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

SUSTRAIL

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Executive Summary

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 Business Case for a set of proposed innovations will be determined in this work package, Work Package 5.

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). There then follows work to ascertain the economic benefits of the change in freight costs and service characteristics for Freight Users, Operators, Infrastructure Managers and Government (D5.2).

A related strand of work is to examine the barriers to implementation of the SUSTRAIL innovations. Part of this is the understanding of technical and phasing issues which will be considered in deliverables 5.4 and 5.7. However a key economic interface between infrastructure managers and freight operators is the track access charge regime, that is payment by train operators to infrastructure managers for the incremental costs associated with running the train service. Such charges are the key mechanism by which infrastructure cost improvements are passed through to freight operators and, in turn, to freight users. Similarly suitable discounts in track access charges for different vehicle types can incentive the adoption of track friendly vehicles. This is an important incentive given that track friendly vehicles may imply higher capital costs for operators, and thus to build a financial case for operators to adopt these vehicles, reductions in on-going recurrent costs need to be present and access charges are such a recurrent cost (they are incurred whenever the vehicle is used).

The research within Task 5.3 has advanced the understanding of railway infrastructure marginal wear and tear costs associated with railway traffic and also researched how implementing price incentives (via differentiated access charges) has influenced operator behaviour.

New work has been undertaken in integrating the two main approaches to analysing what is the direct cost to the infrastructure manager associated with running additional traffic, namely the engineering and econometric approaches. Further new work has been undertaken to understand renewals costs and traffic disaggregation in the econometric approach. Finally, work has been undertaken to assess the effectiveness of existing experiences of access charge differentiation e.g. by vehicle characteristics.

These contributions push the research frontier, however, to be useful to the wider context of SUSTRAIL, have to be interpreted within the wider literature and EC charging principles such as Directive 2001/14.

There are a great variety of access charge systems within the EU, both in terms of the level of charges (cost recovery) and the characteristics of vehicles/routes/time of day etc that they are differentiated across. Further the EC directives on setting access charges, primarily 2001/14, imply that while charges should be based on direct (marginal) cost, mark-ups are allowed provided that they are non-distorting. Thus it is conceivable that many access charge systems could be compatible with the Directive. We do not concern ourselves as to whether each system is actually consistent with the Directive and proceed with the current access charge systems, both in terms of levels of changes and existing differentiation in each of the three case study countries as the ‘base case’.

In terms of enhancing the rail freight offering and incentivising the implementation of the SUSTRAIL innovations, the project requires access charges to:

1) Pass through infrastructure cost savings resulting from technological innovations to the infrastructure (WP4) to freight and passenger operators via lower track access charges and ultimately to freight and passenger users. Not all infrastructure cost savings are passed through, only the proportion which is variable with traffic as this reflects the change to marginal costs of running traffic.
2) Redistribute infrastructure cost savings to freight operators if freight operators utilise track friendly vehicles.

The principle that access charges should reflect the infrastructure damage (and thus cost) incurred from running a train service, implies that the whole cost saving of any infrastructure cost reduction should be fully reflected in changes in access charges. So if infrastructure costs decrease 5% across all vehicle types as a result of the SUSTRAIL infrastructure innovations, then access charges should fall 5% for all services. This effectively means that the whole of the saving relating to the proportion of cost variable with traffic is passed through to the operators of train services (both passenger and freight). This simply reflects that the cost to the infrastructure manager of remedy damage from a train service has fallen. Such a mechanism allows the proportion of infrastructure cost recovered from charges to remain the same before and after the innovations.

Implication: With respect to *Infrastructure* innovations, the proportionate change in infrastructure cost will be reflected in the same proportionate change in access charges relative to the base case.

With respect to infrastructure cost savings arising from innovations to the vehicle, the principle that access charges should reflect the damage (and thus cost) caused to the infrastructure from running the service implies that 100% of the infrastructure cost reduction should be passed through to operators as a reduction in access charges. However this reduction should be specific to those vehicles that do the lower amount of damage (as opposed to being applied to all vehicles).

Implication: With respect to *Vehicle* innovations the absolute change in infrastructure costs resulting from running the less damaging vehicles should be passed to the operators of those vehicles.

The above two strategies to adjust track access charges ensures that, with respect to infrastructure improvements, the cost recovery rate for the infrastructure manager remains the same and with respect to vehicle improvements, that operators pay to reflect the damage that they cause to the infrastructure.

Following the LCC analysis reported in D5.1 and aggregated to case study routes in D5.2, and some subsequent bespoke engineering damage simulation of the vehicle on the track undertaken in SUSTRAIL WP3, the access charge reductions (relative to the base vehicle(s)) are those shown in Table E.1.

Table E.1 Access charge reduction from base in each of the scenarios

	SUSTRAIL 0 – vehicle improvement	**SUSTRAIL 1 – vehicle and track improvement**	**SUSTRAIL 2 – vehicle track and speed improvement**
Vehicles within the SUSTRAIL vehicle class	10.4%	17.4%	15.2%
Other vehicles	0%	6.9%	4.8%

There is a distinction in the Table E.1 between the SUSTRAIL vehicle and other vehicles. All vehicles benefit from the track improvements (which reduce the level of infrastructure access charges). In addition, the SUSTRAIL vehicle requires a further discount because it does less damage to the track than the base vehicle.

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). There then follows work to ascertain the economic benefits of the change in freight costs and service characteristics for Freight Users, Operators, Infrastructure Managers and Government (D5.2).

A related strand of work is to examine the barriers to implementation of the SUSTRAIL innovations. Part of this is the understanding of technical and phasing issues which will be considered in deliverables 5.4 and 5.7. However a key economic interface between infrastructure managers and freight operators is the track access charge regime, that is payment by train operators to infrastructure managers for the incremental costs associated with running the train service. Such charges are the key mechanism by which infrastructure cost improvements are passed through to freight operators and, in turn, to freight users. Similarly suitable discounts in track access charges for different vehicle types can incentive the adoption of track friendly vehicles. This is an important incentive given that track friendly vehicles may imply higher capital costs for operators, and thus to build a financial case for operators to adopt these vehicles, reductions in on-going recurrent costs need to be present and access charges are such a recurrent cost (they are incurred whenever the vehicle is used).

1.2 Structure of this Deliverable

Following this introduction, Chapter 2 will review the existing track access charge structures in place in EC countries with specific emphasis on the three case study countries in SUSTRAIL; Britain, Spain and Bulgaria. The research conducted for this deliverable is then reported in the following Chapters 3-5, with conclusions presented in Chapter 6. The conclusions cover both implications for access charges for the SUSTRAIL Business Case and the wider policy recommendations from the research undertaken within the Task:

- Sub-Task 5.3.1 Engineering analysis (Chapter 3)
- Sub-Task 5.3.2 Econometric analysis (Chapter 4)
- Sub-Task 5.3.3 Evaluation of the effectiveness of access charges (Chapter 5)

- Conclusions: Recommendations for policy and assessment and implementation of SUSTRAIL innovations (Chapter 6)
- Annexes reporting in detail on the research in each Sub Task

Chapters 3 to 5 should be read as summaries of the research conducted. The detailed reporting of the work is contained within 6 Annexes at the end of the main Deliverable.

2. Existing access charge regimes and Research approaches

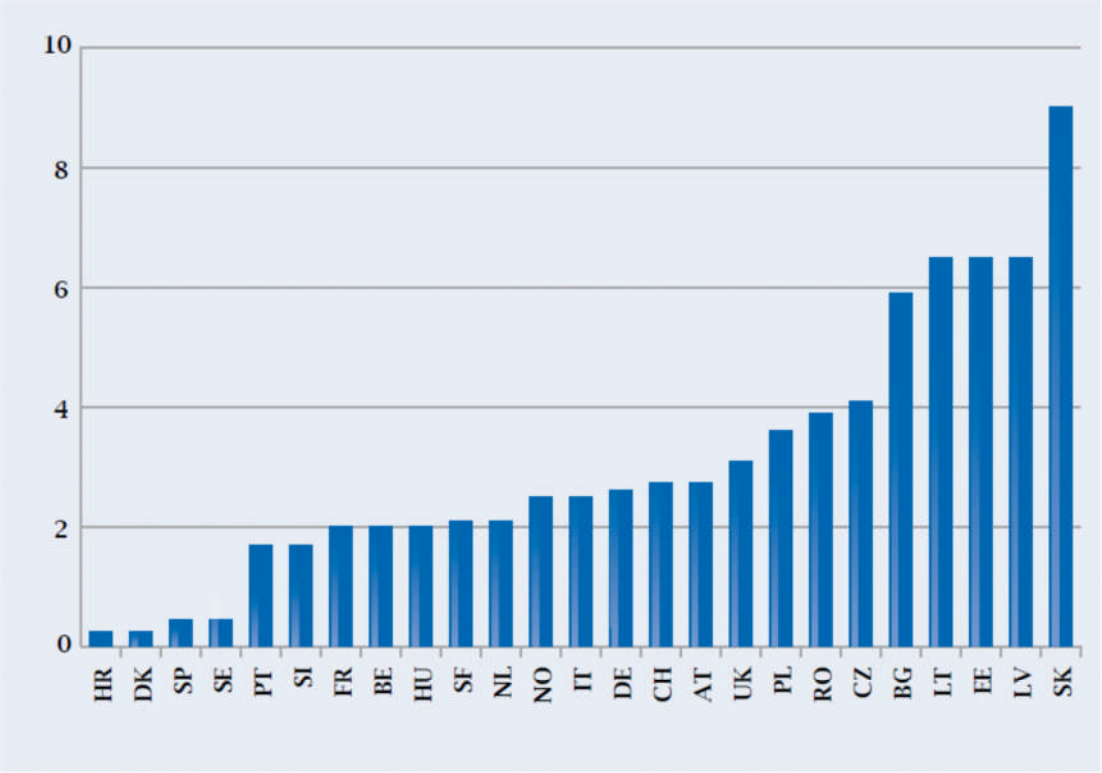
2.1 Existing Levels and Differentiation of Charges in the EC

Tables 2.1 and 2.2 show the charging structure and principles for countries within the EU. Table 2.1 is principally related to the EU15 countries and Table 2.2 principally relates to the New Member States, however there is some overlap. Currently there is a wide degree of charges:

- Charges to recover wear and tear are common across all countries, however the differentiation of this charge is very different from country to country. Some countries charge on a per tonne-km basis e.g. Sweden, while others charge per train-km e.g. Spain and others have a combination of them both e.g. Austria and Bulgaria.
- While further disaggregation (e.g. by detail traffic type) may yield something more comparable irrespective of whether train kms or tonne km m are used, again the extent of further differentiation in countries differs considerably. For example, Britain charges each vehicle comprising a train a different charge based on its relative track damage as determined through engineering, while Spain charges by train-km only differentiating freight trains into three groupings. In terms of cost reflective wear and tear charges, Austria and Britain have the most disaggregated systems (see Chapter 6 for more details)
- Many countries also have introduced several *ad hoc* amendments to their charging systems to incentivise various operator behaviours. For example, Germany's train path charge for freight traffic includes a component to take account of the noise-related impact of train operation. Some member states, such as Czech Republic, have plans to introduce rules for differentiating charges according to noise emissions
- Many countries, but not all, charge some kind of congestion charge and/or scarcity charges. Congestion charge reflect the marginal increase in the probability of delays from running services (for example Britain has such a charge) while scarcity charges reflect the opportunity cost (alternative use) of allocating a path to one operator rather than another. The exact approach taken to levy these charges differs throughout the countries which implement such charges.

