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

SUSTRAIL

Grant Agreement n°: 265740 FP7 - THEME [SST.2010.5.2-2.]
Project Start Date: 2011-06-01
Duration: 48 months

D5.2: Economic benefit final report

Due date of deliverable: 31/12/2014

Actual submission date: 18/05/2015

Work Package Number:	WP5
Dissemination Level:	PU
Status:	Draft
Leader of this deliverable:	University of Leeds, UNILEEDS
Prepared by:	John Nellthorp, UNILEEDS Dan Johnson, UNILEEDS Juan de Dios Sanz Bobi, UPM Kiril Karagyozov, VTU Todor Razmov, VTU Anna Dzhaleva, VTU Mirena Todorova, VTU
Verified by:	Phillip Wheat, UNILEEDS Kevin Blacktop, NR

Dissemination Level	
PU	Public
PP	Restricted to other programme participants (including the Commission Services)
RE	Restricted to a group specified by the consortium (including the Commission Services)
CO	Confidential, only for members of the consortium (including the Commission Services)

Document History			
Version	**Date**	**Author/s**	**Description**
Draft 0.1	16/10/2014	John Nellthorp, Phill Wheat, Dan Johnson	Document Structure
Draft 0.2	27/02/2015	John Nellthorp	Sections 1&2
Draft 0.3	01/05/2015	John Nellthorp, Dan Johnson, Kiril Karagyozov, Todor Razmov	Sections 3-7 draft
Draft Final 1.0	07/05/2015	John Nellthorp, Dan Johnson, Kiril Karagyozov, Todor Razmov. Juan de Dios Sanz Bobi	Complete document
Draft Final 1.1	15/05/2015	John Nellthorp, Dan Johnson	Amendments following QA review
Final 1.2	18/05/2015	John Nellthorp	Further minor amendments to the document

Table of contents

List of Figures

List of Tables

EXECUTIVE SUMMARY

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;
- reduced costs and enhanced profitability for its stakeholders.

This deliverable, D5.2, sets out an assessment of the impacts of the SUSTRAIL improvements under the following of headings – these form a part of the Business Case:

- **freight user benefits** – from the freight customer's perspective, the SUSTRAIL improvements should improve the competitive position of rail freight versus other modes – we use aggregate models of freight demand to estimate the potential impact of the SUSTRAIL improvements on mode share, and provide insights into the benefits to those end users – these benefits flow from the benefits to Infrastructure Managers (IMs) and Freight Operators (FOCs) investigated in D5.1 and further in this deliverable;
- **environmental benefits** – we focus on CO_2, air pollution and noise impacts;
- **potential passenger benefits** – since running freight trains at higher speed should free some paths for additional passenger services, on busy mixed-use lines.

Other elements of the Business Case are presented elsewhere in the set of deliverables D5.1-7: in particular, the Life Cycle Cost (LCC) and performance (RAMS) analysis is reported in D5.1; the access charge analysis is presented in D5.3; implementation is addressed in D5.4 and D5.7; and the overall Business Case synthesis is presented in deliverable D5.6.

The main scenarios being compared are the following (Table ES.1). These are applied to three Case Studies that were described in the interim Business Case (D5.5): one in the UK – the Felixstowe-Peterborough-Nuneaton corridor; one in Bulgaria – from the Greek and Turkish borders in the east to the Serbian border in the west; and one in Spain – the Mediterranean corridor from Valencia to Tarragona.

	Scenario			
	BASELINE	**SUSTRAIL0**	**SUSTRAIL1**	**SUSTRAIL2**
Vehicles	Benchmark	SUSTRAIL vehicles	SUSTRAIL vehicles	SUSTRAIL vehicles
Track	Benchmark	Benchmark	SUSTRAIL track (on curves radius 0-1200m)	SUSTRAIL track (on curves radius 0-1200m)
Max Speed (freight)	Benchmark (120kph)	Benchmark (120kph)	Benchmark (120kph)	140kph

Table ES.1: Business Case scenarios

A substantial task was to scale-up the LCC and RAMS results, and the other evidence on which the analysis is based, to the Case Study corridor level. In the LCC analysis (D5.1), which is a common input to all case studies, most of the track cost items are based on the curves of radius 0-1200m (Table 3.1), which make up only a small proportion of the total (e.g.

7.1% of the UK case study route by length). Using data on track maintenance and renewal costs for the route as a whole (Table ES.2 gives the UK costs), the LCC and RAMS results were scaled-up. In parallel with this, the wagon LCC costs arising from D5.1 were checked and found to be consistent with other models. These wagon LCC costs represent less than 10% of the freight operating companies' cost base, so it was important to provide an overall representation of freight operators' costs, for use in the freight demand modelling exercise.

Item	VTISM- based costs, £millions	Network Rail aggregate data (GB) per route km, £millions
Maintenance	7.06	6.09
Renewals	12.09	11.21
Total	19.15	17.31

Table ES.2: Track costs for the whole route Felixstowe-Peterborough-Nuneaton, £ at 2015 prices

Bringing these elements together, the impacts of the SUSTRAIL vehicle and track on the Infrastructure Manager (IM) and the Freight Operators were estimated. Tables ES.3 and ES.4 give the results for the UK Case Study. The SUSTRAIL vehicle and track together were found to have the greatest overall impact on costs: overall a 10% saving to the IM and 2.4% saving to the freight operators.

	Track LCC data % changes:			Track cost % changes at route level:		
	SUSTRAIL0 (vehicle only)	SUSTRAIL1	SUSTRAIL2 (140kph)	SUSTRAIL0 (vehicle only)	SUSTRAIL1	SUSTRAIL2 (140kph)
Track Maintenance and Renewal Costs				-1.6%	-10.1%	-7.5%
Maintenance				-0.8%	-2.4%	-1.8%
Corrective maintenance	-80%	-80%	-50%	-0.6%	-0.6%	-0.3%
Preventive maintenance	-6%	-45%	-37%	-0.2%	-1.8%	-1.5%
Renewals				-0.8%	-7.7%	-5.6%
General renewals	-10%	-86%	-60%	-0.8%	-7.8%	-5.7%
Investments/innovations	0%	2%	2%	0.0%	0.05%	0.05%

Table ES.3: Impacts of SUSTRAIL0,1&2 on track costs

Impacts on Freight Operators	%change	Baseline	SUSTRAIL0 (vehicle only)	SUSTRAIL1	SUSTRAIL2 (140kph)
Freight Operators' costs		Base	-1.8%	-2.4%	-0.5%
Vehicle maintenance costs		Base	-61%	-61%	-58%
Vehicle ownership costs		Base	46%	46%	46%
Freight operators' fuel costs		Base	No change	No change	3.7%
Other operating costs		Base	No change	No change	No change
Track Access Charges (variable) - SUSTRAIL vehicles		Base	-10.4%	-17.4%	-15.2%
Track Access Charges (variable) - other vehicles			0.0%	-6.9%	-4.8%
Freight service charges (money)		Base	-1.8%	-2.4%	-0.5%

Table ES.4: Impacts of SUSTRAIL0,1&2 on freight operators' costs and revenues

For the purposes of this deliverable – the calculation of end user benefits – table ES.4 assumes that the savings to the IM are passed on to the freight operator through track access charges, and the gains to the freight operator are passed on to end users, giving the maximum achievable demand shift and end user benefit. Track access charges faced by the SUSTRAIL track-friendly vehicle will be reduced more than other vehicles, which still benefit from the SUSTRAIL track improvements. In the final deliverable, we will report on other tests where the IM and freight operator retain a share of the cost savings for investment or other purposes.

Similar to the LCC data, it was necessary to scale the RAMS data using other data sources because the RAMS analysis does not include all sources of delay to freight trains. Including both primary and secondary delays, we found that 23.8% is the proportion of freight delays that are caused by vehicle issues and relevant track issues. We used industry data on delay minutes per 100 train km as a base, and varied the number of delay minutes to reflect the predictions of the RAMS model in each scenario.

Note that the impact on vehicle ownership costs in Table ES.4 combines two separate inputs: vehicle ownership costs are impacted by fleet availability (from RAMS: 95% to 99%) as well as capital cost per wagon net of disposal value (+48% in SUSTRAIL1&2). It could be impacted by journey time as well, if significant rescheduling was allowed, however we assumed that effect does not materialise.

Operators' fuel costs remain constant in the SUSTRAIL0&1 scenarios because the mass reduction in the vehicle body is fully offset by mass increase in running gear (D5.1). In SUSTRAIL2, operations at maximum speed 140kph vs 120kph increase fuel consumption by 3.7% for diesel trains (based on RENFE data provided directly to Task 5.2).

Summarising the impacts on End users, we obtain the following (Table ES.5). The journey time impact assumption is the same as in the Interim Business Case (D5.5). In the UK case, approximately 15% reduction in journey time is estimated whilst operating at maximum freight speed; we assume half this maximum potential gain is achieved in practice = 7.5%. In the Bulgarian case, the speed increase is greater as the initial operating speeds are lower.

			Baseline	SUSTRAIL0 (vehicle only)	SUSTRAIL1	SUSTRAIL2 (140kph)
Impacts on End Users		%change				
	Reliability (delay minutes)		Base	-8%	-14%	-9%
	Journey time		Base	No change	No change	-7.5%
	Freight service charges (money)		Base	-1.8%	-2.4%	-0.5%

Table ES.5: Impacts of SUSTRAIL0,1&2 on End Users (UK)

The main categories of environmental benefits measured and taken into account in this analysis are:

- CO_2 impacts;
- noise impacts;
- various regional and local air pollutants such as NOx, SO2 and particulates ($PM_{2.5}$).

Emissions models tend to be country specific, since the vehicle fleet, network conditions, and the pattern of residential development around rail lines and road varies widely. Each Case Study has made its own assessment, and use of the Handbook on the External Costs of Transport (Ricardo-AEA, 2014) provides a basis for harmonisation of impacts and values (Table ES.6 shows the values on a harmonised EU basis, applied to UK conditions). The SUSTRAIL emission reductions affect both rail and road: rail because the SUSTRAIL vehicles are quieter; and both modes due to mode shift as rail becomes more competitive.

	2015	2030
Marginal external cost of CO_2 , €/tonne	83.71	105.21
Marginal external cost of NO_x , €/tonne	10,895	14,515
Marginal external cost of SO_2 , €/tonne	15,229	20,289
Marginal external cost of PM , €/tonne	69,405	92,465
Marginal external cost of noise , €/000 train km		
- Rail, rural, day	75.05	99.99
- Rail, rural, night	126.86	169.02
- Rail, urban, day	1518.73	2023.34
- Rail, urban, night	2567.93	3421.13
Marginal external cost of noise , €/000 veh km		
- Road (HGV), rural, day	1.90	2.25
- Road (HGV), rural, night	3.42	4.06
- Road (HGV), urban, day	255.24	302.63
- Road (HGV), urban, night	465.11	551.47
Marginal value of noise reduction, €/person/annum		
- 1dBLeq,18hr at 57.5dB	23.26	30.99
- 1dBLeq,18hr at 65dB	35.54	47.35
- 1dBLeq,18hr at 72.5dB	46.30	61.68
Discount factor @4%	1.000	0.555
Discount factor @3%	1.000	0.642

Table ES.6: Values of SUSTRAIL emissions reductions, 2015 and 2030

We can measure the benefits to End Users in monetary terms. Freight users' values of time and reliability are taken from survey evidence in the countries concerned, while the money costs of freight service are naturally in money units: together these constitute the *generalised cost* of freight movement by each mode. Each Case Study developed its own analysis of the freight market, in order to predict the change in market shares following the introduction of the SUSTRAIL improvements, and the benefits to End Users from reduced costs:

- The UK Case Study used the freight model of Great Britain known as 'LEFT' (Fowkes et al, 2006). Earlier work with TRANSTOOLS, a European wide network freight model, was unsuccessful as there was no functioning endogenous mode split in the model. The latest version, LEFT4, used here was developed as part of the EPSRC Green Logistics project (2010) with further enhancements made during the course of the SUSTRAIL. The model predicted a 7.5% increase in rail's mode share on intermodal traffic as a result of the SUSTRAIL improvements.
- The Bulgarian Case Study used a set of customised models for the SUSTRAIL project, building on previous forecasts of population and freight demand growth in the country. The Bulgarian case includes very large untapped markets for intermodal rail freight from/to the ports of Varna and Burgas, as well as international transit traffic between the 'core markets' of the EU in Germany, France, etc and countries to the east and south both inside and outside the EU. As in the UK Case Study, a logit model was used to forecast the rail-road mode split. The analysis is set out in detail in Appendix 3. The model predicted a transformational increase of up to 83% in the market served by rail, as a result of the SUSTRAIL improvements.
- The Spanish Case Study made use of data from the ADIF Network Statement and the Spanish Railway Observatory (OFE) to develop an analysis of the SUSTRAIL improvements in the context of the Mediterranean corridor between Valencia and Tarragona. This case study also benefitted from collaboration with the infrastructure

managers and the operators involved in the rail industry in Spain. Confidentiality of freight contracts, however, put some limits on data availability. Based on the analysis undertaken, a 13% increase in intermodal rail demand was predicted.

The final results in terms of End User benefits and pollution reduction are as follows (Tables ES.7-13). The UK results are expressed in £, and may be converted to euros using a rate of £0.75=€1. These results will be put in context of the Business Case as a whole, in D5.6.

		Benefits, £/year	
Impact Groups	*Impacts*	*2015*	*2030*
End Users	Reliability benefits	117,228	206,540
	Speed benefits	0	0
	Lower freight costs	478,411	842,895
Third parties	CO_2 reductions	20,265	42,655
	Noise reduction	-2,704	-3,602
	Reduced air pollution	1	-592

TableES.7: UK Case Study summary results – SUSTRAIL0, Vehicle only (base speed)

		Benefits, £/year	
Impact Groups	*Impacts*	*2015*	*2030*
End Users	Reliability benefits	213,695	367,849
	Speed benefits	0	0
	Lower freight costs	714,241	1,229,474
Third parties	CO_2 reductions	98,704	171,298
	Noise reduction	9,464	12,609
	Reduced air pollution	61,076	99,751

TableES.8: UK Case Study summary results – SUSTRAIL1, Vehicle+Track (base speed)

		Benefits, £/year	
Impact Groups	*Impacts*	*2015*	*2030*
End Users	Reliability benefits	106,497	185,617
	Speed benefits	445,569	776,590
	Lower freight costs	501,098	873,373
Third parties	CO_2 reductions	103,734	191,610
	Noise reduction	3,722	4,959
	Reduced air pollution	48,046	78,516

Table ES.9: UK Case Study summary results – SUSTRAIL2, Vehicle+Track (enhanced speed)

		Benefits, €million, year	
Impact Groups	*Impacts*	*2015*	*2030*
End Users	Reliability benefits	89	257
	Speed benefits	59 611	172 465
	Lower freight costs	70 061	171 880
Third parties	CO_2 reductions	0	81 620
	Noise reduction	0	-68 286
	Reduced air pollution	0	56 918

Table ES.10: Bulgarian Case Study summary results – SUSTRAIL0 Vehicle only (base speed)

		Benefits, €, year	
Impact Groups	*Impacts*	*2015*	*2030*
End Users	Reliability benefits	89	373
	Speed benefits	86 829	283 354
	Lower freight costs	105 092	290 808
Third parties	CO_2 reductions	0	134 400
	Noise reduction	0	-112 443
	Reduced air pollution	0	93 725

Table ES.11: Bulgarian Case Study summary results – SUSTRAIL1 Vehicle+Track (base speed)

		Benefits, €, year	
Impact Groups	*Impacts*	*2015*	*2030*
End Users	Reliability benefits	89	415
	Speed benefits	101 601	355 525
	Lower freight costs	105 092	311 829
Third parties	CO_2 reductions	0	168 032
	Noise reduction	0	-140 580
	Reduced air pollution	0	168 032

Table ES.12: Bulgarian Case Study summary results – SUSTRAIL2 Vehicle+Track (higher speed)

The Spanish Case Study results are presented differently, being based on a case-by-case assessment of each of the SUSTRAIL scenarios against the background of the ADIF/OFE data. The key findings for the Mediterranean corridor were:

- Spain's rail freight market is in a different position, subject to constraints of geography and constraints in the rail sector: in particular, (i) the difference between UIC and Iberian track gauge can be overcome for passenger traffic by operating with variable-gauge vehicles, whilst for freight traffic the only possibility is to transfer the load at the border to another train, or to road transport; (ii) unbalanced freight flows are a key issue for rail freight in Spain, due to the geographical location of the Iberian Peninsula relative to the rest of Europe; and (iii) heavy gradients (17m/km) and short station loops place limitations on train length and focus attention on payload enhancements per wagon. Nevertheless, the Mediterranean corridor provides a valuable connection between the ports of Algeciras, Valencia and Barcelona, and the European rail network accessed via France. Recent investment in the corridor by SNCF and others reflects the potential for market growth.

- The SUSTRAIL improvements could produce a 19% reduction in rail freight costs to End Users, which is substantial and corresponds to the predicted 13% increase in rail freight demand.
- A qualitative assessment of the environmental benefits finds that the results for the Mediterranean corridor should be consistent with the SUSTRAIL scenarios elsewhere: that is, very little direct impact from SUSTRAIL0 or SUSTRAIL1, and potentially some increase in CO_2 emissions from the higher fuel consumption in SUSTRAIL2. Against these should be set the benefits from the mode shift effect, which were quantified in the UK and Bulgarian cases above.
- If the SUSTRAIL vehicle could be further developed to reduce its tare weight relative to its laden weight – for example by further lightweighting of the body or bogie structure – then the payload gained would be of particular value in the Spanish Case Study given the current train length constraint.

Lastly, research was conducted to evaluate the potential path capacity benefits which could be unlocked by the increased freight speeds following the implementation of the SUSTRAIL vehicle and infrastructure enhancements (SUSTRAIL2 scenario, 140kph maximum freight speed). The work adopts the approach of Johnson and Nash (2008) who identified appropriate rail scarcity charges to make freight and passenger operators pay for their use of rail capacity in line with the opportunity cost of the use of slots. This part of the research was conceived as a single-country case study on a congested network, hence data was gathered and analysed for the UK's West Coast Mainline (WCML). The value of scarce capacity arising from this case study was £14 per path-train km (2015), which when applied to the UK Case Study above gives £2.6million per annum of additional benefits in the SUSTRAIL2 scenario.

In the final Business Case deliverable, D5.6, these results will be combined with the findings on costs and benefits across the full range of the Business Case framework, to provide a cost-benefit analysis and a financial analysis of the SUSTRAIL improvements. The results will also be synthesised with the findings on technical implementation (D5.4 and 5.7) and the overall Business Case presented.

1. INTRODUCTION

1.1 The SUSTRAIL Business Case (WP5) and the role of economic benefits

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;
- 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.

A very substantial part of the Business Case is the expected improvement in Life-Cycle Costs (LCC) and in Reliability, Availability, Maintainability and Safety (RAMS), which are covered separately in deliverable D5.1 (Rantatalo et al, 2015).

This deliverable sets out an assessment of the impacts of the SUSTRAIL improvements under a different set of headings, namely:

- **freight user benefits** – from the freight customer's perspective, the SUSTRAIL improvements should improve the competitive position of rail freight versus other modes – we use aggregate models of freight demand to estimate the potential impact of the SUSTRAIL improvements on mode share, and provide insights into the benefits to those end users – these benefits flow from the benefits to Infrastructure Managers (IMs) and Freight Operators (FOCs) investigated in D5.1 and further in this deliverable;
- **environmental benefits** – we focus on CO_2, air pollution and noise impacts;
- **potential passenger benefits** – since running freight trains at higher speed should free some paths for additional passenger services, on busy mixed-use lines.

These costs and benefits will be brought together in an overall cost-benefit analysis (CBA) as part of the Business Case Synthesis, which will be the final deliverable from WP5. An Interim Business Case Synthesis was given previously in deliverable D5.5 (Nellthorp et al, 2013).

1.2 Inputs to this analysis

Key inputs to the analysis of user and environmental benefits are as shown in Figure 1.1. These include:

- Life Cycle Costs (LCC) and Reliability, Availability, Maintainability and Safety (RAMS) results from Task 5.1.
- Case Study models of rail freight from three countries – the UK, Bulgaria and Spain – which analyse the SUSTRAIL improvements from the freight customer's perspective and estimate the impacts in the market, as well as the environmental benefits.

- An Infrastructure Path Capacity model for a congested mixed-use line – a UK case study was chosen, to reflect congested traffic conditions.

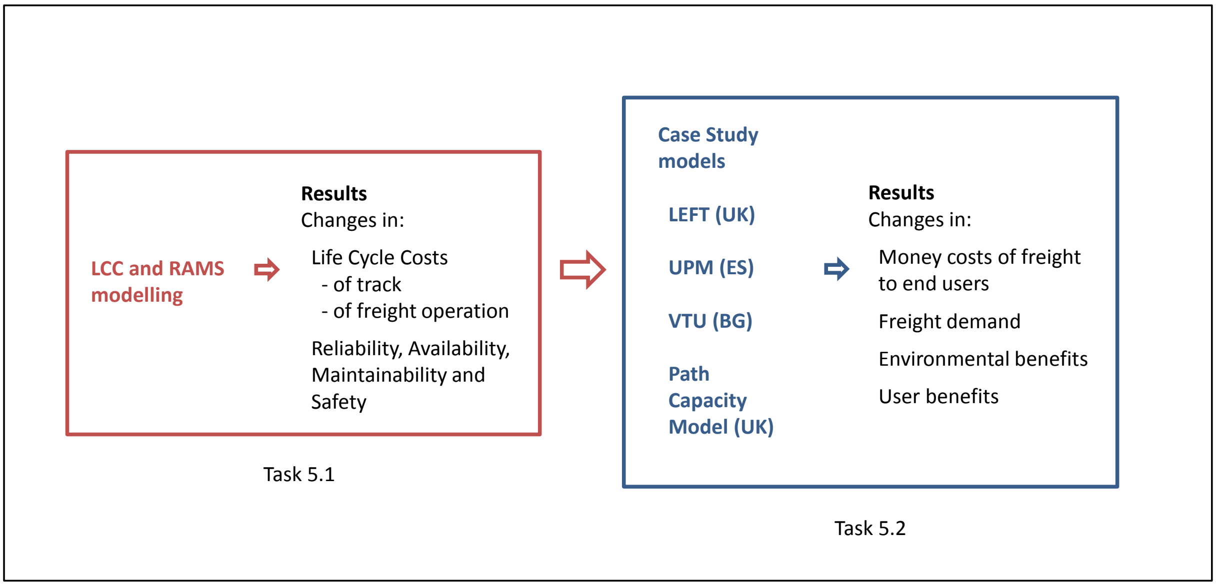


Figure 1.1: Inputs to the analysis

1.3 Scope of this Deliverable

The overall approach to the analysis of user and environmental benefits is outlined in Chapter 2 of this deliverable. The research conducted for this deliverable is then reported in the following Chapters 3-7, with conclusions presented in Chapter 8:

- Approach to User and Environmental Benefits (Chapter 2)
- Impacts of the SUSTRAIL Innovations (Chapter 3)
- Freight and Environmental Benefits for the UK Case Study (Chapter 4)
- Freight and Environmental Benefits for the Bulgarian Case Study (Chapter 5)
- Freight and Environmental Benefits for the Spanish Case Study (Chapter 6)
- Infrastructure Path Capacity Benefits (UK Case Study – busy mixed-use line) (Chapter 7)
- Conclusions (Chapter 8)

2. Approach to User and Environmental Benefits

2.1 Freight user benefits

These are the benefits that accrue to freight customers, the businesses that use the European freight system to distribute their product, due to the SUSTRAIL improvements. These benefits can be grouped and described as:

- *cost reductions* of freight service to the end user;
- *quality improvements* in the freight service – above all reliability improvements and journey time improvements, although other valuable service quality factors could also be considered (e.g. security);
- *improvements in availability* – where rail freight service becomes available in the locations and at the times demanded due to the improvements – in practice freight service will usually be available via other modes, so from the end user's point of view the main impacts will be any potential benefits in cost or quality terms versus the existing offer.

For analysis purposes, cost and quality improvements can be combined using *generalised cost* as measure of the overall disutility of sending freight via a particular mode. Hence equivalent monetary values are needed for reliability and time, and freight demand models use generalised cost in forecasting modal shares. Moreover, an overall measure of the benefits to freight users is given by the change in generalised cost – which can be broken down into money savings and quality improvements to the end users of freight. As set out in D5.5,

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

where

ΔCS is the benefit (or gain in consumer surplus) to freight customers;

i signifies a particular market segment, such as Food, Drink and Agriculture, in year t;

G is generalised cost;

T are freight volumes in tonnes (or tonne-km); and

0 and *1* superscripts signify the baseline and the 'with SUSTRAIL innovations' scenario respectively.

Rail freight is much more competitive in some market segments – e.g. general containerised freight – than in others, hence the analysis is broken down by market segment. Rail freight is also more competitive on longer-distance flows, and this too is built in to the case study models of the freight market in this deliverable.

Having forecast quantities T and freight costs, another useful output for the Business Case is the change in revenues to the freight sector, which can be set against their predicted cost changes to assess the financial impact – part of the Synthesis of the Business Case in forthcoming deliverable D5.6.

2.2 Passenger user benefits

As well as freight user benefits, there may be infrastructure path capacity benefits from freight trains running closer to line speed, freeing-up paths for other traffic using the route. Given the complexity of valuing paths, a development of the existing PRAISE rail forecasting model (Nash, Johnson and Tyler, 2006) is used to value the benefits of additional passenger paths for one case study, based in the UK: this analysis was planned in order to represent impacts arising on the more congested mixed passenger/freight networks in the EU. It is intended that the results from this case study will be used to inform a wider discussion of the likely value of capacity savings in other parts of the European network.

The work aims to identify 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 paths. Chapter 6 gives further details.

2.3 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 NOx, SO_2 and particulates ($PM_{2.5}$).

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 freight model used (LEFT) is capable of estimating the CO_2 emissions impact of many realistic policy options (Fowkes et al, 2006). By contrast, there is no standard method for quantifying and valuing the impacts of noise or air pollution across the EU, however advice is available in the Handbook on the External Costs of Transport (Ricardo-AEA, 2014) and from national methods existing in a some EU countries (e.g. DfT, 2014).

2.4 Scenarios

The Business Case will be based on a comparison of the innovative SUSTRAIL vehicle and track improvements with a baseline scenario representing the status quo, using the set of scenarios shown in Table 2.1.

