 gCO2/(net ton.km) and 161.97 gCO_2/(net ton.km) (

Table 8.6).

Table 8.6. Emissions in gCO_2/(net ton.km). Source OFE.

	Electric		Diesel	
	Smooth profile	**Mountainous profile**	**Smooth profile**	**Mountainous profile**
Metal products	5.47	16.79	13.88	43.71
Construction and mining	6.84	17.98	17.62	49.64
Petrochemical	5.57	16.43	14.23	43.47
Agriculture	7.41	20.06	18.98	53.05
Automotive	30.98	55.37	84.90	161.96
Manufactured	7.21	19.83	19.60	54.81
Intermodal	7.48	15.44	20.15	42.92

8.7 Example of application: metal products

In order to have an idea of the detailed data contained in the OFE report, an example regarding the transportation of Metal products is represented. For this case the used wagon is:

- JJ92 Steel Reel Carrier Wagon



Figure 8.1. JJ92 Steel Reel Carrier Wagon. Source RENFE.

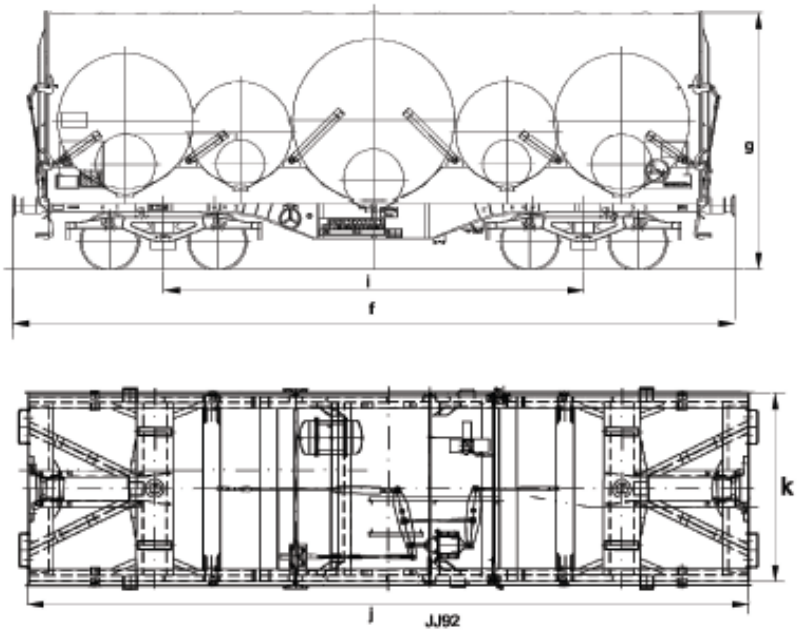


Figure 8.2. JJ92 Steel Reel Carrier Wagon. Lateral and top views. Source RENFE.

8.7.1 Metal products cost example.

Table 8.7 shows the cost of the metal product transportation considering electric and diesel traction for smooth profile and mountainous profile.

Table 8.7. Costs for metal product transportation. Costs in c€/(net ton.km). Source OFE.

Electric		Diesel	
Smooth profile	**Mountainous profile**	**Smooth profile**	**Mountainous profile**
1.93	2.54	2.33	2.84

These costs consider the train characteristics contained in

Table 8.8 and resume the costs detailed in Table 8.9.

Table 8.8. Train characteristics for JJ92 wagon. Source OFE

	Electric traction		Diesel traction	
	Smooth profile	**Mountainous profile**	**Smooth profile**	**Mountainous profile**
Loaded train				
Wagon per train	19	9	24	12
Load limitation	Maximum gradient	Maximum gradient	Maximum gradient	Maximum gradient
Load	1168	553	1475	738
TBR (Gross ton towed)	1649	781	2082	1041
Total mass	1734	866	2206	1165
Total length	248	127	312	168
Empty train				
Wagon per train	35	35	35	35
Load limitation	Maximum length	Maximum length	Maximum length	Maximum length
Load	0	0	0	0
TBR (Gross ton towed)	866	866	866	866
Total mass	971	971	1010	1010
Total length	440	440	444	444

Table 8.9. Operation costs for JJ92 wagon. Source OFE.

Operation costs c€/(net ton.km)	Electric traction		Diesel traction	
	Smooth profile	**Mountainous profile**	**Smooth profile**	**Mountainous profile**
Rolling stocks	**0.92**	**1.16**	**0.97**	**1.21**
Locomotive	0.35	0.60	0.40	0.64
Amortization	0.13	0.23	0.11	0.18
Financing	0.03	0.05	0.02	0.04
Maintenance	0.19	0.32	0.27	0.43
Platforms/Wagons	**0.57**	**0.57**	**0.57**	**0.57**
Hire/Amortization	0.27	0.26	0.27	0.26
Financing	0.05	0.05	0.05	0.05
Maintenance	0.25	0.25	0.25	0.25
Operation	**0.78**	**1.04**	**1.15**	**1.35**
Personnel	0.33	0.57	0.29	0.45
Energy	0.45	0.47	0.86	0.89
Canons (Infrastr. and services)	0.04	0.07	0.04	0.06
Path booking and usage	0.01	0.02	0.01	0.02
Access to terminals	0.03	0.05	0.02	0.04
Internal services in terminals	0.00	0.00	0.00	0.00
Other costs	**0.19**	**0.27**	**0.17**	**0.23**
Other fixed costs traction	0.11	0.19	0.09	0.15
Other fixed costs rolling stocks	0.08	0.08	0.08	0.08
TOTAL	**1.93**	**2.54**	**2.33**	**2.84**

8.7.2 Consumptions and emissions data

Table 8.10 presents the emission data for the metal product transportation.

Table 8.10. Consumptions and emission for the transportation of metal product. Source OFE.

	Electric traction		Diesel traction	
	Smooth profile	**Mountainous profile**	**Smooth profile**	**Mountainous profile**
Energy consumption (kWh/net ton.km)	0.022	0.068	0.053	0.167
Energy consumption at the substation (kWh/net ton.km)	0.022	0.068	0.000	0.000
Diesel consumption (l/net ton.km)	0.000	0.000	0.005	0.016
CO2 Emissions gCO2/(net ton.km).	5.469	16.790	13.877	43.706

9. INTERIM SYNTHESIS

9.1 The Business Case framework

The elements above will be brought together in a Business Case framework with a standard set of outputs (Table 9.1).

Item	Analysis outputs
1.	Description of the innovation
2.	Rationale for the innovation
3.	LCC and RAMS analysis – main findings
4.	Cost-benefit analysis: • financial case for industry stakeholders (NPV, IRR) • socio-economic case (NPV, BCR, IRR)
5.	Impact on rail market share, CO_2 and other emissions
6.	Technical implementation and phasing – recommendations

Table 9.1: Business Case outputs

9.1.1 Description and rationale

Appendix 1 contains examples of the description of the innovation and the rationale for the innovation, based on the set of innovations included in the 'Demonstrator 1' and 'Demonstrator 2' SUSTRAIL vehicles.

The *description* indicates what modifications would be made, compared with a train made up of standard UIC Class R/S wagons with Y25 bogies, running on a conventional mixed passenger/freight line in the EU. For example, the innovation 'Inter-axle linkages'[10] (alone), is currently described as:

- inter-axle linkages to guide the wheel sets – i.e. self steering bogies. The practically applicable solutions are: (i) 'elastic' bogies where fine tuning of suspension stiffness allows for a sufficiently stable bogie with close to radial steering of wheelsets in curves guided by wheel-rail forces; or (ii) bogies with kinematic or self-steering elastic additional interaxle linkages that are as well guided by wheel-rail forces. Self-steering elastic additional interaxle linkages allow retrofitting the existing designs of bogies, and can be positioned outside the space between wheelsets.

This example makes clear that there are still technology choices to be made for the final SUSTRAIL vehicle. Moreover, this is for a single innovation, whereas the final business case will need to integrate multiple innovations. The concise description needed for the business case should also be supported by more detailed information from an engineering perspective which specifies how the innovative vehicle/track differs from its baseline counterpart.

The *rationale* relates the innovation to the goals of SUSTRAIL, showing how the innovation can help achieve the duty requirements for future freight identified in WP2 (Table 1.3). For example:

[10] See Appendix 1, A1.5

- inter-axle linkages allow for the design speed to be increased up to 160 km/h; a reduction of rolling resistance (and traction energy consumption) by 30-50%; a reduction of vertical (within 10%) and lateral (30-50%) forces; reduction of wheel wear by 2-3 times; and a general reduction of dynamic loads and improvement of horizontal ride qualities[11].