Figure 2.1 presents a comparison as to the level of freight access charges across a number of European countries. What is clear is that there is a diverse range of levels of charges across countries

Figure 2.1 Access Charges for a typical 960 Gross Tonne Freight Train (Euros/Train-Km) in 2008



Source: ITF (2008)[1]

Table 2.1 Charging Structures and Basis of charges in Selected EU States

Country	Charge Type	Basis of Charge	Charge Type	Basis of Charge	Charge Type	Basis of Charge
Austria	Usage-related fee	a function of train km; based on cost of operation and differentiated by route categories and traffic type,	weight-dependent fee	a function of GTkm	wear-dependent fee	a function of traction unit factor, differentiated into 3 categories
	Congestion-dependent fee	supplement for congested infrastructure	Infrastructure optimisation incentive			

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[1] International Transport Forum, Charges for the Use of Rail Infrastructure, 2008. Paris.

Country	Charge Type	Basis of Charge	Charge Type	Basis of Charge	Charge Type	Basis of Charge
Belgium	Train path Line charge	a function of the path, the train, the priority, environmental impact, gross weight, time slot and speed	Train path installation charge	a function of the installation, the train, the importance of the installation and time spent occupying the installation	Administrative cost	
Britain	Variable usage charge	Charge which differs per vehicle determined engineering modelling	Coal spillage Charge		Freight only Line Charge	
	Freight Specific Charge		Capacity Charge			
Bulgaria	Track Access Charge	a function of train km and gross ton km, independent of the type of train and track/route section				
	Charge for requested but unused capacity					
Czech Republic	Track Access Charge	a function of train km and gross ton km, independent of the type of train and track/route section				
	Capacity charge	Possibility of price set by auction	Low Noise Bonus	differentiated by vehicle-type)	ETCS Discount	
Denmark	Infrastructure charge	a function of tonne km, length of line and weight of the train				
	Environmental subsidy		Bridge charges	for crossing the Great Belt and Oresund		
France	running charge	A function of train km, differentiated by freight and different categories of passenger train				

Country	Charge Type	Basis of Charge	Charge Type	Basis of Charge	Charge Type	Basis of Charge
	reservation charge	differentiated by passenger/freight, line category and line speed	Freight compensation		Special investment charges	
Germany	Usage based charge component	determined by Train Path Product and Route Category-including 4 different freight train path products)				
	Charge for requested but unused capacity					
Netherlands	Train Path Charge	a function of train km, differentiated by weight categories	HSL (High Speed Line) Levy	a function of train km		
	Reservation Levy (Charge for requested but unused capacity)		Surcharge for Scarcity of Capacity (per train path subject to competing calls on its use)			
Portugal	charges for essential services	a function of train km, differentiated by track section, type of service and traction unit				
	charges for unused requested capacity	a function of the period of pre-notification of the non-use and the volume of unused paths	Reservation charge (for ad hoc requests, differentiated by passenger and freight)			
Spain	Initial Charge	flat fees per train-km, differentiated into three types of freight train				
	Capacity Reservation Charge					

Country	Charge Type	Basis of Charge	Charge Type	Basis of Charge	Charge Type	Basis of Charge
Sweden	Track charge	based on gross tonne km, with differential rates for freight and passenger trains	Train Path Charge	based on km, and set at three different levels		
	Reservation Charge		Passage Charge	for freight crossing the Oresund Bridge and for trains entering and exiting Stockholm, Goteborg and Malmo at certain times	Emissions Charge	based on engine type and fuel usage
Switzerland (SBB)	Minimum Price					
	Low Noise Bonus	differentiated by wheel-size and brake-type	ETCS Discount			

Source: 2015 Network Statements, via www.railnet.eu

Note: Where The Basis for Charge entry is blank this implies that the Network Statement did not provide such justification

Table 2.2 Access Charges in New Member States and the characteristics of differentiation

	Bulgaria	Croatia	Czech Republic	Hungary	Poland	Romania	Slovenia	Slovakia
Country	**BG**	**HR**	**CZ**	**HU**	**PL**	**RO**	**SI**	**SK**
Type of system	**DR (direct costs)**	**DR**	**MC+ (marginal cost plus additions)**		**DR**			**Charges for regulated services shall be determined on the basis of variable economically eligible costs expended on train operation on Railway infrastructure.**
Line categories		**Six**	**Three: european, other nNational and reqional**	**Three**	**Six speed categories**	**V**	**regional - 4, main rail - 3**	**Six**
Train categories		**V**	**V**	**V**	**V**	**V**	**V**	
Freight train categories		**V**					**V**	
Pasenger train categories		**V**					**V**	
Reservation charges	**Per train -Km /for requested but unused capacity/**		**V**	**V**	**V**	**V**	**Fees for late cancellation or non-use of train paths that have been allocated in procedures of the network timetable interim changes**	**V**
Gross ton-Km	**V**		**V**	**V**		**V**		**V**
Train-Km	**V**	**V**	**V**	**V**	**V**	**V**	**V**	**V**
Per station stop			**V**	**Per passenger 4 type, per freight 2 type**	**Stop time**	**V**	**For stops of freight trains and stops of passenger trains**	**For passenger trains - 4 types,for freight trains - 3 types**
Charge for use of ET system	**Per MWh**	**Per train-km**	**Per gross ton-Km**	**per kWh**	**Per train-km**	**V**		**Gross ton-Km**
Remarks	**For combined transportation with block-trains - 10%, of freight vehicles with block-trains - 20%**				**25% discount of basic charge for minimum access to railway infrastructure for a journey of block train composed exclusively with wagons carrying intermodal**	**The increasing coefficients for the train paths ordered or modified later, upon the request of the railway undertaking**		

See Annex 6 for more details. “V” indicates that the characteristic is used to differentiate access charges

2.2 Access charges in the specific SUSTRAIL Case Studies

As can be seen in Figure 2.1 Spain (SP) generally has lower access charges for a given weight of train, while Great Britain (UK) has roughly average charges and Bulgaria (BG) has relatively high charges.

Details of each charging structure is summarised below:

Bulgaria

Source: ECMT (2005)[2] and ITF (2008)

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

Great Britain

Source: ECMT (2005) and ITF (2008) and Network Rail

- The principle of freight access charges is to recover the additional wear and tear costs associated with the infrastructure from running the freight service
- This is different to (franchised) passenger traffic which also pay a contribution to fixed charges
- Charges are levied per vehicle-km. However each vehicle has a different charge rate depending on its characteristics and how these influence infrastructure damage
- Damage determined by relative vertical forces applied by vehicles
- This factor is now being extended to take account of the propensity of the bogie to cause lateral rolling contact fatigue damage. Vehicles are divided between 7 different bands, according to bogie type, which affects the level of charging.
- Approximately 10% of maintenance and renewal expenditures are recovered through (variable) track access charges (Wheat and Nash, 2008)[3].

Spain

Source: ADIF Network Statement (2011)[4] and ITF (2008)

- Freight charges different to passenger charges

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[2] Nash, Chris, Bryan Matthews and Louis S. Thompson, “Railway Reform and Charges for the Use of Infrastructure,” ECMT, 2005, Paris.

[3] Wheat, P. and Nash, C (2008). *Peer review of Network Rail’s indicative charges proposal made as part of its Strategic Business Plan*. Report to ORR.

[4] ADIF (2011). Network Statement Update 2011. Available at http://www.adif.es/es_ES/index.shtml

- Charges comprise of a reservation charge per train path and then a train-km charge
- Charges differ by time of day

The implication of the above is that, just as with the wider comparison of charging regimes in the EU as a whole, across the three case studies there exists a variety of charging structures and levels. As such any hypothetical changes to the access charge regimes used in the SUTRAIL Business Case (to facilitate implementation of the innovations) need to be sensitive to this. This is discussed further in section 6.2 once the research results are presented.

2.3 Approaches to access charge research and motivation for the research work in SUSTRAIL

In the FP6 CATRIN project, approaches to measure the wear and tear cost of running traffic on railway infrastructure were characterised into two sets: bottom-up engineering approaches and top-down econometric approaches[5] Bottom-up engineering models refer to approaches which use engineering relationships to first determine the damage a vehicle causes to the infrastructure and then to utilise intervention rule and unit costs to determine the cost of remedial action with respect to that damage. These techniques can be used to allocate costs to specific vehicle types since the engineering models are sensitive to different vehicle characteristics.

The disadvantage of the engineering approach is that it models elements of work in a piece meal fashion and may miss important linkages within the system. As such it may under estimate marginal cost. It also relies on the availability of robust measures of unit costs for remedial work. Finally the engineering models themselves may rely on judgement which limits their applicability. Ultimately undertaking robust engineering bottom-up modelling of the railway system is a time and resource consuming task.

This contrasts to the econometric approach which uses realised cost data. As such it ‘lets the data speak’. However the econometric approach to date has been unable to disaggregate marginal cost between vehicles to any large degree. Also the econometric approach is not insusceptible to the influence of researcher judgement or the quality and consistency of the underlying data.

With the advantages and disadvantages of each approach in mind, the CATRIN project (Wheat et al, 2009[6]) considered that there are two ways of developing the previous research in

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[5] Link, H., Stuhlemmer, A. (DIW Berlin), Haraldsson, M. (VTI), Abrantes, P., Wheat, P., Iwnicki, S., Nash, C., Smith, A., CATRIN (Cost Allocation of TRansport INfrastructure cost), Deliverable D 1, Cost allocation Practices in the European Transport Sector. Funded by Sixth Framework Programme. VTI, Stockholm, March 2008

[6] Wheat P, Smith A & Nash C (ITS) (2009) CATRIN (Cost Allocation of TRansport INfrastructure cost), Deliverable 8 - Rail Cost Allocation for Europe. Funded by Sixth Framework Programme. VTI, Stockholm

this area. First the results of either approach can be used to validate the results of the other. This addresses the concern that both approaches are not insusceptible to judgement or problems with data quality. Second the two approaches could be combined to exploit the best attributes of each approach. In particular they concluded that the econometric approach was useful to determine the proportion of cost which was variable with traffic. The engineering approach could then be used to allocate this cost to vehicles through the modelling of damage caused to the infrastructure from use of each type of vehicles.

The work in Sub-Tasks 5.3.1 and 5.3.2 continue this research in two ways. Firstly Sub-Task 5.3.1 (reported in Chapter 3) explores a more refined combination of engineering and statistical analysis. The Sub-Task also includes a review of existing best practice in the engineering field to demonstrate that the engineering modelling tools exist to determine relative damage; at least by different damage mechanisms (the contribution of the research in the Sub-Task is to use statistical analysis to determine the cost associated with each damage type). Secondly, Sub-Task 5.3.2 develops the econometric work further in two respects. Further evidence is provided on the variability of the renewals element of infrastructure cost with respect to traffic. This is recognised as an under researched area and is actually a difficult area to model given the inter temporal natural of the determinants of renewal expenditure (see Chapter 4 for a fuller discussion). The work also revisits whether the econometric approach can distinguish between the impact of different traffic types on cost (as opposed to just considering one aggregate traffic type measured, typically, per gross tonne-km).

The final Sub-Task 5.3.3, reported in Chapter 6, is concerned with reviewing the extent to which existing differentiation of access charges has been effective in influencing the behaviour of operators and vehicle manufactures. This is important because for track access charges to be fully cost reflective, track access charging structures are likely to be complex, but understanding if such a complex system actually results in changes in behaviour as envisaged is something that is lacking in the literature. This work was a mixture of desk research and interviews with key industry stakeholders.

3. Sub-Task 5.3.1: Integrating engineering simulation and statistical modelling approaches

This chapter summarises the work undertaken in Sub-Task 5.3.1. The work is fully reported in Annex 1.