	Scenario			
	BASELINE	**SUSTRAIL0**	**SUSTRAIL1**	**SUSTRAIL2**
Vehicles	Benchmark	SUSTRAIL vehicles	SUSTRAIL vehicles	SUSTRAIL vehicles
Track	Benchmark	Benchmark	SUSTRAIL track (on curves radius 0-1200m)	SUSTRAIL track (on curves radius 0-1200m)
Max Speed (freight)	Benchmark (120kph)	Benchmark (120kph)	Benchmark (120kph)	140kph

Table 2.1: Business Case scenarios

The comparison between SUSTRAIL0 and the Baseline allows us to examine the Business Case for the SUSTRAIL vehicle, while the comparison between SUSTRAIL1 and

SUSTRAIL0 reveals the value added by the SUSTRAIL track. A comparison between SUSTRAIL2 and SUSTRAIL1 allows us to consider the case for higher-speed running of freight (at 140kph instead of 120kph) using the capability of the SUSTRAIL vehicle, versus running the SUSTRAIL vehicle at conventional speeds. The last of two of these are probably the key comparisons, representing the impact of the full set of SUSTRAIL innovations. The remaining comparisons serve to identify the contributions of the track, vehicle and speed elements separately.

In this Deliverable, the focus is on the User and Environmental Benefits arising from SUSTRAIL0-2 versus the Baseline scenario. This will provide a key input to the final Deliverable (D5.6), where a full cost-benefit analysis and Business Case assessment will be presented.

The final Deliverable will also use sensitivity testing to consider the implications of a more ambitious SUSTRAIL vehicle. Some of the technology options that were explored early in the project, were specifically ruled out from the SUSTRAIL vehicle, but marked down for a hypothetical ‘futuristic vehicle’. It was agreed between WP3/4/5, that it would be not be feasible to assess the futuristic vehicle using LCC and RAMS (and thus the benefits could also not be assessed). This is because the input data for the LCC/RAMS model is simply not available (too early in the R&D cycle). Instead, we will undertake more broad-brush sensitivity tests in the final Business Case to gain an impression of what the futuristic vehicle could achieve.

2.5 Time period

The assessment period for user and environmental benefits should be long enough to reflect the life of the assets created (or improved). Hence D5.5 used a 30 year assessment period from 2015, reflecting the long life of freight vehicles and track improved. In this Deliverable we focus particularly on results for:

- 2015 – the current year, for which modelling results have been produced;
- 2030 – a future, modelled year, midway through the assessment period, far enough ahead to allow take-up of the SUSTRAIL innovations to become widespread.

2.6 Geographical scope

The UK case study is based on the route from Felixstowe to Nuneaton, via Peterborough and Leicester, one of the UK’s major intermodal freight corridors (257km). The Bulgarian Case Study is based on the international route from the Greek and Turkish borders at Svilengrad to the Serbian border at Kalotina (368km). The Spanish Case Study is based on the Mediterranean Corridor between Valencia and Tarragona (272km). In the Conclusions, we consider the comparability and transferability of these case studies.

It is important to note that the existence of models and data, and therefore the potential to carry out analysis varies significantly between the case studies. The approach taken focuses on making the most of the available material in each case.

Figure 2.1: Case Study locations

2.7 Track access charge assumptions

The results of the Business Case assessment will vary according to the assumptions made about Track Access Charges, and how these change in response to the SUSTRAIL innovations. The guiding principle for the Business Case as a whole is that freight users should benefit from whole system cost reductions, whilst Infrastructure Managers (IMs) and freight operators should also gain in order to incentivise the adoption of track friendly vehicles and improved track. In this Deliverable, it is assumed for the purposes of calculation, that savings to the IM[1] and the freight operators on each route are fully passed through to end users, via reductions in track access charges and the prices of freight service to end users. This allows us to capture the maximum value that could be obtained by the end users, who are the final freight customers. It also reflects the competitive market structure of rail freight where within rail market competition and competition with road freight means pricing is strongly reflective of costs (no excess profits). In the full Business Case Deliverable (D5.6), we will develop this further, showing how the industry can retain a share of these benefits – for use in investment or for other purposes.

2.8 Inputs

The principal inputs to the User and Environmental Benefits estimation were shown in Section 1.2. Task 5.1 has provided:

- Change in IM's maintenance and renewal costs (on 0-1200m curves only);
- Except corrective maintenance, a relatively small item, which has been provided for the whole route but for the track force-related failure mode only;
- Change in freight operators' wagon-related costs of ownership and maintenance;

[1] As discussed in Deliverable D5.3, the saving to IMs from reduced wear and tear costs resulting from the use of track friendly vehicles should be passed through to operators (and thus freight users) vis proportionate reductions in access charges. For IM cost savings resulting from infrastructure improvements only the variable cost element should be passed through since this is element alone reflects the cost saving to the IM from the incremental train.

- Availability and mission success measures for wagons operating on a simulated route, that was based on Swedish data but was designed to represent the UK Route (1.) above.

The Task 5.1 simulations were for the Baseline and SUSTRAIL0/1/2 scenarios. Some additional assumptions have been made in order to make the outputs realistic. Work has been done in Task 5.2 to aggregate the results to the UK Route level and to benchmark their magnitude against other UK data.

The Case Study models have provided other essential inputs, including:

- Change in freight operator’s fuel costs;
- Change in freight operator’s other operating costs;
- Environmental emissions (CO2, local air pollutants and noise).

The availability and mission success measures have been converted into a change in reliability, measured in freight train delay per train km.

We have received advice on suitable assumptions about noise emissions from WP3&4 partners, and have checked the plausibility of key assumptions on cost savings and journey time savings with partners Network Rail, ADIF and other operators in the consortium.

3. IMPACTS OF THE SUSTRAIL INNOVATIONS

3.1 Aggregation from inputs to the Case Study corridor

A significant step in producing the Case Studies was to translate the LCC and RAMS results, and the various other evidence on which the analysis is based, to the Case Study corridor level. This is illustrated in this section using the UK case study. The details of the Bulgarian and Spanish case studies are discussed in Chapters 5 and 6 respectively.

3.1.1 The LCC data

In the LCC analysis (SUSTRAIL D5.1), which is a common input to all case studies, most of the track cost items are based on the curves of radius 0-1200m (Table 3.1), which make up 7.1% of the UK case study route by length (Table 3.2).

Track Renewal Costs	Curves only (radius 0-1200m) on route UK1
Track Maintenance Costs (preventive)	Curves only (radius 0-1200m) on route UK1
Track Maintenance Costs (corrective)	Failure mode related to wheel impact on the entire line (route UK1)
Track Investment Costs	Curves only (radius 0-1200m) on route UK1

Table 3.1: Track LCC scope

Curvature	Route length, %
0-1200m	7.1%
1201-1600m	6.6%
1601-2400m	8.8%
>2400m	77.5%
TOTAL	100.0%

Table 3.2: Route length by curvature (UK: Felixstowe-Nuneaton) Source: SUSTRAIL D1.2, Figure 2.9

The corrective maintenance costs are for the whole route but for the track-force related failure mode only. Exclusions are: turnout failure, overhead cable failure, signal failure, subgrade problems and other track related failures. Turning to the 'wagon LCC' model, this is focused on ownership and maintenance costs of freight vehicles, and does not cover the operating costs of freight trains.

Whilst these various limitations helped to reduce the data requirements for the LCC modelling task, they also mean that in order to generalise the results and apply to other contexts, it is necessary to gather some additional data on track costs and freight operators' costs, which was done in Task 5.2.

3.1.2 Track costs

For the track costs, additional input was provided by Network Rail, which allowed the costs in Table 2.1 to be scaled up to cover other types of track. This was based on the frequency of various maintenance/renewal activities for different track types. It produced multipliers of 4.73 for maintenance and 12.23 for renewals on the UK Case Study route (Table 3.3).

			% of track maintenance:				Combined weight	
			19	4	6	71	in renewals	
Route % by curvature:		Renewals weighting	Inspection weighting	Grinding weighting	Tamping weighting	Rest (incl defect repairs)		Normalised
0-1200m	7.1%	5	1.5	3	1.1	1	0.355	1
1201-1600	6.6%	5	1	3	1	1	0.33	0.93
1601-2400	8.8%	2.5	1	3	1	1	0.22	0.62
>2400m	77.5%	1	1	1	1	1	0.775	2.18
SUM	100.0%							4.73

Combined weight in maintenance				
Inspection weighting	Grinding weighting	Tamping weighting	Rest (incl defect repairs)	Normalised
2.0235	0.852	0.4686	5.041	1
1.254	0.792	0.396	4.686	0.850079307
1.672	1.056	0.528	6.248	1.133439076
14.725	3.1	4.65	55.025	9.242585062
				12.23

Table 3.3: Multipliers on LCC preventive maintenance and renewal costs (UK: Felixstowe-Nuneaton)

In order to check that the order of magnitude of the track maintenance and renewals costs derived from the LCC model was correct following this adjustment, the results were compared with the track maintenance and renewal costs per track km from the VTISM model for the UK Case Study route (SUSTRAIL D2.5, Table 3.1), and also with Network Rail's GB average costs (Network Rail, 2013). While the latter two matched well, the LCC-derived costs were significantly lower, and it was decided to scale the former to fit the latter: maintenance costs were scaled-up by a factor of 5.6, whilst renewals and investment were scaled-up by a factor of 9.5. As far as we can tell, these differences in scale arise from differences between the network simulated in the LCC analysis and the UK Case Study network. An important caveat is that the factors in Table 3.3 apply to the Baseline costs of the Case Study route, however the LCC model was designed to focus only on the cost changes between the Baseline and the SUSTRAIL scenarios, and therefore any cost changes should be factored-up only by the 5.6 or 9.5 factors above.

Item	VTISM- based costs, £millions	Network Rail aggregate data (GB) per route km, £millions
Maintenance	7.06	6.09
Renewals	12.09	11.21
Total	19.15	17.31

Table 3.4: Track costs for the whole route Felixstowe-Peterborough-Nuneaton, £ at 2015 prices

3.1.3 Freight operators' costs

For freight operators' costs, a comparison was made between the 'wagon LCC' model produced in SUSTRAIL Task 5.1 and the cost model by MDS-Transmodal (2012) for the similar Felixstowe-Manchester route, updated to 2015. The latter was helpful in giving a complete picture of freight operators' costs, including the wagon ownership and maintenance costs covered by the LCC model. It was found that for wagon ownership and maintenance costs, the models were not too far apart (£33 vs £41 per operating hour for a 24 wagon train). Furthermore, on a daily or annual comparison, the wagon ownership and maintenance costs were comparable, with a delta of -16% on a daily basis, or +6% on an annual basis.

It is important to be open about the differences in assumptions as well, in particular:

- the MDST model assumed operation for 275 days/year, 24 hours/day, but at a lower speed (50kph) and over a shorter route (425km one way);
- whilst the SUSTRAIL model assumed operation for 16 hours/day, apparently 365 days per year less the 5% 'unavailable' days, at an average 94kph over a 750km route (one way).

Given these differences, the comparability of wagon ownership and maintenance results is reassuring.

A key feature of the MDST model is that it covers all cost items for the Freight Operator. This reveals that wagon ownership and maintenance costs equal between 6.6% (MDST) and 8.3% (extrapolating from the SUSTRAIL simulation) of the Freight Operator's total costs of operation. This in turns implies that the large % changes in ownership and maintenance costs arising from the SUSTRAIL model must be scaled-down considerably to give % changes in freight operators' total costs (Table 2.5).

Freight Operators' costs		Cost share in Baseline Scenario:
	Vehicle maintenance costs	3.6%
	Vehicle ownership costs	3.0%
	Freight operators' fuel costs	41.5%
	Other operating costs	42.4%
	Track Access Charges (variable)	9.4%
		100.0%

Table 3.5: Freight operators' cost shares (UK route)

3.1.4 The RAMS data

Similar to the LCC data, it is necessary to scale the RAMS data using other data sources because the RAMS analysis does not include all sources of delay to freight trains. Including both primary and secondary delays, we find that 23.8% is the proportion of freight delays that are caused by vehicle issues and relevant track issues. We use ORR (2015) data on delay minutes per 100 train km, and allow 23.8% of this to vary with the 'mission success' indicator from the RAMS analysis. Full details of the method are given in Appendix B

3.2 Summary of the impacts of the SUSTRAIL innovations

The above key data and assumptions, combined with further evidence and assumptions set out in the 'Impacts' spreadsheet (see Appendix 2), allow us to quantify the impacts of the SUSTRAIL vehicle and track. These are the first-round impacts, before any demand response feeds back into the system.

3.2.1 Track costs

The track maintenance and renewal cost impacts are shown in Table 2.6.

	Track LCC data % changes:			Track cost % changes at route level:		
	SUSTRAIL0 (vehicle only)	SUSTRAIL1	SUSTRAIL2 (140kph)	SUSTRAIL0 (vehicle only)	SUSTRAIL1	SUSTRAIL2 (140kph)
Impacts on IMs (Network Rail)						
Track Maintenance and Renewal Costs				-1.6%	-10.1%	-7.5%
Maintenance				-0.8%	-2.4%	-1.8%
Corrective maintenance	-80%	-80%	-50%	-0.6%	-0.6%	-0.3%
Preventive maintenance	-6%	-45%	-37%	-0.2%	-1.8%	-1.5%
Renewals				-0.8%	-7.7%	-5.6%
General renewals	-10%	-86%	-60%	-0.8%	-7.8%	-5.7%
Investments/innovations	0%	2%	2%	0.0%	0.05%	0.05%
	Note: assuming 4% discount rate			Note: assuming 4% discount rate		
	Note: LCC model (D5.1) showed 0% impact on renewals. This was considered un-realistic and together with the IM (Network Rail) it was decided to set this to 9.8% in order to yield the same £ cost saving for renwals as for maintenance.			Note: SUSTRAIL0 savings are added to SUSTRAIL1&2 to reflect the impact of the missin renewals cost saving for the IM.		
				Implies track improvements provide:		
					-8.5%	-5.9%
					... of the SUSTRAIL1&2 impact.	

Table 3.6: Impacts of SUSTRAIL0,1&2 on track costs

3.2.2 Track access charges

The impact on track access charges differs between intermodal (SUSTRAIL-relevant) freight and other freight (Table 3.7), because other freight benefits from the reduction in track costs due to the SUSTRAIL track, but not from the track-friendly vehicle. The Table assumes that cost savings are passed through to End Users.

Infrastructure innovations (included in SUSTRAIL1&2):			
	Track cost % changes at route level:		
	SUSTRAIL0	SUSTRAIL1	SUSTRAIL2
Impacts on IMs (Network Rail)	(vehicle only)		(140kph)
Track Maintenance and Renewal (M&R) Costs	n/a	-10.1%	-7.5%
(needed for Track Access Charges to intermodal traffic)			
Track M&R Costs excluding impact of SUSTRAIL vehicle on track costs	n/a	-8.5%	-5.9%
(needed for Track Access Charges to non-intermodal traffic)			
	Note: from sheet 'Track cost assumptions'; assuming 4% discount ra		
Vehicle innovations (included in SUSTRAIL0,1&2):			
	Track cost £/year changes at route level:		
	SUSTRAIL0	SUSTRAIL1	SUSTRAIL2
	(vehicle only)		(140kph)
Impacts on IMs (Network Rail)			
Track Maintenance and Renewal Costs	-304207		
	Note: from sheet 'Track cost assumptions'; assuming 4% discount ra		
Track Access Charges (variable)			
	SUSTRAIL0	SUSTRAIL1	SUSTRAIL2
			(140kph)
% of variable cost base examined in the cost model		81%	
% change in variable Track Access Charges	-10.4%	-17.4%	-15.2%
% change in variable Track Access Charges from Infrastructure Improvements		-6.9%	-4.8%
% change in variable Track Access Charges from Vehicle Improvements	-10.4%	-10.4%	-10.4%

Table 3.7: Impacts of SUSTRAIL0,1&2 on Track Access Charges

3.2.3 Freight operators

Following these impacts through the supply chain to rail freight operators, we obtain the following set of impacts in each scenario (Table 3.8).

Impacts on Freight Operators	%change	Baseline	SUSTRAIL0 (vehicle only)	SUSTRAIL1	SUSTRAIL2 (140kph)
Freight Operators' costs		Base	-1.8%	-2.4%	-0.5%
Vehicle maintenance costs		Base	-61%	-61%	-58%
Vehicle ownership costs		Base	46%	46%	46%
Freight operators' fuel costs		Base	No change	No change	3.7%
Other operating costs		Base	No change	No change	No change
Track Access Charges (variable) - SUSTRAIL vehicles		Base	-10.4%	-17.4%	-15.2%
Track Access Charges (variable) - other vehicles			0.0%	-6.9%	-4.8%
Freight service charges (money)		Base	-1.8%	-2.4%	-0.5%

Table 3.8: Impacts of SUSTRAIL0,1&2 on freight operators' costs and revenues

Note that the impact on vehicle ownership costs combines two separate inputs: vehicle ownership costs are impacted by fleet availability (from RAMS: 95% to 99%) as well as capital cost per wagon net of disposal value (+48% in SUSTRAIL1&2). It could be impacted by journey time as well, if significant rescheduling was allowed, however we assume that effect does not materialise.

Operators' fuel costs remain constant in SUSTRAIL0&1 because of the following assumptions: mass reduction in the vehicle body is fully offset by mass increase in running gear (D5.1); and operations at maximum speed 140kph vs 120kph increase fuel consumption by 3.7% for diesel trains (based on RENFE data provided directly to Task 5.2).

The Other operating costs include: loco costs; train crew costs; overheads; and returns paid on capital. No change is expected in these items due to SUSTRAIL innovations.

3.2.4 End users and third parties

Finally, we have a set of impacts on the End users and Third parties who are the main focus of this deliverable. The reliability impact is based on the RAMS data and supporting assumptions (§3.1.4 above). The journey time impact assumption is the same as in the Interim Business Case (D5.5). Approximately 15% reduction in journey time is estimated whilst operating at maximum freight speed; we assume half this maximum potential gain is achieved in practice = 7.5%. Freight service charges to End users are assumed to vary so as to fully pass on the savings made by Freight operators (whether from their own costs or Track access charges). This assumption will relaxed in D5.6, allowing Freight Operators to retain a benefit for themselves, over and above the cost savings which counteract the additional capital cost of the SUSTRAIL vehicles.

			Baseline	SUSTRAIL0 (vehicle only)	SUSTRAIL1	SUSTRAIL2 (140kph)
Impacts on End Users		%change				
	Reliability (delay minutes)		Base	-8%	-14%	-9%
	Journey time		Base	No change	No change	-7.5%
	Freight service charges (money)		Base	-1.8%	-2.4%	-0.5%
Externalities						
	CO2	%change	Base	No change	No change	3.7%
	Local air	%change	Base	No change	No change	3.7%
	Noise	decibels	Base	-12dB	-12dB	-11dB

Table 3.9: Impacts of SUSTRAIL0,1&2 on End Users and 3rd parties

The environmental impacts are based on:

- CO_2 emissions and local air pollution increased in proportion to the change in fuel consumption (SUSTRAIL2 only) – in addition there will be some mode shift effects that are evaluated in the results below;
- Noise emissions reduced by 12dB in the SUSTRAIL0&1 scenarios, and 11dB in the SUSTRAIL2 scenario with higher-speed running (on the advice of WP3).

4. Freight and Environmental Benefits for the UK Case Study

4.1 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.

4.2 LEFT model

4.2.1 Overview

The LEeds Freight Transport model (LEFT) was developed in the course of the ITeLS project (Lalwani et al, 2004) and the Rail Research UK (RRUK) (Fowkes et al., 2006) 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.

4.2.2 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 (DfT, annual):

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, although all traffic recieves benefits from the improved track.

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 Fowkes et al (2006). 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 Fowkes et al (2004) to yield commodity specific valuations of delay time per tonne and shown in Table 4.1 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 4.1: 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 4.2** below

Table 4.2: 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} . These can be converted into monetary values using appropriate external cost unit valuations.

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%.

4.3 Data

4.3.1 Road Tonnes and Tonne-kms

Base data on road tonnes and tkms 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 DfT (2007)) and one from the questionnaire based Continuing Survey of Road Goods Transport (CSRGT), reported in DfT (annual). We have chosen to take a figure somewhere in-between. 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.

4.3.2 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 4.3 shows how this base rail traffic for 2006 is distributed across distance bands

Table 4.3: 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 Shen et al (2009). 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 4.4 below.

Table 4.4: 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

4.4 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 specitivity 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.

4.5 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 (train-friendly) and TU (train-unfriendly) (see section 4.2.2 for definitions, 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 (Taplin, 1982; Taplin, 1997; Taplin, Hensher, and Smith, 1999), 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 Beuthe et al (2001), 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 compared to the literature. Consequently the entered elasticity figures were scaled down by a factor of 0.88. This took account of the findings of Li, Hensher and Rose (2011), 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 4.5 below.

Table 4.5: 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.

4.6 Scenario assumptions

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.

Table 4.6 shows the commodity related vehicle types which are affected by our improvements.

Table 4.6: 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
Chemicals	FEA	10	10	Intermodal flat wagon	Y
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	N
Others	IWA	10	40	Hopper Wagon	N

As can be seen from the table, only 20% 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.

4.7 Emissions modelling and valuation

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 modelled and valued here

- Carbon dioxide (CO_2)
- Nitrogen oxides (NO_x)

- Particulates (PM_{10})
- Sulphur dioxide (SO_2)

4.7.1 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 Johnson, Fowkes, Whiteing and Maurer (2008).

4.7.2 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 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 and PM_{10} from rail freight transport, obtained from AEA Technology (1999, Table A38).

Table 4.7 summarises the variables which are suggested for calculating rail emissions in our framework.

Table 4.7: 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 PM_{10}: 0.22
Output variables	Emissions for SO_2, CO_2, NO_x and PM_{10}, in kt

4.7.3 Valuation of SUSTRAIL emissions reductions

The SUSTRAIL emission reductions affect both rail and road: rail because the SUSTRAIL vehicles are quieter; and both modes due to mode shift as rail becomes more competitive.

	2015	2030
Marginal external cost of CO_2 , €/tonne	83.71	105.21
Marginal external cost of NO_x , €/tonne	10,895	14,515
Marginal external cost of SO_2 , €/tonne	15,229	20,289
Marginal external cost of PM , €/tonne	69,405	92,465
Marginal external cost of noise , €/000 train km		
- Rail, rural, day	75.05	99.99
- Rail, rural, night	126.86	169.02
- Rail, urban, day	1518.73	2023.34
- Rail, urban, night	2567.93	3421.13
Marginal external cost of noise , €/000 veh km		
- Road (HGV), rural, day	1.90	2.25
- Road (HGV), rural, night	3.42	4.06
- Road (HGV), urban, day	255.24	302.63
- Road (HGV), urban, night	465.11	551.47
Marginal value of noise reduction, €/person/annum		
- 1dBLeq,18hr at 57.5dB	23.26	30.99
- 1dBLeq,18hr at 65dB	35.54	47.35
- 1dBLeq,18hr at 72.5dB	46.30	61.68
Discount factor @4%	1.000	0.555
Discount factor @3%	1.000	0.642

Table 4.8: Values of SUSTRAIL emissions reductions, 2015 and 2030

4.8 Results

The UK Case Study results for user and environmental benefits are summarised in Tables 4.9-4.11.

		Benefits, £/year	
Impact Groups	*Impacts*	*2015*	*2030*
End Users	Reliability benefits	117,228	206,540
	Speed benefits	0	0
	Lower freight costs	478,411	842,895
Third parties	CO_2 reductions	20,265	42,655
	Noise reduction	-2,704	-3,602
	Reduced air pollution	1	-592

Table 4.9: UK Case Study summary results – SUSTRAIL0, Vehicle only (base speed)

		Benefits, £/year	
Impact Groups	*Impacts*	*2015*	*2030*
End Users	Reliability benefits	213,695	367,849
	Speed benefits	0	0
	Lower freight costs	714,241	1,229,474
Third parties	CO_2 reductions	98,704	171,298
	Noise reduction	9,464	12,609
	Reduced air pollution	61,076	99,751

Table 4.10: UK Case Study summary results – SUSTRAIL1, Vehicle+Track (base speed)

		Benefits, £/year	
Impact Groups	*Impacts*	*2015*	*2030*
End Users	Reliability benefits	106,497	185,617
	Speed benefits	445,569	776,590
	Lower freight costs	501,098	873,373
Third parties	CO_2 reductions	103,734	191,610
	Noise reduction	3,722	4,959
	Reduced air pollution	48,046	78,516

Table 4.11: UK Case Study summary results – SUSTRAIL2, Vehicle+Track (enhanced speed)

5. Freight and Environmental Benefits for the Bulgarian Case Study

5.1 Introduction

This case study is focused on container traffic being moved by rail along the corridor: Kalotina - Sofia - Plovdiv - Svilengrad. At present much of this traffic is moved by road to and from the ports of Varna and Burgas, however rail and terminal infrastructure improvements are planned. This chapter forecasts future container demand, and the potential mode share for rail using a binomial logit model. It then applies the cost (LCC) and performance (reliability and speed) data from SUSTRAIL WP5 to provide a cost-benefit analysis of scenarios SUSTRAIL0,1&2.

A full description of the Bulgarian case study is provided in Appendix 3. This covers material relevant to this deliverable (user and environmental benefits summarized below) but also the full cost benefit analysis for the case study. The latter will be discussed in deliverable D5.6 in the context of the results from the other case studies.

5.2 Bulgarian freight model

Bulgaria is forecast to have growing GDP per capita and a declining population over the period 2015-2044. Using a model of containerisation by Ueda et al (2005), container traffic through the Bulgarian ports is forecast to grow strongly (Table 5.1).

	2015	2025	2030	2035	2040	2044
Elasticity coefficient	2,33	2	1,5	0,5	0,5	0,5
Real GDP growth, forecast	0,85%	2,16%	2,39%	2,47%	2,49%	2,50%
Increase of the number of containers, forecast	1,99%	4,31%	3,59%	1,23%	1,25%	1,25%
TEU, forecast through ports	180 186	260 115	322 494	376 919	400 911	421 293

Table 5.1 Forecast of containers handled by the seaports of Bulgaria

The inland origin/destination of the freight is allocated using a gravity model, based on generalized cost (Razmov et al, 2013, see Appendix C). To determine the market shares of road and rail transport the following logit model is applied:

(4) $$Pb_{ij}^{m} = \frac{\exp(-\beta.Gr_{ij}^{m})}{\sum_{m=1}^{2}\exp(-\beta.Gr_{ij}^{m})}$$ where:

Pb_{ij}^{m} - percentage of containers (market share) for the planning region i, which are served by port j by road (m = 1) and rail (m = 2) transport;

costs of transporting a tonne with a container from or to the planning region i from or to port j by transport mode m;

Gr_{ij}^{m} - generalized costs, which are calculated with transportation between the planning region i and port j with transport mode m.