The rationale should also acknowledge any important expected consequences, including negative ones. Referring to inter-axle linkages again:

- disadvantages that are necessary to mention include: increase of unsuspended mass (approximately 900 kg per wagon); more complicated production and repair technology; and generally bigger initial cost of the design compared to traditional ones. LCC analysis shows that the increase in initial expense is compensated in approximately 2.5 years by reduced wear and damage of wheels.

9.1.2 LCC and RAMS analysis

These will be central to the final Business Case. They directly provide some of the key results – life-cycle cost implications and performance benefits of the SUSTRAIL innovations – and they also provide key inputs to the CBA.

At this stage we only have indicative LCC and RAMS calculations based on judgmental scores (0-10 scale) estimated by the WP3 research team against a set of relevant criteria (see Chapter 2).

In the final Business Case we expect to have LCC results in cost units (€). These will describe the change in costs for the Infrastructure Manager and Freight Operators, as a result of implementing the SUSTRAIL vehicle and track innovations (separately and in combination).

The format of the LCC results will include:

- NPV over a stated period of years, from 2015 onwards;
- breakdown of the NPV into key cost headings:
  - IM: capital costs (separating enhancement/renewal costs); maintenance costs; operating costs;
  - Freight operators: capital costs; maintenance costs; operating costs.

The detailed data behind these results will be passed through to the CBA in the form of a stream of cost data for each cost heading over time – for example as shown in Table 9.2.

Units: € (2015 base year for prices and values)																			
		Year																	
		2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2028	2029	data series
Infrastructure Manager (IM)																			continue
ΔCosts	Capital - enhancement																		to end of
	Capital - renewals																		asset life
	Maintenance																		
	Operation																		
	SubTOTAL																		
Freight Operators (FOC)																			
ΔCosts	Capital																		
	Maintenance																		
	Operation																		
	SubTOTAL																		

Table 9.2: LCC outputs

[11] The extent to which these improvements can be achieved for the SUSTRAIL vehicle will be considered during the remaining research.

We also expect in the final Business Case to have RAMS outputs in the form of:

- key metrics of reliability, availability, maintainability and safety, e.g.:
  - mean time between failure (MTBF);
  - function probability;
  - mean time between maintenance (MTBM); mean time to maintain (MTTM);
  - hazard rate, mean time between hazard system failures (MTBHSF) or numbers of accidents.

For the CBA, it is important that the reliability implications for the Freight Operator due to whole system behaviour (track and trains) is passed through from the RAMS analysis to the CBA. The data input requirements for reliability were discussed in section 3.2. Again, the reliability data should cover the period from 2015 until the end of the asset life of the systems affected by the SUSTRAIL innovations.

Safety data in the form of an accident rate or numbers of accidents for the case study networks should cover the same time period.

9.1.3 Cost-benefit analysis

The results are expected to take the following form:

- financial case for industry stakeholders
  - net present value (NPV) using a discount rate of 6%[12] for IMs and 9% for freight operators, reflecting commercial conditions;
  - financial internal rate of return (IRR).
- socio-economic case
  - net present value (NPV) using a social discount rate of 3.3%;
  - benefit:cost ratio (BCR), a commonly-used value-for-money indicator;
  - overall societal internal rate of return (IRR).

Table 9.3 (overleaf) describes the scope of the cost-benefit analysis (CBA) and the final column indicates which Task will provide each element. Both the financial results and the socio-economic case will be derived from the same basic set of data, although the scope of the socio-economic case is wider, encompassing end user time and reliability benefits, and the environmental effects of the SUSTRAIL innovations.

In all these calculations the appraisal will start in 2015, consistent with the expected completion of the SUSTRAIL research, and will extend to encompass the asset lives of the chosen SUSTRAIL innovations. Where appropriate, for example if the asset lives extend beyond a feasible period for forecasting freight demand, we may curtail the appraisal period and adopt residual values, following standard practice in CBA. Only a subset of these years can be shown in Table 9.3 given limitations of space.

The societal NPV is the sum of benefits, net of costs, to all stakeholders. The financial NPV is a subset of this, calculated using different (higher) discount rates as shown above. We will adopt a base year of 2015 for discounting and for prices. Appendix 3 describes the cost-benefit analysis framework in greater detail.

[12] See Appendix 3 for justification of the discount rates.

On the following pages, using our initial assessments from the UK case study, a set of Present Values for specific impacts are presented (Tables 9.4 and 9.5). These cannot be added up to an overall NPV at this stage, since the other key elements are not yet available (e.g. LCCs). They do, however, indicate how the input data from the preceding Tasks will be used within the Business Case Synthesis.

Cost Benefit Analysis components, All case studies													
Units: € (2015 base year for prices and values)			Year								Present		
			2015	2030	+ interpolation/extrapolation to other years						Value	Source:	
Impact Groups	Impacts												
Infrastructure Mgr.	ΔCosts	Capital - enhancement										LCC & RAMS (5.1)	
		Capital - renewals										LCC & RAMS (5.1)	
		Maintenance										LCC & RAMS (5.1)	
		Operation										LCC & RAMS (5.1)	
		SubTOTAL											
	ΔRevenues	Track access charges										Benefit allocation after Freight Model Benefits (5.2); Track Access Charges (5.3)	
		SubTOTAL											
	Net Benefit	TOTAL											
Freight Operators	ΔCosts	Capital										LCC & RAMS (5.1)	
		Maintenance										LCC & RAMS (5.1)	
		Operation - Track access charges										LCC & RAMS (5.1); Track Access Charges (5.3)	
		Operation - other										LCC & RAMS (5.1)	
		SubTOTAL											
	ΔRevenues	Freight service income										Benefit allocation after Freight Model Benefits (5.2); Track Access Charges (5.3)	
		SubTOTAL											
	Net Benefit	TOTAL											
Passenger Operators	Net Benefit	Path capacity benefits (UK only)										Passenger Capacity Benefit Model (5.2.3)	
End Users	Net Benefits	Reliability benefits										Freight Model - User Benefits (5.2)	
		Speed benefits										Freight Model - User Benefits (5.2)	
		Freight service charges										Benefit allocation after Freight Model Benefits (5.2)	
		TOTAL											
3rd Parties	ΔBenefits	CO_2 reductions										Freight Model - Environmental Benefits (5.2)	
		Local emissions reduction										Freight Model - Environmental Benefits (5.2)	
		Accident reduction										LCC & RAMS (5.1); Freight Model (5.2)	
	ΔCosts	Grant & subsidy requirements										Derived from overall CBA results (5.5)	
	Net Benefit	TOTAL											
Net Present Value (societal)													

Table 9.3: Scope of the cost-benefit analysis

Table 9.4 shows a set of interim CBA results for End Users, which are based on the simplifying assumptions for the SUSTRAIL vehicle in the UK case study, as set out in section 6.7. The benefits are projected to grow over the period 2015 to 2030, assuming there is a gradual replacement of the fleet at a constant rate, that rail freight grows over time as projected in section 6.8, and that users' values of time and reliability grow in proportion with real GDP per capita (the conventional assumption). After 2030, growth of benefits continues only in proportion with real GDP per capita. These assumptions should be replaced with better-informed estimates as the SUSTRAIL innovations are defined more precisely, analysis is carried out, and the implementation profile is determined.

The Present Value to End Users is found to be €533million in the social CBA (discount rate 3.3%). This can be broken down, with some further analysis, into:

- Reliability benefits;
- Speed benefits;
- Reduced freight service charges – which derive from
    - reduced track access charges;
    - reduced vehicle maintenance expenses;
    - reduced fuel and non-fuel operating costs.

Table 6.10 indicates that these calculations are sensitive to the share of traffic in different distance bands. The final Business Case will disaggregate the benefits as shown above.