3.1 Introduction

It was intended at the time of writing the SUSTRAIL Description of Work (DOW) to carry out new analysis to inform the engineering formula used by the British Office of Rail Regulation (ORR) for allocating costs to vehicles based on the amount of vertical track damage that they do. Britain had (and still has) the most sophisticated approach to differentiated track access charges (with respect to wear and tear damage mechanisms) in Europe and it was envisaged that improving this methodology would be useful therefore in both the British and wider European context.

However, between writing the SUSTRAIL DOW and starting the project considerable new research had been carried out with regard to understanding the relative damage caused by different vehicles on the network. As a result of this new work, in 2013 ORR decided to replace the old formula with a new one (effective from 1st April 2014). It was therefore determined that the research frontier had shifted, with the more important challenge being to understand the relative cost of different damage mechanisms; with the damage mechanisms themselves being relatively well understood. A new approach, in the same spirit as the original DOW, was therefore developed. This new approach is focused on understanding the relative cost of different damage mechanisms and combinations of damage types.

3.2 Summary of previous approaches

To summarise briefly, there are two methods for producing estimates of marginal costs (Wheat and Smith, 2008). Top-down methods relate actual costs to traffic volumes, controlling for characteristics of the infrastructure. Bottom-up methods can be characterised as using some form of engineering model to estimate the damage inflicted by different types of vehicle on the network. Then assumptions can be made about the intervention / remediation required to deal with that damage, combined with estimates of unit costs of that remediation activity, to give the marginal cost estimates.

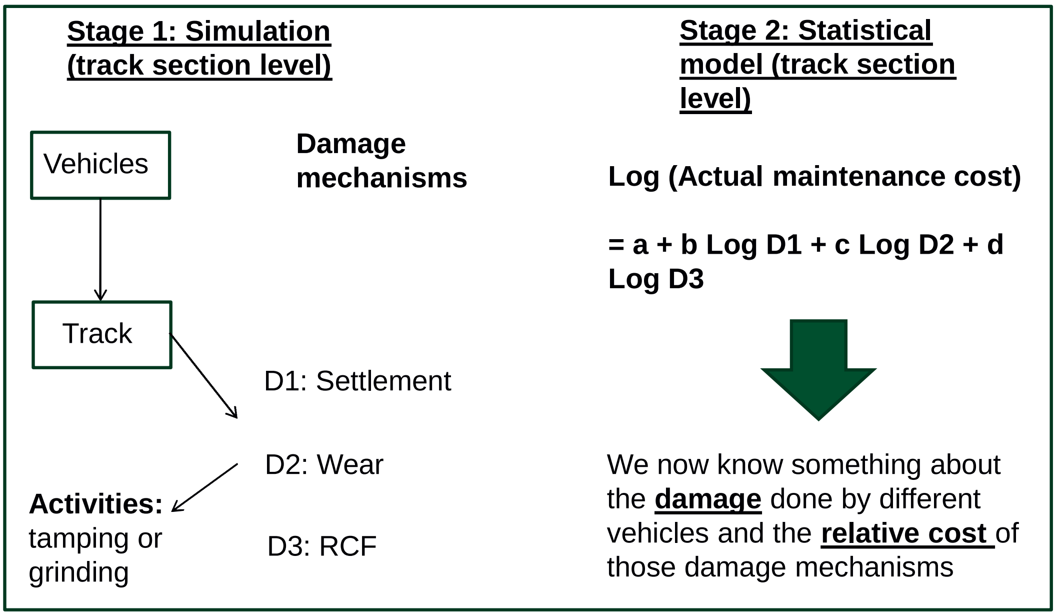
Both methods have strengths and weaknesses. The advantage of top-down methods is that they use actual cost data. Their weakness lies in the fact that it is likely to be very hard to capture the complexity of factors that will affect the relationship between traffic and cost, and in particular, it has proved difficult to get any sensible estimates of the relative cost of passenger and freight vehicles. The bottom-up method is very good at capturing complexity and it is possible to model and gain estimates of the relative damage of different vehicle types. The problem is how then to translate these damage estimates into cost, given that assumptions have to be used about what remedial activity is undertaken and when, and what the unit cost of that activity will be (the latter will vary considerably depending on, inter alia, the location, the nature of the job, the length of possession and the scale of the activity).

The research question therefore is as follows: how can we obtain better estimates of the relative cost of different damage mechanisms (which in turn can then help estimate the relative marginal cost of different vehicle types).

3.3 Methodology and data

Our proposed method consists of two stages. The first stage involves an engineering simulation exercise in which traffic (of certain vehicles and mixes of vehicles) is run down a network of known characteristics, to produce estimates of the resulting damage (denote these D1, D2, and D3, to represent the three main damage mechanisms: settlement, wear and rolling contact fatigue). For this exercise we choose actual track sections from Sweden where we have data on the maintenance and renewal costs, the traffic volumes and the infrastructure characteristics. The second stage involves establishing a statistical relationship between actual costs (maintenance and or renewal) for actual track sections on a network (in our case the Swedish network) and damage. The approach is summarised in Figure 3.1 below.

Figure 3.1: Overview of the methodology



We now know something about the **damage** done by different vehicles and the **relative cost** of those damage mechanisms

Our proposed approach is therefore positioned within the existing literature and would particularly enhance ORR’s approach to allocating variable costs to vehicle by providing new evidence on the relative cost of different damage mechanisms, in turn leading to better estimates of the relative marginal cost of different vehicle types. The approach could also be used to determine absolute marginal cost and cost variability levels to compare against the results of top-down and other engineering models.

3.4 Results

The first stage of the results shown here have been submitted as a conference paper to the Institute of Mechanical Engineers Stephenson Conference: Research for Railways. The second stage results were also presented at that conference though not included in the conference paper. Earlier versions of this paper have also been published in Rail Professional[7].

The output from the simulation runs are the vertical track force and ‘Tgamma’. The vertical track force was used to calculate a damage index, which is the vertical force raised to the power 1.21. This damage index is then used to calculate track settlement. Tgamma was used to calculate wear and RCF damage. All damages for each track section were measured per gross tonne-km. It should be noted that damage is estimated at a number of points along the section (that is, each section is split up into segments covering 40 or 200 metres for wear/RCF and settlement respectively). Thus it is necessary to produce a measure of overall damage for each of the three damage types over the whole section. In the case of wear and RCF these are the summations of the damage over each of the segments. For settlement, an average measure is taken, as a summation would not make engineering sense.

The summary damage measures per gross-tonne km are then scaled up based on the total annual gross tonne-km run by each of the vehicle types (with assumptions made about the small balance of traffic comprising other vehicles) in order to produce an annual total estimated damage. It is this measure that can then be related to annual costs in the second stage of the modelling. The summary, total damage measures are shown in Table 1 for a small sample of the track sections modelled to illustrate the outputs of this stage[8].

The damage measures in Table 1 are thus summary, total simulated damage measures per section, per year for a sample of the sections modelled. In total we modelled 45 track sections. In stage 2 of the methodology, the objective is to relate the maintenance (and also renewal) costs to these damage estimates. In carrying out this exercise it is important to control for factors such as the length of section and the characteristics of the section, as this could affect the cost of rectifying damage, quite apart from the damage itself. This control is akin to including track length and traffic volumes, alongside track characteristics variables in the rail infrastructure marginal cost studies in the wider literature (for example, Wheat, Smith and Nash, 2009). In terms of a priori expectations, there may be scale economies which, for a given level of damage, reduce the cost of rectification; likewise, rectification costs may be different depending on the track standards required for different levels of permitted linespeed.

We adopt a relatively simple functional form to illustrate the approach. Tables 2 and 3 shows the results from two of the models estimated.

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[7] Smith, A.S.J., Wheat, P.E., Iwnicki, S. and Odolinski, K (2014), ‘What are the costs of an extra service?’, Rail Professional, February 2014, Issue 199, pp. 79-81.

[8] Note the results in this table differ slightly from those submitted to the Stephenson Conference due to small changes in the approach to scaling up the damage measures to reflect the total traffic running on the section.

Table 1 – Total settlement, wear and RCF

Track section no.	Vehicle	Loading condition	Settlement	Wear	RCF
629	RC2	Laden	8 124 944	241 185 202	779 506
	RC4	Laden	12 224 247	359 302 285	1 130 643
	Wagon 1	Tare	84 876	1 760 971 694	689 436
		Laden	51 855 441	806 124 839	6 170 866
	Wagon 2	Tare	6 484	5 819 123	61 751
		Laden	592 918	4 485 641	50 996
	Other	Tare/Laden	11 545 155	503 358 037	1 407 044
	Total		84 434 065	3 681 246 822	10 290 242
326	RC2	Laden	1 062 205 791	42 806 064 383	61 939 846
	RC4	Laden	1 084 876 192	43 449 915 719	61 865 695
	Wagon 1	Tare	338 937 865	2 833 678 900	30 219 139
		Laden	20 793 210 944	330 970 869 899	2 518 502 686
	Wagon 2	Tare	1 100 101 751	3 942 329 362	13 278 398
		Laden	3 685 347 475	8 826 016 918	60 725 290
	Other	Tare/Laden	3 363 990 468	51 881 304 524	329 214 667
	Total		31 428 670 486	484 710 179 705	3 075 745 722
821	X11	Tare	6 769 439	11 957 134 380	33 596 643
	X11	Laden	30 477 723	42 540 754 012	107 525 747
	X31	Tare	39 931 083	71 292 886 957	198 891 518
	X31	Laden	238 622 178	336 159 732 011	846 669 702
	Other	Tare/Laden	275 666 389	318 566 454 424	812 143 205
	Total		591 466 811	780 516 961 784	1 998 826 815
654	X12/14	Tare	0	0	0
	X12/14	Laden	793 106 283	9 911 293 329 729	370 551 152
	Other	Tare/Laden	734 645 658	8 764 365 897 263	358 274 066
	Total		1 527 751 941	18 675 659 226 991	728 825 218
652	X12/14	Tare	18 938 296	1 877 652 983	14 033 850
	X12/14	Laden	1 560 901 574	90 945 803 045	940 090 049
	Other	Tare/Laden	3 193 816 442	421 837 633 064	1 321 158 708
	Total		4 773 656 311	514 661 089 091	2 275 282 607

Table 2: Estimation results, model 1

	Coef.	Std. Err.	T	P>t	[95% Conf.	Interval]
Constant	16.4467	0.1746	94.18	0.000	16.0940	16.7994
Wear	0.0670	0.0441	1.52	0.137	-0.0221	0.1560
Rcf	0.0023	0.0930	0.02	0.981	-0.1856	0.1902
Settlement	0.2401	0.0881	2.72	0.009	0.0622	0.4181

R^2=0.3787, Adj. R^2=0.3333, Mean VIF=2.08

Table 3: Estimation results, model 2

	Coef.	Std. Err.	t	P>t	[95% Conf.	Interval]
Constant	16.3307	0.1669	97.83	0.000	15.9925	16.6689
Wear	0.0434	0.0399	1.09	0.283	-0.0374	0.1242
Rcf	-0.0509	0.0851	-0.60	0.553	-0.2234	0.1216
Settlement	0.1972	0.0824	2.39	0.022	0.0301	0.3642
Route tl	0.3193	0.1546	2.06	0.046	0.0060	0.6327
Qualave	-0.5089	0.3122	-1.63	0.112	-1.1415	0.1237
Settlement*Qualave	-0.3646	0.1348	-2.70	0.010	-0.6378	-0.0914
Qualave^2	-0.3712	0.1803	-2.06	0.047	-0.7365	-0.0058

Model 2: R^2=0.5560, Adj. R^2=0.4720, Mean VIF=3.18

In these tables the variables wear, Rcf and settlement are the three damage measures resulting from the first stage modelling. Route tl is the length of the section. Qualave is a quality class variable, which is mainly dependent on the permitted linespeed. Other variables are squared or interaction terms on those core variables.