Having applied the model, the respective market shares of road and rail transport by ports and planning regions are obtained (Table 5.2).

Northwestern region (Vratsa)	road	rail	Market share	
From the port to Northwestern region	Total generalized costs	Total generalized costs	road	rail
Burgas	43,67	59,07	95,10%	4,90%
Varna	38,73	54,45	95,38%	4,62%
Constanta	51,77	85,37	99,85%	0,15%
Ambarli	79,07	98,92	97,86%	2,14%
Thessaloniki	45,07	69,96	99,18%	0,82%
Piraeus	104,68	122,95	97,12%	2,88%
Durres	114,98	152,77	99,93%	0,07%
Rijeka	103,39	166,72	100,00%	0,00%
Bar	114,64	144,96	99,71%	0,29%

North Central (Veliko Tarnovo)	road	rail	Market share	
From the port to North Central region	Total generalized costs	Total generalized costs	road	rail
Burgas	20,25	38,72	97,23%	2,77%
Varna	21,22	38,32	96,43%	3,57%
Constanta	35,46	66,21	99,73%	0,27%
Ambarli	54,35	83,73	99,65%	0,35%
Thessaloniki	56,78	87,98	99,76%	0,24%
Piraeus	118,26	144,48	99,36%	0,64%
Durres	133,57	172,51	99,94%	0,06%
Rijeka	127,98	186,46	100,00%	0,00%
Bar	133,38	164,71	99,76%	0,24%

Northeastern (Shumen)	road	rail	Market share	
From the port to Northeastern region	Total generalized costs	Total generalized costs	road	rail
Burgas	13,18	32,01	97,41%	2,59%
Varna	9,26	24,21	94,68%	5,32%
Constanta	22,12	69,68	99,99%	0,01%
Ambarli	55,10	91,11	99,90%	0,10%
Thessaloniki	67,37	95,79	99,58%	0,42%
Piraeus	128,76	154,51	99,30%	0,70%
Durres	145,02	184,85	99,95%	0,05%
Rijeka	148,01	198,80	99,99%	0,01%
Bar	145,31	177,04	99,78%	0,22%

Southwestern (Sofia)	road	rail	Market share	
From the port to Southwestern region	Total generalized costs	Total generalized costs	road	rail
Burgas	34,73	49,73	94,73%	5,27%
Varna	46,71	64,61	96,92%	3,08%
Constanta	57,04	89,57	99,81%	0,19%
Ambarli	66,76	87,23	98,10%	1,90%
Thessaloniki	34,48	62,70	99,57%	0,43%
Piraeus	91,91	113,84	98,56%	1,44%
Durres	82,89	140,56	100,00%	0,00%
Rijeka	101,00	154,51	100,00%	0,00%
Bar	83,19	132,76	99,99%	0,01%

South Central (Plovdiv)	road	rail	Market share	
From the port to South Central region	Total generalized costs	Total generalized costs	road	rail
Burgas	22,97	39,98	96,37%	3,63%
Varna	34,79	54,65	97,86%	2,14%
Constanta	49,23	86,00	99,92%	0,08%
Ambarli	46,90	71,65	99,16%	0,84%
Thessaloniki	40,37	74,94	99,87%	0,13%
Piraeus	104,44	128,85	99,10%	0,90%
Durres	102,60	157,95	100,00%	0,00%
Rijeka	117,39	171,90	100,00%	0,00%
Bar	103,05	150,14	99,99%	0,01%

Southeastern (Sliven)	road	rail	Market share	
From the port to Southeastern region	Total generalized costs	Total generalized costs	road	rail
Burgas	10,64	24,47	93,48%	6,52%
Varna	22,51	37,67	94,88%	5,12%
Constanta	35,50	79,88	99,98%	0,02%
Ambarli	42,77	77,88	99,88%	0,12%
Thessaloniki	53,47	87,77	99,87%	0,13%
Piraeus	113,89	144,11	99,70%	0,30%
Durres	125,76	171,06	99,98%	0,02%
Rijeka	133,48	185,01	100,00%	0,00%
Bar	126,05	163,25	99,92%	0,08%

Table 5.2 Market shares of road and rail transport from and to planning regions and to and from ports

The table shows that the most important for rail transport are the Bulgarian ports. It does not make sense to transport containers by rail from Durres ports, Rijeka and Bar.

5.3 Data

Data on the number of containers transported per year by road through Bulgaria for the period 2009-2013 was sourced from NSI and Eurostat (Table 5.3), and was used in forecasting further ahead (Table 5.4).

Transit transport data - primary and calculated	2009	2010	2011	2012	2013
tonnes per year (tractors + trucks over 25 tonnes)	10 411 200	12 540 700	14 153 700	18 531 600	22 453 600
% truck tractors and trucks of over 25 tonnes of total shipments	98,15%	98,42%	96,79%	97,44%	98,44%
all types of trucks	10 607 600	12 742 500	14 623 000	19 018 700	22 810 100
exports (tonnes)	4 003 400	4 134 100	5 179 500	5 132 000	6 428 500
imports (tonnes)	2 229 300	2 662 900	3 778 600	3 771 700	4 182 600
total (tonnes)	6 232 700	6 797 000	8 958 100	8 903 700	10 611 100
transit (tonnes)	4 374 900	5 945 500	5 664 900	10 115 000	12 199 000
transit trucks of over 25 tonnes and truck tractors	214 695	292 567	274 155	492 797	600 417
import and export containers	375 832	301 486	369 132	411 701	374 290
tonnes transported in containers	4 284 490	3 436 946	4 208 101	4 693 394	4 266 905
% container import and export	68,74%	50,57%	46,98%	52,71%	40,21%
transit - containers	147 586	147 938	128 785	259 767	241 438

Table 5.3 Data on transit container transportation by road

Table 5.4 presents the forecasts for transit containers per year for the whole country by transport mode.

2015	2020	2030	2040	2044
Total number of containers – land transport				
220 879	224 929	242 632	265 968	276 211
Containers – road transport				
187 667	191 108	206 149	225 977	234 680
Containers – rail transport				
33 211	33 820	36 482	39 991	41 531

Table 5.4 Forecast of container transit transport by years

5.4 Scenario assumptions

Traffic forecasts are carried out for the three types of innovation in railway infrastructure and setting in operation the new rolling stock: SUSTRAIL 0, SUSTRAIL 1 and SUSTRAIL 2. The construction projects provided to be implementated and projects ongoing at the moment in the rail section are taken into account.

5.4.1 Option SUSTRAIL 0

With developing forecasts for option SUSTRAIL 0, it is assumed that:

1. The railway section is under rehabilitation (the railway infrastructure is being improved without leaving the existing route).
2. The design speeds of traffic in the rail section are restored. The design speeds are understood as speeds that have been set in implementation of the last renewal projects in the rail section.
3. The new type of wagons is being set in operation.
4. The new type of wagons will be used for container transportation because it is where the potential of effective use is greatest and this type of services might be eligible for railway undertakings.
5. A new organization of traffic by introducing specialized container trains with constant composition (block trains) is under implementation.
6. Block trains will consist only of wagons of the new type.
7. The traffic of block trains is commensurable with the speed of passenger trains, which is reflected in the schedule of trains.

The forecasts of rail traffic have taken into account the dependencies: speeds - generalized costs - traffic - rolling stock.

5.4.2 Option SUSTRAIL 1

With developing forecasts for option SUSTRAIL 1, it is assumed that:

1. The rail section is under modernization (innovations are being implemented): with innovations carried out in railway infrastructure, it is possible to go beyond the route existing now).
2. The design speeds of 120 km/h are implemented for passenger trains and of 100 km /h for freight trains.
3. Automatic level crossing devices are under implementation.
4. ERTMS Level 1 is being set in operation.
5. New type wagons are being set in operation.
6. The new type of wagons will be used for container transportation, because it is where the potential of effective use is greatest and this type of services might be eligible for railway undertakings.
7. A new organization of traffic by introducing specialized container trains with constant composition (block trains) will be established.
8. Block trains will consist only of wagons of the new type.
9. The traffic of block trains is commensurable with the speeds of passenger trains. Speeds are considered with the opportunities provided by railway infrastructure after innovations, which is reflected in the schedule of trains. The speed limit of container trains in this case is 120 km/h, which is the speed limit of passenger trains traffic.

The forecasts of rail traffic have taken into account the dependencies: speeds - generalized costs - traffic - rolling stock.

5.4.3 Option SUSTRAIL 2

With developing forecasts option SUSTRAIL 2, it is assumed that:

1. The rail section is under modernization (innovations are being implemented): with innovations carried out in railway infrastructure, it is possible to go beyond the route existing now).
2. The design speeds of 160 km/h are implemented for passenger trains and of 120 km /h for freight trains.
3. Automatic level crossing devices are under implementation or crossing with other road or rail infrastructure is carried out on two levels.
4. ERTMS Level 2 is being set in operation.
5. New type wagons are being set in operation.
6. The new type of wagons will be used for container transportation, because it is where the potential of effective use is greatest and this type of services might be eligible for railway undertakings.
7. A new organization of traffic by introducing specialized container trains with constant composition (block trains) will be established.
8. Block trains will consist only of wagons of the new type.
9. The traffic of block trains is commensurable with the speed of passenger trains. Speeds are considered with the opportunities provided by railway infrastructure after innovations and the capabilities of the new type of wagons which is reflected in the schedule of trains. The speed limit of container trains in this case is 140 km/h, which is also the speed limit with running of the new type of wagons.

The forecasts of rail traffic have taken into account the dependencies: speeds - generalized costs - traffic - rolling stock.

5.5 Benefits for end users

5.5.1 Benefits of increased reliability of shipments

The benefits related to increased reliability of shipments are connected with reduced train delays. They depend on the traffic forecasts defined in train kilometers for the different options. The main parameters, which serve as a basis to determine the benefits of increased reliability of shipments due to setting the new rolling stock in operation and rail infrastructure improvements, are shown in Table 5.5.

Baseline Delay minutes, per 100 train km	15,80	minutes
Speed SUSTRAIL 0, Delay minutes, per 100 train km	14,56	minutes
Reliability, time saved, hour per train km	0,000207	hour/train km
neto tons per train	228,00	ton km/train
Unit price for freight delay	0,17	€/ton min
Unit price for freight delay	10,39	€/hour per train km.

Table 5.5 Basic parameters used to determine the benefits of increased reliability of shipments (reduced time of trains delay)

Due to the fact that the transport service is improving in terms of reduced delay times, with determining the respective benefits the rule of half is used in the following way:

$$R^{Benefit}_{reliability,ij} = \frac{1}{2}\left(Tkm^{0}_{reliability,ij} + Tkm^{1}_{reliability,ij}\right)\left(D^{0}_{reliability,ij} - D^{1}_{reliability,ij}\right)c_{reliability}$$ where:

$R^{Benefit}_{reliability,ij}$ - benefits of time savings for shippers and companies using rail and moving from i to j thanks to reduced train delays in EUR;

$Tkm^{0}_{reliability,ij}$ and $Tkm^{1}_{reliability,ij}$ - forecasts of train kilometers with "no project" option and "with project" option determined for railway station i, j;

$D^{0}_{reliability,ij}$ and $D^{1}_{reliability,ij}$ - delay of goods by freight trains with "no project" option and "with project" option respectively in hours per train kilometer;

$c_{reliability}$ - value of one hour delay per train kilometer in EUR.

5.5.2 Benefits of time savings

The sources of the effect of investment and technological solutions on time savings by scenarios obtained from shortening the travel are connected with the increase of speeds (design, technical and in the section) for rail traffic and the improved capacity of railway sections.

<u>Determination of speed and travel time in railway transport</u>

The speeds of passenger and freight trains are based on a study of TTS (Train Traffic Schedule) for 2013. The speeds are determined for options: Baseline, SUSTRAIL 0; SUSTRAIL 1 and SUSTRAIL 2. Under option SUSTRAIL 0 the improvements in rail infrastructure lead to recovery of design speeds set in construction of lines. With options SUSTRAIL 1 the speeds provided for freight trains are of 120 and with options SUSTRAIL 2 the provided speeds for freight trains are 140 km/h. The technical speed of trains is obtained as the design speed (v_{np}) for the respective options is adjusted by a coefficient of technical speed (β). The economic analysis requires the section speed of freight trains. It is defined as the technical speed is adjusted by a coefficient of section speed ($\beta_{уч,тов}$):

$$v_{уч,тов} = v_{np}\beta\beta_{уч,тов}.$$

For respective options it is considered that there are improvements in rail infrastructure as well as that the rail freight traffic with new rolling stock is performed by trains with constant composition (block trains). This is taken into account with determination of the coefficient of section speed.

For Baseline option the section speed is determined on the basis of the TTS acting for 2013.

Table 5.6 Speeds of trains

Variant	Design speed	Coefficient of technical speed	Coefficient of section speed	Section speed
Baseline	Determined by TTS for 2013			38,28
SUSTRAIL 0	95	0,9	0,652	55,75
SUSTRAIL 1	120	0,9	0,652	70,42
SUSTRAIL 2	140	0,9	0,652	82,16

Value of time

The value of saved time is determined for each option considered in regard to Baseline option.

The values of saved time are defined per unit prices for Bulgaria listed in "Requirements for CBA in the transport sector in Bulgaria" (JASPERS, 2008) determined to 2007. The values for Bulgaria are adjusted based on elasticity of 0.7 of GDP growth. The value obtained for 2015 is € 0.9 per t/h.

The unit costs pointed out for 2015 are adjusted every year with GDP growth multiplied by the elasticity coefficient of 0.7.

The benefits of time savings are determined by the rule of half way in the following way:

$$R^{Benefit}_{VoT,\,frrail,ij} = \tfrac{1}{2}\left(Q^{0}{}_{frrail,ij} + Q^{1}{}_{frrail,ij}\right)\left(T^{0}{}_{frrail,ij} - T^{1}{}_{frrail,ij}\right).q_{frrail,ij}.c_{frrail},$$ където:

$R^{Benefit}_{VoT,\,frrail,ij}$ - benefits from time savings for shippers and companies using rail transport and moving from i to j;

$T^{0}{}_{frrail,ij}$ и $T^{1}{}_{frrail,ij}$ - travel time for goods transported by freight trains with options "no project" and " with project" respectively;

$q_{frrail,ij}$ - average weight of a freight train in tonnes;

c_{frrail} - value of one ton goods transported by a freight train for the respective year.

Time saved, hour per ton km (SUSTRAIL 0)	0,008186	hour/ton km.
Time saved, hour per ton km (SUSTRAIL 1)	0,011924	hour/ton km
Time saved, hour per ton km (SUSTRAIL 2)	0,013952	hour/ton km
Unit price for freight	0,78	€/ton per hour (2015)

Table 5.7 Basic parameters used with calculation of benefits of time savings

Table 5.8 presents the benefits of increased reliability of transportation (reduced train delays) and benefits of time savings for the end users (increased speeds) by options and time sections. The railway line operation after the improvements of rail infrastructure and setting the new vehicles in operation starts from 2018. Until then it is assumed that they absorb investments and traffic is adjusted to the new service.

Value of unit prices VoT	2015	2018	2020	2025	2035	2040	2044
Unit price for freight	0,78	0,81	0,83	0,87	0,96	1,01	1,03
Unit price for freight delay	10,39	10,84	11,19	11,71	12,87	13,51	13,85
Benefits of time saved	SUSTRAIL 0						
Baseline, tkm	9 396 167	10 469 037	11 429 933	14 835 896	21 767 768	23 673 829	25 321 218
SUSTRAIL 0, tkm	9 396 167	13 958 147	15 676 507	21 736 476	32 681 860	35 589 026	38 103 243
Benefits (speed)	59 611	80 841	92 619	130 754	213 867	244 404	268 221
Baseline, train km	41 211	45 917	50 131	65 070	95 473	103 833	111 058
SUSTRAIL 0, train km	41 211	61 220	68 757	95 335	143 341	156 092	167 119
Benefits (Reliability)	89	120	138	195	318	364	399
Total benefits	**59 700,05**	**80 961,14**	**92 757,41**	**130 948,43**	**214 185,44**	**244 767,88**	**268 620,12**
Benefits of time saved	SUSTRAI 1						
Baseline, tkm	9 396 167	10 469 037	11 429 933	14 835 896	21 767 768	23 673 829	25 321 218
SUSTRAIL 1, tkm	9 396 167	16 233 655	18 439 408	26 207 148	39 733 573	43 287 887	46 362 506
Benefits (speed)	86 829	128 721	148 660	213 736	351 861	402 244	441 564
Baseline, train km	41 211	71 200	80 875	114 944	174 270	189 859	203 344
SUSTRAIL 1, train km	41 211	71 200	80 875	114 944	174 270	189 859	203 344
Benefits (Reliability)	89	160	188	279	465	532	584
Total benefits	**86 917,95**	**128 880,96**	**148 847,17**	**214 015,06**	**352 325,36**	**402 775,53**	**442 147,55**
Benefits of time saved	SUSTRAI 2						
Baseline, tkm	9 396 167	10 469 037	11 429 933	14 835 896	21 767 768	23 673 829	25 321 218
SUSTRAIL 2, tkm	9 396 167	17 692 189	20 207 461	29 059 688	44 224 103	48 190 382	51 621 752
Benefits (speed)	101 601	158 846	184 247	267 479	441 782	505 134	554 591
Baseline, train km	41 211	77 597	88 629	127 455	193 965	211 361	226 411
SUSTRAIL 2, train km	41 211	77 597	88 629	127 455	193 965	211 361	226 411
Benefits (Reliability)	89	174	206	309	517	592	650
Total benefits (Euro)	**101 689,59**	**159 020,74**	**184 452,17**	**267 788,90**	**442 299,26**	**505 726,36**	**555 241,63**

Table 5.8 Benefits of increased reliability of transportation and benefits of time saved

5.6 Emissions modelling and valuation

5.6.1 Benefits of air pollution cost savings

All air pollution costs are caused by major air pollutants - CO, NO_2, SO_2, $PM_{2,5}$.

The costs arising from air pollution include: health costs; property damage, loss of crops and losses caused by damage to ecosystems (biosphere, soil, water).

The most important category is the cost of health care. Therefore the proximity and density of population exposed to pollution of transport is a key factor in air pollution.

The most important category is the cost of health care. Therefore, a key factor in air pollution is the proximity and density of the population exposed to pollution from transport.

The level of expenditure in road transport depends on the standard emission of vehicles as determined by the year of production. Furthermore, the level of exhaust emissions from vehicles depends on speed, fuel type and geographic location of the road.

The benefits of reduced air pollution have been determined based on modal shift from trucks to rail with implementation of the relevant options for railway infrastructure improvement of and setting the new wagons in operation.

The values of air pollution costs are defined in unit values given in the Handbook on External Costs of Transport, Report for the European Commission: DG MOVE, Ricardo-AEA/R/ED57769, Issue Number 1, 8th January 2014 (Table 20: Air pollution costs in €ct/vkm (2010) for heavy goods vehicles, EU average for trucks and Table 21: Marginal air pollution costs (2010) for rail transport, EU average for rail transport) and are reduced to 2015. They are adjusted for each year with GDP growth multiplied by a coefficient of elasticity of 0.7.

The unit values of air pollution costs are presented in Table 5.9 and their forecasts are presented in Table 5.10.

Vehicle	Urban	Suburban	Interurban	Motorway
	(€ct/vkm)	*(€ct/vkm)*	*(€ct/vkm)*	*(€ct/vkm)*
HGV (>32 tons)	12,21	9,48	6,94	5,72
Rail transport electric locomotive	**Urban**	**Suburban**	**Interurban**	**Motorway**
			(€ct/tkm)	
			0,08	

Table 5.9 Unit value of air pollution costs to 2015

Value of unit prices	2015	2018	2020	2025	2035	2040	2044
HGV (€ct/vkm)	6,94358	7,24423	7,47937	7,82594	8,59774	9,02736	9,25701
Freight electric locomotive	0,08000	0,08346	0,08617	0,09017	0,09906	0,10401	0,10665

Table 5.10 Forecasts of unit value of air pollution costs by time sections

The benefits of reduced costs for air polluting emissions shall be determined as follows:

$$R_{airpol}^{Benefit} = \sum_{ij} \left(R_{airpol,fr,ij}^{Benefit} + R_{airpol,frrail,ij}^{Benefit} \right)$$ where:

$$R_{airpol,fr,ij}^{Benefit} = (V_{km}{}^{0}{}_{fr,ij} - V_{km}{}^{1}{}_{fr,ij}).C_{airpol,fr,ij};$$

$$R_{airpol,frrail,ij}^{Benefit} = (T_{km}{}^{0}{}_{frrail,ij} - T_{km}{}^{1}{}_{frrail,ij}).C_{airpol,frrail}$$ where:

$R_{airpol}^{Benefit}$ - total benefits of reduced costs for air polluting emissions with implementation of the option of railway infrastructure improvement and setting the new rolling stock in operation;

$R_{airpol,fr,ij}^{Benefit}$ - benefits from reduced costs for air polluting emissions caused by trucks moving from i to j;

$R_{airpol,frrail,ij}^{Benefit}$ - benefits from reduced costs for air polluting emissions caused by freight trains running from i to j;

$V_{km}{}^{0}{}_{fr,ij}$, $V_{km}{}^{1}{}_{fr,ij}$ - freight vehicle kilometers with options "no project" and "with project" implemented in section (i, j);

$T_{km}^{0}{}_{fr,ij}$, $T_{km}^{1}{}_{fr,ij}$ - Tonne-kilometers performed by rail options "no project" and " with project" implemented in section (i, j);

$C_{airpol,fr,ij}$ - unit value of air pollution costs from freight road transport in euro cents per kilometer truck;

$C_{airpol,frrail}$ - unit value of air pollution costs from railways in euro cents per ton kilometer.

Table 5.11 presented the total value by time sections and options of benefits of cost savings of air pollution.

Value of unit prices	2015	2018	2020	2025	2035	2040	2044
HGV (€ct/vkm)	6,94358	7,24423	7,47937	7,82594	8,59774	9,02736	9,25701
Freight electric locomotive	0,08000	0,08346	0,08617	0,09017	0,09906	0,10401	0,10665
SUOUSTRAI 0							
Benefits of Air pollution	**2015**	**2018**	**2020**	**2025**	**2035**	**2040**	**2044**
Vehicle km diverted	0	306 062	372 507	605 314	957 377	1 045 193	1 121 230
Ton km diverted	0	3 489 110	4 246 575	6 900 580	10 914 093	11 915 197	12 782 026
Total benefits	0	19 260	24 202	41 150	71 501	81 961	90 160
SUOUSTRAI 1							
Benefits of Air pollution	**2015**	**2018**	**2020**	**2025**	**2035**	**2040**	**2044**
Veh-km diverted	0	505 668	614 866	997 478	1 575 948	1 720 531	1 845 727
Tkm diverted	0	5 764 618	7 009 475	11 371 252	17 965 805	19 614 058	21 041 288
Total benefits	0	31 820	39 948	67 809	117 699	134 918	148 418
SUOUSTRAI 2							
Benefits of Air pollution	**2015**	**2018**	**2020**	**2025**	**2035**	**2040**	**2044**
Veh-km diverted	0	633 610	769 959	1 247 701	1 969 854	2 150 575	2 307 064
Tkm diverted	0	7 223 152	8 777 529	14 223 792	22 456 336	24 516 553	26 300 534
Total benefits	0	39 871	50 024	84 819	147 118	168 641	185 515

Table 5.11 Benefits of reduced air pollution costs by options and time sections

5.6.2 Benefits of reducing the climate change costs

The costs related to climate change are very complex in view of the fact that they are long-term, global and difficult to predict damage.

The impact of transport on climate change is due primarily to the greenhouse gases: carbon dioxide (CO_2),, nitrous oxide (N_2O) and methane ($C\ H_4$).

The costs of climate change are defined by the unit values pointed out in the Handbook on External Costs of Transport, Report for the European Commission: DG MOVE, Ricardo-AEA/R/ ED57769, Issue Number 1, 8th January 2014 (Table 36: Marginal climate change costs for road transport (buses and HGVs), EU average (prices of 2010) and are reduced to 2015. They are adjusted every year with GDP growth multiplied by the elasticity coefficient of 0.7.

The benefits of cost savings for climate change have been determined based on modal shift from trucks to rail with implementation of respective options for railway infrastructure improvement and setting the new wagons in operation.

The fact that traffic is not urban is considered.

The unit values of costs of climate change are presented in Table 5.12 and their forecasts are presented in Table 5.13.

Vehicle	Interurban	Motorway
	(€c/vkm)	*(€c/vkm)*
HGV	8,65	7,18

Table 5.12: The unit values of climate change costs to 2015

The Table 6.16 below shows the forecasted unit values of costs of climate change for trucks.

Value of unit prices	2015	2018	2020	2025	2035	2040	2044
HGV (€ct/vkm)	8,6492	9,0237	9,3166	9,7483	10,7097	11,2449	11,5309

Table 5.13 Forecast for unit values of climate change costs by time sections

The benefits of reduced costs for climate change is defined as follows:

$R^{Benefit}_{cl.ch.,ij} = (V_{km}{}^{0}{}_{cl.ch.,ij} - V_{km}{}^{1}{}_{cl.ch.,ij}).C_{cl.ch.,ij}$ where:

$R^{Benefit}_{cl.ch.,ij}$ - total benefits of reduced costs of climate change with implementation of options for railway infrastructure improvement and setting the new rolling stock in operation;

$V_{km}{}^{0}{}_{cl.ch.,ij}$, $V_{km}{}^{1}{}_{cl.ch.,ij}$ - freight vehicle kilometers with "no project" option and "with project" option implemented in section (i, j);

$V_{km}{}^{0}{}_{cl.ch.,ij}$, $V_{km}{}^{1}{}_{cl.ch.,ij}$ - freight vehicle kilometers generated by road freight transport with "no project" option and "with project" option in section (i, j);

$C_{cl.ch.,ij}$ - unit cost of climate change due to freight road transport in euro cents per freight vehicle kilometer.

- Freight car kilometers generated by road freight transport "no project" option and "project" made in section (i, j);

The impact of rail transport is low and therefore it is not considered.

Table 5.14 presented the total value of benefits of cost savings for climate change by time sections and options.