	Benefit to End Users, 2015 €, undiscounted				Benefit to
	Food, drink & agriculture	Others	TOTAL	Discount factor @3.3%	End Users, € (PV 2015)
2015	41661	1414762	1456423	1.000	1456423
2016	103922	3810927	3914850	0.968	3789787
2017	166184	6207092	6373277	0.937	5972582
2018	228446	8603258	8831704	0.907	8012048
2019	290708	10999423	11290131	0.878	9915113
2020	352969	13395588	13748557	0.850	11688412
2021	415231	15791753	16206984	0.823	13338294
2022	477493	18187918	18665411	0.797	14870834
2023	539755	20584084	21123838	0.771	16291845
2024	602016	22980249	23582265	0.747	17606889
2025	664278	25376414	26040692	0.723	18821287
2026	726540	27772579	28499119	0.700	19940126
2027	788802	30168744	30957546	0.677	20968273
2028	851063	32564910	33415973	0.656	21910381
2029	913325	34961075	35874400	0.635	22770897
2030	975587	37357240	38332827	0.614	23554074
2031	994123	38067028	39061151	0.595	23234851
2032	1013111	38794108	39807219	0.576	22922204
2033	1033677	39581628	40615305	0.557	22640392
2034	1055901	40432633	41488534	0.540	22388345
2035	1078603	41301935	42380538	0.522	22139104
2036	1101793	42189926	43291719	0.506	21892637
2037	1124710	43067477	44192187	0.490	21634080
2038	1148104	43963280	45111385	0.474	21378575
2039	1171985	44877717	46049701	0.459	21126089
2040	1197534	45856051	47053585	0.444	20897035
2041	1223640	46855713	48079353	0.430	20670465
2042	1250683	47891224	49141907	0.416	20452355
2043	1279574	48997511	50277085	0.403	20256345
2044	1309132	50129354	51438485	0.390	20062214

Table 9.4: Rail freight improvement: benefits to End Users, at Present Values (2015)

Table 9.5 shows the type of CBA results which will be achievable for CO_2 emissions, again using a simplified analysis for the UK case study. The quantity of emissions reduction due to the SUSTRAIL vehicle innovations is crudely projected to grow from zero to 300,900 tonnes per annum, over the period 2015 to 2030, assuming there is a gradual replacement of the fleet over this period. After 2030, the size of the emissions reduction is capped at that level. These assumptions should be replaced with better-informed estimates as the SUSTRAIL innovations are defined more precisely, analysis is carried out, and the implementation profile is determined.

The results for CO_2 reduction benefits at Present Values (2015) have been calculated first using the EU IMPACT 'central' values [3] uplifted from a 2000 to a 2015 basis, and then as a sensitivity test using the 'central estimate' UK official values from WebTAG [33]. The Present Value is €306million, or €665million, respectively. The 'low' WebTAG values are comparable to the IMPACT 'central' values, which is consistent with the gradual increase in CO_2 values in recent years as methods have evolved.

					ΔCO_2	ΔCO_2
			Marginal value,		reduction	reduction
		ΔCO_2	€ per tonne,		benefit, €	benefit, €
		emissions,	2015 prices	Discount	(PV 2015)	(PV 2015)
		tonnes	(IMPACT 'central')	factor @3.3%	(IMPACT 'central')	(WebTAG 'central')
2015		-13811	45	1.000	624402	1442981
2016		-32951	47	0.968	1508743	3382846
2017		-52092	49	0.937	2410804	5254669
2018		-71233	51	0.907	3326158	7060232
2019		-90373	54	0.878	4250719	8801275
2020		-109514	56	0.850	5180726	10479500
2021		-128654	58	0.823	6112716	12116429
2022		-147795	60	0.797	7043514	13695292
2023		-166936	62	0.771	7970212	15216300
2024		-186076	64	0.747	8890153	16679770
2025		-205217	66	0.723	9800919	18086112
2026		-224357	68	0.700	10700312	19435824
2027		-243498	70	0.677	11586344	20729485
2028		-262639	72	0.656	12457222	21967744
2029		-281779	74	0.635	13311338	23151317
2030		-300920	77	0.614	14147254	24280978
2031		-300920	79	0.595	14068817	25687938
2032		-300920	81	0.576	13980954	26980226
2033		-300920	83	0.557	13884347	28163732
2034		-300920	85	0.540	13779644	29244088
2035		-300920	87	0.522	13667462	30226676
2036		-300920	89	0.506	13548384	31116640
2037		-300920	91	0.490	13422966	31918896
2038		-300920	93	0.474	13291735	32638139
2039		-300920	95	0.459	13155190	33278854
2040		-300920	97	0.444	13013804	33845325
2041		-300920	99	0.430	12868027	34341640
2042		-300920	102	0.416	12718282	34771705
2043		-300920	104	0.403	12564973	35139246
2044		-300920	106	0.390	12408479	35447818

Table 9.5: CO_2 reduction benefits, at Present Values (2015)

It must be emphasised that the numbers in this section are based on the *assumed* impacts of the SUSTRAIL vehicle innovations stated in Section 6.7, for the purpose of developing the methodology. In the final business case they will be replaced by estimates derived from the next phase of research.

9.1.4 Impact on rail market share, CO_2 and other emissions

The impact on rail market share is derived from the demand analysis carried out as part of the three case studies.

Using the UK case study as an example, Table 9.6 shows the impact of the assumed set of SUSTRAIL innovations, based on the initial analysis described in Chapter 6. Market shares with the innovations in place are labelled 'SCEN'. This equates to a 12.7% increase in rail market share for Food, drink and agriculture, and a 7.4% increase for Other rail freight (including a wide range of containerised freight) in 2030.

Year	**2006**	**2015**		**2030**	
Scenario	**BASE**	**BASE**	**SCEN**	**BASE**	**SCEN**
Rail market share (%) by segment					
Food, drink and agriculture	0.5	0.5	0.5	0.5	0.6
Others	7.9	8.2	8.8	8.5	9.1
Bulk freight	22.3	21.7	21.7	20.7	20.7
TOTAL	11.0	10.2	10.5	9.2	9.5

Table 9.6: Indicative rail freight market share outputs (%), based on interim assumptions about cost and performance impacts

The impact on CO_2 emissions, and other emissions with regional/local implications, is also estimated within the case studies. Again using the UK case study as an example, Table 9.7 shows the type of output expected.

		Base	*Scenario*	*%change*
2015 Road	Vkms (bill)	32992	32930	-0.2
	CO2 (ktonnes)	28793	28736	-0.2
	SO2 (ktonnes)	7.33	7.32	-0.2
	NOx (ktonnes)	167.93	167.58	-0.2
	CO (ktonnes)	35.06	34.99	-0.2
	PM10 (ktonnes)	3.32	3.31	-0.2
Rail	Vkms (bill)	58	62	5.8
	CO2 (ktonnes)	975	825	-15.3
	SO2 (ktonnes)	0.90	0.76	-15.3
	NOx (ktonnes)	5.43	4.60	-15.3
	CO (ktonnes)	2.76	2.34	-15.3
	PM10 (ktonnes)	0.34	0.29	-15.3
Total	Vkms (bill)			
	CO2 (ktonnes)	29768	29561	-0.7
	SO2 (ktonnes)	8.23	8.08	-1.9
	NOx (ktonnes)	173.36	172.17	-0.7
	CO (ktonnes)	37.83	37.32	-1.3
	PM10 (ktonnes)	3.66	3.60	-1.6
2030 Road	Vkms (bill)	47955	47847	-0.2
	CO2 (ktonnes)	42238	42138	-0.2
	SO2 (ktonnes)	10.75	10.73	-0.2
	NOx (ktonnes)	245.78	245.15	-0.3
	CO (ktonnes)	51.49	51.36	-0.3
	PM10 (ktonnes)	4.87	4.85	-0.3
Rail	Vkms (bill)	84	90	7.1
	CO2 (ktonnes)	1399	1199	-14.3
	SO2 (ktonnes)	1.29	1.11	-14.3
	NOx (ktonnes)	7.79	6.68	-14.3
	CO (ktonnes)	3.96	3.40	-14.3
	PM10 (ktonnes)	0.49	0.42	-14.3
Total	CO2 (ktonnes)	43638	43337	-0.7
	SO2 (ktonnes)	12.05	11.84	-1.7
	NOx (ktonnes)	253.57	251.83	-0.7
	CO (ktonnes)	55.46	54.75	-1.3
	PM10 (ktonnes)	5.36	5.27	-1.5

Table 9.7: Indicative changes in emissions of CO_2 and other pollutants, based on interim assumptions about the SUSTRAIL innovations

9.1.5 Technical implementation and phasing – recommendations

Key information will include:

- the time profile for introduction of the new vehicle into the European fleet over the period from 2015 onwards (potential % share of UIC Class R/S vehicles, by year, indicating any expected variation by country/area/market segment, and resulting % share of freight benefitting, by tonne-km in market segments above);
- the time profile for introduction of the track innovations on the European mixed-traffic network from 2015 onwards (% of network covered, by year, indicating any expected variation by country/area/market segment, and resulting % share of freight benefitting, by tonne-km in market segments above);
- the findings on optimal phasing from Task 5.4 on which these profiles are based;
- anticipated barriers to implementation;
- actions required to overcome the barriers to implementation, and the indicative timing and cost/revenue/performance implications of these actions, which needs to be incorporated into the CBA.