In model 1, maintenance cost is modelled as a function of the three damage mechanisms (all variables transformed into natural logarithms). In model 2 we include route length and average quality class as control variables. We start with a full translog model and test the Cobb-Douglas restrictions.

The conclusion from models 1 and 2 is that it is important to control for the size of the section and also the characteristics of the infrastructure (e.g. the quality class variable, which principally reflects the permitted linespeed on the section). There may be scale economies which, for a given level of damage, reduce the cost of rectification; likewise, rectification costs may be different depending on the track standards required for different levels of permitted linespeed. That said, in both models 1 and 2, and particularly in model 2, it is hard to obtain statistically significant estimates of the cost elasticity with respect to the different damage mechanisms. The settlement elasticity is the largest in absolute terms and is statistically significant at the 1% and 5% levels in models 1 and 2 respectively. In model 1 the wear coefficient is close to being significant at the 10% level, but the RCF coefficient is highly insignificant. In model 2 both the wear and RCF coefficients are highly insignificant and the RCF coefficient is wrong sign (though statistically insignificant). The coefficient on settlement is fairly stable between the two models.

The problem of not being able to obtain statistically significant estimates of the different traffic types may result from only having 45 observations (this being the maximum that could be carried out for this project). We note that the previous literature relating costs to traffic has likewise struggled to obtain statistically significant elasticities for different traffic types.

Since the model includes only maintenance costs, it is not entirely surprising that only settlement damage is significant in the model, since tamping is the remediation action for settlement (and this cost is included in maintenance). By contrast, remediation action for wear and rolling contact fatigue includes rail replacement (which is a renewal cost), though grinding and re-profiling may also occur which is included in maintenance costs. Whilst in principle renewal costs can also be included in this methodology, in practice, as we are working at track section level, many of the sections have zero renewals costs. We therefore do not report a model with the dependent variable constructed based on the sum of maintenance and renewal costs (though we did estimate such a model and it produced results very similar to the maintenance only model). A corner solution approach, as set out in Andersson, Smith, Wikberg and Wheat (2012) is needed for renewals at section level, and such an approach is beyond the scope of the current study.

It is worth noting the overall cost variability with respect to damage resulting from the models run. At the sample mean the sum of the elasticities on the three damage mechanisms is in the range of roughly 20-30%. The CATRIN project (Wheat et. al., 2009) found a range of (mean) maintenance elasticities with respect to traffic of broadly 20% to 35%. However, it was also found, as expected, that the elasticity increased with traffic density (tonne-km per track-km). Whilst the elasticities in this paper are elasticities with respect to damage and the elasticities in the CATRIN project are elasticities with respect to traffic, clearly damage results from tarffic running on the network. Therefore, in terms of the proportion of cost variable with traffic / usage we consider that our results are in line with previous estimates in the literature.

Turning to the computation of marginal cost, the results are shown in Table 4.

Table 4: Average Marginal costs ÖRE (1 ÖRE =1 SEK/100)

	Variable	Obs	Mean	Std. Dev.	Min	Max
Model 1:	Wear	45	0.003	0.022	0.000	0.146
	RCF	45	0.009	0.039	0.000	0.261
	Settlement	45	0.065	0.184	0.002	1.095
Model 2:	Wear	45	0.003	0.022	0.000	0.151
	RCF	45	-0.262	1.374	-9.254	-0.003
	Settlement	45	0.053	0.202	-0.008	1.333

These are based on the average of the marginal costs computed for each track section

Since the elasticities in model 1 were all positive, we use model 1 to draw conclusions. The results suggest that settlement is the most costly damage mechanism, with a marginal cost that is just over seven times that of rolling contact fatigue and twenty-one times that of wear. RCF damage is in turn three times more costly, per unit of damage, than wear. In interpreting these findings it is important to remember that the estimation is based on 45 sections and not all the parameter estimates were statistically significant. Further, as noted, the dependent variable only includes maintenance. If renewal had been included in the model, thus permitting a more complete comparison of relative costs, it is likely that the relative damage costs would be very different.

This is, to our knowledge, the first time that the relative cost of damage mechanisms has been estimated in this way, based on a combination of engineering simulations, combined with actual cost data. As noted earlier, whilst engineering models are adept at estimating damage, the challenges is to convert damage into cost. The traditional ”bottom-up” approaches faces many problems, since an assessment needs to be made of the remediation activity that will be done, and its timing, and then the unit cost of these activities. Depending on the nature of the network, and the combination of the damage types, these estimates could vary widely. The advantage of our top-down approach is that it uses actual cost data to derive relative marginal costs.

Table 5 provides a simple illustration of how this approach might be useful for track charging purposes. For three vehicle types, running on a given network, estimates of damage can be obtained. The problem noted in previous approaches is that whilst these relative damage measures can be predicted with reasonable accuracy based on simulation models, it is then not clear what the relative costs will be. The latter is important for infrastructure managers to know and, given European legislation, to support track access charging regimes differentiated by vehicle.

The different vehicles in Table 5 produce different amounts of the different types of damage mechanisms; some resulting in more of one type of damage and less of other types. The final column of the Table shows that, by using the relative marginal costs coming out of model 1, reported above, we can constructed a weighted damage measure, weighted according the relative marginal cost. Since settlement is the most damaging mechanism, according to model 1, then vehicle 2 has by far the highest cost weighted damage index, and thus would attract a higher access charge. Of course, as noted, we are not claiming that this is a definitive result, for the reasons set out earlier, but put this forward to demonstrate the potential power of the approach.

Table 5: Illustration of the outputs of the methodology

	Wear	RCF	Settlement	Simple Sum of Damage Measures	Cost-weighted Damage Index
Vehicle 1**	10	20	15	45	385
Vehicle 2	5	25	25	55	605
Vehicle 3	20	5	10	35	245
Relative marginal cost (Wear = 1.00)*	1	3	21		

* This is based on the results of model 1, with the marginal cost of wear normalised to unity.

** The damage numbers are simply created for the purpose of the illustration for three hypothetical vehicle types.

3.5 Conclusions

This paper fills an important gap in the literature concerning the translation of damage measures into measures of the cost of remediation of damage. It does so by combining engineering simulation models (stage 1), which are well understood, with top down econometric methods linking cost and damage (stage 2). This second stage is the first time a relationship between actual cost and damage has been attempted using track section data. The approach has been implemented using Swedish data. The combination of these two approaches provides a new methodology for comparing the relative cost of damage done by different vehicles on rail infrastructure, which in turn can be used to inform track access charges differentiated by vehicle-type.

We consider that our research has demonstrated the feasibility of the approach. Whilst the time taken to undertake the engineering simulations is not trivial it is also not prohibitive. The econometric results indicate that it is possible to obtain sensible relationships between cost and the different damage mechanisms; though the statistical significance of some of the findings has been limited in this case by the relatively small sample size. Bringing together then, information on damage and relative cost of the different damage mechanisms, is potentially a powerful means of obtaining cost information that can be used to produce vehicle-differentiated track access charges. The principal advantage of this approach, compared to existing methods, is that it is based on actual cost data on actual track sections, as opposed to assumptions about the remedial work done and the unit costs of those activities; these assumptions can be potentially hard to justify and are highly uncertain.

We find that settlement is the most costly of the three damage mechanisms, followed by RCF and then wear, with settlement being approximately seven times more costly that RCF and RCF approximately three times more costly than wear. As noted we caveat this finding because of the relatively small sample and the fact that we have only been able to include maintenance costs in the approach. Taken at face value, this result suggests that vehicles resulting in more settlement and RCF damage should attract higher track access charges, though of course the results are only indicative. The overall variability of cost with respect to damage – of between roughly 20-30% is also in line with previous evidence on the variability of costs with respect to traffic for maintenance of around 20-35% (from the CATRIN project). This finding is important for charging purposes as it establishes in aggregated the amount of cost that variable access charges should be seeking to recover.

Whilst the approach has been shown to be feasible, we offer some comments about future research. Further work might focus on generating more observations, exploiting panel data. This approach should be feasible using Swedish data, though it would be a significant research project. The approach is in principle applicable to many European railways where track section data is available, though again we do not claim that the approach is straightforward or trivial. That said, given that previous approaches rely in any case on engineering simulations, which is the most time consuming aspect of the work, we consider that the econometric second stage has a potential to contribute greatly to better understanding of the relative marginal cost of different vehicle types (and indeed different vehicle types running on different types of infrastructure); particularly in view of the well-established problem with existing approaches to translating damage into cost.

4. Sub-Task 5.3.2: Econometric Analysis

4.1 Introduction

This chapter summarises the research undertaken under Sub-Task 5.3.2. The structure of the Chapter is firstly a brief introduction to the econometric approach to marginal wear and tear cost estimation. Then the outstanding research issues are briefly reviewed from the perspective of how the work builds on previous work, namely the FP6 project CATRIN. The following three sub-sections provide a review of each of the case studies and their findings. Key policy conclusions are discussed in the final chapter, section 6.1.

4.2 The econometric approach

The econometric studies report on estimations of cost functions using data on different geographical parts of the railway. Thus data many be available at such aggregation as track sections (such as in Swiss case study) or at zones (such as recent work in Sweden and the British case study). Once the cost function is estimated it allows us to derive the marginal cost associated from increasing traffic.

A cost function in economics relates cost to the drivers of cost which in this case are the traffic using the infrastructure and characteristics of the infrastructure such as it's length and quality.

To illustrate the method, consider a variable cost function which has double log functional form and two traffic types A (passenger) and B (freight):

$$\ln(C_i) = \alpha + \beta_1 \ln(Q_{Ai}) + \beta_{11} \ln(Q_{Ai})^2 ... + \beta_2 \ln(Q_{Bi}) + \beta_{21} \ln(Q_{Bi})^2 + \gamma \ln(I_i) \qquad (4.1)$$

Where

- C_i is the maintenance and, if applicable, renewal cost per annum for section or zone i;
- Q_i is outputs for section or zone i ; here in terms of traffic with vehicles of different types (A and B). In the above formulation a squared term is also included; and
- I_i is a vector of fixed input levels for section or zone i – these include the infrastructure variables (e.g. track length and track quality).

Given that we succeed in the estimation of the function in (1) the marginal cost can be derived as the product of the average cost (AC) and the cost elasticity ε. In the example above we included the square of the traffic variable Q_A which means that the elasticity with respect to traffic type A is non-constant if β_{11} is non-zero.

$$\varepsilon_A = \frac{dC}{C}\frac{Q_A}{dQ_A} = \frac{d\ln C}{d\ln Q_A} = \beta_1 + 2\beta_{11}\ln(Q_A) \qquad (4.2)$$

In the remainder of this report we refer to this elasticity as the usage elasticity with respect to traffic A. The average cost is simply the cost C divided by the relevant output variable Q. However, the average cost will depend on the traffic volume Q. Therefore the marginal cost will usually depend on the traffic volume.

$$MC = \varepsilon AC = \varepsilon\frac{C}{Q_A} = [\beta_1 + 2\beta_{11}\ln(Q_A)]\frac{C}{Q_A} \qquad (4.3)$$

Two additional observations should be highlighted.