SUSTRAIL 0							
Benefits	**2015**	**2018**	**2020**	**2025**	**2035**	**2040**	**2044**
Veh-km diverted	0	306 062	372 507	605 314	957 377	1 045 193	1 121 230
Total benefits	0	27 618	34 705	59 008	102 532	117 530	129 288
SUSTRAIL 1							
Benefits	**2015**	**2018**	**2020**	**2025**	**2035**	**2040**	**2044**
Veh-km diverted	0	505 668	614 866	997 478	1 575 948	1 720 531	1 845 727
Total benefits	0	45 630	57 285	97 237	168 779	193 471	212 829
SUSTRAIL 2							
Benefits	**2015**	**2018**	**2020**	**2025**	**2035**	**2040**	**2044**
Veh-km diverted	0	633 610	769 959	1 247 701	1 969 854	2 150 575	2 307 064
Total benefits	0	57 175	71 734	121 630	210 965	241 829	266 026

Table 5.14: Benefit from reduced costs of climate change by options and time sections

5.6.3 Benefits of reducing the cost of noise

Noise can be defined as an unwanted sound or sounds of different duration, intensity and other characteristics causing mental harm to people. Generally, two types of negative effects of noise in transport can be distinguished:

- Cost related to irritability, usually leading to economic and social costs such as limitation of breaks, discomfort and inconvenience and it is based on the preferences of people.

Value of Health care: transport noise can lead to physical damage to human health such as appearance of deafness (at noise levels above 85 decibels) and to stress, palpitations, high blood pressure, hormonal changes, poor sleep. The negative effects of noise on human health leads to various types of expenses such as medical costs, costs measured in lost productivity and higher mortality.

There are three key factors that determine the costs related to noise:

- Time during the day and night: at night irritability is much stronger than during the day.

- Population density close to the source of noise.

- Existing noise levels depending on the volume, type and speed of traffic.

For road and rail infrastructure noise depends on vehicle speed, type (share of trucks and freight trains) and their condition.

The costs of noise are defined by unit values pointed out in the Handbook on External Costs of Transport, Report for the European Commission: DG MOVE, Ricardo-AEA/R/ED57769, Issue Number 1, 8th January 2014 (Table 28: Illustrative marginal noise costs for the EU*, € per 1000 vkm) and are reduced to 2015. They are adjusted for every year with GDP growth multiplied by the elasticity coefficient of 0.7.

The unit values of costs of noise for trucks are presented in Table 5.15. The costs of noise depend on the period (day or night), the type of traffic (dense or unsaturated) and conditions (urban, suburban or rural). The unit values of costs of noise are determined by assuming that traffic is unsaturated, daily traffic is 75%, night traffic is 25% and transportation is implemented in rural conditions.

Mode	Time of day	Traffic type	Urban	Suburban
HGV	Day	Dense	81,0	4,5
		Thin	196,6	12,7
	Night	Dense	147,8	8,3
		Thin	358,2	23,1
Freight train	Day	Dense	484,8	23,9
		Thin	1 169,6	46,3
	Night		1 977,6	78,3
Marginal costs for noise in € per 1000 vkm				

Table 5.15: Unit values of costs for noise to 2010

The benefits of cost savings for noise are determined on the basis of modal shift from trucks to rail. The Table 5.16 below shows the forecast of unit values of costs of noise with shipments by trucks and by rail.

Unit price	2015	2018	2020	2025	2035	2040	2044
HGV day	1,54	1,61	1,66	1,74	1,91	2,00	2,05
HGV night	2,77	2,89	2,99	3,13	3,44	3,61	3,70
Freight train day	60,85	63,49	65,55	68,59	75,35	79,12	81,13
Freight train night	102,86	107,32	110,80	115,94	127,37	133,73	137,14

Table 5.16: Forecasts for unit values of costs of noise by time sections for freight road and rail transport

The average value of costs of noise are received with distribution of traffic– day to night 68% to 32% taken from General Transport Master Plan of Bulgaria, General Report 2 - "Analysis of the existing transport system and the shortcomings that must be overcome" for passenger transport.

The benefits of reduced costs for noise emissions are determined as follows:

$$R_{noise}^{Benefit} = \sum_{ijk}\left(R_{noise,fr,ijk}^{Benefit} + R_{noise,rail,ijk}^{Benefit}\right);$$

$$R_{VoA,fr,ijk}^{Benefit} = \left(V_{km}{}^{0}{}_{fr,ijk} - V_{km}{}^{1}{}_{fr,ijk}\right) C_{noise,fr,k};$$

$$R_{VoA,rail,ijk}^{Benefit} = \left(V_{km}{}^{0}{}_{frrail,ijk} - V_{km}{}^{1}{}_{frrail,ijk}\right) C_{noise,frrail,k}$$ where:

$R_{noise}^{Benefit}$ - total benefits of reduced costs for noise emissions with implementation of options for rail infrastructure improvements and setting the new rolling stock in operation;

$R_{noise,fr,ijk}^{Benefit}$ - benefits of reduced costs for noise emissions caused by trucks moving from i to j for traffic type k (traffic during the day and traffic at night);

$R_{noise,rail,ijk}^{Benefit}$ - benefits from reduced costs for noise emissions caused by freight trains moving from i to j for traffic type k (traffic during the day and traffic at night);

$V_{km}{}^{0}{}_{fr,ijk}$, $V_{km}{}^{1}{}_{fr,ijk}$ - freight vehicle kilometers with variants "no project" option and "with project";

$V_{km}{}^{0}{}_{rail,ijk}$, $V_{km}{}^{1}{}_{rail,ijk}$ - reduced to kilometers transported by rail with variants "no project" option and "with project";

$C^{0}{}_{noise,fr,k}$, $C^{1}{}_{noise,fr,k}$, $C^{0}{}_{noise,rail,k}$ and $C^{1}{}_{noise,rail,k}$ - costs of noise in euro cents per 1,000 vehicle kilometers respectively for traffic during the day and traffic at night for road and rail transport with options "no project" and "withproject".

And - cost of noise cents per 1000 km respectively car traffic realized during the day and realized traffic at night for road and rail transport for "no project" option "project".

Table 5.17 presented the total value by time sections and options of benefits from noise cost savings.

SAUSTRAIL 0							
Years	2015	2018	2020	2025	2035	2040	2044
HGV (1000 veh-km) diverted	0	306	373	605	957	1 045	1 121
Incremental costs noise	0	-23 106	-29 035	-49 368	-85 781	-98 330	-108 166
SUSTRAIL 1							
HGV (1000 veh-km) diverted	0	506	615	997	1 576	1 721	1 846
Incremental costs noise	0	-38 175	-47 926	-81 352	-141 206	-161 864	-178 059
SUSTRAIL 2							
HGV (1000 veh-km) diverted	0	634	770	1 248	1 970	2 151	2 307
Incremental costs noise	0	-47 834	-60 015	-101 759	-176 500	-202 322	-222 565

Table 5.17: Benefits from reduced costs for noise by options and time sections

In this case there are no benefits and costs of noise due to the fact that rail transport is noisier than freight road transport. (Note: in the UK case study, it was feasible to value a noise reduction for rail freight – see §4.7-8).

5.7 Results

The Bulgarian Case Study results for user and environmental benefits are summarised in Tables 5.18-20. This is an extract from the overall Business Case CBA Results spreadsheet found on the Extranet (CBA framework v6.xls).

		Benefits, €million, year	
Impact Groups	*Impacts*	*2015*	*2030*
End Users	Reliability benefits	89	257
	Speed benefits	59 611	172 465
	Lower freight costs	70 061	171 880
Third parties	CO_2 reductions	0	81 620
	Noise reduction	0	-68 286
	Reduced air pollution	0	56 918
	Accident reduction	0	4 785

Table 5.18: Bulgarian Case Study summary results – SUSTRAIL0 Vehicle only (base speed)

		Benefits, €million, year	
Impact Groups	*Impacts*	*2015*	*2030*
End Users	Reliability benefits	89	373
	Speed benefits	86 829	283 354
	Lower freight costs	105 092	290 808
Third parties	CO_2 reductions	0	134 400

	Noise reduction	0	-112 443
	Reduced air pollution	0	93 725
	Accident reduction	0	7 879

Table 5.19: Bulgarian Case Study summary results – SUSTRAIL1 Vehicle+Track (base speed)

		Benefits, €million, year	
Impact Groups	*Impacts*	*2015*	*2030*
End Users	Reliability benefits	89	415
	Speed benefits	101 601	355 525
	Lower freight costs	105 092	311 829
Third parties	CO_2 reductions	0	168 032
	Noise reduction	0	-140 580
	Reduced air pollution	0	168 032
	Accident reduction	0	9 850

Table 5.20: Bulgarian Case Study summary results – SUSTRAIL2 Vehicle+Track (higher speed)

6. FREIGHT AND ENVIRONMENTAL BENEFITS FOR THE SPANISH CASE STUDY

6.1 Introduction

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 central/northern Europe and 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).

6.1 Spanish freight model

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 neighbouring 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 that the inbound and outbound flows are unbalanced (unequal), creating inefficiency through empty stock movements. 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 Iberian gauge). There are bilateral agreements between the operators in both sides of the border, solved in a clear 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 the shift to standard UIC gauge is a very slow process.

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, it 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.

6.1.1 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-kilometers 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.

6.1.2 Summary of Spanish Freight Services

The national data is obtained from the Freight Report by Spanish Railway Observatory (OFE) and ADIF Network Statement. There are some relevant aspects to freights: in the total domain of the network there are 332 circulations per day and 72,166 km-train per day, which represents the 6,6% and 13,8% overall respectively; the average of train trip per day is 217 Km and the yearly tonnes supported by Km are 7,564,000 (4,2% of the market total volume)

Price in rail freight is free and fixed in private contracts between customers and operators.

For the case of CONTREN RENFE MERCANCIAS freight transport is public and there is fixed fares for the intermodal flat transport. CONTREN RENFE fare differentiates:

- Empty containers (20’, 30’, 40’, 45’, transport exclusively).
- Load containers transportation (transport exclusively):

  20’ (<20,5 Tm), 30’ (<30 Tm), 40’, 45’
- Origin and destination costs. Rate for each UTI dispatched from/to terminal:

  ADIF fare + Additional costs for dispatch and operation in private terminals and ports.
- Percentage increase fare for dangerous good transportation.
- Additional cost arising from custom dispatch according to international fare.
- Discount fare for volume
- Containers rental fares

In the above terms, baseline costs are sensible in the following terms

	Average Price (€/tonne)	Income (eurocent/tonne.km)
Multiproduct(including bulk)	10.92	3.63
Siderurgical	13.64	2.56
Automotive	23.26	4.94
Intermodal	13.93	2.6
Average	11.99	2.75

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

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

Table 6.1: Baseline costs

6.1.3 Cost structure of Spanish freight services

Data considered for cost analysis represents this input structure:

- Network data: distances, capacity, stations, itinerary and traffic considerations, restrictions about track of the stations, power supply -OCL or diesel- access, access charges, user charges, operational charges,
- Operator data: rolling stock, operational costs, investment, maintenance, cost cycle life),
- CO2 emissions.

All data are coherent with ADIF network statement (www.adif.es) and OFE report (the Spanish Railway Observatory see www.observatorioferrocarril.es/) where service cost considers all the factors that play in the train circulation. These can be split in Infrastructure costs and Rolling stock costs

Infrastructure costs includes all the access charges that should be paid to the railway infrastructure manager (ADIF or TP Ferro) for the **use of the lines**, and for the **access and use of additional services** in ADIF terminals, National Ports and private terminals:

- **Fixed costs:** costs that are charged independently of number of trains operated. For example the fixed part of the access charge to the Railway Network.
- **Variable costs:** all the costs in function of the distances travelled by the trains.

Rolling stock costs includes all the costs due to the availability of wagons and locomotives:

- **Fixed costs**: Costs independent of the activity of the trains: wagon and locomotive depreciation and financing, driver costs, assurances and taxes
- **Variable costs**: costs dependent on fuel consumption, driver subsistence allowances, maintenance and repairs.

Infrastructure costs, under OFE Hypothesis, can be represented by following terms

- Only ADIF terminals
- Access charges based on ADIF statement:
  - Mode A: Access tariff. Depending on the level of traffic. Fixed Cost

- Mode B: Tariff for capacity reserve. Variable cost
- Mode C: Operating tariff. Variable Cost
- Variable cost due to the use of the infrastructure
    - Access to terminals
    - Dispatch from terminals
    - Operation in terminals

Rolling stock costs, under OFE hypothesis, are represented by the following tems:

- Maximum train length: 450 m
- 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.
- Smooth profile: Leon – valladolid line.
- Mountainous profile: Gijón – León line.
- 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%.

Whereas General costs are considered in this sense:

- 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.

Cost structure for Locomotives

- Fuel based on annual journey and average consumption.
- Electrical energy costs based on ADIF statement document.
- Cost of a locomotive: fixed euros +euro/kW+euros per tonn 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%.
- The maintenance costs of the locomotive are proportional to the purchase cost: 4 % for electric and 7% for diesel per annum.

Cost Structure for wagons

- Cost of a wagon: fixed euros +euro/axle of the wagon+euro per tonn 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 cost for the wagons is proportional to the acquisition cost: 3% per annum.

Personnel costs

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

Output data:

- costs in €/ton and c€/ton Km per commodity, traction, timetable and itinerary
- Weight of critical variables: the trip (distance of the itinerary), tare of the train, traction (electrified line vs. Oil), train length, infrastructure manager charges and elasticity about the commodity.

Following table represents the output data to consider representative as Spanish market.

	Electric		Diesel	
	Smooth profile	**Mountainous profile**	**Smooth profile**	**Mountainous profile**
Siderurgical products	1.93	2.54	2.33	2.84
Construction and minery	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

Table 6.2: Spanish case study output data

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).

	Electric		Diesel	
	Smooth profile	Mountainous profile	Smooth profile	Mountainous profile
Siderurgical products	5.47	16.79	13.88	43.71
Construction and minery	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

Table 6.3: Emissions in gCO2/(net ton.km). Source OFE.

6.2 Scenario Data

In this part of the document it is described relevant data from freight market in Spain getting from ADIF network statement and applying the methodology of the OFE (Spanish Rail Observatory).

The general overview of the Spanish mark

In the total domain of the network:	332 circulations per day, i.e. 6.6% overall
	72 166 km-train per day, i.e. 13.8% overall
Average of train trip per day:	217 Km
Yearly tonnes supported by Km:	7.564.000 (4,2% of the market total volume)

From this overview and using the available data of Spanish sources, next paragraphs described the analysis of the selected scenario for SUSTRAIL in terms of more usable for improvements on freight operation.

6.2.1 Infrastructure scenario

Length:	365km.
Location:	'Mediterranean Corridor'
Electrified	3000V DC overhead line.

Track path:	Mostly double track (some single).
Track type:	mostly ballasted track; rails a mix of UIC54 and UIC60; sleepers mostly concrete.
Track quality:	good 83%; medium 12.2%; poor 4.8% (of 200m sections).
Speeds:	line speed typically 100-160/220km/h; 75km/h for freight.
Traffic:	mixed freight and passenger; approx. 18 freight trains/day, maximum 6 at any location. Operational restriction for freight-passenger crossings
Track gauge:	1668mm; merging to mixed track 1435/1668 mm from French Border to Suth East

Min. curve radius:	354m.
Maximum gradient:	1.4%.
Average train length:	420m.
Axle load limitations:	25t.

Figure 6.1: Mediterranean corridor location

Under these generalconditions,the particular tracks used in the SUSTRAIL analysis are:

- Spain – Valencia to Sagunto-Cargas

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

- Spain – Sagunto-Cargas to Vila Real

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

- Spain – Vila Real to Tarragona

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

6.2.2 Infrastructure cost inputs to be considered in the SUSTRAIL Spanish case

Derived from analysis of different documents relative to economics from infrastructure manager public documentation (budget of the Spanish Governemnt for 2015, account report from ADIF and ADIF network statement document) it is possible to get an approximate figure for general maintenace and investment in the scenario line according to the following inputs:

- ADIF budget for maintenance of the convenctional network: 585 M€
- ADIF budget for renewals of the convenctional network: 220 M€

From this general data, we can apply following results to the scenario of case of study:

- Data from the line scenario:

  Track length:277 km (single track 57 km; double track: 220 km)

  Radius curve of 1200 m represents a tortal length of 25.93 Km equivalent to 11,7% of the complete length

- Operational conditions:

  Maximum speed in the line: 200 km/h
  Freight medium speed in the line approaches to 80 km/h
  Restrictions when passenger trains are crossing to freight trains

- The figures extracted from available data of 2015 relevat to ADIF are transpossed to the scenario in the following terms:

  - 33.34 keur/ km in terms of maintenance
  - 10.17 keur/km in terms of renewals.

6.2.3 Rolling stock and Rail services

Transport sevices oriented to seven commodity groups:

1. Siderurgical products
2. Construction and mining
3. Petrochemical
4. Agriculture
5. Automotive
6. Manufacture

7. Intermodal

The hypothesis of empty wagon is considered and there are two time weight of infrastructure use: peak or valley.

6.2.3.1 Waggons available to circulate in the case of study

The wagons used for each group are:

1. **Renfe JJ92 - Steel Reel Carrier(Siderurgical products)**
   Max load (t): 64.7
   Average tare (t): 25.3
   Max speed (km/h): 120
   Length between buffers (m): 12.04

2. **Renfe TT4 - Coal Hopper (Minery)**
   Max load (t): 53
   Average tare (t): 27.0
   Max speed (km/h): 100
   Length between buffers (m): 18

3. **Renfe RR92 - Fuel Tanker (Petrochemical)**
   Max load (t): 65.5
   Average tare (t): 24.5
   Max speed (km/h): 120
   Length between buffers (m): 16.74

4. **Renfe TT5 - Cereal Hopper (Cereals)**
   Max load (t): 56
   Average tare (t): 24.0
   Max speed (km/h): 100
   Length between buffers (m): 14.16

5. **Renfe MA5 - Double-deck car carrier (Automotive)**
   Max load (t): 21.5
   Average tare (t): 27.7
   Max speed (km/h): 100
   Length between buffers (m): 27

6. **Renfe JJ4 - Sliding doors (Manufactured)**
   Max load (t): 61
   Average tare (t): 29.0
   Max speed (km/h): 120
   Length between buffers (m): 21.7

7. **Renfe MMC3E - Flat wagon 60' (Intermodal)**
   Max load (t): 70.3

Average tare (t): 19.7
Max speed (km/h): 100
Length between buffers (m): 19.74

6.2.3.2 Locomotives in use in the case of study

The electric loco used for the electrical consumption analysis is Renfe 253, whose technical data is:

- Constructor: Bombardier
- Model: *TRAXX2E F140DC*
- Renfe codification: Serie 253
- Power (kW): 5400
- Weight (t): 87
- Load per axle (t): 21.8
- Max speed (km/h): 140
- Gauge: Iberian (1668 mm)

The diesel loco used for the diesel consumption analysis is Renfe 335, whose technical data is:

- Constructor: Vossloh
- Model: *Euro 4000*
- Renfe codification: Serie 335
- Power (kW): 3178
- Weight (t): 123.7Load per axle (t): 20.5
- Max speed (km/h): 120
- Gauge: Iberian (1668 mm)

6.2.4 Freight Operation

The operational path connection from corridor to major logistic infrastructures: Madrid, Zaragoza, Bilbao. Next table shows the connections from the infrastructure scenario in order to understand the train routes.

	Option 1	Option 2	Option 3	Option 4	Option 5	Option 6	Option 7	Option 8
Departure	Valencia	Valencia	Madrid	Madrid	Madrid	Madrid	Madrid	Zaragoza
Arrival	Zaragoza	Zaragoza	Valencia	Valencia	Zaragoza	Bilbao	Bilbao	Bilbao
Distance (km)	547	353	399	486	392	491	585	354
Electrification	3KV	NO	NO	3KV	3KV	NO	3KV	3KV
Profile	S	M	M	S	S	M	M	S

S: smooth, M: mountainous

Table 6.4: Rail connections between major centres

And the geographical routes could be drawn in the next picture:

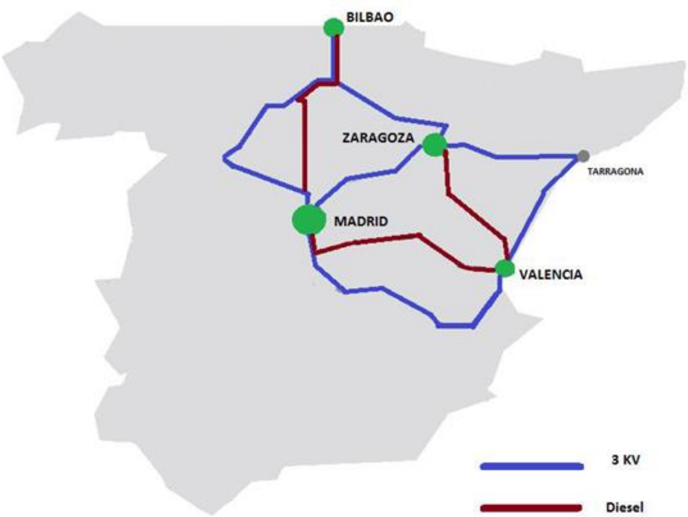


Figure 6.2: Mediterranean corridor plus routes to the west and north

Under this frame, the implemented model extracts results in the following terms:

1. Interaction with total network (3607 Km in 8 possible links)
2. Large routes (1000 Km in sections of 100Km)

Considering these opportunities of transport, and taking in account that the infrastructure is used for passenger and freight trains, first step is the harmonization of the data to understand the possibilities of the infrastructure scenario. For this reason the suitable data of freight trains can be followed in next table where there are considered all impact variables relevant to the scenario line and its connectivity to the total network.

Traffic flow *Impact variable*	**Very High** > 1500	**High** 800 / 1500	**Medium** 300 / 800	**Low** 100 / 300	**Very Low** <100	**Not in service**	**TOTAL**
Average trains	0	1025	409	174	45	0	**1653**
Kms of network	0	90	665	311	673	51	**1790**
% Km used	0,00%	5,03%	37,15%	17,37%	37,60%	2,85%	**100%**
sections	0	11	38	22	37	12	**120**
Kind of train	Trains/week by Operator Services						**TOTAL**
Large Distance	0	205	137	66	12	0	420
Regional	0	94	55	44	18	0	212
Commuters	0	645	150	49	5	0	848
Freights	**0**	**76**	**62**	**13**	**9**	**0**	**160**
Other services	0	5	5	2	1	0	13

Table 6.5: Scenario Operation: SUSTRAIL BASE. Variables versus density traffic sections

Using these data, the assumptions about uses of infrastructure are easily followed in the next figures where there are described the use in terms of traffic flow and services of the trains.

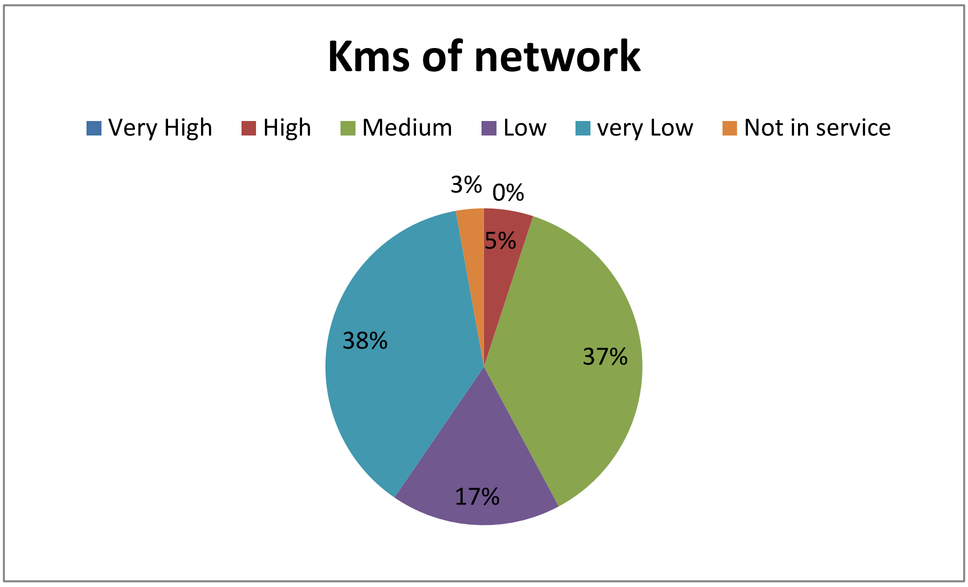


Figure 6.3: Description of infrastructure in terms of the traffic flow

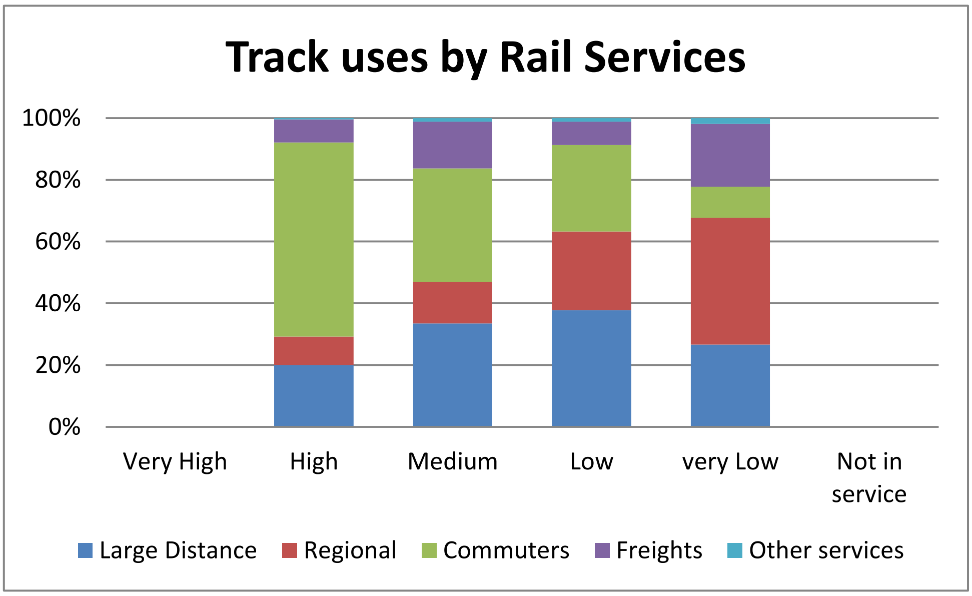


Figure 6.4: Use of the infrastructure by train services

From the available data, it is possible to have a global representation of uses of the line in the next figure:

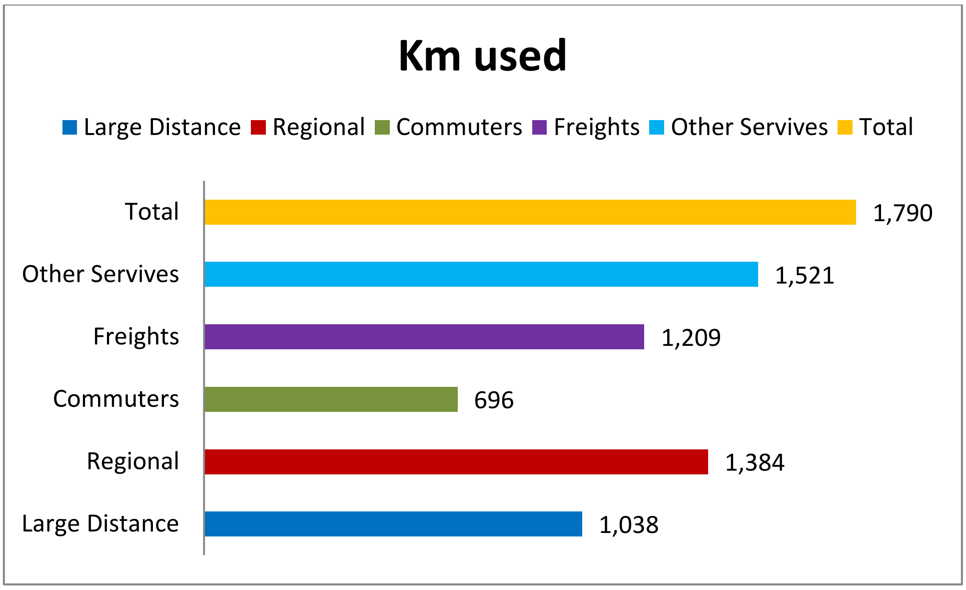


Figure 6.5: Daily routes of trains

And, under these conditions, the data of km train/week are determined in the following table:

Type of train	KM Train/week	
Large Distance	135839	30,8%
Regional	87339	19,8%
Commuters	152029	34,4%
Freights	**61467**	**13,9%**
Other Servives	4669	1,1%

Table 6.6: Train km/week by type

Where an overall assumption can be drawn in the next figure:

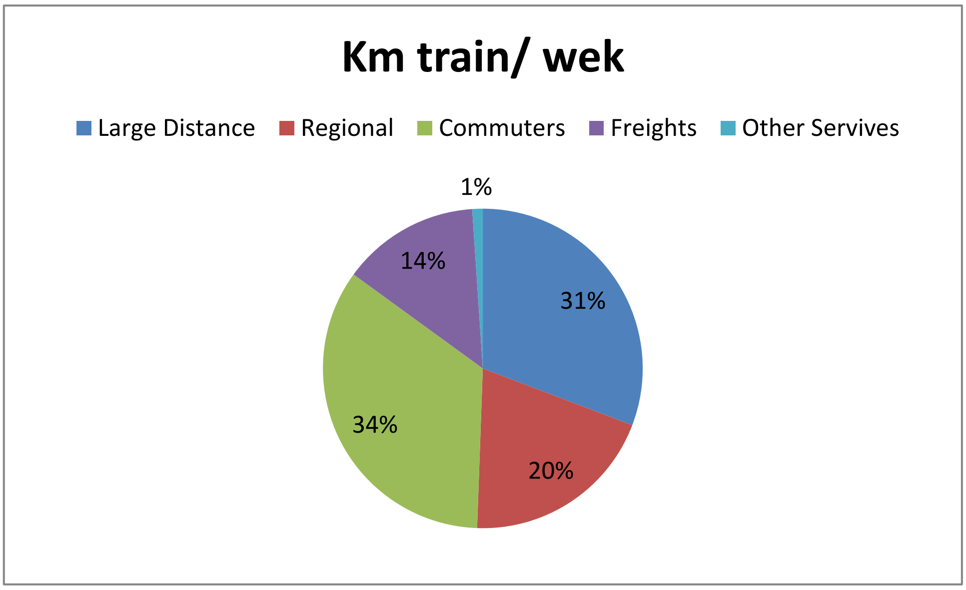


Figure 6.6: Train service assumptions

6.2.5 Cost analysis of the base scenario

Representative use of selected track in the Mediterranean Corridor is applicable only under normal operation concept in coherence with market options. So, in order to consider the main freight support, we represent the operational path connection from corridor to major logistic infrastructures like Madrid, Zaragoza, Bilbao.

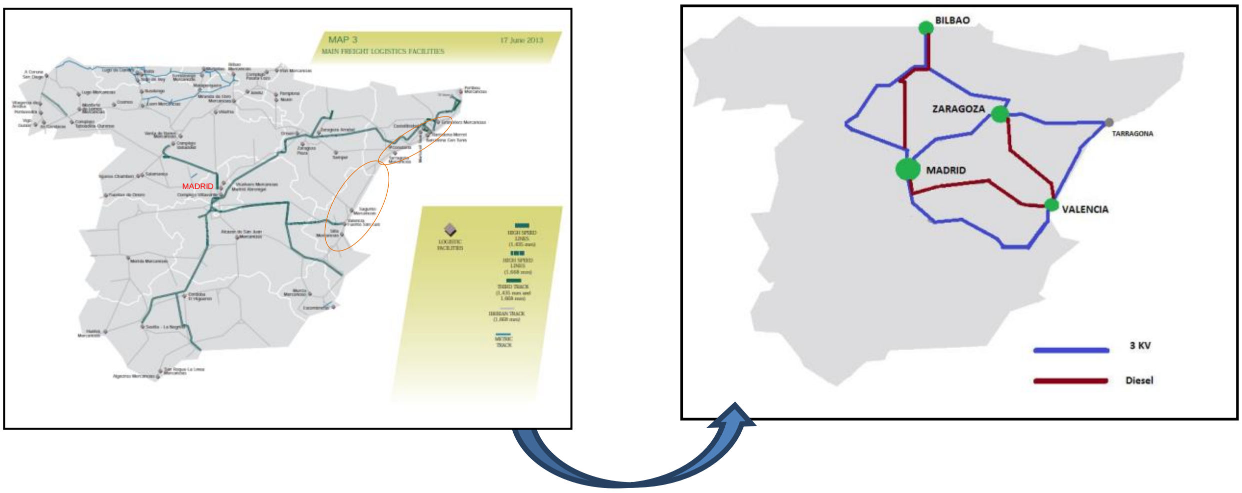


Figure 6.7: Route linkages

This assumption aims to take in account a more realistic domain of the Spanish network, where one of the critical aspects comes from the geographical constraints that supposes a strong value over mechanical and dynamic behavior of the train translated into shorter trains.

Data considered for cost analysis represents this input structure:

- Network data: distances, capacity, stations, itinerary and traffic considerations, restrictions about track of the stations, power supply -OCL or diesel- access, access charges, user charges, operational charges,
- Operator data: rolling stock, operational costs, investment, maintenance, cost cycle life),
- CO2 emissions.

All data are coherent with ADIF network statement (www.adif.es) and OFE report (the Spanish Railway Observatory see www.observatorioferrocarril.es/) where service cost considers all the factors that play in the train circulation as describen in 4.3.5.

Following table represents the cost structure by infrastructure and rolling stock in euros per ton transported and cent of euro per ton and kilometer. Being commodity type identified as follows:

1. Siderurgical (metal) products
2. Construction and mining
3. Petrochemical
4. Agriculture
5. Automotive
6. Manufacture
7. Intermodal

COST	€/t	Cnt €/ t-km	ADIF cnt€/t-km	Rollig Stock cnt€/t-km
Comodity type				
1	13.91	3.22	0.8	2.94
2	9.88	2.29	0.3	2.08
3	8.19	1.91	0.26	1.72
4	9.15	2.12	0.28	1.92
5	17.3	3.99	0.51	3.64
6	9.09	2.11	0.28	1.91
7	8.24	1.91	0.34	1.64

Table 6.7: Cost per tonne and tonne-km

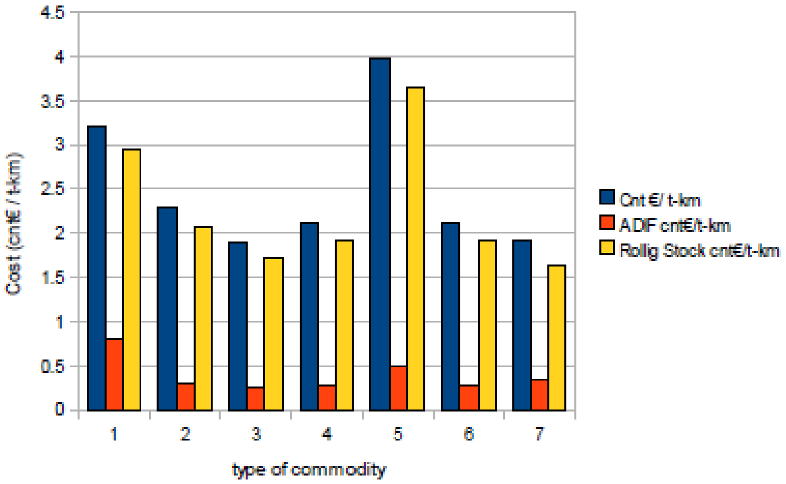


Figure 6.8: Cost per tonne-km

In this cost result are included the hypothesis of an average percentage of empty wagon considered (max 20% of train length) and time weight of infrastructure use (peak or valley).

The application over the scenario is followed in the next stage, where we consider only intermodal commodity due to the fact of SUSTRAIL wagon is developed towards this service.

So, we have 8 options to use the scenario line as shown in Table 6.4.

The cost structure for intermodal transport is described as follows:

OPTIONS								
	Option 1	Option 2	Option 3	Option 4	Option 5	Option 6	Option 7	Option 8
Locomotive type	Electric	Diesel	Diesel	Electric	Electric	Diesel	Electric	Electric
Timetable	1	1	1	1	1	1	1	1
Load Type	7	7	7	7	7	7	7	7
Transported Load (t)	686	735	784	588	588	980	686	686
Track Characteristic								
Maximum Train Length (m)	500	400	400	500	500	420	480	450
Max number of wagons	24	19	19	24	24	20	23	21
% empty wagon	30	30	30	30	30	30	30	30
Track use								
Nº needed wagons	14	15	16	12	12	20	14	14
Nº of possible wagons (track)	24	19	19	24	24	20	23	21
Nº of possible wagons (traction)	14	15	16	12	12	20	14	14
train length	295,26	315	334,74	255,78	255,78	413,7	295,26	295,26
CO2 emissions (kg/t-km)	0,01239022	0,01802564	0,017616821	0,01098848	0,010402983	0,014282963	0,01128383	0,01075399
COST (€/t)	7,50238245	7,61162437	8,320001092	7,33512438	6,123439137	8,462050442	8,03428524	5,28135053
COST (cnt €/t.km)	1,37155072	2,15626753	2,085213306	1,50928485	1,562101821	1,723431862	1,37338209	1,49190693
Total Cost (€)	5146,63436	5594,54391	6522,880856	4313,05314	3600,582212	8292,809433	5511,51967	3623,00646
ADIF Cost (€)	799,859479	868,653047	1008,96627	760,96856	735,5263404	1165,042402	862,775053	809,919972
Rolling Stock Cost (€)	4346,77488	4725,89087	5513,914586	3552,08458	2865,055872	7127,767031	4648,74462	2813,08649
ADIF specific Cost (cnt €/t.km)	0,2131583	0,33479912	0,322543051	0,26628893	0,319105902	0,242121951	0,21498967	0,33351451
Rolling Stock Specific Cost(cnt €/t.km)	1,15839242	1,82146841	1,762670255	1,24299592	1,242995918	1,481309911	1,15839242	1,15839242
Opciones	1	2	3	4	5	6	7	
Good to transport	Siderurgical	Coal	Hydrocarbon	Cereal	Cars	Manufactured	Intermodal	
Slot time	Valley	Peak						

Table 6.8: Cost structure for intermodal transport

Where transport cost in cents of euro per tonne-km over the results for infrastructure costs and operator costs are drawn as follows per different routes options:

Figure 6.9: Composition of transport costs

6.3 Emissions modelling

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 by 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.

$$E_{traction} = E_n \cdot C_{rail} \tag{1}$$

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:

$$E_{substation} = E_{traction} \cdot C_{network} \tag{2}$$

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, $C_{emission}$:

$$E_{CO_2} = E_{substation} \cdot C_{emission}$$

Data of emissions, comparing baseline model with SustRail:

	Diesel	
	Baseline	**SustRail**
gCO_2/(net ton.km)	20.15	20.89

Table 6.9: CO_2 emissions data

The emission of CO_2 is 3.7% higher in the SustRail case with higher speed operation of freight trains (SUSTRAIL2).

6.4 Scenario assumptions

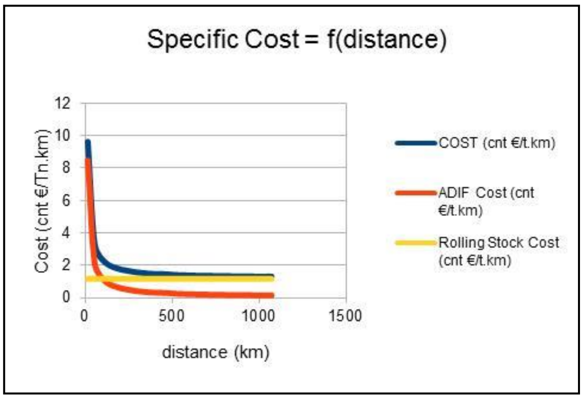
The described scenario are relevant to give some results of different variables of cost structure and operation procedures previous to understand the SUSTRAIL results in Spanish Scenario.

- Influence of the timetable suppose an increment of + 3% from “valley” to “peak” time when IM access charges are considered

- For all commodities all access and infrastructure charges are relevant in first range of 200 Km. Following figures are relevant when intermodal transport is under electric traction.

Traction Type	1	nº of possible wagons (traction)	14
Timetable	1	Maximum train length allowed	450
Load Type	7	nº of possible wagons (track)	21
Tonnage Loaded	686	empty wagon	30
Track use			
Number of needed wagons	14		
Gross tonnage	1048,8		
Train length	295,26		
Average CO2 Emissions (g/Tn.km)	20,59099415		

Table 6.10: Train composition and emissions data



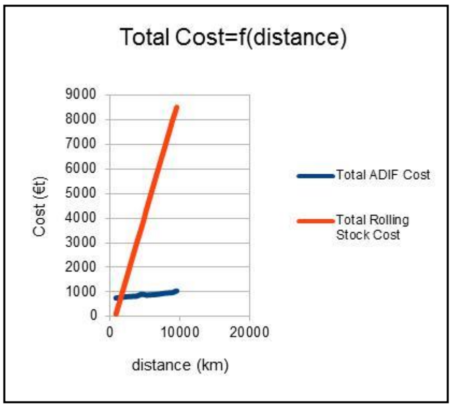


Figure 6.10: Cost functions

- Impact of tare of the wagon is important to be considered under SUSTRAIL results in the following terms where TIME SCHEDULE (valley or peak is considered) and TYPE of locomotive are considered:

		Tare percentage				
	locomotive	Electrical				
	timetable	peak				
		-5%	-2,50%	0%	2,50%	5%
COST (cnt €/t.km)		1,294997449	1,29750855	1,300019655	1,30253076	1,305041861
Adif Charges (cnt €/t.km)		0,141509927	0,14156858	0,141627235	0,14168589	0,141744543
Rail operator costs(cnt €/t.km)		1,153487522	1,15593997	1,15839242	1,16084487	1,163297318
Emissions (g/Tn.km)		16,61590323	16,7284981	16,84109291	16,9536878	17,06628259

		Tare percentage				
	locomotive	Electrical				
	timetable	valley				
		-5%	-2,50%	0%	2,50%	5%
COST (cnt €/t.km)		1,33435605	1,33686715	1,339378256	1,34188936	1,344400462
Adif Charges (cnt €/t.km)		0,180868528	0,18092718	0,180985836	0,18104449	0,181103144
Rail operator costs(cnt €/t.km)		1,153487522	1,15593997	1,15839242	1,16084487	1,163297318
Emissions (g/Tn.km)		16,61590323	16,7284981	16,84109291	16,9536878	17,06628259

Table 6.11: Impact of the tare of the wagon – electric locomotive

		Tare variations				
	locomotive	Diesel				
	timetable	peak				
		-5%	-2,50%	0%	2,50%	5%
COST (cnt €/t.km)		2,003838	2,01088921	2,054287503	2,06133848	2,068389463
Adif Charges (cnt €/t.km)		0,148472	0,14868728	0,151534758	0,15175034	0,151965914
Rail operator costs(cnt €/t.km)		1,855367	1,86220193	1,902752745	1,90958815	1,916423549
Emissions (g/Tn.km)		20,22726	20,364491	20,57720543	20,7144393	20,8516731

		Tara				
	locomotive	Diesel				
	timetable	valley				
		-5%	-2,50%	0%	2,50%	5%
COST (cnt €/t.km)		2,032839308	2,03989029	2,084899748	2,09195073	2,099001708
Adif Charges (cnt €/t.km)		0,177472776	0,17768835	0,182147003	0,18236258	0,182578159
Rail operator costs(cnt €/t.km)		1,855366532	1,86220193	1,902752745	1,90958815	1,916423549
Emissions (g/Tn.km)		20,22725721	20,364491	20,57720543	20,7144393	20,8516731

Table 6.12: Impact of the tare of the wagon – diesel locomotive

- Results: impact train tare vs consumed energy over maximum train in the line

		Tare influence									
		Electric Locomotive					Diesel Locomotive				
		-5%	-2,5%	0%	2,5%	5,0%	-5%	-2,5%	0%	2,5%	5,0%
Energy (MW.h)		56,7805	57,1652	57,55	57,9348	58,3195	73,1866	73,6813	74,176	74,6707	75,1654
Energia (%)		-1,337%	-0,669%	0,000%	0,669%	1,337%	-1,334%	-0,667%	0,000%	0,667%	1,334%

Table 6.13: Impact train tare vs consumed energy over maximum train in the line

- Impact of energy prices in cost structure

		Energy Variations							
	Locomotive	Electric				Diesel			
	Timetable	Peak		Valley		Peak		valley	
		±5%	±10%	±5%	±10%	±5%	±10%	±5%	±10%
COST (cnt €/t.km)		±1,468%	±2,937%	±1,425%	±2,851%	±2,573%	±5,147%	±2,535%	±5,071%
Adif Charges (cnt €/t.km)		±0,310%	±0,619%	±0,242%	±0,485%	±1,067%	±2,133%	±0,887%	±1,775%
Rail operator costs(cnt €/t.km)		±1,610%	±3,220%	±1,610%	±3,220%	±2,693%	±5,387%	±2,693%	±5,387%
Emissions (g/Tn.km)		±5,000%	±10,00%	±5,000%	±10,00%	±5,000%	±10,000%	±5,000%	±10,000%

Table 6.14: Impact of energy prices in cost structure

- Impact of tare train in the cost structure

		Tare							
	Locomotive	Electric				Diesel			
	Timetable	peak		valley		peak		valley	
		±2,5%	±5%	±2,5%	±5%	±2,5%	±5%	±2,5%	±5%
COST (cnt €/t.km)		±0,193%	±0,386%	±0,187%	±0,375%	±0,343%	±0,686%	±0,338%	±0,676%
Adif Charges (cnt €/t.km)		±0,041%	±0,083%	±0,032%	±0,065%	±0,142%	±0,285%	±0,118%	±0,237%
Rail operator costs(cnt €/t.km)		±0,212%	±0,423%	±0,212%	±0,423%	±0,359%	±0,718%	±0,359%	±0,718%
Emissions (g/Tn.km)		±0,669%	±1,337%	±0,669%	±1,337%	±0,667%	±1,334%	±0,667%	±1,334%

Table 6.15: Impact of tare train in the cost structure

- Impact of access charges in the cost structure

		IM access charges Variations							
	locomotive	Electrical				Diesel			
	Timetable	Peak		Valley		Peak		Valley	
	percentage	±5%	±10%	±5%	±10%	±5%	±10%	±5%	±10%
COSTE (cnt €/t.km)		0,545%	1,089%	0,676%	1,351%	0,369%	0,738%	0,437%	0,874%

Table 6.16: Impact of access charges in the cost structure

6.5 Results

In general terms, according to previous steps and considering the Impacts of the SUSTRAIL Innovations set out in Chapter 3, the implementation of the SUSTRAIL innovations in the Spanish context is really constrained by the length of trains as a result of the geography of Spain. So, the SUSTRAIL wagon offers an increment of speed, but does not offer any payload advantage. Instead of this, the advantage results from the achievements of more reliable and available trains in the network.

6.5.1 SUSTRAIL results under constraints from the Spanish scenario

The Spanish case study in SUSTRAIL provides an opportunity to contrast the other European freight models (above) with the particular Spanish scenario:

i. The improvements of SUSTRAIL are in accordance with the Spanish network, the rolling stock and the freight transport concept in Spain.
ii. The more problematic point from the modelling perspective is the geographical location of the Iberian Peninsula which forces an unbalanced traffic from and to the rest of Europe (given the commodity flows involved).
iii. As a result of this, freight can be represented by short trains (strongly constrained by Spanish geography) making a typical trip under 350km, which implies a poor market share if rail is compared with road. We estimate rail has a 6% share of the market in the Spanish case study corridor selected for SUSTRAIL (based on ADIF/OFE data).
iv. A high potential rail capacity is available in the Mediterranean Corridor, where only a 15% is heavily used under high density traffic near the big city areas, but these areas are not included in the Spanish scenario (free from disturbances from commuters if we consider the harbour and logistic terminal access). It implies that 36% of the capacity infrastructure is available for SUSTRAIL improvements.
v. Curves radius 0-1200 m are considered; it is implies a total of 51.86 km
vi. The Spanish case study has the following particularities that are relevant when interpreting the results:

    - The Spanish case study is based in the Mediterranean Corridor and today is operated in mixed traffic conditions over an infrastructure designed for passenger use at 200 Km/h.
    - The case study presents a good quality in the track in accordance with these services, however rather poor quality in the sections used for operational movements with freight trains (e.g. passing loops of 300-500m in stations).

- It implies that some of the infrastructure improvements of SUSTRAIL presents a poor impact in this scenario (absence of joints, switches are available up to 200 km/h and 100 Km/h in deviated branch) if it is understood that some of the improvements ideas of the project could be assumed as a sensitive state of the art in this particular infrastructure; but demonstrates that SUSTRAIL improvements are realistic solutions because they aren't in contradiction with the use of today of this scenario.
- Freight trains run up to 120 km/h, but average speed is 80 km/h.
- Due to infrastructure limitations, freight trains often stop in stations to cross with passenger trains. This impacts on safety and availability.
- From an operational point of view, the tight constraints in the Spanish scenario are taken from the ratio payload versus tare in wagons to get more efficient trains against the possible length of the train derived from the high gradient in the line (17m/km). SUSTRAIL prototype doesn't offer any advantage in this respect, so the load is a constant for each commodity.
- Only a 14% of the infrastructure use is for different usages than passenger services, including freights, so and as we can see in the following stages, the SUSTRAIL assumptions in terms of safety (derailments are strongly reduced) and reliability and availability parameters of the wagons innovations are very important to assume a better condition of the train running in the infrastructure with a high potential criteria of the usage of the infrastructure (capacity in use for the market) and cost savings (in terms of charges).
- Relevant to SUSTRAIL results is the fact that the freight train schedule does not present any advantage due to safety administrative constraints, e.g. freight trains regularly face speed limits during the itinerary in practice.

6.5.2 Cost Relevant infrastructure impacts

LCC analysis in the SUSTRAIL project is not in contradiction with the Spanish case study: the hypothesis and consclusions are valid for the network.

When we apply the SUSTRAIL scenarios in the Spanish Case Study, as described in this document, the key outputs could be assumed including a feasible reduction of the access charges:

i. SUSTRAIL Baseline: track maintenance costs are 16,570 k€; renewals 5,054 k€; but only 20% can be attributed to circulation of freight trains. The track access charges are 2,034 k€.

ii. SUSTRAIL 0 (only new vehicle) applied a LCC reduction only by freight trains of 0.8% in terms of maintenance, equivalent to 32.56 k€ against the scenario base. No variations about renewals. Total reduction: 132.56 k€. The reduction of the track access charge is a 1,8% , then the new charges will be reduced 36.62 k€.

iii. SUSTRAIL 1 (vehicle 120 Km/h and Infrastructure improvements), considering only freight traffic, applied a LCC reduction of 11% approached by 9.5% for maintenance and 1.5% for renewals; equivalent to a reduction of 1,822.7 k€ by maintenance and 75.81 keur for renewals. Total reduction: 1,898.51 k€. The access charges change by -9.3%, so the reduction of the charges is 189.1 k€.

iv. SUSTRAIL 2 (vehicle 140 Km/h and infrastructure improvements) may not be markedly different from SUSTRAIL 1 in the Spanish line, due to the fact that line is cleared for up to 200 Km/h. Track access charges will be reduced by 6,7%, so the new charges will be 136.30 k€ less.

v. Related to access charges, derived from the demand for freight traffic, a reduction of 2% can easily expected due to the best running conditions of the train that it is direct assumed in a reduction of 0.7% of the cost expressed in cents of euros per ton and kilometer.

If we consider only the intermodal commodity, where the SUSTRAIL wagons have an impact, the above results implies that SUSTRAIL supposes a potential reduction of 23.3% of the total costs derived from the use of the infrastructure considered as today in the Spanish market.

6.5.3 Cost Relevant Freight operators impacts

i. SUSTRAIL base: vehicle maintenance costs are 2,250 eur. We have assumed that the maintenance cost is 3% of the cost of acquisition. The ownership costs are 85.000 eur, which is the cost of acquisition. We have assumed that the cost of termination is 0 eur.

ii. SUSTRAIL 0 (only new vehicle): applied a LCC reduction only by freight train of 61% in terms of maintenance, equivalents to a 1,372 eur against scenario base. Our SustRail wagon costs 180,000 eur.

iii. SUSTRAIL 1 (vehicle 120 Km/h and Infrastructure improvements) have the same results achieved in SustRail 0. The freight operator´s fuel cost are calculated from 0,01-0,02 (l/ tn-km). Our trains run at 80 km/h, so the fuel costs increase with the increasing speed.

iv. SUSTRAIL 2 (vehicle 140 Km/h and Infrastructure improvements) have the same results achieved in SustRail 0 and SustRail 1. The freight operator´s fuel costs are 3,7% higher, which means 39,220 eur more than the other cases.

If we consider only the intermodal commodity, where impact of SUSTRAIL wagons innovations are feasible, the above results implies that SUSTRAIL supposes a potential reduction of 2% of the total costs derived from the operator costs considered as today in the Spanish market.