10. CONCLUSIONS AND IMPLICATIONS FOR WP3&4

10.1 Business Case applications and next steps

The Business Case for the SUSTRAIL innovations has been developed alongside the engineering analysis from the start of the project. The prioritisation of Duty Requirements and the selection of innovations have been carried out with regard to the potential costs and benefits for end users, the rail industry and stakeholders in general, as represented by the business case criteria.

In the next phase of SUSTRAIL, the Business Case will be developed further, for the selected track and vehicle innovations (Table 10.1). We anticipate there will be six scenarios (3*2).

Scenarios	Baseline vehicle (Y25)	Improved 'Conventional' Vehicle	Futuristic Vehicle
Baseline Track	i	ii	iii
Improved Track	iv	v	vi

Table 10.1: Business Case scenarios

The Business Case will be based on the impact of implementing the SUSTRAIL package of improvements, compared with the Baseline scenario. Thus five tests are of interest:

- Futuristic Vehicle on Improved Track (vi) versus Baseline (i)
- Conventional Vehicle on Improved Track (v) versus Baseline (i)
- Baseline vehicle (Y25) on Improved Track (iv) versus Baseline (i)
- Futuristic Vehicle on Baseline Track (iii) versus Baseline (i)
- Conventional Vehicle on Baseline Track (ii) versus Baseline (i)

The first and second of these are the key tests, representing the impact of the full set of SUSTRAIL innovations. The difference between these two will be the contribution of the more ambitious Futuristic Vehicle improvements compared with the Improved Conventional Vehicle. The remaining tests serve to identify the contributions of the track and vehicle elements separately.

The upgraded track will embody a number of innovations currently being selected from the list in Section 5.2. The upgraded vehicles are expected to include the innovations listed in Table 1.4.

10.2 Data and modelling requirements for WP3&4 (and WP5)

In order to make the Business Case for the final set of SUSTRAIL innovations, a range of data and modelling results will be required. These will come from WP3, WP4 and WP5.

Table 10.2 summarises these, and also indicates the expected timescale within which they should be provided and to which Task leader (in parentheses).

WP3 inputs

- Definition and rationale for the vehicle options being tested at the Final Assessment stage (by Jan 2014, to Tasks 5.1 and 5.5).
- LCC & RAMS input data requested via the data input form, for the vehicle options being tested at the Final Assessment stage (by Jan 2014, to Task 5.1). This will allow 5.1 to provide the Business Case with cost impacts (investment, maintenance, operations) and performance impacts (reliability, availability, maintainability and safety) for each of the options.
- CO_2 emissions reductions caused by the Futuristic and Improved Conventional vehicles, running on each of the track options, for the Final Assessment (by Jan 2014, to Task 5.2). This will require evidence/assumptions about motive power (locomotives, energy sources), and fuel/energy consumption data may be key to the calculations.
- Noise and other measurable emissions of the Futuristic, Improved Conventional and Baseline vehicles, running on each of the track options (Improved/Baseline) for the Final Assessment (by Jan 2014, to Task 5.2).
- Speed, braking and acceleration performance of the different vehicle options (by Jan 2014, for use in 5.2.3 and in 5.2 for speed benefits).
- Damages emerging from different vehicle/track simulation runs to be captured and results provided (by Jan 2014, to Task 5.3).

WP4 inputs

- Definition and rationale for the track options being tested at the Final Assessment stage (by Jan 2014, to Tasks 5.1 and 5.5).
- LCC & RAMS input data requested via the data input form, for the track options being tested at the Final Assessment stage (by Jan 2014, to Task 5.1). This will allow 5.1 to provide the Business Case with cost impacts (investment, maintenance, operations) and performance impacts (reliability, availability, maintainability and safety) for each of the options.
- Data on the relationship between maximum operating speed (100/120/140km/h) and the average train speed for freight trains on the IMs' particular networks in the UK, Spain and Bulgaria (by Jan 2014, to Task 5.2). This is to enable an estimate of (expected) freight journey time savings.
- Any Noise and CO_2 emissions related to the track – in particular: noise and CO_2 emissions impact from track maintenance and renewal, including disposal/recycling of track and trackbed components (by Jan 2014, to Task 5.2).
- Damages emerging from different vehicle/track simulation runs (by Jan 2014, to Task 5.3).

WP5 inputs

-Task 5.1

5.2 will take data from Task 5.1 on:

- the Life Cycle Costs of each Option (track and vehicle combinations) for IMs and Freight Operating Companies (by Feb 2014 for Final Assessment);
- the Reliability, Availability, Maintainability and Safety performance of each Option (same timescale).

-Task 5.3

5.2 will take data from Task 5.3 on:

- track access charges under each Option (by March 2014 for Final Assessment):
- scenarios, in the form of access charge regimes, for the purpose of allocating benefits and costs to industry parties within the business case. It is envisaged that there will be two scenarios:
  - Current access charge regime in each country
  - Cost reflective access charge regime using research findings in 5.3.1 and 5.3.2.

-Task 5.4

5.4 will provide 5.5 with:

- the optimal time profile for introduction of the new vehicle into the European fleet;
- the optimal time profile for introduction of the track innovations on the European network;
- the cost/revenue/performance implications of the actions required to overcome barriers to implementation for each option, which need to be incorporated into the CBA.

-Task 5.5

5.2 will provide Task 5.5 with the benefits of the Vehicle and Track Options over the appraisal period in terms of: freight and passenger user benefits; noise benefits; and CO_2 benefits (by end April 2014 for Final Assessment).

5.1 will provide LCC and RAMS results to 5.2 by end Feb 2014 – after processing for the CBA these will form the core of the Business Case in 5.5.

As above, 5.4 will inform 5.5 on phasing and implementation of each combinations of options (track and vehicles).

Table 10.2: Business Case data and modelling requirements from WP3,4&5

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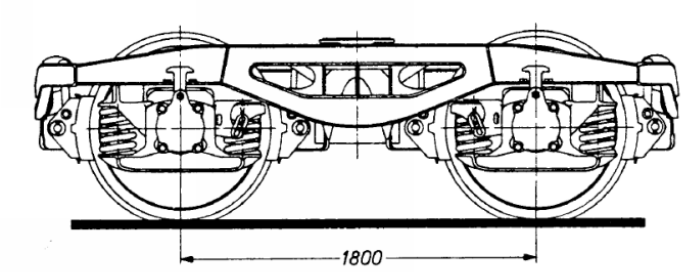
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APPENDIX 1: DESCRIPTION OF THE WP3 INNOVATIONS

A1.1 Tuned primary suspension

Source: Per-Anders Jönsson , KTH Sweden

A1.1.1 Current situation



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

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

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

A1.1.2 Description of the option

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

A1.13 The difference

Tuned primary suspension which reduces forces.

A1.1.4 Expected outcome

Reducing of track forces with X%, Can be verified by measurements and simulations.

A1.1.5 Requirement

The following duty requirement of WP2 will be addressed by the innovation:

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

A1.2 Energy harvesting

Source: Tobias Herrmann, Berlin University

A1.2.1 Current situation

Actually freight cars don't have any energy supply. Reasons are mainly the interoperability and the missing demand. A freight car has to be developed easy and cheap. And until now, developments like telematics systems are seen very critical and as very expensive. But under the growing pressure outgoing from the street sector, something have to be changed and a telematics system, which can reduce the maintenance costs, could help. Therefore an energy supply will be needed. The best option will be an energy main line through all the wagon, but this option is utopia. Other possibilities for energy harvesting are solar modules, piezo-elements or bearing generators. Piezo-elements generate too less energy and solar modules are dependent from the sun. Another disadvantage is the loss of power through mud and dirt

A1.2.2 Description of the option

On these grounds, the TUB decided to use bearing generators and rechargeable batteries. With that combination the freight car is less dependent from velocity. Typical bearing generators are developed by PJM, FAG and perhaps KES. The price is about 800 Euro for one bearing generator (PJM). To the topic rechargeable batteries I can't say something until now.

A1.2.3 The difference

Actually we have no energy harvesting in freight cars. With bearing generators we have it and generates energy for the telematics system.

A1.2.4 Expected outcome

With a look only on the energy harvesting, the bearing generator makes a freight car just more expensive. But if we look at the whole system/topic telematics, it is possible to reduce the maintenance costs and the freight cars more safe. For the bearing generator a possible measurement is the measure of the power curve dependent from the velocity. For the rechargeable batteries perhaps measurements of capacity, charging time unchanging time are possible.