- First, while the theoretical specification above includes different outputs in terms of different vehicle types, the reality is more problematic. This is because in reality, the correlation between different outputs is so strong that the econometric model has difficulty in distinguishing between the effect from different vehicle types. This issue has been re-examined in the Swiss case study which contains seven traffic types with encouraging results
- Secondly, input prices are often assumed to be constant between sections or areas and thus are not included in the studies (input prices are theorectically required in a cost function in the absence of this assumption).

In addition to the double log functional form, the Swiss case studies has used the Box-Cox functional form. This is given by replacing the log (ln) transformation of variables by the Box-Cox transformation given by:

$$w^{(\lambda)} = \frac{w^{\lambda} - 1}{\lambda} \qquad (4.4)$$

where w is the variable to be transformed and λ is a parameter to be estimated. This transformation is flexible since it nests both the log transformation ($\lambda \to 0$) and the linear transformation ($\lambda = 1$). This means that there is a natural statistical test of the appropriateness of the double log functional form. As with the double log model, both usage elasticities and marginal costs can be derived from this model post estimation. However, even in models with no second order terms for traffic (that is, ignoring the squared terms in equation (1)), the Box-Cox models allow usage elasticities to vary with traffic levels since:

$$\varepsilon_A = \frac{dC}{C}\frac{Q_A}{dQ_A} = \frac{d\ln C}{d\ln Q_A} = \hat{\beta}_1(Q_A{}^{\hat{\lambda}})/(C^{\hat{\lambda}}) \qquad (4.5)$$

This functional form nests several functions as special cases. It lets the data determine the appropriate functional form without (necessarily) having to rely on second order approximations as with the Translog function which requires more parameters to be estimated. Thus the Box-Cox is potentially very flexible while still relatively parsimonious which has the benefit of fitting the data well and yielding relatively precise parameter estimates.

As with the double log models, marginal costs are computed as the product of the estimated elasticity and fitted average cost.

4.3 Building on the State-of-the-art: Outstanding research issues from the CATRIN project

The econometric approach was first used in railways by Johansson and Nilsson (2004[9]) in the FP5 project UNITE. From there it was widely applied in the FP6 project CATRIN (Wheat et al, 2009). The CATRIN project was an attempt to conduct several case studies using as similar as possible methodology and cost definitions. As such a key aim of the work was to produce a set of recommended values that could be used to determine marginal cost in countries where full econometric analyses were not possible.

It was found that the elasticity of cost with respect to traffic, which can be viewed as the proportion of cost found to vary with traffic, was much more comparable across countries, as opposed to comparing marginal costs directly. As such the preferred generalisation method was to produce recommended cost elasticities and then suggest that countries compute marginal cost as the product of the elasticity and average cost (cost divided by traffic). This follows since the elasticity is (by definition) the ratio of marginal cost to average cost and thus marginal cost is the elasticity multiplied by average cost.

The CATRIN project was able to provide elasticity values with respect to maintenance cost by low, medium and high traffic densities (as measured by tonne-km per track-km). These are given below:

Table 4.1 Recommend cost elasticities from the CATRIN project

Traffic density classification **Traffic density range (tonne-km / track-km per annum)**	**Low** **< 3,000,000**	**Medium** **3,000,000-10,000,000**	**High** **> 10,000,000**
Recommended Usage Elasticty	0.2	0.3	0.45

Full details can be found in Chapter 7 of Wheat et al (2009).

However there were two key limitations of the CATRIN recommendations:

1) Evidence on the variability of renewals costs with respect to traffic was much weaker than that for maintenance costs. In particular only two case studies considered

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[9] Johansson, P. and Nilsson, J. (2004). “An economic analysis of track maintenance costs”. *Transport Policy* **11(3),** pp. 277-286.

renewals costs (combined with maintenance), as opposed to six for maintenance only. Further it is widely accepted that it is more difficult to model renewals costs because railway assets have long lives and so renewal activity depends on cumulative traffic (as opposed to just todays traffic). Further, renewals expenditure for a given track section maybe lumpy in nature again reflecting the long asset lives. CATRIN recommended an elasticity for the renewal cost category of 0.35 although it was caveated that this was much less certain than the maintenance only result (based on 0.28 to 0.35 for the maintenance and renewal cost category combined).

2) When models included passenger and freight traffic types separately (as opposed to only including total traffic), there was little consensus as to whether marginal costs were substantially greater for one compared to the other or whether the difference was more subtle (per gross tonne-km). This is demonstrated by Table 4.2 from the CATRIN project which show passenger to have higher marginal costs per gross tonne-km than freight but at dramatically different ratios between the three studies which disaggregated traffics.

Table 4.2 Marginal cost estimates by passenger and freight from the CATRIN project, Euro per thousand gross tonne-km

	Marginal Cost			
Country	**Passenger**	**Freight**	**Total (for comparison)**	**Ratio of Passenger to Freight**
Sweden	1.058	0.140	0.461	7.559
Switzerland (Maintenance)	0.265	0.184	0.321	1.438
France	2.103	0.692	1.390	3.036

Source: Wheat et al (2009)

The implication is that more evidence is needed, and the Swiss case study is an attempt to disaggregate traffic into two and then seven traffic types.

The key contributions of each of the three case study areas is now reviewed.

4.4 Swedish evidence

As set out in the DOW, there was no new econometric research undertaken in Sweden as part of this Sub-Task. However, post the CATRIN project, various work has been conducted and so it was appropriate to review such work. The full review of the work is contained within Annex 2.

There have been a number of methodological approaches applied to data in Sweden. These include panel data econometrics for the analysis of maintenance costs (as used in the Swiss Case Study in SUSTRAIL) and for renewal costs both Survival Analysis and corner solutions modelling. There has also been dedicated analysis of operations costs (primarily snow removal) which is relatively unique in the literature. Table 4.3 summarises the approaches and results in terms of implied cost elasticities.

Given the focus of SUSTRAIL on evidence for renewal cost variability and for disaggregation of cost variability between traffics, we major on this aspect of the findings here (the Annex covers more elements).

Table 1 - Previous marginal maintenance, operation and/or renewal cost studies on Swedish data

Studies	Cost category	Output	Data type	Functional form	Mean cost elasticity w.r.t. output
Johansson and Nilsson (2004)	Maintenance	Gross tonnes	Panel data, pooled OLS	Translog	0.17
Andersson (2006)	Maintenance	Gross tonnes	Panel data, pooled OLS	Double log, quadratic terms	0.21
	Operation	Trains	Panel data, pooled OLS	Double log, quadratic terms	0.37
	Maintenance and renewals	Gross tonnes	Paneld data, pooled OLS	Double log, quadratic terms	0.26
Andersson (2007)	Maintenance	Gross tonnes	Panel data, fixed effects	Double log, quadratic and cubic terms	0.27
	Operation	Trains	Panel data, fixed effects	Double log, quadratic and cubic terms	-0.014
	Maintenance and renewals	Gross tonnes	Panel data, fixed effects	Double log with quadratic and cubic	0.133
Andersson (2008)	Maintenance	Gross tonnes	Panel data, fixed effects	Double log, quadratic and cubic terms + renewal dummy	0.26

Studies	Cost category	Output	Data type	Functional form	Mean cost elasticity w.r.t. output
	Operation	Trains	Panel data, fixed effects	Double log, quadratic and cubic terms + renewal dummy	-0.04
Grenestam and Uhrberg (2010)	Operation	Trains	Panel data, fixed effects	Double log, quadratic term	0.182
Andersson and Björklund (2012)	Renewals	Gross tonnes	Panel data, survival analysis	log-likelihood, no higher order terms	-0.3[a]
Andersson et al (2012)	Renewals	Gross tonnes	Panel data, corner solution models	double log in outcome equation, no higher order terms	0.55

[a] Elasticity of expected life time with respect to traffic volume – a negative implies costs increase with traffic

4.4.1 Renewals modelling

Renewal costs were estimated within the aggregate of renewals and maintenance costs in Andersson (2007) using a standard econometric cost function treatment. This resulted in an insignificant cost elasticity. The lumpy and cyclical nature of renewals makes this kind of model specification challenging, and this approach requires sufficient variation in the data and sufficient variables to characterised the infrastructure, to yield appropriate results. A different approach is used in Andersson and Björklund (2012). They use survival analysis on track renewals costs (i.e. only the rails, sleepers and ballast costs). They calculate the marginal track renewal costs as the change in present values of renewal costs due to a premature renewal caused by increased traffic volumes. They find a weighted average marginal cost of SEK 0.0021 per gross tonne-km.

A different approach is used in Andersson et al. (2012), in which corner-solution models are estimated using data on 190 track sections over 11 years. The cost variable is again track (only) renewal cost. The preferred two-part model (originally proposed by Cragg 1971) consists of a selection equation (probability of renewal) and an outcome equation (quality of renewal), which results in a weighted marginal cost of SEK 0.009 per gross tonne-km with an cost elasticity of 0.55. This is notably higher than SEK 0.0021, and Anderson and Björklund (2012) stress that they use an average cost estimate for track segments, while observation specific costs at a more aggregate level (track section level) are used in the other study.

The Andersson et al (2012) also provided elasticity estimates for track sections with different characteristics as shown in Table 4.4. This demonstrates that the elasticity of renewals cost with respect to traffic is increasing with traffic density, which is intuitive, given we would expect traffic relate costs to increase as a proportion of total cost with more traffic. It also shows that improving track capability (measured by rail weight) decreases marginal cost per tonne-km and the older the track, the higher the impact of traffic i.e. greater marginal cost associated with older track (measured by switch age in this case).

In sum the evidence from Sweden is that from using one method over another, average marginal costs of renewal are four times greater. Taking factoring the elasticity from Andersson et al (2012) by this ratio indicates an approximate cost elasticity from the survival analysis of Anderson and Björklund (2012) to be around 0.13. This is obviously a big discrepancy and a natural question is to ask which is to be believed. Firstly it should be noted that the cost category considered is track renewals costs i.e. the costs associated with rail, sleepers and ballast. These would, a priori be expected to have large usage related costs. Secondly Anderson and Björklund (2012) noted that in their modelling they relied on a network wide average cost renewal estimate which could have skewed their results. As such it is reasonable to give more weight to the Andersson et al (2012) work.

Table 4.4 Variations in marginal costs and elasticities by rail weight, switch age and tonnage density

	Marginal cost (SEK per Gross Tonne-km)	**Elasticity**	**Number of observations**
Rail weight (kg)			
<45	0.077	0.602	249
45–55	0.02	0.548	1014
>55	0.007	0.523	396
Switch age (years)			
0–10	0.006	0.586	191
11–20	0.013	0.536	683
21–30	0.028	0.544	538
>30	0.067	0.573	251
Tonnage	(mtgt)		
0–5	0.038	0.575	995
6–10	0.008	0.525	266
11–20	0.006	0.514	255
>20	0.007	0.487	146

Reproduced from Table 5 in Andersson et al (2012)

4.4.2 Distinction between passenger and freight traffic

There has been some work in Sweden examining whether freight trains have lower or higher marginal costs per gross tonne-km than passenger trains. Work by Andersson (2009) in the CATRIN project found dramatically higher marginal costs for passenger than freight based on maintenance only cost (ratio of seven to one, see Table 4.2 in this deliverable).

More recent work by Odolinski and Smith (2014) has estimated cost elasticities for passenger and freight traffic which imply much more comparative marginal costs. Unfortunately the passenger elasticity was not statistically significant which means there is a limit to the usefulness of this decomposition.

4.5 Swiss case study research

The Swiss study is reported in detail in Annex 3. It comprised an econometric study examining maintenance and renewal costs and relating this to seven traffic types (although for comparison models were run for a single aggregate traffic and for two traffic types (passenger and freight).