6.5.4 Cost Relevant End Users impacts

Results about the impacts on end users will be analyzed from a qualitative point of view:

i. SUSTRAIL 0: the new wagon will have fewer failures, so the time needed to repair it is lower than the base case. The reliability will improve. The journey time does not change because the speed is the same as the base scenario. The freight service charges have no change because our new wagon has no improvement on the size.

ii. SUSTRAIL 1: new track will improve the reliability. The capacity of the lines, and the market opportunity supposes a 13% increment in the use of SUSTRAIL innovations, where availability in the service and reduction of maintenance operational times are considered to verify a reduction of the cost by a total increment of the tonnes transported due to best LCC considerations. Next figure represents expectations of the price evolution:

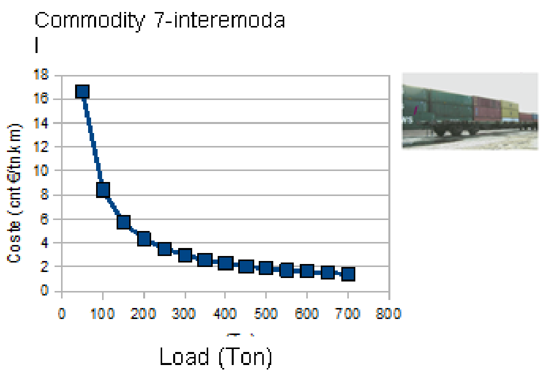


Figure 6.11: Expected pricing by load

It is a very good and relevant result. The available data of Spanish market from The OFE (the Spanish railway Observatory) assumes an average cost of 2,60 c€/ton·km. Using SUSTRAIL innovation, it is expected an average quota of 2,09 c€/ton·km what implies a reduction of of 19% of the costs in terms of the end-of user concept.

iii. SUSTRAIL 2: the reliability will improve, but less than the SustRail 1, because the increase of speed could cause more failures. The journey time will be reduced. The freight service charges will be the same as the base scenario.

Two major results:

1. **A potential increment of 13% of the market considering the use of SUSTRAIL 1 (wagon and infrastructure innovation).**
2. **Price reduction: the available data of Spanish market from The OFE (the Spanish railway Observatory) assumes an average cost of 2,60 c€/ton·km. Using SUSTRAIL innovation, it is expected an average quota of 2,09 c€/ton·km which implies a reduction of of 19% of the costs to the end user.**

6.5.5 Externality impacts

We have no measure of the externalities (CO_2 emissions, local air pollution and noise), so we are going to analyze it from a qualitative viewpoint:

- The CO_2 emissions assumed in the transport, the local air and the noise in SUSTRAIL 0 and SUSTRAIL 1 will be the same as the base scenario. OFE (Spanish railway Observatory) reports 0,034 kg/ton·km and SUSTRAIL innovation applied only for transport consumption is 0,032 kg/ton.km. It is a small reduction.

- SUSTRAIL 2 has an important change about the CO_2 emissions and the local air. The increased speed will cause more emissions than the other cases and the fuel consumed will also be higher for 140 km/h.

Generally, the SUSTAIL findings on CO_2 emissions during the complete cycle (not only the train movements) are assumed to be consistent with Spanish case study. Also, noise reduction analysis in SUSTRAIL should be applicable to Spanish scenario from the point of view that none of the SUSTRAIL scenarios presents any apparent incompatibility with Spanish case study.

7. INFRASTRUCTURE PATH CAPACITY BENEFITS

7.1 Introduction

The aim of this work is to identify the benefits of improved utilisation of rail capacity on the West Coast Mainline (WCML) which could be potentially unlocked by the increased freight speeds following the implementation of the SUSTRAIL vehicle and infrastructure enhancements. The work adopts the approach of Johnson and Nash (2008) who identify appropriate rail scarcity charges to make freight and passenger operators pay for their use of rail capacity in line with the opportunity cost of the use of slots.

We do not calculate how much capacity will be unlocked by the SUSTRAIL enhancements per se, rather this work focuses on a section of the UK's West Coast Main Line as a case study for the value of scarce capacity.

7.2 Background

Our approach for valuing scarce capacity requires estimation of the opportunity cost of a slot. The authors used the PRAISE rail demand forecasting software to calculate these costs. PRAISE forecasts rail demand between OD pairs on a network, taking account of fares, journey times, desired departure times.

In order to calculate the cost of a slot to freight, Johnson and Nash (2008) used information on marginal social costs of road and rail freight to calculate value per train km. The authors found a value for a path of the freight service is £8.65 per train km (£14 in 2015 prices). They found the value for a peak passenger slot was around 67% higher than use by freight, although lower in the off-peak. The freight value may be less if operators require more than one standard slot per train run and if the slot is not always used.

7.3 West Coast Mainline

The West Coast Main Line (WCML) see (Figure 7.1) is a major intercity network in the UK, linking Greater London, West Midlands, North West, North Wales and Central Scotland. It is also one of the busiest freight routes in Europe carrying 43% of UK rail freight traffic. Given the sheer scope of the network it would be impossible to model all movements so we are focusing on a section of it, principally the 437 mile stretch from London to Glasgow. It is an important and heavily utilized part of Britain's rail network . This stretch of the network has a number of operators with overlapping franchises in partial competition with each other.

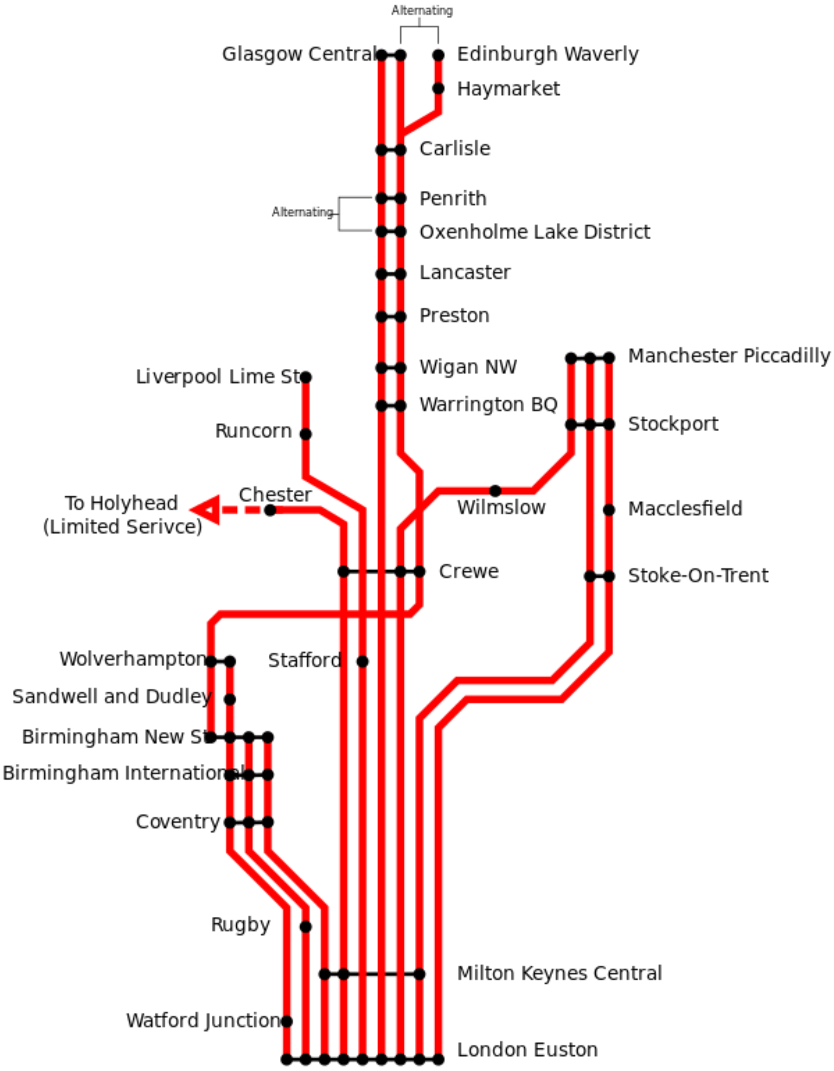


Figure 7.1: West Coast Mainline Route Map (Source: Virgin Trains website)

7.4 Methodology

7.4.1 PRAISE

The opportunity cost of a slot for this type of service can be estimated as the sum of:

- the change in traffic lost by rail by the removal of this train multiplied by the price
- the change in consumers' surplus to rail users
- the additional external costs to road users and the public.

Less the change in train operating, infrastructure and external costs.

We use the PRAISE methodology for the demand side and off model calculations for the operating and external costs calculations. PRAISE originated from work carried out to look at the impacts of privatization on competition (Preston et al, 1999).

PRAISE forecasts rail demand between Origin – Destination (OD) pairs on a network, taking account of fares, journey times and desired departure times. We used a simplified version of the model for tractability and to speed up run times. The objective here was to see whether this approach can yield sensible estimates and demonstrating an approach which may be relatively easily transferred to other case study applications on larger networks.

This model computes the effect of changes in service levels on the average Generalised Journey Time (GJT) capturing the time related aspects of the journey, converted into a standardized in-vehicle time minutes. The average GJT for each OD pair takes into account the weighting of each service in line with the number of passengers estimated to be travelling on each service. Whilst we had aggregate revenue and ticket sales data for each OD pair, the lack of information on tickets meant we assumed constant fares across services for a given OD. Accordingly, in this implementation of the model, choice of a particular service was governed by individuals' desired departure times and services' journey times.

Following the removal of a rail service some passengers will switch to another service, whilst others will switch mode and some will not travel at all. An upper level of the model scales overall changes in rail demand following service level changes based on generalized journey time elasticities applied to average GJTs for each OD pair.

We use a simulation approach based on 500 representative individuals with differing desired departure times drawn randomly from a distribution to represent traveler heterogeneity. Each simulated individual chooses the journey with the lowest GJT.

The cost model employs a cost accounting approach incorporating costs that are related to operating hours, costs that are related to train kilometers and fixed costs. We used National Rail Trends accounts for costs (ORR, 2015), with additional information on average costs and train km from Network Rail.

PRAISE yields results for changes in the following aspects of societal welfare which can be used to capture the impacts in an appraisal:

- Consumer surplus- this measures changes in user benefits, monetizing the impact of the changes in GJT and the change in the number of rail passengers
- Operating profits
- External costs – this measures changes in costs on non-users. External cost valuations are used in conjunction with modal switch values and vehicle kilometers to generate values, which can be used in an appraisal.

We run the model for 2008 and for both a 2015 and 2030 'forecast year' to derive sets of capacity valuations for each year. These years vary in terms of capacity utilization – our 2008 figures were before the finalization of the upgrade to WCML and the introduction of a more frequent timetable, so future years take subsequent passenger and service growth into account.

7.4.2 External costs and benefits

External costs comprise those costs imposed on non-users by rail itself when usage changes, and those imposed by other modes of transport whose volumes are changed by the change in rail demand. For external costs and benefits of other modes of transport we use values (per vehicle km) from the study of Sansom et al (2001) uplifted them to 2015 prices using the Consumer Price Index (ONS,2015). This includes changes in noise, LAQ, Greenhouse Gases, Safety, Infrastructure, Congestion, Fuel Duty and the Mohring effect.

In the appraisal, diversion factors taken from earlier work (Johnson and Nash, 2008) were used to estimate the extent of switching between different modes following a change in rail demand. To calculate the total number of car and coach vehicle kms that have been switched the total distance of the trip needs and average load factors were used. Again these calculations were based on Johnson and Nash (2008).

This information on changes in vehicle kms is applied to the external cost factors per vehicle km to calculate the external cost changes on all modes.

7.5 Data

7.5.1 Case Study Area

Ticket sales and revenue data were taken from a dataset of LENNON data provided to us from Virgin Trains and ATOC. The dataset comprised the top 300 flows, by OD pair, of revenues and passengers on Virgin services on the West Coast Mainline in the operating year 2007-2008. Within these OD pairs there were many which were not ‘in scope’ for our purposes. To simplify the process further we just focused on northbound flows. Using this approach we were able to simplify this network to the following 38 flows as illustrated in Table 7-1.

Table 7-1: Chosen O-D pairs on network

Originating London	Originating Crewe	Originating Wigan	Originating Preston	Originating Lancaster	Originating Carlisle	Originating Oxenholme	Others
London Milton Keynes							
London Stafford							Stafford Crewe
London Crewe							Milton Keynes Crewe
London Wigan	Crewe Wigan						Warrington Wigan
London Preston	Crewe Preston	Wigan Preston					
London Lancaster	Crewe Lancaster	Wigan Lancaster	Preston Lancaster				
London Oxenholme		Wigan Oxenholme	Preston Oxenholme	Lancaster Oxenholme			
London Carlisle	Crewe Carlisle	Wigan Carlisle	Preston Carlisle	Lancaster Carlisle		Oxenholme Carlisle	
London Glasgow	Crewe Glasgow	Wigan Glasgow	Preston Glasgow	Lancaster Glasgow	Carlisle Glasgow	Oxenholme Glasgow	
London Edinburgh	Crewe Edinburgh	Wigan Edinburgh	Preston Edinburgh	Lancaster Edinburgh	Carlisle Edinburgh	Oxenholme Edinburgh	

7.5.2 Demand

The ticket sales and revenue data described above is reported in aggregate per year for each flow. It was estimated that this covered 95% of the Virgin flows on the WCML network. The supplied demand and revenue figures were initially uplifted by (just over) 5% to take into account the omitted smaller flows. Virgin is the dominant operator on most of our case study flows, but where there were other operators we imputed revenues and ticket sales based on the estimated market share of each operator derived from our base model run for each OD.

In order to adjust the figures for 2008 to be more representative of the current passenger loadings on the WCML, we calculated a demand uplift factor using data from National Rail Trends data (ORR, 2015).

For each of the 38 OD pairs we created a separate timetable using the timetable information from Table 65 from the UK Rail Timetable Winter Edition (Network Rail, 2007).

7.5.3 Generalised Journey Times and values

In the calculation of GJTs, additional to in vehicle times (IVTs) we included an interchange penalty where appropriate taken from the PDFH (ATOC, 2010). An adjustment time penalty was also added to reflect the cost of adjustment of desired departure times (as derived from the NRTS data) to passengers' actual departure time. Generalised journey time elasticities of -0.9 were taken from the industry standard Passenger Demand Forecasting Handbook (PDFH, ATOC 2010).

The user benefit calculations require monetising of the changes in GJTs using a value of time taken from inflation adjusted WebTAG rail business, commute and other figures (DfT, 2014). We used journey purpose information from the National Rail Travel Survey (NRTS). The National Rail Travel Survey is a representative survey of journeys undertaken by rail in 2004 based on interviews with individual travellers. The proportions of these purposes within each OD pair were used in conjunction with the WebTAG values to give an average value of time for these classes of flows.

The value of adjustment time is used to weight the difference between a passenger's most desired and actual departure time. The adjustment time was valued at half the IVT in line with Whelan and Johnson (2002)).

7.5.4 Departure Time Profiles

The PRAISE model makes reference to 'departure time profiles' to generate desired departure times for each simulated individual. Appropriate profiles are required in order to generate accurate numbers of individual train loadings.

Whereas previously we have relied on synthetic generic data, in this work we were able to utilise the data on actual departure times from the National Rail Travel Survey. This improvement represents an important contribution of this work. We collated all the journeys which matched our OD pairs to identify the reported times of departure. From these we create a distribution of desired departure times for each OD pair which were random perturbations from observed departure times.

7.5.5 Costs

Given we are only changing the service level of Virgin trains, we only require variable costs for this operator. We assume fixed rolling stock charges here.

7.6 Results

Based on an initial examination of passenger loadings on the London to Glasgow services we found that the 1808 service was the heaviest loaded and used this as the basis of our 'peak' scarcity calculations. The impact of removing this service are shown in Table 7-2 for 2008, 2015 and 2013 respectively. Here we have aggregated up the revenue changes over the 38 O-D pairs following the removal of the 1808 service from London to Glasgow.

Consumer surplus change is estimated by using the rule of a half to the change in Generalised Costs (from multiplying GJT by the value of time). Given the increases in Generalised Cost and the reduced demand, this is necessarily negative.

Given the modal switch to road based modes there is a net increase in external costs.

The removal of the service reduces revenues and costs but the net effect is to increase profits (producer surplus) for 2008 and 2015. The low value in 2008 possibly represents the impact on demand of the on-going engineering works and consequent disruption to WCML services at the time. As explained earlier, services in subsequent years ran enhanced timetables with less disruption. Predicted passenger growth to 2030 is enough to offset the benefit from the cost savings. The profit, consumer surplus and external effects are summed to give the overall welfare change following the removal of this service of over £500k PA. This represents the value of this slot which is positive (ie by removing this slot we have a negative welfare impact). We divided this by the kilometre distance between London and Glasgow (705 km) and by 250 weekday operating days to give a figure per km which may be compared to other estimates. This gives a figure of £2.6 per train km for this peak service run at current demand levels.

Table 7-2: Value of capacity of peak service (2015 £)

	Change following removal of peak service (£ per year)						**Scarcity value per km (£)**
Year	Revenue	Cost	Profit	Consumer Surplus	External. Costs	**Welfare change**	
2008	-415,947	-733,490	317,544	-490,819	-119,927	-293,202	1.67
2015	-482,498	-733,490	250,992	-569,350	-138,955	-457,313	2.60
2030	-751,716	-733,490	-18,226	-887,029	-215,932	-1,121,187	6.38

7.7 Conclusions

This work calculates the value of capacity in terms of the opportunity cost of making paths available to the main franchised operator on an the West Coast Main Line in Britain. The context to this is assessing the potential benefit in terms of freed up capacity if the considered SUSTRAIL enhancements to freight track and vehicles allow the running of an extra path per hour to the current timetable. This work does not calculate how much capacity will be unlocked by the SUSTRAIL enhancements.

We used available ticket sales data for the WCML applied to a customised detailed rail passenger simulation model which produces estimates of demand and revenue changes. These changes are considered along with publicly available operating and external cost information to calculate the opportunity cost to the franchisee of the use of a slot and thus impute the value of scarce, ie peak, capacity on this route.

We also only focus on a particular section of the WCML, from London to Glasgow and whilst we consider all flows which impact on this part of the network information on smaller flows was not available as was information from other smaller operators.

In terms of passenger trains, we used what we judged as the highest loaded service, the 18:08 service from London to Glasgow peak slot by the inter-city operator has the highest social value.

We found lower values than in previous work conducted on the ECML, which corresponds to the reputation of ECML as a particularly capacity constrained network. Our results for 2015 found that, taken in isolation, operators would actually make a loss on the peak service, ie by removing this service from the timetable we find their profits increase. Overall though we find a negative impact on societal welfare from removing the service given the large reductions in consumer surplus and the increase in external impacts, primarily from the modal shift to car. We value this peak slot at £2.6 per train km at 2015 levels of demand, which is considerably lower than the values found on the ECML, (approximately £23 per km in 2008). Although we have factored in the growth in passenger demand, given the increase in services run over the network and the impact this will have on spare capacity, this should be seen as a lower bound estimate. The predicted growth in rail demand to 2030 works to offset the operating costs and increases the value of the path to around £6.4 per train km. These are clearly lower bound estimates, given that many passengers in the peak will be paying premium fares, but as explained above we were only supplied aggregate ticket sales information for each flow so worked with average fares for each flow.

Container freight trains may also potentially use any extra capacity freed up provided they move at reasonable speeds and run on most occasions they are allocated a path. Earlier work by the author valued the use of such a path at around £14 per km. This value is network independent and largely based on external cost savings eg from the resulting change in the number of HGVs on the road network. Our findings would suggest the consideration of further additional freight services as a possible use of freed up capacity along with passenger services as long as they can operate on one path and run very regularly.

Applying the £14 per km value to a daily train path in each direction on the UK Case Study route yields a benefit of £2.62million at 2015 prices, assuming a 265.6km route * 2 directions * 365 days per annum. This will be included in the Business Case.

8. CONCLUSIONS

This deliverable has set out an assessment of the freight user benefits, environmental benefits and potential passenger benefits of the SUSTRAIL improvements.

The freight user benefits were estimated by carefully tracing through the impacts from the SUSTRAIL innovations to the Infrastructure Manager and the Freight Operators, and finally to the End Users. These benefits comprise financial cost savings, reliability gains and time savings from faster rail services where these occur. The environmental benefits comprise changes in CO_2, NO_x, SO_2, $PM_{2.5}$ emissions and noise exposure. While these are smaller in magnitude compared with the End User benefits, they are still substantial and will make a significant contribution toward the cost-benefit performance of the project in the final deliverable (Business Case synthesis, D5.6).

The deliverable also included a special case study focusing on path capacity benefits from faster freight on congested mixed-use lines. This research was successful, and produced results for the benefit created by additional paths freed-up on the network. Again the results will feed into the Business Case synthesis.

Three different general case studies were developed: one in the UK; one in Bulgaria; and one in Spain. The results demonstrate that the value of the SUSTRAIL improvements to End Users and to environmental sustainability is widespread across the European network of mixed-use lines. However, some differences also emerged: the Bulgarian case study demonstrated the greatest untapped potential for increasing rail mode share, using the SUSTRAIL improvements to raise whole-system performance; the UK case study demonstrated a very high level of benefits despite a more modest mode share gain – due to the intensive intermodal traffic on the corridor studied; whilst the Spanish case study supported the overall case that the SUSTRAIL improvements would yield significant End User benefits, but also highlighted some of the constraints faced by rail freight in the Iberian peninsula due to gauge issues and other limitations, and suggested that in Spain the SUSTRAIL improvements would need to be a part of a wider package of measures to expand the rail freight market.

In the final deliverable (D5.6), the results presented in this technical report will be incorporated into the Business Case for the SUSTRAIL improvements, and will be set alongside the findings on Implementation aspects from D5.4/5.7 as part of the overall Business Case conclusions.

9. REFERENCES

[1] Ricardo-AEA (2014), *Update of the Handbook on External Costs of Transport*. Report for EC DG-MOVE. London: Ricardo-AEA.

[2] Fowkes, A.S., Johnson, D.H., Whiteing, A. E. and Nash, C.A., (2006), Freight Modelling Final Report. Rail Research UK Report 3/5, RRUK.

[3] Johnson, D. H., & Nash, C. A. (2008). Charging for Scarce Rail Capacity in Britain: A Case Study. The Review of Network Economics, 7(1), 53-76. doi:10.2202/1446-9022.1138

[4] Rantatalo, M., Famurewa, S. and Juntti, U. (2015), *SUSTRAIL D5.1 LCC and RAMS analysis*, SUSTRAIL (The sustainable freight railway: Designing the freight vehicle – track system for higher delivered tonnage with improved availability at reduced cost), EU 7th Framework Programme, Grant # 265740 FP7 - THEME [SST.2010.5.2-2.].

[5] Wheat, P., Smith, A. and Matthews, B. (2014), *SUSTRAIL D5.3: Access Charge Final Report*, SUSTRAIL (The sustainable freight railway: Designing the freight vehicle – track system for higher delivered tonnage with improved availability at reduced cost), EU 7th Framework Programme, Grant # 265740 FP7 - THEME [SST.2010.5.2-2.].

[6] Blacktop, K. et al (2014), *SUSTRAIL D5.4: Technical implementation and phasing issues*, SUSTRAIL (The sustainable freight railway: Designing the freight vehicle – track system for higher delivered tonnage with improved availability at reduced cost), EU 7th Framework Programme, Grant # 265740 FP7 - THEME [SST.2010.5.2-2.].

[7] Nellthorp, J. et al (2013), *SUSTRAIL D5.5: Interim Business Case Synthesis Report to Guide WP3 and WP4*, SUSTRAIL (The sustainable freight railway: Designing the freight vehicle – track system for higher delivered tonnage with improved availability at reduced cost), EU 7th Framework Programme, Grant # 265740 FP7 - THEME [SST.2010.5.2-2.].

[8] Milotti et al (2015), *SUSTRAIL D5.7: An impact analysis for operation of the optimised freight vehicle and track system*, SUSTRAIL (The sustainable freight railway: Designing the freight vehicle – track system for higher delivered tonnage with improved availability at reduced cost), EU 7th Framework Programme, Grant # 265740 FP7 - THEME [SST.2010.5.2-2.].

[9] Franklin, F., Jablonski, A., Todorova, M. and García Moreno, E. (2012), *SUSTRAIL D1.2 Overview of route and track parameters*, SUSTRAIL (The sustainable freight railway: Designing the freight vehicle – track system for higher delivered tonnage with improved availability at reduced cost), EU 7th Framework Programme, Grant # 265740 FP7 - THEME [SST.2010.5.2-2.].

[10] Nash, C., Johnson, D. and Tyler, J. (2006), *Scoping Study for Scarcity Charges*, Report for the Office of Rail Regulation. Leeds: Institute for Transport Studies.

[11] Department for Transport (DfT) (2014), *Transport Analysis Guidance ('WebTAG')*. Online at: https://www.gov.uk/transport-analysis-guidance-webtag

[12] MDS Transmodal (2012), *Impact of changes in track access charges on rail freight traffic*, Stage 1 Report. London: ORR.

[13] Office of Rail Regulation (ORR), *National Rail Trends / Data Portal*. Online at: https://dataportal.orr.gov.uk. London: ORR.

[14] Lalwani C, Mason R, Potter A and Yang B (2004), Transport in Supply Chains. Cardiff: Cardiff Business School, Cardiff University.

[15] Department for Transport (2007), Road Freight Statistics 2006. London, Department for Transport.

[16] Shen, S., Fowkes, A.S., Johnson, D.H. and Whiteing, A.E. (2009). Econometric modelling and forecasting of freight transport demand in Great Britain. European Transport Conference, Leeuwenhorst, The Netherlands.

[17] Taplin J H E (1982), Inferring Ordinary Elasticities from Choice or Mode-Switch Elasticities, Journal of Transport Economics and Policy, 16(1), 55-63.

[19] Taplin J H E (1997), A generalised decomposition of travel-related demand elasticities into choice and generation components, Journal of Transport Economics and Policy, 31(2), 183-191.

[20] Taplin J H E, Hensher D A, and Smith B (1999), Preserving the Symmetry of Estimated Commuter Travel Elasticities, Transportation Research B: Methodological, 33(3), 215-232.

[21] Li, Z., Hensher, D.A., and Rose, J.M., (2011), Identifying sources of systematic variation in direct price elasticities from revealed preference studies of inter-city freight demand, Transport Policy , vol. 18, no. 5, pp. 727-734, 2011.

[22] Ueda, H., Miyake, K., Kado, H., and Nagano, H. (2005), An analysis of marine container transportation in the Asian region, Proceedings of the Eastern Asia Society for Transportation Studies, Vol. 5, pp. 617 - 630, 2005.

[23] Razmov, T., and E. Jelezov (2013), Methodology of determining the financial and economic efficiency of concessioning a seaport of national importance, Almanac of University of Transport, ISSN 1314-362X, No 4, Sofia.