A1.2.5 Requirement

The following duty requirement of WP2 will be addressed by the innovation:

- (Req. 11) Independent power supply

A1.2.6 Environmental condition

The energy/power generating with the bearing generator is dependent from the velocity of the freight car. The capacity of the rechargeable batteries could dependent from the temperature.

A1.2.7 Operating conditions

If the train set will drive for a longer time with a lower speed and if the batteries are empty, the system will not have enough energy to work. The detection methods will not work and the safety level of the freight car will decrease.

A1.3 Thermal monitoring of axel boxes

Source: Defossez Francois, Mermec

A1.3.1 Current situation

"MERMEC proposes to developp a monitoring system for the measurements of the temperature of the axle boxes. The current situation is that these measurements are mainly done by wayside monitoring system which are intalled on the track to inspect the vehicle. The problems of such measurements are the they are not made continuously, and furthermore, they are made from a certain distance of the axle boxes. If more frequent measurement are needed, more monitoring must be installed, that could be very exepensive."

A1.3.2 The difference

"The main difference between the previous system and the proposed innovation is that those sensors are embedded on the train. That allows to make measurments coninuously on the axle, or at least more often, and have the opportunity to decide when it must be done. The fact that the sensors are on/near the axle can also give better precision on the measurements."

A1.3.3 Expected outcome

"The main idea is to design a simple, integrated, easy to install and economically efficient system. Another idea is to design a portable system, that could be installed temporarily on a freight wagon. In this case, the monitoring system could make measurments for a short period, maybe on problematic wagons that needs to be checked, and then could be reomved and installed on another one. This solution could decrease the maintenance costs. Indeed hot axle box detectors are expensive system, not easy to install, and several systems have to be installed on the line. Moreover, linked with some acceleration or velocity sensors, a complete axle monitoring system could decrease the number of axle failures."

A1.3.4 Requirement

"Condition monitoring systems are not really related to some duty requirements highlighted by WP2. However, they can give the opportunity to check the safety of the system during the tests, and also to give some data and measurments that could be good imputs for calculations and simulations."

A1.3.5 Additional questions (Q) and answers (A)

Q1: What type of problems will be addressed/solved by implementing the technology/solution;

This system provides a continuously temperature monitoring of axle box with automatic threshold in order to deliver on time only the interesting data with alarms. The movement detection sensor allows acquiring the data only during the movement. With a wireless system and power supplies by battery, this is a full autonomous system. The data can be automatically transferred at the local hot spot acquisition like station or depot. With a central data, the monitoring of the axle boxes can be continuous along the displacement of freight vehicle with low maintenance task.

Q2: What type of measurements can be done;

The system delivers a temperature data of each axle boxes of the implemented bogie. With these data, the system can detect the extreme temperature and particularly before the abnormal elevation in order to deliver as soon as possible the alarm.

Q3: What system/components of the vehicle can be investigated.

The system follows the evolution of axle box temperature principally linked with axle bearing

A1.4 Vibration based axel monitoring

Source: Stefano Bruni, Politecnico di Milano

A1.4.1 Current situation

Monitoring of wheel set axle integrity for freight cars is currently performed according to time-based / mileage-based inspection intervals. As a result, inspections can be done at time distances up to 6-years. Meanwhile, the axle is subject to largely unknown service conditions and disturbances, including impact from flying ballast, extreme weather conditions etc. which may lead to the generation and possible propagation of a failure. Given that a broken axle is very likely to lead to a derailment and to a very critical safety condition, it is needed to improve the current methods and practice for monitoring the structural integrity of the axles during service.

A1.4.2 Description of the option

The proposed system is an on-board measuring system.

A1.4.3 The difference

If proven successful (investigations are ongoing) it would allow detecting a cracked axle from measurements taken during service. Otherwise, in the present situation the monitoring of axles is performed as part of the maintenance process, and requires that the freight car is taken out of service and inspected in a workshop. Also to be considered is that freight cars are often used across wide railway networks, and planning the workshop inspection may entail a rather large planning effort.

A1.4.4 Expected outcome

Due to safety prescriptions, I do not expect that having on-board the axle integrity monitoring system will allow to avoid completely maintenance inspections, but could make the scheduling of these more flexible, so a reduction around 20-25% in the axle inspection costs could be assumed (this is largely tentative). Very important is that the most important 'remuneration' for this monitoring system would lie in the improved safety of railway transportation, particularly (but non limited to) the case of freight cars transporting dangerous goods. This is a case of an innovation that could be considered despite not reducing costs, provided the benefits are sufficiently large.

A1.4.5 Requirement

This innovation is not actually addressing any of the duty requirements in the table. It is rather improving safety, particularly in case the frieght car is carrying dangerous materials, and could potentially reduce costs related with failures/derailments.

A1.4.6 Environmental condition

The innovation requires the installation of either permanent or non-permanent measuring equipment on the wheelset / axlebox. There is an obvious need to provide adequate protection to the equipment, ensure data acquisition and collection, and provide power supply e.g. through energy harvesting.

A1.4.7 Operating conditions

The innovation can be applied to any type of freight car. No limitations based on operating conditions. Extreme temperatures, increased level of vibration (e.g. due to worse track

condition and/or higher speed) can be harmful to the innovation but can be managed (at an increased cost) if required.

A1.4.8Additional questions (Q) and answers (A)

Q: What type of problems will be addressed/solved by implementing the technology/solution;

A: improve reliability and availability of freight cars, increase of safety, especially for vehicles carrying dangerous material

Q: What type of measurements can be done;

A: Proposed measurements are: axlebox acceleration, possibily complemented by axlebox temperature

Q: What system/components of the vehicle can be investigated.

A: wheelset axle and axle-boxes

A1.5 Inter-axel linkage

Source: Anna Orlova

A1.5.1 Current situation

The technology review of radially steered bogies showed that only passive systems are practically applicable to freight wagons.

A1.5.2 Description of the option

Applying additional inter-axle linkages to guide the wheel sets. To take advantage of the interaxle linkages the bogie should have horizontally soft primary suspension. The practically applicable solutions are self-steering either 'elastic' bogies where fine tuning of suspension stiffness allows having sufficiently stable bogie with close to radial steering of wheelsets in curves guided by wheel-rail forces, or bogies with kinematic or self-steering elastic additional interaxle linkages that are as well guided by wheel-rail forces. Self-steering elastic additional interaxle linkages allow retrofitting the existing designs of bogies, can be positioned outside the space between wheelsets.

A1.5.3 The difference

The interaxle linkages can provide the design speed up to 160 km/h. Additional inter-axle linkages ignited by wheel-rail forces are reported to provide the reduction of rolling resistance by 30-50%, reduction of wheel wear by 2-3 times, reduction of traction energy consumption (especially in curves), general reduction of dynamic loads, improvement of horizontal ride qualities. This all goes in line with the aims of SUSTRAIL project.

Disadvantages that are necessary to mention include increase of unsuspended mass (approximately 900 kg per wagon), complicating production and repair technology, generally bigger initial cost of the design compared to traditional ones. The disadvantages can be overrun by estimating the life cycle cost in general that shows that initially bigger expense is compensated in approximately 2.5 years by reduced wear and damage of wheels.

A1.5.4 Expected outcome

Design speed up to 160 km/h - verified by simulation and measured during running tests. Reduction of rolling resistance (and traction energy consumption) by 30-50% - verified by simulation and measured through force in the coupling during running tests and compared to reference vehicle. Reduction of vertical (within 10%) and lateral (30-50%) forces - verified by simulation and measured during running tests in comparison with reference vehicle. Reduction of wheel wear 2-3 times - verified by simulation, measurement needs to be made in operation tests for service mileage of at least 50 000 km.

A1.5.5 Requirement

- (Reg.1) Increased stability of motion and better curving (reduced wheel-rail forces) will allow to rise the speed of freight (same forces are produced at higher speeds).
- (Reg.7) Reduced rolling resistance will lead to reduction of traction energy used by locomotive.
- (Reg. 12) Lateral forces will be reduced due to better stability on straight track and better curving ability (passive radial positioning of wheelsets).

A1.5.6 Environmental condition

If no non-metal parts are used in the design of inter-axle linkages, the innovation should be independent of environmental conditions

A1.5.7 Operating conditions

None of the listed concern the innovation. The only concern could be the narrow bottom loading gage on UK line. Environmental conditions such as rain, snow, leaves can affect the friction coefficient between wheel and rail. As far as forces between wheel and rail guide the wheel sets, the interaxle linkages might work with slightly different efficiency (but always positively)

A1.6 Battery

Source: Alija Cosic KTH

A1.6.1 Current situation

Not described, low efficiency of locomotive.