4.5.1 Data and approach

The data for the estimations are provided by the Swiss national railway company (SBB), who owns most part of the Swiss national railway network, including most important national and international railway tracks. The network is split in different track sections and transport nodes. Data on costs for maintenance and renewal costs as well as traffic density for the years 2003 and 2012 and for 80 track sections in each year. However, the tracks are not homogeneous; they differ in track length, rail and sleeper types, ballast, curvature, slope etc. As such, data has been obtained for each track section relating to physical information about the railway out of the SBB data system DfA (Datenbank für feste Anlagen).

The traffic types available comprised:

- InterCity/EuroCity
- Express trains/Interregio
- Regional trains
- Commuter trains
- Special passenger trains
- Freight Trains
- Special freight trains

The controlling infrastructure variables comprised:

- Track length (main track) [km]
- Mean maximum speed of passenger trains (km/h)
- Fraction of switch metres of total track length [%]
- Fraction of bridge metres of total track length [%]
- Fraction of tunnel metres of total section length [%]
- Fraction of radius metres <500m [%
- Fraction of slope > 2 percent [%]
- Fraction of track length with noise/fire protection [%]
- Supporting walls (m2) per km of track
- Fraction of sleepers with age > 25 years [%]
- Fraction of platform edge of total track length [%]

- Dummy for marshalling yards [0/1]
- Dummy for one-track sections [0/1]

A Box Cox model was estimated (see section 4.2 in this deliverable for a description) and an important methodological advancement was made in terms of appropriately including certain second order terms in the model (see section 2.3 in Annex 3).

4.5.2 Results: Cost elasticities

The results with respect to the cost elasticities of maintenance and renewal with respect to traffic are best summarised by Figures 4.1 and 4.2.

Figure 4.1 shows the cost elasticity estimates (averaged over all track sections) for the three models estimated. Model A is the model where traffic is measured as one aggregate variable (total gross tonne-km). Model B distinguishes passenger and freight gross tone-km separately. Model C includes all seven traffic types separately. What is show is the sum and breakdown of the cost elasticities. What is striking from this is two things. Firstly, the sum of the elasticities for each model is roughly the same; between 0.48 and 0.53. This is reassuring as this total represents the proportion of cost which is variable with traffic. Given each model uses the same cost data, the finding of consistency is intuitive.

The actual size of the elasticity (averaged gives) 0.5 indicates that 50% of maintenance and renewal costs are determined variable with traffic. In relation to past studies such as those referred to in Sweden and CATRIN in general this does look like it is at the high end. In particular in CATRIN there were two studies. One for Britain concluded an estimate of 0.49 which is almost identical to this estimate. However it was noted that the British study did not look at a full range of maintenance and renewals costs (the elasticity was scaled down to 0.35 to reflect this) However the other, which was actually a study in Switzerland found only 0.28. Both studies examined maintenance and renewal expenditure. The data in the revised Swiss study is more aggregated than in the previous study which might explain some of the difference (and there is an argument to prefer more aggregated data as it is closer to the aggregation where managerial decisions are made).

Figure 4.1 Summary of cost elasticity estimates from the three models estimated in the Swedish Case Study – averaged over all track sections

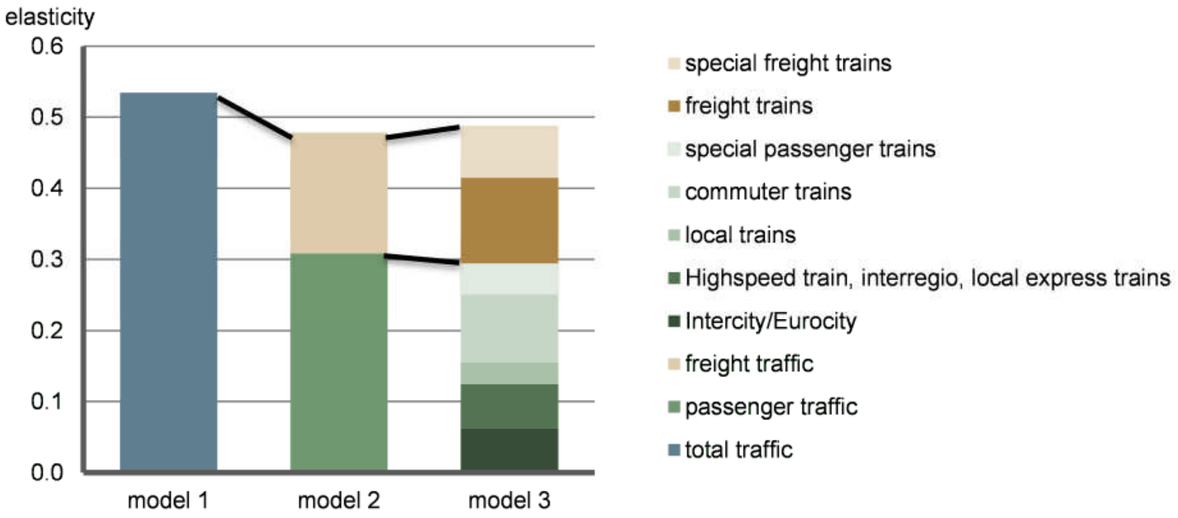
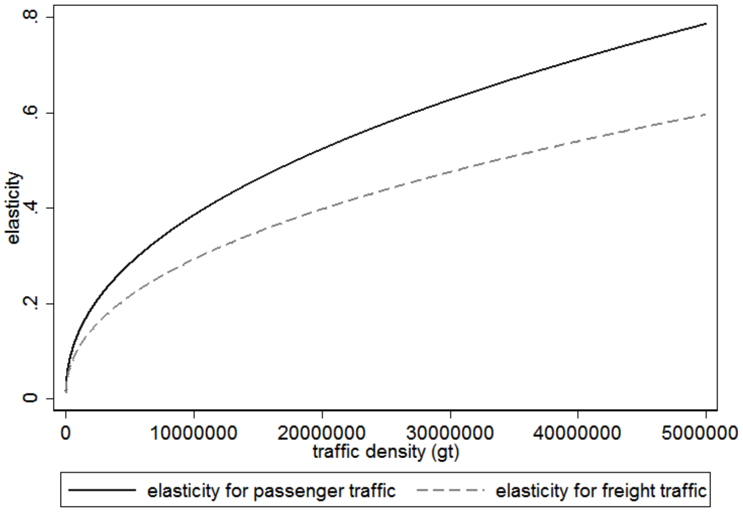


Figure 4.2 shows how the cost elasticities vary for Model B with the level of each traffic (passenger and freight). The results for models a and C are similar. The importance of this Figure is to highlight that the elasticities increase with usage, that is more of total maintenance and renewals costs are found variable with traffic as traffic increases. This is intuitive and gives us some assurance that the model is sensible.

Figure 4.2 Variation in Passenger and freight elasticity from model B (drawn holding infrastructure variables and other traffics constant)



4.5.3 Results: Marginal costs by traffic types

Table 4.5 shows the marginal costs estimated from the models (averaged over track sections).

Table 4.5 Marginal costs for different traffic types

Model	**Traffic**	**Marginal Costs[CHF/gtkm]**	**Average Costs[CHF/gtkm]**	**Cost ratio [in %]**
Model A	Total traffic	0.00270	0.00505	0.53455
Model B	Passenger traffic	0.00251	0.00812	0.30842
	Freight traffic	0.00226	0.01332	0.16991
Model C	Intercity/Eurocity	0.00130	0.02096	0.06196
	Express train, interregio, local express trains	0.00150	0.02397	0.06247
	Local trains	0.00320	0.10459	0.03059
	Commuter trains	0.00299	0.03074	0.09714
	Freight trains	0.00164	0.01364	0.12031
	Special freight trains	0.04051	0.55307	0.07324
	Special passenger trains	0.01887	0.44707	0.04222

The marginal costs for total traffic are calculated based on model A and constitute 0.00270 CHF/gtkm. Compared to Marti et al. (2009) the marginal costs of model A are clearly higher. In the project CATRIN the estimated marginal costs for the same cost category were 0.00132 CHF/gtkm. One possible explanation is the higher aggregated track section. Because of that, there are less extreme values and outlier. Also the mapping of the costs is probably more appropriate in the higher aggregation. Compared with other international studies, the marginal costs are on a comparable level with the marginal costs in Austria (marginal costs for maintenance only: ~0.00226 CHF/gtkm) and Great Britain (marginal costs for maintenance only: ~0.00326 CHF/gtkm (Wheat et al, 2009).

With model B, we can do separated mc-calculations for passenger and freight traffic. Accordingly, a small increase in passenger traffic has about the same effect on marginal cost like a small increase in freight traffic on average. The MC for passenger is 0.00251 CHF/gtkm and for freight is about 0.00226 CHF/gtkm. Both values are slightly smaller than the MC for total traffic although this finding stemming from the slightly smaller estimated sum of elasticities for model B compared to model A. Because there are almost no international results to compare this two, at least for the cost category of maintenance and renewals together, it's difficult to check the plausibility of the results.

Model C allows MC calculations for even more distinct traffic. The calculations show following results:

- MC for Intercity/Eurocity trains and international trains are 0.00130 CHF/gtkm and are about the same level as MC for express train, interregio and local express trains.
- Local trains and commuter trains have similar marginal costs (0.00320 CHF/gtkm compared to 0.00299 CHF/gtkm). Compared to the faster passenger trains, the MC for the slower trains are higher. There are different possible reasons for the higher MC of local and commuter trains;
    - Because of the higher amount of stops, local and commuter trains causes more damage by braking and accelerate, compared to express trains and international trains.
    - Especially commuter trains often operate in densely populated regions and on tracks with high traffic density. Both aspects make the maintenance work more difficult and

  more expensive (smaller opportunity windows, night work, special noise prevention etc.)
  - Different underbody: express and international trains often have better running gear which makes less damage on the tracks.
- The marginal costs for normal freight trains (95% of total freight traffic) are about 0.00164 CHF/gtkm.
- The special passenger and special freight trains have extremely high marginal costs. But theirs share in total traffic are extremely small, which explains why the results are not accurate.

Further we find evidence that mixing traffic of different types can result in lower overall cost elasticities and, all other things equal, lower marginal costs. This might support some of the hypotheses being examined in Task 5.3.1 of SUSTRAIL, namely then mixing traffic may reduce the amount of remedial work that is needed to be undertaken for a given amount of total tonne-km. This is because different traffics have different damage characteristics and that some damage mechanisms correct the effects of other damages mechanisms.

4.6 British case study research

The British case study represents a new approach to analysis of maintenance and renewals costs, through estimation of a Vector Auto Regression (VAR) model. The data comprises of 10 zones of the British infrastructure manager, from 1995 to 2009. The innovation in this work is the application of dynamic analysis to a long(er) panel than has commonly been available in the literature. We collect maintenance and renewal cost separately, as well as traffic, track length and both infrastructure manager caused delay minutes and number of broken rails which proxy for the condition of the infrastructure.

4.6.1 Model formulation

The aim of the modelling is to estimate the marginal cost of traffic while simultaneously, allowing for past maintenance and renewals to determine the level of current maintenance and renewals. As such we aim to capture a trade off between maintenance and renewal activities and also that undertaking previous levels of maintenance (and renewal) influence the required levels of maintenance (and renewal) today.