[24] Sansom, T., Nash, C., Mackie, P., Shires, J.D. and Watkiss, P. (2001), *Surface Transport Costs and Charges: Great Britain 1998*, A Report for the DETR.

[25] Preston, J., Whelan, G.A., and Wardman, M.R. (1999) “An Analysis of the Potential for On-track Competition in the British Passenger Rail Industry,” *Journal of Transport Economics and Policy*, 36: 77-94.

[26] ATOC (2010) “Passenger Demand Forecasting Handbook,” Association of Train Operating Companies, London.

APPENDIX 1: PATH CAPACITY BENEFITS CASE STUDY

Benefits from Increased Capacity Usage on West Coast Mainline (Task 5.2.3)

A1.1 Introduction

The aim of this work is to identify the benefits of improved utilisation of rail capacity on the West Coast Mainline (WCML) which could be potentially unlocked by the increased freight speeds following the implementation of the SUSTRAIL vehicle and infrastructure enhancements. The work adopts the approach of Johnson and Nash (2008) who identify appropriate rail scarcity charges to make freight and passenger operators pay for their use of rail capacity in line with the opportunity cost of the use of slots.

We do not calculate how much capacity will be unlocked by the SUSTRAIL enhancements, rather this work focuses on a section of the UK's West Coast Mainline as a case study for the value of scarce capacity.

Scarce capacity is one of the most difficult issues to deal with in infrastructure charging – charges should give operators incentives to expand services only where the value of the service is at least as high as the cost it causes and where capacity is scarce it should ensure that it is used to provide the services of greatest value. This has become a more important issue recently given the growth of rail traffic and costs of expansion of the rail network (the West Coast Mainline upgrade completed in 2008 cost around £10 billion and facilitated the implementation of higher frequency timetables from 2009).

Currently decisions about the allocation of slots are based on administrative procedures, so that once granted a slot through franchise agreements, operators have little incentive to make more efficient use of capacity.

Currently in Britain capacity charges are levied based on the cost of congestion. However, this is only the appropriate capacity cost where the train in question constitutes an additional train to what would otherwise have been run; where the train in question runs instead of some other train, the appropriate capacity cost is the opportunity cost of trains forced off the system by the lack of capacity. Where capacity constraints bind, the use of a slot by a particular operator leads to the inability of others to obtain their slots.

The way in which we estimate the value of capacity here is to use a passenger demand forecasting model, PRAISE, to consider a situation on the WCML characterized by scarce capacity and a degree of competition.

A1.2 Background

Our approach for valuing scarce capacity requires estimation of the opportunity cost of a slot. The most attractive conceptual solution to allocate capacity is to 'auction' scarce slots to the highest bidding operator. Many practical difficulties prevent the realisation of this in practice, such as the interdependence of slots and the fact that the willingness to pay for a slot will only reflect the true social value if the appropriate subsidy regimes are in place to reflect user and external benefits. Johnson and Nash argue that auctioning works best with a tax/subsidy regime in place and where alternative uses of path are not directly competitive. It is impractical to use this approach to determine entire timetables, it may be used on a smaller scale to look at small changes to existing timetables.

Nilsson (2002) looks at auctioning in detail, arguing it is feasible. He suggests an approach in which train operating companies bid for the timetable they want, with an indication of how their bid would be affected if the were allocated slots earlier or later than they desired. An optimization program then produces the best allocation and operators have a chance to change their bid in the light of this. This procedure does not seem very different from the iterative procedure already followed in timetabling but it has not been adopted in practice to date.

An alternative, explored here and for the East Coast Mainline in Johnson and Nash (2008), is for the track charging authority to attempt to calculate directly the costs involved. For instance, if a train has to be run at a different time from that desired, it is possible to use studies of the value people place on departure time shifts to estimate the value to its customers of the cost involved. Similarly, the costs of slower speeds may be estimated from passengers' values of time. The authors used the PRAISE rail demand forecasting software. PRAISE forecasts rail demand between OD pairs on a network, taking account of fares, journey times, desired departure times.

In order to calculate the value of a slot to freight, Johnson and Nash (2008) used information on marginal social costs of road and rail freight to calculate value per train km. These included excess revenues (from Track Access Charges) over marginal cost of rail freight (including infrastructure, operating and external costs). Additionally, for an additional container train there is the external benefit of removing hgvs from the road network. The authors found a welfare benefit (ie a value for a path) of the freight service is £8.65 per train km (£14 in 2015 prices). They found the value for a peak passenger slot was around 67% higher than use by freight, although lower in the off-peak. It is important to note that the freight value may be less if operators require more than one standard slot per train run. If the slot is only actually used on 50% of occasions then its value is obviously halved

A third approach, recommended by Hylen (1998), is to charge the long run average incremental cost of expanding capacity on sections of infrastructure where capacity is constrained. However, this is a very difficult concept to measure (the cost of expanding capacity varies enormously according to the exact proposal considered and it is not easy to relate this to the number of paths created since they depend on the precise number and order of trains run).

West Coast Mainline

The West Coast Main Line (WCML) is a major intercity network in the UK, linking Greater London, West Midlands, North West, North Wales and Central Scotland. It is also one of the busiest freight routes in Europe carrying 43% of UK rail freight traffic.

Given the sheer scope of the network it would be impossible to model all movements so we are focusing on a section of it, principally the 437 mile stretch from London to Glasgow. It is an important and heavily utilized part of Britain's rail network and has the following characteristics which make it an interesting case study of scarce capacity:

- Competition for slots on the network between operators with overlapping franchises and freight operators.
- North of Lancaster 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. Some freight speeds are also constrained by not using electrified locomotive stock.
- Passenger operators would like a fourth path per hour north of Lancaster and a more regular interval timetable. If freight could be speeded up there is clearly potential for an extra path and considerable benefits from this freed up capacity. We have assumed that this extra path will run from London to Glasgow.

The stretch of the network has a number of operators with overlapping franchises in partial competition with each other:

- London Midland (LM) operating slower stopping services from London as far north as Liverpool (overlapping the Virgin services from London to Crewe).
- Transpennine (TP) operating services from Manchester to Glasgow (overlapping the Virgin services from Preston to Glasgow)
- Virgin (VT) operating services from London to Glasgow/Edinburgh.

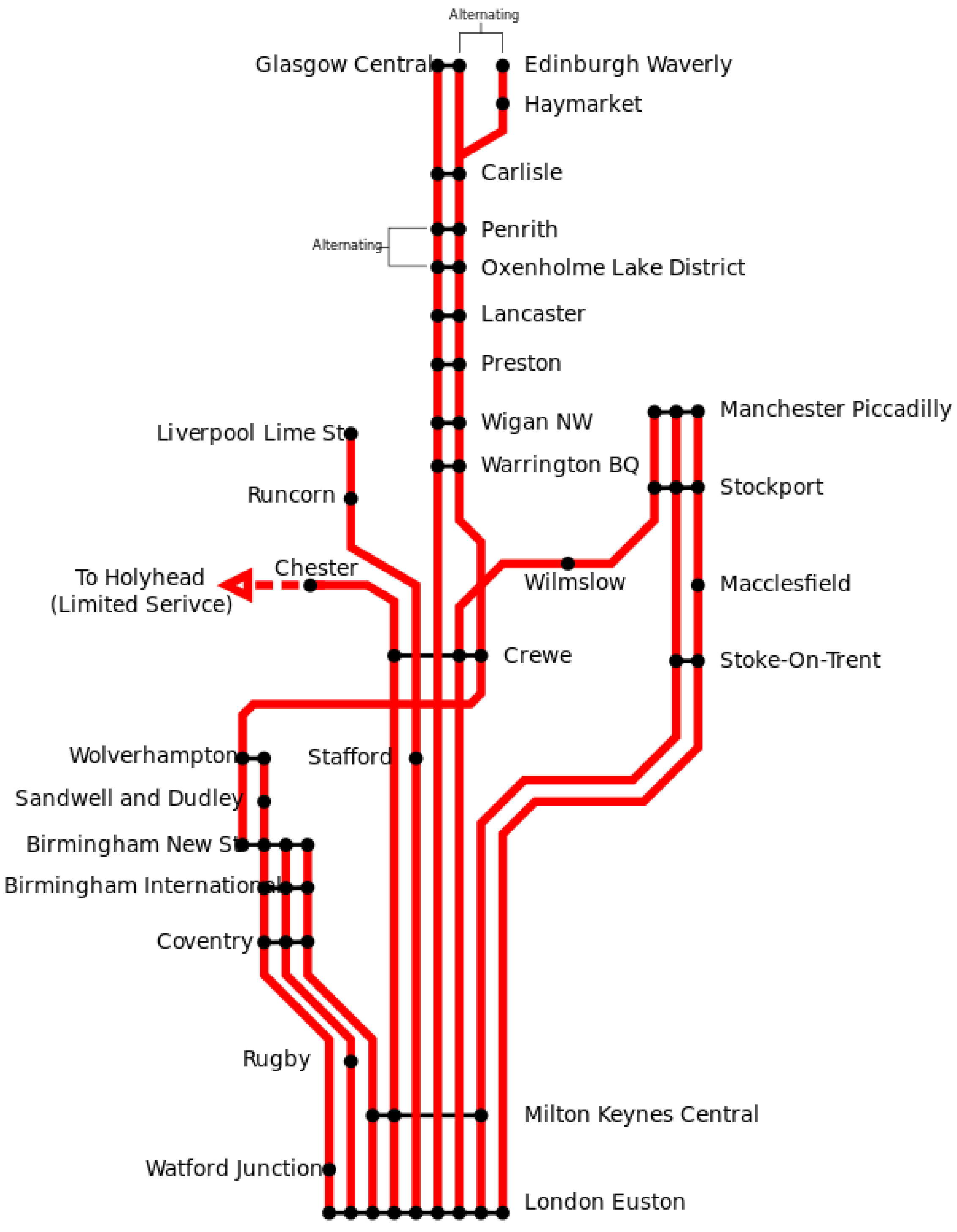


Figure 1: West Coast Mainline Route Map (Source: Virgin Trains website)

A1.3 Methodology

9.1.1 Introduction

The opportunity cost of a slot for this type of service can be estimated as the sum of:

- the change in traffic attracted to rail by the removal of this train multiplied by the price it pays
- the change in consumers' surplus to rail users as a result of the removal of train services
- the additional external costs to road users and the public at large from the train losing passengers to road.

Less the train operating, infrastructure and external cost savings from failing to run this train.

9.1.2 PRAISE

We use the PRAISE methodology for the demand side and off model calculations for the operating and external costs calculations. PRAISE originated from work carried out to look at the impacts of privatization on competition (Preston et al, 1999).

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. It is useful for looking at issues concerning capacity (Johnson and Nash, 2008) as well as competition, between different operators (Preston et al., 1999) and also yield management systems (Johnson and Nash, 2012).

Typically such rail forecasting approaches use the Generalised Cost (GC) concept – this is a composite measure of cost to the passenger taking into account the financial element, ie fares, and the time related costs such as in-vehicle, interchange and schedule adjustment time, converted into a monetary value using an appropriate value of time. Given we were not changing fares in our modelling we worked with journey times rather than Generalised Cost for the demand estimation. Fares information was still required for imputing resultant revenue changes. The model computes the effect of changes in service levels on the average Generalised Journey Time (GJT). This is Generalised Cost minus the fare element; capturing the time related aspects of the journey described above, converted into a standardized in-vehicle time minutes (eg schedule adjustment time has a different weighting to in vehicle time so needs to be weighted appropriately). The average GJT for each OD pair takes into account the weighting of each service in line with the number of passengers estimated to be travelling on each service.

Following the removal of a rail service some passengers will switch to another service ie at an earlier or later departure time, whilst others will switch mode and some will not travel at all. An upper level of the model scales overall changes in rail demand following service level changes based on generalized journey time elasticities applied to average GJTs for each OD pair.

As with other implementations of PRAISE we use a simulation approach based on 500 representative individuals with differing desired departure times drawn randomly from a distribution to represent traveler heterogeneity. In a departure from earlier versions of PRAISE which use a multinomial logit model to assign a probability to each journey opportunity for each individual, we took a more simplistic approach, assuming that each simulated individual chooses the journey with the lowest GJT. The objective here was to experiment to see whether this approach can yield sensible estimates. Additionally, in greatly reducing the number of calculations required given the high number of ODs required for the network, this enables a spreadsheet based implementation of the model speeding up run times considerably and demonstrating an approach which may be relatively easily transferred to other case study applications on larger networks.

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

PRAISE yields results for changes in the following aspects of societal welfare which can be used to capture the impacts in an appraisal:

- Consumer surplus- this measures changes in user benefits, monetizing the impact of the changes in GJT and the change in the number of rail passengers
- Operating profits
- External costs – this measures changes in costs on non-users. External cost valuations are used in conjunction with modal switch values and vehicle kilometers to generate values, which can be used in an appraisal.

We run the model for 2008 and for both a 2015 and 2030 'forecast year' to derive sets of capacity valuations for each year. These years vary in terms of capacity utilization – our 2008 figures were before the finalization of the upgrade to WCML and the introduction of a more frequent timetable, so future years take subsequent passenger and service growth into account.

External costs and benefits

External costs comprise those costs imposed on non-users by rail itself when usage changes, and those imposed by other modes of transport whose volumes are changed by the change in rail demand.

For external costs and benefits of other modes of transport we again use values from the study of Sansom et al (2001). It should be noted that strictly these values were estimated for 1998 so we uplifted them to 2015 prices using the Consumer Price Index (ONS,2015). To apply these values we need to know how much traffic transfers to or from road and the types of road and time of day in question.

Diversion Factors & Passenger Trips.

The change in rail passenger trips can be used to calculate the modal shift between rail, car, coach and not travel or new journeys. An integral part of these calculations are the application of diversion factors to the change in passenger trips. For example, if the number of rail trips are assumed to have increased by 10,000 per year, diversion factors can be used to ascertain where those journeys have come from. In the appraisal, the following diversion factors (Table A3) were used to estimate the sources of new rail journeys and vice versa.

Table A3: Diversion Factors

Diversion Factors	Passenger%	Vehicle%
Car (passenger)	68%	42.5%
Coach (passenger)	24%	2%
New	8%	

Source: Train Operating Company Figures (1998)

To calculate the modal shift in terms of car and coach vehicle kms requires the average loadings of both car and coach vehicles to be taken into account, alongside the length of the trips made by both modes. In the case of car a loading factor of 1.6 (taken from the Transport Economics Note, DfT, 2003) has been used and in the absence of any supporting data, we have assumed for coach a loading factor of 25. This allows the number of car and coach journeys to be calculated.

This information can be taken forward and used to calculate the external cost changes on all modes. All the factors used for the calculation of the environment have been taken directly from a report carried out by ITS for the DETR which examined surface transport costs and charges for Great Britain for 1998 (Sansom et al., 2001). We used the mid-points of the reported costs per vehicle kilometre for road and rail travel. The UK average values for environmental factors, infrastructure costs and congestion costs, and tax are presented in Table A4. These values were implemented by uplifting by 43% to 2015 prices using the CPI (ONS, 2015).

Table A4: UK Average Values of External Factors per vkm (£s in 1998 Prices and Values)

Impact Type	Coach	Car	Passenger Rail	Freight Rail
Noise	0.021	0.0027	0.122	0.170
LAQ	0.093	0.0053	0.279	0.166
Greenhouse Gases	0.014	0.0030	0.067	0.131
Safety	0.052	0.011		
Infrastructure costs	0.060	0.0006	1.116	1.19
Congestion costs	0.1671	0.0971		
Fuel Duty	0.0526	0.0386		
Mohring effect	1.47		1.55	

Road Infrastructure costs are based on the average values for vehicle kms, vehicle type and road types. We assume that infrastructure costs have already been charged to the train operator through the variable access charge.

For car and coach travellers the change in patronage leads to a change in congestion costs imposed on non-users.

In the absence of sufficient revenue data, we took fares information from previous work (Johnson and Nash 2007), which allowed us to approximate a marginal profit figure of 1.6 pence per passenger kilometre for changes in coach patronage. We assumed coach service costs would expand, maintaining existing load factors . This will increase external costs, but there will be benefits to existing users from increased frequencies (the Mohring effect), taken from Sansom et al, of 14.7 pence per vehicle km.

The impact of indirect tax directly affects government revenues. For cars the government levies fuel duty and VAT on fuel duty. Rail and coach travel are not subject to VAT, so VAT not paid on fares expenditure which would have otherwise incurred VAT has to be calculated as a cost of these modes. Values per average UK vehicle kms have been taken from the Sansom et al. (2001) publication are also presented in Table A4.

VAT is charged at 20%, so changes in VAT payments from Rail and from Fuel Duty can be derived from the change in rail revenues.

We have assumed there will not be any effect on subsidy payments. We have also included average benefits to existing users from increased frequencies (the Mohring effect), taken from Sansom et al, as shown in the final row of Table A4.

A1.4 Data

Case Study Area

Ticket sales and revenue data were taken from a dataset of LENNON data provided to us from Virgin Trains and ATOC. We are grateful to our source for their help and the permissions granted to use this dataset.

The dataset comprised the top 300 flows, by OD pair, of revenues and passengers on Virgin services on the West Coast Mainline in the operating year 2007-2008. Given we were focusing on the capacity constrained section of the network north of Lancaster, within these OD pairs there were many which were not deemed as ‘in scope’, eg London<> Birmingham and London <> Manchester. To simplify the process further we just focused on northbound flows.

In order to represent demand that has its origin or destination outside of the immediate study network, we merged a number of ODs which represented similar journeys using the same stretch of ‘in scope’ infrastructure. Several examples illustrate our simplifying approach:

- Revenues and demand figures for services using the stretch of the network from Preston to Carlisle were pooled together into the Preston to Carlisle OD – this included Blackpool to Carlisle and Manchester to Carlisle).
- Flows on the London to Liverpool services beyond Crewe were classed Crewe.
- Revenues and demands for services from Watford and Milton Keynes further north were pooled in with London flows.
- Services to Warrington were merged with services to Wigan.

Using this approach we were able to simplify this network to the following 38 flows as illustrated in Table 7-1.

Table A5: Chosen O-D pairs on network

Originating London	Originating Crewe	Originating Wigan	Originating Preston	Originating Lancaster	Originating Carlisle	Originating Oxenholme	Others
London Milton Keynes							
London Stafford							Stafford Crewe
London Crewe							Milton Keynes Crewe
London Wigan	Crewe Wigan						Warrington Wigan
London Preston	Crewe Preston	Wigan Preston					
London Lancaster	Crewe Lancaster	Wigan Lancaster	Preston Lancaster				
London Oxenholme		Wigan Oxenholme	Preston Oxenholme	Lancaster Oxenholme			
London Carlisle	Crewe Carlisle	Wigan Carlisle	Preston Carlisle	Lancaster Carlisle		Oxenholme Carlisle	
London Glasgow	Crewe Glasgow	Wigan Glasgow	Preston Glasgow	Lancaster Glasgow	Carlisle Glasgow	Oxenholme Glasgow	
London Edinburgh	Crewe Edinburgh	Wigan Edinburgh	Preston Edinburgh	Lancaster Edinburgh	Carlisle Edinburgh	Oxenholme Edinburgh	

Demand

The ticket sales and revenue data described above is reported in aggregate per year for each flow so does not include further detail on ticket types or chosen services. It was estimated that this covered 95% of the Virgin flows on the WCML network. This data is necessarily not up to date as it is no longer seen as commercially sensitive thus facilitating access for our purposes.

Despite efforts, we were unable to obtain matching ticket sales data for other operators. Virgin is the dominant operator on most of our case study flows, but where there were other operators we imputed revenues and ticket sales based on the estimated market share of each operator derived from our base model run for each OD (which includes all timetabled services).

The supplied demand and revenue figures were initially uplifted by (just over) 5% to take into account smaller flows which were omitted from the supplied data.

In order to adjust the figures for 2008 to be more representative of the current passenger loadings on the WCML, we calculated a demand uplift factor using data from National Rail Trends data (ORR, 2015). This figure was derived by calculating an average load factor per train for Virgin Trains in the period 2008-9 to 2013-14 (the latest figures). For each of these years we observe passenger kilometres and train kilometres, giving an average load factor per train. We found that over the 6 years of data we had that this load factor rose by 16% on average. This was used to uplift our 2008 demand figures to reflect the average growth in passengers net of the effect from frequency enhancements.

For Demand in 2030 we further uplifted demand each year by 3%, extrapolating from the average passenger growth on the WCML over the last 3 years, as evidenced in the National Rail Trends.

Timetables

We used the timetable information from Table 65 from the UK Rail Timetable Winter Edition (Network Rail, 2007), covering the period December 2007-May 2008 which was the best fit with the ticket sales data information. For each of the 38 OD pairs we created a separate timetable from this source as shown in Table A6 for London to Glasgow

Table A6: Timetable for London to Glasgow

Operator	VT	VT	TP	VT	VT	VT	VT	VT	VT	VT	LM	VT	VT	VT
London Euston	646	746		846	1029	1146	1346	1446	1546	1549			1715	1808
Crewe	831	931		1032		1332	1532	1632	1732	1734	1749			1954
Wigan	901	1001		1102		1402	1602	1702	1802		1817		1920	
Preston	918	1018	1029	1119	1244	1419	1619	1718	1818		1839	1840	1940	2035
Glasgow	1150		1314	1346	1454	1655	1846	1947	2057			2111	2155	2304

In this example we see inter operator interchanges for the 746 and the 1549 services exiting London Euston. In these situations, revenues estimated for the services were divided equally between the operators.

Generalised Journey Times (GJTs)

For simplicity we ignored dwell times and just used time between departures to calculate in vehicle times. Additional to in vehicle times (IVTs) we included an interchange penalty where appropriate taken from the PDFH (ATOC, 2010) and based on the value from Full/Reduced tickets for the appropriate distance band.

An adjustment time penalty was also added to each individuals' GJT to reflect the cost of adjustment of their desired departure times (as simulated based on the NRTS data) to the actual departure time. The adjustment time was valued at half the IVT in line with Whelan and Johnson (2002)).

Generalised Journey Time Elasticities

These were taken from the industry standard Passenger Demand Forecasting Handbook (PDFH, ATOC 2010), which recommended an elasticity of -0.9 for flows to/from the London Travelcard Area to/from the Rest of the country. This is also the value used in MOIRA.

Values of time and adjustment time

Whilst the demand model is based on GJT, the user benefit calculations require monetising of the changes in generalised costs using a value of time. The value of time used was a weighted average of business, leisure and commute time values taken from WebTAG rail business, commute and other figures uplifted to reflect inflation between 2010-2015 (DfT, 2014).

Given we had no breakdown by purpose or ticket type in our data, we used journey purpose information from the National Rail Travel Survey (NRTS). The National Rail Travel Survey is a representative survey of journeys undertaken by rail in 2004 based on interviews with individual travellers. As such it contains information about journeys, timings, interchanges, tickets and final destinations. The NRTS aimed to produce a comprehensive picture of *weekday* rail travel across the whole of Great Britain, covering who uses the railways, where, when and for what purposes.

We classified the NRTS WCML in- scope ODs into 3 flow types – London long distance, London commuting and Non-London. The proportions of these purposes within each flow type were used in conjunction with the WebTAG values to give an average value of time for these classes of flows[2].

The value of adjustment time is used to weight the difference between a passenger's most desired time of departure and the actual timetabled departure time. As with the Whelan and Johnson work we assumed adjustment time had half the value of IVT.

Departure Time Profiles

The model makes reference to 'departure time profiles' to generate desired departure times for each simulated individual. Appropriate profiles are required in order to generate accurate numbers of individual train loadings. Whereas previously we have relied on MOIRA data for this which is synthetic and based on a broad categorisation of flows, in this work we were able to take the opportunity to utilise the data on actual departure times from the National Rail Travel Survey. This improvement represents an important contribution of this work.

We were able to collate all the journeys which matched our OD pairs (or where a leg of an interchanged journey was between one of our OD pairs) to identify the reported times of departure. From these we create a distribution of desired departure times for each OD pair which were random perturbations from observed departure times (where the degree of perturbation was scaled to be smaller for OD pairs with many services and many observed departure times). Figure 1 below shows a constructed desired departure time profile based on passengers travelling from London to Preston. The peak period appears to be between 5 and 6.30 pm.

[2] Another approach we explored was using older demand data from previous work (Whelan and Johnson, 2002) which broke down demand into Full, Reduced and Season sales. For non-London flows we assumed that full and reduced sales were 'other' journey purpose and that season sales were 'commute' journey purpose. For London flows we assumed that Full sales were 'business' journey purpose. Based on the proportions of each ticket type from the earlier work and the allocations to journey purpose we were able to calculate a trip purpose weighted value of time for each flow.

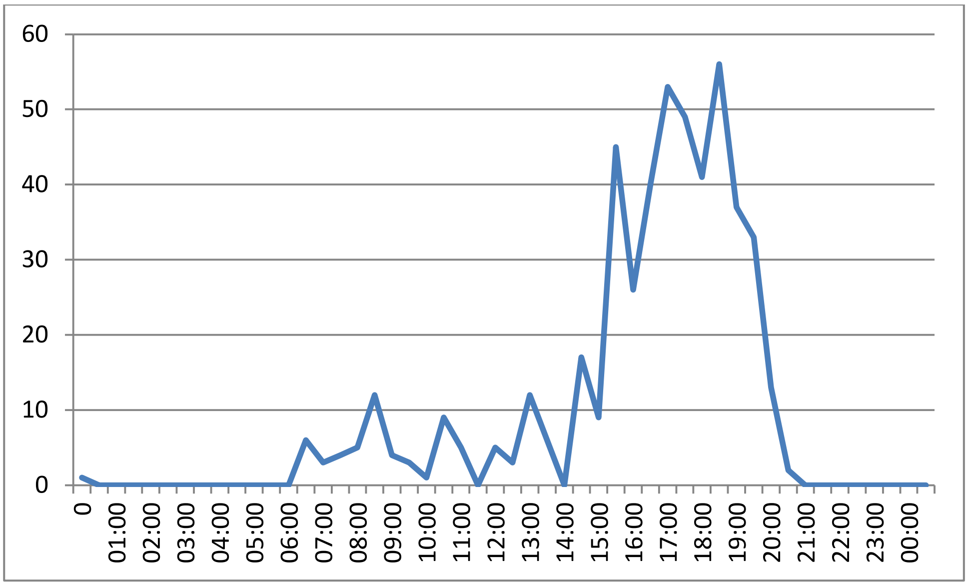


Figure 1: Departure time profile for London to Preston

Costs

Given we are only changing the service level of Virgin trains and are only interested in changes in demand and welfare, we only require variable costs for this operator. We used National Rail Trends accounts for costs (ORR, 2015), with additional information on average costs and train km from Network Rail data.