A1.6.2 Description of the option

The battery will be installed in the locomotive power train. The presence of the battery will give an opportunity to down scale the combustion engine. Thereby the efficiency of the locomotive can be kept at a high level On these grounds, the TUB decided to use bearing generators and rechargeable batteries. With that combination the freight car is less dependent from velocity. Typical bearing generators are developed by PJM, FAG and perhaps KES. The prize is about 800 Euro for one bearing generator (PJM). To the topic rechargeable batteries I can't say something until now.

A1.6.3 The difference

Usually the battery is not present in a conventional drive train in the locomotives.

A1.6.4 Expected outcome

The drive trains with the battery installed are very common in Electric and Hybrid Electric Vehicles. The expected improvements will be verified through lower fuel consumption and thereby increased efficiency.

A1.6.5 Requirement

Reduction in energy usage by the vehicle.

A1.6.6 Environmental condition

Depends on the ambient temperature and the load cycle. There is a slight drop in the performance of the batteries with the decrease in the surrounding temperature.

A1.6.7 Operating conditions

Depends on the load cycle.

During the winter there will be expected lower performance of the batteries.

A1.7 Induction motor

A1.7.1 Current situation

A1.7.2 Description of the option

A1.7.3 The difference

A1.7.4 Expected outcome

A1.7.5 Requirement

The induction machine is not innovation in itself. It is chosen based on its reliability and its robustness. Compared with the Permanent Magnet synchronous machines it has lower efficiency and lower power density. However it is cheaper and more reliable. It will address the improvement number 1. Modest increase in freight speed.

A1.7.6 Environmental condition

Should not be any problem with different environmental conditions. The efficiency of the machine is temperature dependent, the efficiency drops with the increase in temperature. Hence the better cooling conditions will give the more optimal utilization of the machine.

A1.7.7 Operating conditions

This has to be taken into account in the design procedure of the machine. The maximal surrounding temperature and the cooling conditions.

A1.8 Ultra capacitor

Source: Alija Cosic KTH

A1.8.1 Description of the option

Ultra capacitor is used to support the battery. The battery size can thereby be optimized and kept smaller. The battery will take care of the energy storage problem while the ultra-capacitor will take care of the high power demanded during the acceleration of the vehicle.

A1.8.2 The difference

Describe the difference between the innovation and the previous system. Usually the current drive train doesn't contain any ultra-capacitor.

A1.8.3 Expected outcome

The innovation will help to increase the efficiency of the locomotive.

A1.8.4 Requirement

It will address the requirement: 7. reduction in energy used by rail vehicle.

A1.8.5 Environmental condition

Usually the capacitors are less sensitive to extreme surrounding temperatures compared with the batteries

A1.8.6 Operating conditions

The capacitors should not be much affected by different operating conditions. The energy storage is low so the acceleration performance can be affected during the heavier load operation cycles. However this should be of concerned in the design stage.

No bigger changes are expected.

APPENDIX 2: SCATTERPLOTS OF THE WP3 INNOVATIONS

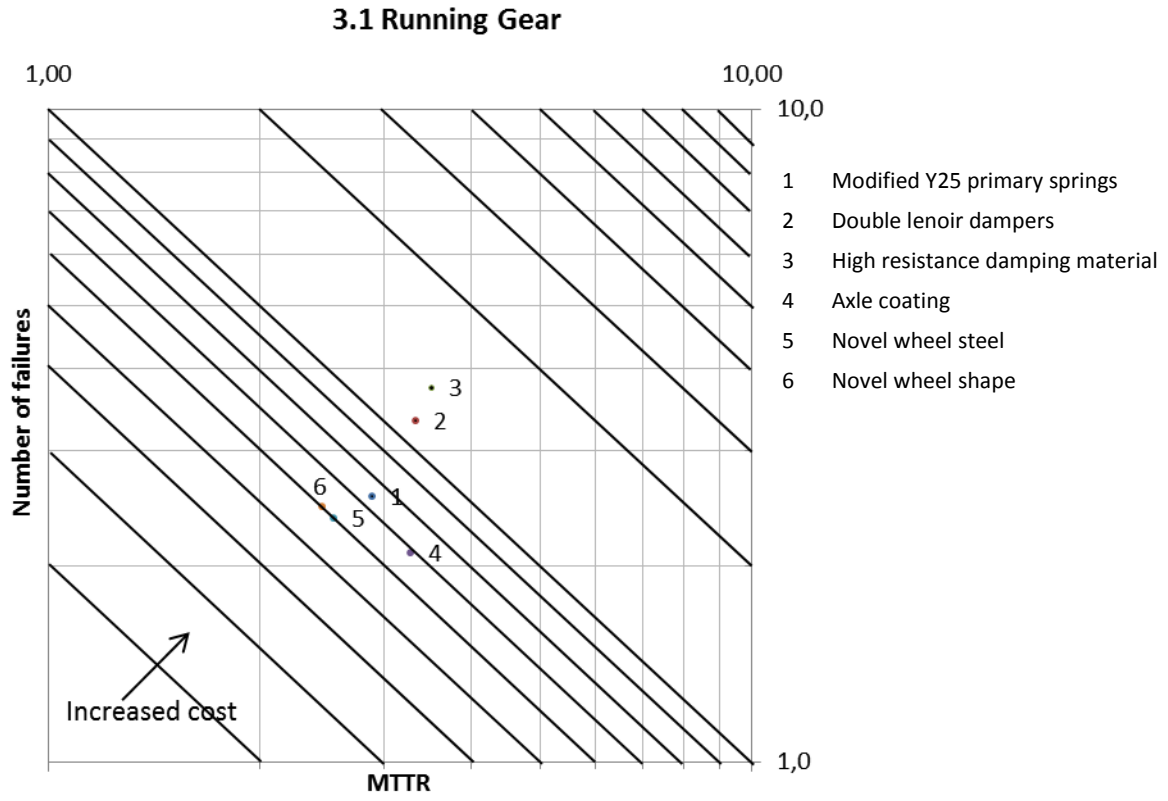


Figure A2.1: Number of failure and MTTR scatter plot of Running gear WP3.1 innovations

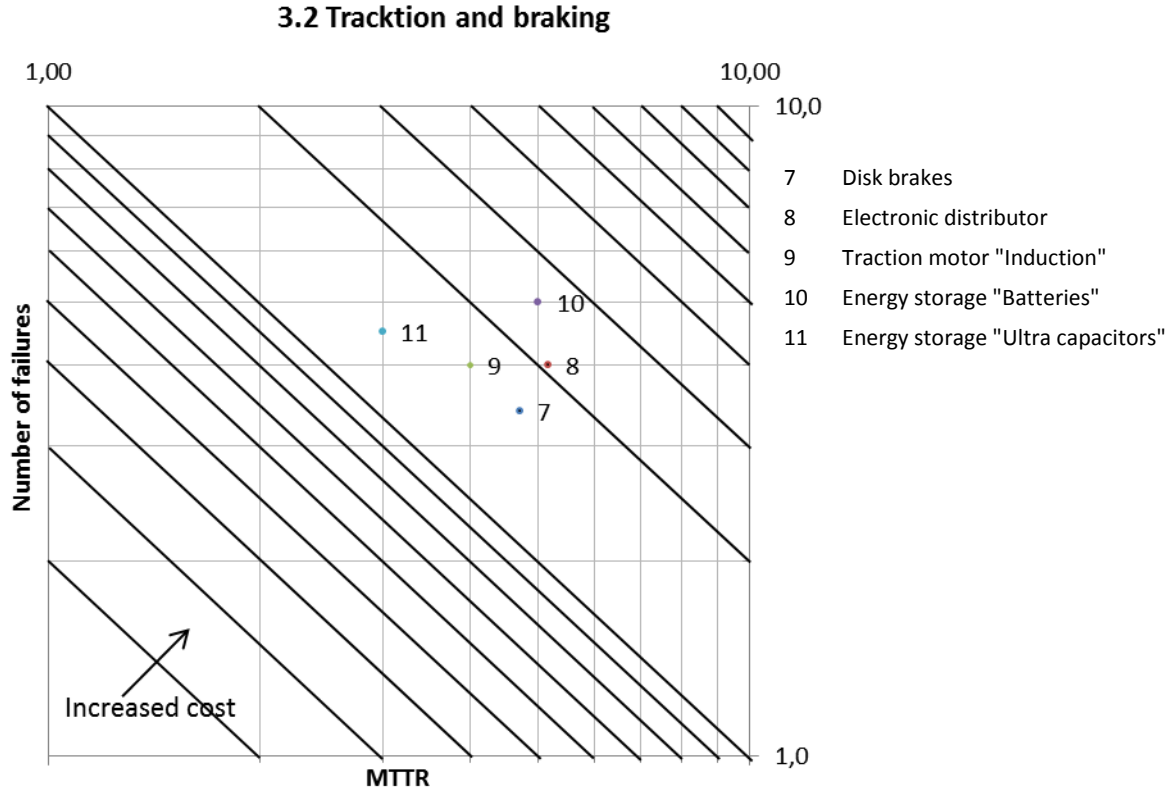


Figure A2.2: Number of failure and MTTR scatter plot of Traction and braking WP3.2 innovations