The model that is estimates can be represented, in its simplest form as:

$$\begin{aligned}\ln(M_{it}) &= \alpha_1 + \phi_{11}\ln(M_{it-1}) + \delta_{11}\ln\left(R_{it-1}\right) + \beta_{11}\ln(Q_{it}) + \gamma_1\ln(I_{it}) \\ \ln(R_{it}) &= \alpha_2 + \phi_{21}\ln(M_{it-1}) + \delta_{21}\ln\left(R_{it-1}\right) + \beta_{21}\ln(Q_{it}) + \gamma_2\ln(I_{it})\end{aligned} \qquad (2.1)$$

i=1,…,N and t=2,…,T

where M is maintenance cost, R is renewal cost, Q is traffic and I is an infrastructure condition measure. By forming the model is this way we can relate todays maintenance to all previous levels of maintenance and renewals and traffic. We can then use “Impulse Response Analysis” to understand (forecast) how future maintenance or renewal cost will evolve in the future if there is an increase or decrease in one of the costs in the present time period.

Deriving the elasticity of cost with respect to traffic – short run and long run

We can also derive the relevant cost elasticity and thus marginal cost with respect to traffic changes. The concepts of short run and long run are relevant here given that there are feedbacks in the model that mean maintenance and renewal costs do not fully adjust to a change in traffic in a single time period.

The **short run elasticity** of cost with respect to traffic refers to the proportional impact on cost in the current time period from a 1% increase in traffic. Using the model in (2.1), it is given simply as

$$\varepsilon_{MQ}^{S} = \frac{\partial lnM_{it}}{\partial lnQ_{it}} = \beta_{11}$$

for maintenance cost and $\varepsilon_{RQ}^{S} = \beta_{21}$ for renewals cost.

However, the inclusion of lagged terms for maintenance and renewals cost in each equation means that the full impact on maintenance and renewals cost is not realised until further into the future. The **long run elasticity** of cost with respect to traffic captures the proportional impact of cost once all the impacts over time are traced through the model. In the model in (2.1) the long run elasticity can be calculated by considering the long run equilibrium. Equilibrium is whether the maintenance and renewal cost variables have no tendency to change. That is $M_{it} = M_{it-1} = M_i^*$.For the maintenance equation:

$$\ln(M_i^*) = \alpha_1 + \phi_{11}\ln(M_i^*) + \delta_{11}\ln\left(R_i^*\right) + \beta_{11}\ln(Q_i) + \gamma_1\ln(I_i)$$

Rearranging:

$$\ln(M_i^*) = \frac{\alpha_1}{\left(1-\phi_{11}\right)} + \frac{\delta_{11}}{\left(1-\phi_{11}\right)}\ln\left(R_i^*\right) + \frac{\beta_{11}}{\left(1-\phi_{11}\right)}\ln(Q_i) + \frac{\gamma_1}{\left(1-\phi_{11}\right)}\ln(I_i)$$

This implies[10]:

$$\varepsilon_{MQ}^{L} = \frac{\partial lnM_i^*}{\partial lnQ_i} = \frac{\beta_{11}}{(1-\phi_{11})}$$

And the equivalent for renewals cost is

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[10] This is a simplification. In reality there will be a secondary impact in each equation arising from responses to the change in traffic in the other equation. However such an effect is, in this empirical implementation, small, and so for this study it is ignored when computing the long run elasticity.

$$\varepsilon_{RQ}^{L} = \frac{\beta_{21}}{(1-\phi_{21})}$$

This work is new in this field, and work is ongoing to understand fully the results of the work. The expectation is that this kind of analysis will become more relevant as the time series of available datasets start to become longer. Hence this work has value, even if the, in the shorter term, the analysis is not as robust as from other forms.

4.6.2 Cost elasticity results

We now turn to the implied cost elasticities with respect to traffic. These are summarised in Table 4.6. In addition to the results for the separate Maintenance and Renewal cost categories, the short and long run elasticities are presented for a single equation combined cost model (the sum of maintenance and renewal cost). The final column presents the results from a static model (no lagged terms) for each of the cost categories for comparison purposes.

Table 4.6 Estimated cost elasticities with respect to traffic British Case Study [all statistically significant at the 5% level except *]

Cost Category	**Dynamic Model Short Run**	**Dynamic Model Long Run**	**Static Model**
Maintenance	0.27	0.75	0.68
Renewal	0.28*	0.54*	0.72
Combined	0.29	0.82	0.70

For both cost categories the short run elasticities are roughly the same, 0.27 and 0.28 for maintenance and renewal costs respectively. 0.27 implies that a 1% increase in traffic results in a 0.27% increase in maintenance cost in the same time period. The long run elasticities are, as expected, higher at 0.75 and 0.54 for maintenance and renewal costs respectively, although the renewal elasticity is not statistically significant. These seem high particularly the maintenance elasticity when compared to other evidence. The consensus from the CATRIN project (Wheat et al, 2009) was that for medium traffic density lines/zones, the elasticity of cost with respect to traffic is 0.3. For renewals there was less evidence, but a figure of 0.35 was proposed. Wheat and Smith (2008), specifically for Britain found an elasticity in their preferred model of 0.378 for maintenance cost only when they analysed a cross section of data for the year 2005/06. However this was high relative to some of the other model specifications. Therefore 0.75 looks very high, particularly given that the maintenance costs considered contain most cost elements (in contrast Wheat and Smith (2008) only considered permanent way and signalling and telecoms which are expected to be most influenced by traffic).

However, it would appear that these higher elasticities are not an artefact of the dynamic functional form, as similar elasticities are yielded from the static variants of the models (no lagged dependent terms). The underlying reason for the higher elasticities is not clear. It could be due to the aggregate nature of the zones in this study. Indeed the Swiss case study in this project (D5.3 Annex 3) does provide some supporting evidence that aggregating to a higher geographical level does increase the estimated elasticity. Alternatively it could be due to the reliance on data which varies considerably over time in the presence of a cost shock, attributed to the fallout from the Hatfield accident, which may have had some unexpected influence in these results. However the inclusion of a relatively flexile time trend would have been thought to compensate for the majority of this effect. Finally, the model does not include a large number of infrastructure characteristics. In particular there are no variables which capture the operational capability of the lines, such as the maximum permitted linespeed or the maximum permitted axel load. The latter maybe an important controlling factor given that the traffic variable does not reflect weight of trains.

4.6.3 Overall appraisal of this approach

The potential benefits of this approach over the static approaches to date include:

- Explicit modelling of the maintenance/renewal cost trade-off
- Explicit modelling of year on year budgetary constraints
- The distinction between instantaneous response (short run) to extra traffic versus longer term changes

In this implementation it has been demonstrated that there is support in the data for a dynamic data structure over the static data structure, although using this particular dataset, the empirical benefits over the static approach are not obvious in terms of specifically informing marginal cost estimates. In one sense it is reassuring that the static approach does provide a useful approach for estimating marginal cost of infrastructure wear and tear with respect to traffic. However this should be verified with reference to other datasets.

Overall this approach should be developed further as longer data sets become available.

5. Sub-Task 5.3.3: Evaluating the effectiveness of access charges

5.1 Introduction

The aim of this work was to understand what impact (or not) different access charge regimes already in place within Europe have had on the behaviour of various industry players and how changes to these regimes, particularly in respect of differentiation by vehicle-type, would influence future behaviour. Differentiation by wagon type is of particular interest in the context of SUSTRAIL, and so this has been the focus of this work.

We have sought to achieve the above aim by reviewing relevant literature, and reports and network management statements, as well as conducting interviews with key industry stakeholders. The full detail of the work is set out in Annex 5 and Annex 6.

The current rules for the calculation of track access charges are set out in Directive 2001/14, and provide for charges to be based on the direct cost of operating the train services. The recast of the first railway package (Directive 2012/34) proposes to introduce more detailed guidance on how these costs are to be calculated in the form of an implementation act, as well as requiring differentiation of charges according to noise (primarily to address the issue of freight wagons with cast iron brake blocks) and to provide for lower charges for locomotives fitted with ECTS.

It is well established that wear and tear costs vary more closely with gross tonne km than with vehicle or train km (Wheat et al, 2009), whilst models exist to predict the impact of vehicle characteristics such as speed, axleload and unsprung mass. The capacity a train takes up depends largely on its speed relative to that of other trains on the line, whilst obviously environmental costs vary by type of vehicle and particularly between diesel and electric traction.

Whilst charging practises vary across Europe, many infrastructure managers do not differentiate by any of the above factors in their charges. The principal infrastructure managers to have implemented track access charges differentiated by locomotive or wagon type are those in Austria and Britain. Sweden’s track access charges include an emission component (based on fuel consumption) and, since 2012, Germany’s train path charge for freight traffic includes a component to take account of the noise-related impact of train operation. Some member states, such as Czech Republic, have plans to introduce rules for differentiating charges according to noise emissions. Similarly few countries have any way of charging for capacity that takes account of the amount of capacity used.

Charges in Austria are differentiated by type of locomotive, according to whether a locomotive imposes high, average or low track damage, whilst in Britain, there is a highly detailed differentiation by vehicle type and commodity carried. The vehicle-type component is based on a function of the vehicle's tear weight, number of axles, unsprung mass, yaw stiffness, the maximum or operating speed, Ride Force Count, and Operating Weight. The Ride Force Count is a metric that has been developed to provide a quantitative assessment of the 'track friendliness' of a wagon's suspension/bogie type, following vehicle dynamics modelling. As Network Rail explain, "the purpose of this adjustment is to incentivise the use of 'track friendly' suspension/bogie types which will result in lower infrastructure costs. This adjustment ranges from a reduction of 14.2 per cent to an increase of 9.8 per cent" (Network Rail, 2014). This differentiation results in a price list table which runs to more than 2000 rows. The differentiation according to Ride Force Count results in the very worst vehicles paying charges that are 14% higher than the base charge (a 1.14 ratio) and the very best vehicles paying charges that are 12% lower than the base charge (a 0.88 ratio).

5.2 Responses to wear and tear charge issues

Our interviewees estimated that there are approximately 500,000 wagons in operation across Europe. Of these, it is estimated that approximately 300,000 are owned by the freight operating companies, with the remaining 200,000 wagons being approximately equally split between those which are owned by leasing companies and those which are owned by the end user. We asked our interviewees about the possible effect of the ownership model on the incentives track access charges could have. There was a strong sense that a lot of the incentives are common, irrespective of whether the wagons are owned or leased by those operating them.

Our interviewees explained that very vehicle manufactured for the European market could, during its life, end up being based in multiple countries, except for those manufactured for the British market. However, whilst there is interoperability of wagons across mainland Europe, each of the member state governments are different, and each of the member-state infrastructure managers have different models on how they maintain their track and how they structure their track access charges. So before a leasing company or freight operator embraces a wagon design that may be beneficial in terms of track access charges in, for example, Germany, they must consider that this wagon may go on to be used in a number of other European countries where its design has no or fewer such benefits in relation to the track access charges in those other countries. This consideration must weaken any incentive effect.

It was explained to us that wagons are designed to last approximately 30-40 years. However, wagons actually tend to last a lot longer, and it is not unusual to see wagons that are 40 or 50 years old in operation. Where they are broadly compatible with contemporary wagons, the presence of these old, fully depreciated wagons in the market enables the leasing companies to combine the old with the new and hold down the daily lease rates for their customers; and in doing so, they gain a competitive edge over their competitor leasing companies. Were there to be more innovation in the wagon design, however, this practice may prove more difficult.

One of our British interviewees stated that the track-friendly bogie incentives 'have delivered', in that you would find it quite unusual today to see a new wagon that didn't have some form of track friendly bogie fitted. So in Britain, "there is a modern expectation that this is what you do" and the trade that is being made in essence involves the cost of those bogies, the whole life costs of the wagon, and the utility to be gained from that wagon. However, another of our British interviewees referred to the impacts on the composition of the fleet as being “glacially slow, indicating that the very best bogies are not being introduced at any sort of noticeable rate.