Whether rolling stock leasing costs should be regarded as fixed is open to question. In the short run, TOCs regard these as fixed because they have rolling stock leasing contracts lasting a number of years. We assume fixed rolling stock here.

A1.5 Results

The modelling approach requires running the model in its base form and then again without a peak service. The model then calculates the impact on demands, revenues, consumer surplus and external costs from the removal of the peak service. The valuation of these impacts in an appraisal format allowed us to calculate the welfare impact following the removal of a path and hence the value of scarcity.

Based on an initial examination of passenger loadings on the London to Glasgow services we found that the 1808 service was the heaviest loaded. So we decided to use this as the basis of our 'peak' scarcity calculations.

The impact of removing this service are shown in Table A7 for 2008, 2015 and 2013 respectively. Here we have aggregated up the revenue changes over the 38 O-D pairs following the removal of the 1808 service from London to Glasgow.

Consumer surplus change is estimated by using the rule of a half to the change in Generalised Costs (from multiplying GJT by the value of time). Given the increases in Generalised Cost and the reduced demand, this is necessarily negative.

External effects are estimated by applying the marginal costs in Table A4 to the changes in vehicle kms derived from the application of the diversion factors shown in Table A3. Given the modal switch to road based modes there is a net increase in external costs.

The removal of the service reduces revenues and costs but the net effect is to increase profits (producer surplus) for 2008 and 2015. The low value in 2008 possibly represents the impact on demand of the on-going engineering works and consequent disruption to WCML services at the time. As explained earlier, services in subsequent years ran enhanced timetables with less disruption. Predicted passenger growth to 2030 is enough to offset the benefit from the cost savings. The profit, consumer surplus and external effects are summed to give the overall welfare change following the removal of this service of over £500k PA. This represents the value of this slot which is positive (ie by removing this slot we have a negative welfare impact). We divided this by the kilometre distance between London and Glasgow (705 km) and by 250 weekday operating days to give a figure per km which may be compared to other estimates. This gives a figure of £2.6 per train km for this peak service run at current demand levels. These are clearly lower bound estimates, given that many passengers in the peak will be paying premium fares, but as explained above we were only supplied aggregate ticket sales information for each flow so worked with average fares for each flow.

Table A7: Value of capacity of peak service (2015 £)

Change following removal of peak service (£ per year)							**Scarcity value per km (£)**
Year	Revenue	Cost	Profit	Consumer Surplus	External. Costs	**Welfare change**	
2008	-415,947	-733,490	317,544	-490,819	-119,927	-293,202	1.67
2015	-482,498	-733,490	250,992	-569,350	-138,955	-457,313	2.60
2030	-751,716	-733,490	-18,226	-887,029	-215,932	-1,121,187	6.38

A1.6 Conclusions

This work calculates the value of capacity in terms of the opportunity cost of making paths available to the main franchised operator on an the West Coast Mainline in Britain. The context to this is assessing the potential benefit in terms of freed up capacity if the considered SUSTRAIL enhancements to freight track and vehicles allow the running of an extra path per hour to the current timetable. This work does not calculate how much capacity will be unlocked by the SUSTRAIL enhancements.

We used available ticket sales data for the WCML franchisee applied to a customised detailed rail passenger simulation model which produces estimates of demand and revenue changes. These changes are considered along with publicly available operating and external cost information to calculate the opportunity cost to the franchisee of the use of a slot and thus impute the value of scarce, ie peak, capacity on this route.

Our approach is, however, limited in its scope, deriving the value of capacity based on the value of slots to the current dominant operator in the face of small changes to an existing timetable and where there is good knowledge of the demand and cost characteristics of their operations.

We also only focus on a particular section of the WCML, from London to Glasgow and whilst we consider all flows which impact on this part of the network information on smaller flows was not available as was information from other smaller operators.

In terms of passenger trains, we used what we judged as the highest loaded service, the 18:08 service from London to Glasgow peak slot by the inter-city operator has the highest social value.

We found lower values than in previous work conducted on the ECML, which corresponds to the reputation of ECML as a particularly capacity constrained network. Our results for 2015 found that, taken in isolation, operators would actually make a loss on the peak service, ie by removing this service from the timetable we find their profits increase. Overall though we find a negative impact on societal welfare from removing the service given the large reductions in consumer surplus and the increase in external impacts, primarily from the modal shift to car. We value this peak slot at £2.6 per train km at 2015 levels of demand, which is considerably lower than the values found on the ECML, (approximately £23 per km in 2008). Although we have factored in the growth in passenger demand, given the increase in services run over the network and the impact this will have on spare capacity, this should be seen as a lower bound estimate. The predicted growth in rail demand to 2030 works to offset the operating costs and increases the value of the path to around £6.4 per train km.

Container freight trains may also potentially use any extra capacity freed up provided they move at reasonable speeds and run on most occasions they are allocated a path. Earlier work by the author valued the use of such a path at around £14 per km (assuming only 1 path is needed and it is used all the time).. This value is network independent and largely based on external cost savings eg from the resulting change in the number of HGVs on the road network. Our findings would suggest the consideration of further additional freight services as a possible use of freed up capacity along with passenger services as long as they can operate on one path and run very regularly.

Acknowledgements

The Virgin Trains revenue and ticket sales data was kindly provided to us by Virgin via our contact Tony Magee at the Association of Train Operating Companies (ATOC). Tony also helped with the understanding of the raw data provided.

We would also like to acknowledge the help of Margaret Shaw at Department for Transport's Rail Statistics office who kindly created the subset of National Rail Travel Survey data used in the analysis.

References

ATOC (2010) "Passenger Demand Forecasting Handbook," Association of Train Operating Companies, London.

Department for Transport (2004). Transport Economics Note, Integrated

Transport Economics and Appraisal Division.

Department for Transport (2014). **Transport Analysis Guidance UNIT A1.3, User and Provider Impacts,** January 2014, www.webtag.gov.uk, *https://www.gov.uk/transport-analysis-guidance-**webtag***

Johnson, D. H., & Nash, C. A. (2008). Charging for Scarce Rail Capacity in Britain: A Case Study. **The Review of Network Economics**, *7*(1), 53-76. doi:10.2202/1446-9022.1138

Johnson, D. H., & Nash, C. A. (2012), Competition and the Provision of Rail Passenger Services. **Journal of Rail Transport Planning & Management.**

ONS, Consumer Price Index, http://www.ons.gov.uk/ons/rel/cpi/consumer-price-indices/march-2015/stb---consumer-price-indices---march-2015.html

ORR Data Portal (2015), https://dataportal.orr.gov.uk

Network Rail, (2007), UK Rail Timetable Winter Edition 08, The Stationery Office.

Nilsson, J-E (2002) "Towards a Welfare Enhancing Process to Manage Railway Infrastructure Access," Transportation Research A, 36: 419-436.

Preston, J., Whelan, G.A., and Wardman, M.R. (1999) "An Analysis of the Potential for On-track Competition in the British Passenger Rail Industry," *Journal of Transport Economics and Policy*, 36: 77-94.

Sansom, T., Nash, C., Mackie, P., Shires, J.D. and Watkiss, P. (2001) "Surface Transport Costs and Charges: Great Britain 1998," A Report for the DETR.

Whelan, G.A., and Johnson, D.H. (2004), Modelling the impact of alternative fare structures on train overcrowding, International Journal of Transport Management 2 (2004) 51–58

APPENDIX 2: AGGREGATION STEPS

The following are key extracts from the process undertaken to aggregate from the LCC and RAMS models to the Case Study Route level. These extracts are for the UK route.

Track cost assumptions

Outline

The SUSTRAIL Task 5.1 model gives a detailed analysis of the impact of SUSTRAIL scenarios on maintenance and renewal costs.
It does not give complete maintenance or renewal costs, so we use the SUSTRAIL D2.5 VTISM model to provide the totals. We adjust these from 2014-19 to 2015 costs.
We then control the more detailed SUSTRAIL numbers to these totals.

We note that the SUSTRAIL D2.5 VTISM model is comparable in orders of magnitude to a simple average of Network Rail routes for 2015/6 costs, which gives some additional confidence in the numbers.
We generalise to the GB network using the available national-level data.

Quantities (Baseline scenario)	Felixstowe-Peterborough-Nuneaton route: £/track km/year 2015	Felixstowe-Peterborough-Nuneaton route: £/year 2015	GB network: £/track km/year 2015	GB network: £/year 2015
Base for Impacts on IMs (Network Rail)				
Track Maintenance and Renewal Costs	37,328	19,149,312	32,417	1,065,000,000
Maintenance	13,752	7,055,010	11,943	375,000,000
Corrective maintenance	192.44	98,720	167	5,247,345
Preventive maintenance	13,560	6,956,290	11,776	369,752,655
Renewals	23,576	12,094,303	20,474	690,000,000
General renewals	18,036	9,252,484	15,663	527,869,515
Investments/innovations	5,540	2,841,819	4,811	162,130,485
	Note: VTISM-based numbers		Note:	
			Implies track km =	32,854
			Route km =	15,753

Impacts of SUSTRAIL

Impacts on IMs (Network Rail)	Track LCC data % changes: SUSTRAIL0 (vehicle only)	SUSTRAIL1	SUSTRAIL2 (140kph)	Cost shares of Track LCC items in route total, in Baseline scenario:	Track cost % changes at route level: SUSTRAIL0 (vehicle only)	SUSTRAIL1	SUSTRAIL2 (140kph)	Track cost £/year changes at route level: SUSTRAIL0 (vehicle only)	SUSTRAIL1	SUSTRAIL2 (140kph)
Track Maintenance and Renewal Costs					-1.6%	-10.1%	-7.5%	-304206.6	-1937723	-1428134
Maintenance					-0.8%	-2.4%	-1.8%	-152103	-453785	-349097
Corrective maintenance	-80%	-80%	-50%	0.7%	-0.6%	-0.6%	-0.3%	-106705	-106705	-66690
Preventive maintenance	-6%	-45%	-37%	4.0%	-0.2%	-1.8%	-1.5%	-45399	-347080	-282407
Renewals					-0.8%	-7.7%	-5.6%	-152103	-1483938	-1079037
General renewals	-10%	-86%	-60%	8.1%	-0.8%	-7.8%	-5.7%	-152103	-1492587	-1087685
Investments/innovations	0%	2%	2%	2.5%	0.0%	0.05%	0.05%	0	8648	8648

Note: assuming 4% discount rate (Track LCC data % changes)

Note: LCC model (D5.1) showed 0% impact on renewals. This was considered un-realistic and together with the IM (Network Rail) it was decided to set this to 9.8% in order to yield the same £ cost saving for renwals as for maintenance.

Calculated on the following sheet. Needed because: most Track LCC items do not cover the whole route, only 0-1200m radius curves; maintenance and renewal actions occur with different frequency on curves vs straight track; and starting cost shares are not equal.

Note: assuming 4% discount rate (Track cost % changes at route level)

Note: SUSTRAIL0 savings are added to SUSTRAIL1&2 to reflect the impact of the missing renewals cost saving for the IM.

Implies track improvements provide: -8.5% (SUSTRAIL1), -5.9% (SUSTRAIL2) … of the SUSTRAIL1&2 impact.

Note: assuming 4% discount rate (Track cost £/year changes at route level)

Implies track improvements provide (£/year): -1633517 (SUSTRAIL1), -1123928 (SUSTRAIL2) … of the SUSTRAIL1&2 impact.

Track cost results

Impacts on the IM
Baseline Scenario data

SUSTRAIL Task 5.1 model (updated to 2015)
For the route Felixstowe-Peterborough-Nuneaton (UK).

	LCC £ PV@4% over 30 years (2015 update) £		Implied whole route, £PV	*Cost shares of Track LCC items in route total*	Implied whole route, £ per annum equivalent	Implied whole route, £ per annum (grouped for comparison)
Track Maintenance and Renewal Costs			45,643,815			
Maintenance						1,263,382
Corrective maintenance	317,923	Whole route *but* track force-related failure mode only	317,923	*0.7%*	17,678	
Preventive maintenance	1,832,340	0-1200m radius curves only	22,402,374	*4.0%*	1,245,703	
Renewals	3,705,765	0-1200m radius curves only	17,537,140	*8.1%*	975,168	1,274,682
Track Investment Costs	1,138,193	0-1200m radius curves only	5,386,378	*2.5%*	299,514	
Maintenance	2,150,263		22,720,297			
Renewals and investment	4,843,958		22,923,518			
Equivalent annual costs, £/year						
Maintenance	119,567		1,263,382			
Renewals and investment	269,352		1,274,682			

Notes: The cost data is for a restricted set of cost heads:
- corrective maintenance only includes 'track damage costs due to track force failure mode'
- exclusions are: turnout failure, overhead line failure, signal failure, subgrade problems and other track-related failures.

The cost data is also not for the whole route:
- with the exception of corrective maintenance, all other costs are for the 0-1200m radius curves only.

Route length % by curvature:	
0-1200m	7.1%
1201-1600m	6.6%
1601-2400m	8.8%
>2400m	77.5%
TOTAL	100.0%

Source: D1.2 Figure 2.9

SUSTRAIL D2.5 VTISM results
For the route Felixstowe-Peterborough-Nuneaton (UK).

£/track km/year for 2014-19 as below	£/year 2015	
14,000	7,055,010	whole route
24,000	12,094,303	whole route
	19,149,312	

Source: D2.5 Table 3.1

Year	GDP deflator (CPI-based)
2015	109.4
2016	111.3

Source: DfT (2014) TAG Data Book

Note: NR average maintenance and renewals cost:
33,000 £/track km / year.

Comparing column L with column O, the SUSTRAIL LCC analysis produces much lower maintenance and renewal costs than VTISM.
Due to various omitted items.
VTISM-based numbers are used in sheet IVa.
See notes at the top of sheet IVa.

Ratio of VTISM-based annual costs to raw LCCs:

Maintenance	59.0
Renewals and investment	44.9

Ratio of VTISM-based annual costs to implied route-level LCCs:

Maintenance	5.6
Renewals and investment	9.5

Caution: these ratios apply to Baseline costs, but not to cost changes for SUSTRAIL scenarios - in that case only the latter ratios apply (VTISM-based annual costs to implied route-level LCCs.

Simple Average, for comparison
Based on maintenance and renewals expenditure by Network Rail, 2015/16 (CP5 Strategic Plan, Supporting Documents).

£, 2015/6 (GB)		£, 2015/6, per route km		£, 2015/6, Felixstowe-Nuneaton	
375	million	£0.024	million per route km	£6.094077	million per annum
690	million	£0.044	million per route km	£11.213102	million per annum
				17.31	

Sources: Network Rail (2013) Renewals Expenditure Summary
Network Rail (2013) Maintenance Activity and Expenc
DfT (2015) Statistics Table RAI0101 Length of nationa

Note that based on 2006 data in D2.3 Table 2.23:
Track maintenance and renewals is only:
10% of NR's expenditure
6.4% track maintenance
3.2% track renewals
14% of NR's expenditure excluding financing costs and enhancement
9.5% track maintenance
4.8% track renewals

Renewals expenditure may fluctuate with available funding and priorities;
the 2015/16 planned expenditure > track maintenance.

Note also that overall maintenance (not only track), for England and Wales (E&W) = £
704.2 million, 2015/6
Track maintenance for E&W is 337.1 million, 2015/6
Overall renewals for E&W is 2616 million, 2015/6
Track renewal for E&W is 634 million, 2015/6

Proportion of total M+R expenditure in model 29%
i.e. % of track maintenance and renewal in ALL E&W maintenance and renewal = 29%

Sources: Network Rail (2013) Renewals Expenditure Summary
Network Rail (2013) Maintenance Activity and Expenditure Summary

Track Access Charges

In line with principles in D5.3 section 6.2.2, we will adjust Track Access Charges in the following way:

- Infrastructure innovations: we need to calculate the infrastructure cost saving as a proportion of total maintenance and renewals cost (will typically be a small number). Then reduce access charges (ideally variable access charges only) by this (small) proportion.
- Vehicle innovations: the absolute change in infrastructure costs resulting from running the less damaging vehicles should be passed to the operators of those vehicles.

Infrastructure innovations (included in SUSTRAIL1&2):

Track cost % changes at route level:	SUSTRAIL0 (vehicle only)	SUSTRAIL1	SUSTRAIL2 (140kph)
Impacts on IMs (Network Rail)			
Track Maintenance and Renewal (M&R) Costs (needed for Track Access Charges to intermodal traffic)	n/a	-10.1%	-7.5%
Track M&R Costs excluding impact of SUSTRAIL vehicle on track costs (needed for Track Access Charges to non-intermodal traffic)	n/a	-8.5%	-5.9%

Note: from sheet 'Track cost assumptions'; assuming 4% discount rate

Vehicle innovations (included in SUSTRAIL0,1&2):

Track cost £/year changes at route level:	SUSTRAIL0 (vehicle only)	SUSTRAIL1	SUSTRAIL2 (140kph)
Impacts on IMs (Network Rail)			
Track Maintenance and Renewal Costs	-304207		

Note: from sheet 'Track cost assumptions'; assuming 4% discount rate

Track Access Charges (variable)

	SUSTRAIL0	SUSTRAIL1	SUSTRAIL2 (140kph)	
% of variable cost base examined in the cost model		81%		Source: Wheat and Smith (2012); required because certain costs are more variable w.r.t. traffic than others.
% change in variable Track Access Charges	-10.4%	-17.4%	-15.2%	Note: This line is for the SUSTRAIL vehicle
% change in variable Track Access Charges from Infrastructure Improvements		-6.9%	-4.8%	Note: If TAC change is needed for other traffic on the route, should use this row. SUSTRAIL2 result includes speed penalty.
% change in variable Track Access Charges from Vehicle Improvements	-10.4%	-10.4%	-10.4%	

Therefore £ change in variable Track Access Charges:

£/000 gross tonne km	Baseline scenario	SUSTRAIL1	SUSTRAIL2	FEAA Domestic Intermodal CP5 price list, 2015/16 charges per mile	per km	
Diesel loco (Class 66/0)	1.682176092	1.5657	1.6020			Source: Network Rail CP5 Track Usage Price List
FEAA wagon (Tare)	0.65765927	0.5436	0.5578	1.0584	0.657659	
FEAA wagon (Loaded)	0.884086932	0.7307	0.7498	1.4228	0.884087	

For the SUSTRAIL vehicle only (SUSTRAIL 0), absolute saving in track maintenance and renewal cost is:

304,207 £/year for the whole route

Assuming 24 trains each way each day (broadly compatible with route capacity and a majority - but not all - trains taking the studied route rather than the North London alternative during the appraisal period 2015-2044), the total costs of freight operation on the route would be:

Cost, £ per 50 train-km: 493 Source: sheet IIId. FOC costs and Wagon LCCs

Annual train km = 3,570,480 assuming 5% unavailable and 275 operating days/annum for a wagon corresponding to 290 days/annum of operation for the service as a whole.

Total FOC cost, £ = 35,195,178

		Weight, tonnes/train	000 gross tonne km	Track Access Charge,£	
Total track access charges (variable) =	loco	126	449,880	756,778.19	
	wagons	1004	3,584,762	2,917,617.50	Assume 69% load factor in TEUs (as MDST 2012).

%change in Track Access Charges (variable) = -8.3%

%change in Track Access Charges (variable) on Wagons only = -10.4%

RAMS data

RAMS simulation for wagon alone

	Benchmark Wagon	SUSTRAIL Wagon
Successful	94.28%	98.82%
Started	0.75%	0.14%
Requested	4.98%	1.04%
	100.01%	100.00%

RAMS simulation for wagon+track:

	Baseline	SUSTRAIL0	SUSTRAIL1	SUSTRAIL2
Successful	93%	95.42%	97.11%	95.79%
Started	0.08%	0.04%	0.02%	0.04%
Requested	6.46%	4.54%	2.87%	4.17%
	100.00%	100.00%	100.00%	100.00%

It is necessary to scale the RAMS data using other data sources because the RAMS analysis does not include all sources of delay to freight trains.

Delays (freight operator's responsibility)

Kruger et al (2013) find that 5% of delays to freight trains are caused by vehicle failures. An additional 26% are caused by 'operator' issues, the most common cause of which is given as 'late departure from freight terminal'.

RAMS analysis (above) finds that failure before mission is 6.64 times more likely than failure during mission.

Assuming that only those pre-mission failures occurring in the last 2 hours before departure will cause delays, and that the delays are 75% shorter on-mission than in the depot due to the proximity of shunting/marshalling facilities a

Vehicle-caused delays during mission	5.0%
Vehicle-caused delays before mission	2.1%

Assuming that 10% of 'vehicle' delays in this dataset are related to the locomotive, these reduce to:

Vehicle-caused delays during mission (wagons)	4.5%
Vehicle-caused delays before mission (wagons)	1.9%
TOTAL	6.4%

Thus out of all the delays whose cause is the responsibility of the operator ('operation' and 'vehicles'): 32% of all freight delays,

... the proportion caused by wagon failures is: 20%

Delays (IM's responsibility)

Kruger et al (2013) find that 8% of delays are due to infrastructure issues, and an additional 3% are due to 'planned track work'.

An analysis of defect statistics on Network Rail's GB network (D1.4 Table 3.11) indicates that approximately 16% of infrastructure defects are track defects of the types addressed by the SUSTRAIL track improvements.

Other types of common infrastructure defect not addressed by SUSTRAIL are: switch and crossing failures; level crossing failures; signalling and track circuit failures; overhead line equipment/power supply failures; and bridge strike

Thus, assuming that the 8% infrastructure defects are allocated by the various defect causes, the total % of freight delays due to SUSTRAIL-type track failures is:

Relevant track-caused delays 4.3% of all freight delays.

Secondary delays

Finally, it is important to recognise that many of the delays on the network are caused by delays to other trains, which have a 'secondary delay' impact on the freight trains that are our main focus.

Much of the delay in the category 'traffic management' used by Kruger et al (2013) is caused by conflicting movements, trains ahead, overtaking, crossing other routes and track scarcity/congestion.

Assuming that the timetable would be operable without delay if all trains ran exactly to time, and attributing this 'secondary delay' to the original primary causes in the same proportions we obtain:

Primary delay:	45%
Secondary delay	55%

Causes:	Primary	Secondary *(attributed):*	TOTAL	TOTAL Relevant Causes
vehicles	6.4%	*7.9%*	*14.2%*	23.8%
relevant track issues	4.3%	*5.3%*	*9.6%*	
other infrastructure issues	6.7%	*8.3%*	*15.0%*	
operations (not vehicles)	24%	*29.8%*	*54.0%*	
other	3%	*3.7%*	*6.7%*	
TOTAL	45%	55%	100%	

Hence 23.8% is the proportion of freight delays due to vehicle and relevant track issues.

Baseline delay data

Baseline (delay minutes):

15.8 mins per 100 train-km (ORR data 2014-15 Q3)

SUSTRAIL Scenarios

The changes in '% mission unsuccessful' in the RAMS analysis due to the SUSTRAIL vehicles and track are:

	Baseline	SUSTRAIL0	SUSTRAIL1	SUSTRAIL2
% mission unsuccessful	6.54%	4.58%	2.89%	4.21%

These include the pre-mission failures, which we considered above are likely to lead to smaller delays:

	Baseline	SUSTRAIL0	SUSTRAIL1	SUSTRAIL2
Pre-mission failures	6.46%	4.54%	2.87%	4.17%
Pre-mission failures (adjusted)	0.40%	0.28%	0.18%	0.26%
Failures during mission	0.08%	0.04%	0.02%	0.04%
All relevant failures	0.48%	0.32%	0.20%	0.30%

Assume that the number of delay minutes increases or decreases with the number missions that are not successfully completed, and the proportion of delay minutes affected by this are the relevant delay minutes = 23.8% of total.

Hence the predicted change in reliability due to the SUSTRAIL innovations is:

	Baseline	SUSTRAIL0	SUSTRAIL1	SUSTRAIL2
Delay mins,	15.8	14.6	13.6	14.4

Overview of SUSTRAIL impacts - inputs to UK Case Study

All per tonne km		Baseline	SUSTRAIL0	SUSTRAIL1	SUSTRAIL2	Source:		
	Units		(vehicle only)		(140kph)	5.1	5.2	5.3
Impacts on IMs	%change							
Track Maintenance and Renewal Costs		Base	-1.6%	-10.1%	-7.5%	Y		
Maintenance		Base	-0.8%	-2.4%	-1.8%	Y		
Corrective maintenance		Base	-0.6%	-0.6%	-0.3%	Y		
Preventive maintenance		Base	-0.2%	-1.8%	-1.5%	Y		
Renewals		Base	-0.8%	-7.7%	-5.6%	Y		
General renewals		Base	-0.8%	-7.8%	-5.7%	Y		
Investments/innovations		Base	0.0%	0.05%	0.05%	Y		
Track Access Charges (variable) - SUSTRAIL vehicles		Base	-10.4%	-17.4%	-15.2%			Y
Track Access Charges (variable) - other vehicles		Base	0.0%	-6.9%	-4.8%			Y
			for wagons					
		Baseline	SUSTRAIL0	SUSTRAIL1	SUSTRAIL2			
Impacts on Freight Operators	%change		(vehicle only)		(140kph)			
Freight Operators' costs		Base	-1.8%	-2.4%	-0.5%			
Vehicle maintenance costs		Base	-61%	-61%	-58%	Y		
Vehicle ownership costs		Base	46%	46%	46%	Y		
Freight operators' fuel costs		Base	No change	No change	3.7%		Y	
Other operating costs		Base	No change	No change	No change		Y	
Track Access Charges (variable) - SUSTRAIL vehicles		Base	-10.4%	-17.4%	-15.2%			Y
Track Access Charges (variable) - other vehicles			0.0%	-6.9%	-4.8%			Y
Freight service charges (money)		Base	-1.8%	-2.4%	-0.5%		Y	
		Base	-0.9%	-1.2%	-0.27%			
Impacts on Passenger Operators								
Path capacity benefits (UK Case Study only)		Base	0%	0%	*tbc*			
Impacts on End Users	%change							
Reliability (delay minutes)		Base	-8%	-14%	-9%	Y		
Journey time		Base	No change	No change	-7.5%		Y	
Freight service charges (money)		Base	-1.8%	-2.4%	-0.5%		Y	
Externalities								
CO2	%change	Base	No change	No change	3.7%		Y	
Local air	%change	Base	No change	No change	3.7%		Y	
Noise	decibels	Base	-12dB	-12dB	-11dB		Y	

APPENDIX 3: BULGARIAN CASE STUDY

This is contained in a separate Word Document.