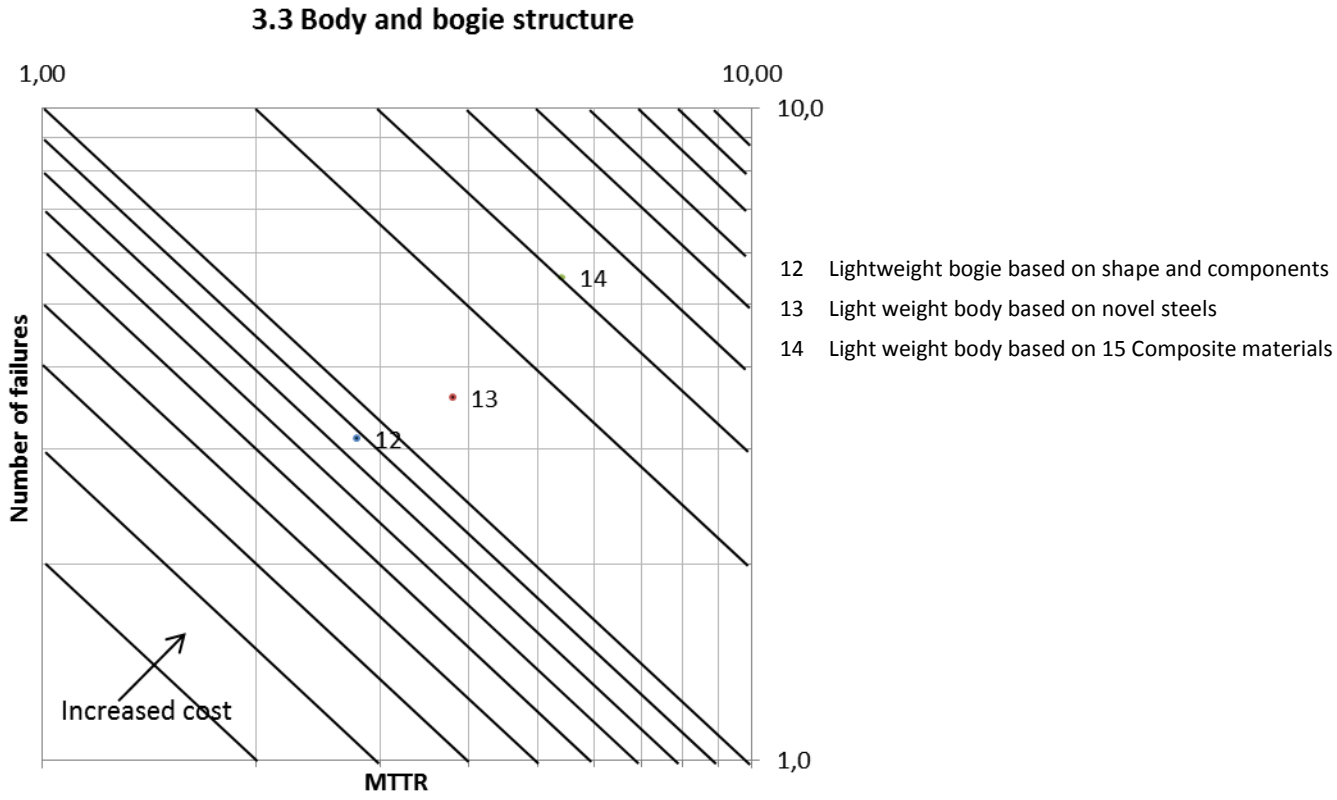


Figure A2.3: Number of failure and MTTR scatter plot of Body and bogie structure WP3.3 innovations

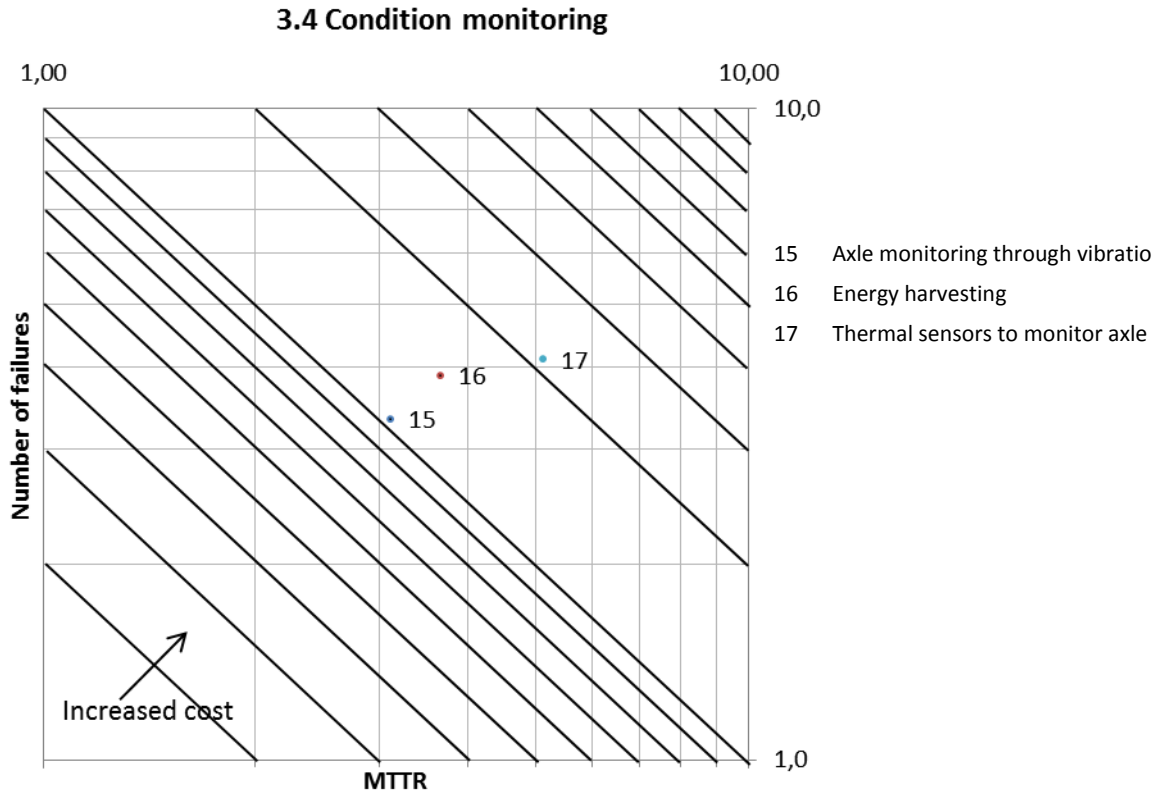


Figure A2.4: Number of failure and MTTR scatter plot of Condition monitoring WP3.4 innovations

APPENDIX 3: COST-BENEFIT ANALYSIS FRAMEWORK

A3.1 Introduction

The Business Case combines a cost-benefit analysis (CBA) of the innovations considered in the project with a summary of technical implementation and phasing. The CBA provides:

(i) the overall social Net Present Value (NPV) of the innovation;

(ii) the impact on IMs, Freight Operating Companies and other key groups specifically – i.e. the distribution of the whole-system savings;

A3.1.1 NPV

This is a calculation of the change in social welfare (or social surplus) across all groups.

To be precise, social surplus is the sum of consumer surplus, producer surplus, government surplus and externalities. Using Δ to signify a change:

$$\Delta SS = \Delta CS + \Delta PS + \Delta GS + \Delta Ext \qquad (1)$$

CS is made up of the benefits to *end users* from consumption of services (in SUSTRAIL primarily freight and passenger rail services).

PS is made up of the benefits to *producers* from production of services – i.e. the difference between total revenue TR and total cost TC. In SUSTRAIL the producers will be the IMs and freight operators (FOCs). Evidently the allocation of surplus to the IM, the freight operator and the end users is

GS is the net financial position of the government sector, so if the SUSTRAIL innovations require grant or subsidy, they will create a ΔGS, with a negative sign since + is always used to represent a positive impact on the group concerned, and - is a negative impact.

Externalities, such as noise and CO_2 emissions, also impact on welfare and will be included in the CBA. Valuation techniques will be used to express these impacts in the same units as CS, PS and GS – i.e. € .

A3.1.2 Impacts on IMs, Freight Operators, End Users and 3rd Parties

In SUSTRAIL we are interested in the Business Case for vehicle and track improvements from the perspective of particular interested parties – for reasons of acceptability. For example, we want to understand what is the expected rate of return on investment for IMs of a package of track upgrades, and what are the financial implications for FOCs. Similarly what is the expected rate of return on investment for FOCs of a package of vehicle upgrades, and what impact will that have on IMs? And what will be the 'whole-system' effect, include track-train interactions: seen from the perspective of the IM and the FOC respectively? Answering these questions is central to the Businesss Case.

Of course we also need to demonstrate the benefit to *end users*, which will be the value to them of any improvement in service quality or availability, net of any change in cost. Hence Track Access Charges are key, in modelling how any infrastructure cost changes are passed through from the IMs to the FOCs. And freight charges are key in modelling how the FOCs' costs are passed through to the the end user, the customer.

Therefore the Business Case, will be extracting not only the change in social surplus ΔSS from the CBA (equation (1)), but also selected elements of the CBA, i.e. the impact on:

end users: ΔCS

IMs: ΔPS_{IM}

FOCs: ΔPS_{FOC}

where $$\Delta PS = \Delta PS_{IM} + \Delta PS_{FOC} \quad (2)$$

government: ΔGS

citizens: ΔExt

noting that citizens as consumers benefit from freight improvements, but also stand to gain or lose from any change in environmental externalities.

A3.2 CBA Parameters

CBA needs to cover the future period over which SUSTRAIL innovations could make an impact (to the IMs, Freight Operators, and others).

A long-term perspective is appropriate because:

- the assets to be modified have long asset lives (both track and vehicles);
- the process of phasing new vehicles into the fleet will take many years – subject to the findings of Task 5.4;
- the European Commission is interested in long-term economic growth perspective.

These factors have much in common with infrastructure investment in general, and in that field there are established conventions for how to proceed. The *appraisal period* is the time interval (in years) considered in the CBA. This is chosen based on key considerations:

- the typical starting assumption is the life of the longest-lived asset (created or modified) – D2.5 Table 2.5 shows these range widely, although rails typically 20-25 years, concrete sleepers typically 50 years, structures typically 50-100 years;
- it is recognised that uncertainties increase and forecasting becomes more difficult the further into the future we look; and
- we can use *residual values* if necessary, to estimate any important costs or benefits beyond the appraisal period.

The HEATCO guidelines for infrastructure investment at the European level recommend a typical appraisal period of around 40 years (Bickel et al, 2006). In the period since the HEATCO study there has been some movement towards longer appraisal periods (and lower disccount rates – these go together). For example, the UK has moved closer to the practice in countries such as Denmark, Sweden, The Netherlands and Switzerland (which have appraisal periods of 40/50/60 years or infinity) by changing from 30 years to 60 years – where infrastructure is involved (DfT, 2012). SUSTRAIL is concerned with some longer-lived assets including infrastructure. We propose to use a period of 60 years for track innovations (N=60) to allow a product development phase initially, then a replacement cycle for assets with lives up to 50 years.

This will require assumptions about demand growth rates and various economic parameters over the 60 year appraisal period, as usual in long-term infrastructure or policy-related CBAs. Alternatively, the CBA for rail vehicles could be limited to ~30 years, and residual values used to bring infrastructure innovations into line with that

It will require setting a start year for the appraisal period, for which we propose 2015 since that is the year in which the SUSTRAIL Business Case is likely to be published. Hence the full appraisal period would be 2015-2044, or up to 2015-2074.

It will also require setting a base year for prices and values. We propose using 2015, since that is consistent with the appraisal period.

A3.2.1 Discount rates

Discount rates also should be set. Consistent with convention in infrastructure appraisal again (Bickel et al, 2006) we propose a rate in the region of 3% for the social NPV calculation (equation (1) above), and for the government and citizens in the analysis by group. This is essentially a Social Time Preference Rate (STPR) based rate.

Further research specifically for SUSTRAIL has led us to refine this to 3.3%, based on: ρ=1.0 (for the EU: Evans and Sezer, 2004); Φ=1.25 (Layard, Nickell and Mayraz, 2008); g~1.85% (OECD Economic Outlook, 2012, Ch4, mean of Baseline (1.7%) and More Ambitious Fiscal Consolidation and Structural Reform (2.0%) scenarios).

For the IM's and FOC's perspective, a commercial discount rate is appropriate. Choosing a rate is much more subjective, and susceptible to sector/segment-specific conditions. However market data is available, and based on this we propose to use the following rates:

- 6% for the IM financial calculations, reflecting low risk utility industry funding;
- 9% for the FOC financial calculations,

Last decade we might have proposed 10%, however with future market prospects subdued following the global downturn, the above rates are more realistic.

Note that the calculation of an Internal Rate of Return (IRR) for IMs and FOCs on investments they make, will not require a discount rate. However, for any impact on them from others' investments, the IRR may not be appropriate (or calculable).

Discount rates input to the NPV as follows:

$$NPV = \sum_{t=0}^{N-1} \frac{B_t}{(1+r)^t} \qquad (3)$$

where years are indexed 0 to N-1

B_t is the amount in Year t (for example the ΔSS_t), to be discounted at rate r.

A3.2.2 Valuation of CO_2 and noise.

Suitable values are available from HEATCO [1] and from the EU 'IMPACT' study (Maibach et al, 2008). Safety values are also readily available from the same sources if required – i.e. if Task 5.1 predicts any impact on safety from the SUSTRAIL innovations.

A3.3 Data Flows from Tasks 5.1-4

Task 5.1 will feed results on Life Cycle Costs (LCC) and Reliability, Availability, Maintainability and Safety (RAMS) to Task 5.5. These will be for the Baseline Scenario and for the various SUSTRAIL Options to be tested, and for each of the three Case Studies (UK, ES and BG). See Section 3.2.

Life cycle costs will be for the IM and the freight operator (FOC), and will include: investment costs; renewal; maintenance; and operation, over the appraisal period (and beyond if asset lives require it, in order to calculate residual values for the CBA).

RAMS results will cover the appraisal period. An important set of data flows to define will be the links between the the RAMS indicators and the Benefits to end users in CBA. In particular:

- reliability of freight services – D2.2 and D2.5 have identified freight operators' need for service reliability. It is essential to include reliability measures which can be valued in CBA. See Section 3.2.
- speed – end-to-end journey time and the valuation of any changes (e.g. valuation of freight time savings – Bickel et al 2006). These may need to come from the IMs in WP4 as a separate dataflow (see 3.3.1).
- availability, maintainability and safety are covered in 9.1.2 and 10.2.

Future freight demand and how it responds to changes in price, quality and availability will be the responsibility of 5.2. Data flows between 5.2 and 5.5 will include freight flows, over the appraisal period, under each scenario being tested (Baseline + different Options).

Valuation of passenger paths potentially made available by the SUSTRAIL innovations will be provided by 5.2.3.

Access charges will be provided by 5.3: it is particularly important that these flow to the freight demand model in 5.2. The data received by 5.5 from 5.2 may be in the form of *generalised cost* for freight service, including money and quality factors.

Optimal timing and phasing of investment: 5.4 will provide options and technical analysis; 5.5 will run alternative phasing scenarios through the CBA.

A3.4 Risk Analysis

Over a projection up to 60 years in for some infrastructure innovations, it will be essential to look at a range of possible outcomes, rather than a single point estimate. For example, there will be a range of possible trajectories for fuel costs, and there will be a range of possible scenorios for background economic growth.

We propose to handle this in the CBA using @RISK – the Excel Add-in – to manage input data with ranges / probability distributions attached, and to produce not just NPV and IRR, but distributions on NPV and IRR.

This means that input data from 5.1-5.4 is encouraged to have:

- ranges, confidence intervals, or probability distributions, reflecting a range of scenarios.