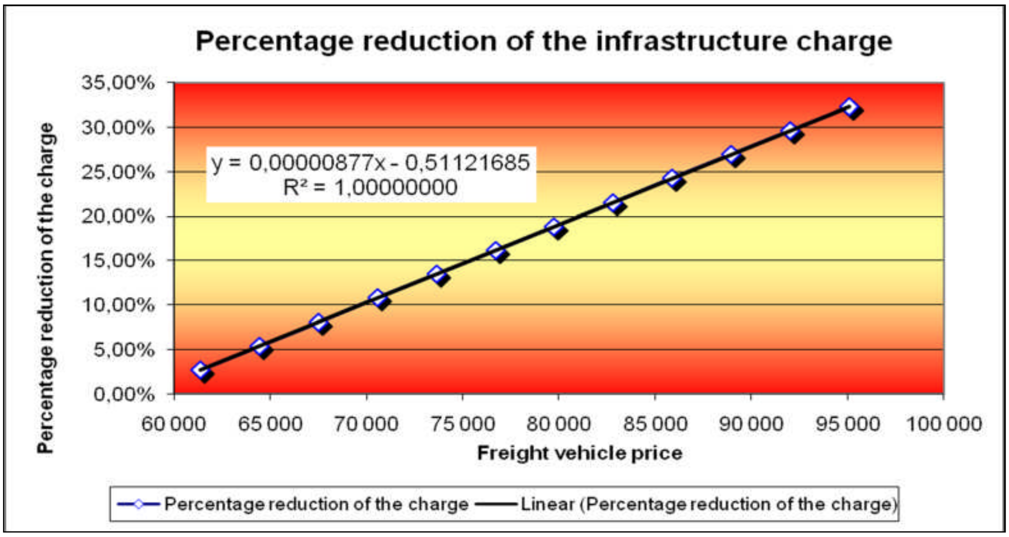
The differentiation in Austria, it was explained to us, “is very low and just a factor of 0.0263 minus 0.0237”, depending on whether the locomotive is “track-destroying” or “track-saving”. Because the incentive is small, it has not had a great impact.

An interesting ‘what-if’ analysis was undertaken in Annex 6 for Bulgaria, looking at the extent to which access charges would need to be lowered to make the freight operator no better or no worse off from adopting a vehicle with higher capital cost. The analysis drew on the cost structure of freight operators in Bulgaria and assumed no benefits to operators from the new wagons (only benefits to the infrastructure manager). Further it was assumed capital costs were the only cost element to change rather than any other Life Cycle Cost elements.

The results of such analysis can be summarised in Figure 5.1. This shows the percentage reduction in access charges relative to the current base system to compensate the operator for the higher capital price. A 50% increase in the capital price (90 000€) requires a 26% reduction in access charges.

In reality, it is unlikely that the overall LCC will increase by this much (or even at all) because of maintenance benefits and there will also be additional performance benefits which enhance the freight offering. This implies that such a dramatic reduction in access charges to incentivise adoption may not be required. However this does highlight the relatively large changes in access charges required to really effect operators ‘bottom lines’.

Figure 5.1 Percentage reduction in access charges required to leave the operator no worse off from adopting vehicles with different capital prices



5.3 Responses relating to capacity issues and other incentives

Turning back to the interviews, concerns were expressed about attempting to incentivise faster freight trains via track access charges. If, for example, there was a charge discount for running faster, but by running faster the vehicles impose greater damage on the tracks, increasing the track-damage related component of the charge, it would be difficult to understand how these two factors balance; and the worry would be that if you, as an operator, run faster, then the charge payment would be higher. More generally, it was argued that there are great difficulties with incentivising many things all at once.

In light of growing interest in noise-differentiated charges, it was highlighted o us that track-friendly bogies are, in continental Europe, now starting to be marketed as noise-friendly, on the basis that if it is track friendly then it must be noise friendly. However, it was suggested to us that the link between track-friendliness and noise-friendliness is crucially associated with track condition and weather.

In conclusion, the country with the most highly differentiated track access charges by type of vehicle is Britain, and it appears that even the relatively modest differentiation now in place is sufficient to influence purchasers of new vehicles intended to run in Britain to fit track friendly bogies. The current charge differentials are not in general high enough to lead to premature retirement of existing vehicles. However, were the ‘central’ charge to be raised (as was discussed during the most recent review of track access charges during 2013) then the differential either side of the central charge would be greater, probably providing a greater incentive to retire the least track-friendly wagons early and/or to invest in the ‘most’ track-friendly bogies. Of course, this would be likely to have knock-on consequences for operator costs and the overall competitive position between rail and road freight.

On the continent, there is a problem in that many vehicles are intended to run in a variety of countries, either on international traffic or because they may be moved between countries in the course of their lives. There are few incentives for track friendly bogies and even those that exist are limited in effectiveness because they apply in a single country. The diversity of charging structures and levels found in Europe means that the impact of incentives is limited. If incentives are to be used more widely they will need to be applied consistently across countries.

The influence of revised track access charges may be limited and slow to take effect, because of the long lives of wagons, the current low level of replacement investment, the relatively small size of discounts for track friendly bogies and the risk involved in buying a more expensive wagon that will only recoup its cost if it is used for a long life. The effect of these factors might be lessened by introducing larger differentials, but if these exceeded differences in direct cost then this would be in contradiction to existing EU legislation.

There is less evidence that track access charges could readily be used to encourage speeding up of freight trains to increase track capacity. Clearly there are fears that this could lead to complex charges, with different incentives leading in different directions. It appears that the use of charging to encourage the operation of freight trains at higher speeds needs to be simple and its implications need careful thinking through.

6. Conclusions: Implications for EC Policy and the Business Case

This deliverable should be viewed as contributing to research under three themes. The work under Task 5.3 has advanced the understanding of railway infrastructure marginal wear and tear costs associated with railway traffic and also researched how implementing price incentives (via differentiated access charges) has influenced operator behaviour.

These contributions push the research frontier, however, to be useful to the wider context of SUSTRAIL, have to be interpreted within the wider literature and EC charging principles such as Directive 2001/14.

The chapter is structured as follows. Section 6.1 discusses the general policy implications of the research in Task 5.3. This is more general than the implications for SUSTRAIL but does provide a link to general EC policy on price incentives for railway undertakings. Section 6.2 then discusses the implications specifically for the SUSTRAIL business case, drawing on the policy context and wider research base. These factors together imply that the business case should consider two access charge scenarios for each case study.

6.1 Policy implications of the research

Each of the research Sub-Task has reported its activity within the preceding three chapters. We now synthesise these into wider policy recommendations.

With respect to the combined engineering and statistical work reported in Chapter 3, the work represents a new approach to combining the positive elements of both the statistical (econometric) cost analysis approach and the engineering approach. Once developed further, it could be particularly useful in informing the appropriate differentiation of charges between vehicles with different characteristics. In particular it provides a useful bridge between engineering modelling of various damages and remedial costs borne by the infrastructure manager. This is often a weaker element of the engineering approach as determining appropriate interventions in response to damage and the associated unit costs are often very context specific and thus difficult to generalise.

Thus this work could help refine the extent to which track friendly vehicles should have lower access charges as in future this may be determined more in relation to differences in remedial cost rather than engineering damage. At present we do not see charging policy recommendations emerging yet from this work, but we do recommend that this research be pursued further as it could well lead to useful policy conclusions.

With respect to the econometric work reported in Chapter 4, two key contributions have been made. Firstly we have advanced the understanding of the variability of renewals costs with traffic, through a number of studies. The work reported in Sweden (Andersson et al 2012) points to 55% of renewals costs being variable with traffic (this however refers to track renewals only). The study in Switzerland points to combined maintenance and renewals costs being approximately 50% variable with traffic. The results in Britain also indicate a higher elasticity for both maintenance and renewals costs (of the order of 70% for both) although we note that renewals costs refer to track renewals only and the maintenance figure looks an anomaly relative to other evidence. However this latest evidence for Britain does indicate elasticities higher than those received in the literature for Britain to date.

All-in-all, the most recent evidence, which uses larger datasets and state-of-the-art methods, points to a higher cost variability with respect renewals costs than reported in the FP6 project CATRIN (CATRIN always acknowledged that the evidence on renewals costs was limited). CATRIN recommended a cost elasticity (the proportion of cost variable with traffic) of 35% for the renewal cost category (Wheat et al, 2009). The evidence from this project points to something higher, and 45% would seem reasonable.

Secondly, the research in Chapter 4 has discussed the extent to which we can use the econometric approach to disaggregate marginal cost estimates by traffic type. The aim here is to act as a useful objective cross check to estimates which arise from engineering models. Prior to this research, results in doing this exercise have been mixed, with some studies e.g. Andersson (2009) finding very low cost elasticities with respect to freight traffic (implying low marginal costs for freight in this case). The most recent work reported here in Switzerland indicates much more correspondence between freight and passenger traffic (in terms of marginal costs) which is encouraging from the perspective of developing the econometric approach. The precise policy implication of this is not clear, other than to say that the econometric models support that per tonne km passenger and freight do, on a rough average, the same damage (or marginal cost). However this does not preclude variations within a class such as wagons with track friendly or unfriendly bogies, and the engineering approach (or in future the approach in Chapter 3) would be the most appropriate to determine this.

Further we find evidence in the Swiss case study that mixing traffic of different types can result in lower overall cost elasticities and, all other things equal, lower marginal costs. This might support some of the hypotheses being examined in Task 5.3.1 of SUSTRAIL, namely then mixing traffic may reduce the amount of remedial work that is needed to be undertaken for a given amount of total tonne-km. This is because different traffics have different damage characteristics and that some damage mechanisms correct for the effects of other damages mechanisms.

With respect to the review of the effectiveness in access charges reported in Chapter 5, the country with the most highly differentiated track access charges by type of vehicle is Britain, and it appears that even the relatively modest differentiation now in place is sufficient to influence purchasers of new vehicles intended to run in Britain to fit track friendly bogies. The current charge differentials are not in general high enough to lead to premature retirement of existing vehicles.

On the continent, there is a problem in that many vehicles are intended to run in a variety of countries, either on international traffic or because they may be moved between countries in the course of their lives. There are few incentives for track friendly bogies and even those that exist are limited in effectiveness because they apply in a single country. Overall, the diversity of charging structures and levels found in Europe means that the impact of incentives is limited. If incentives are to be used more widely they will need to be applied consistently across countries.

The influence of revised track access charges may be limited and slow to take effect, because of the long lives of wagons, the current low level of replacement investment, the relatively small size of discounts for track friendly bogies and the risk involved in buying a more expensive wagon that will only recoup its cost if it is used for a long lifespan. The effect of these factors might be lessened by introducing larger differentials, but if these exceeded differences in direct cost then this would be in contradiction to existing EU legislation.

6.2 Access charge scenarios for the SUSTRAIL Business Case

What is clear from Chapter 2 is that there are a great variety of access charge systems within the EU, both in terms of the level of charges (cost recovery) and the characteristics of vehicles/routes/time of day etc that they are differentiated across. Further the EC directives on setting access charges, primarily 2001/14, imply that while charges should be based on direct (marginal) cost, mark-ups are allowed provided that they are non-distorting. Thus it is conceivable that many access charge systems could be compatible with the Directive. We do not concern ourselves as to whether each system is actually consistent with the Directive and proceed with the current access charge systems, both in terms of levels of changes and existing differentiation in each of the three case study countries as the ‘base case’.

6.2.1 The need for access charge variation in the SUSTRAIL project

In terms of enhancing the rail freight offering and incentivising the implementation of the SUSTRAIL innovations, the project requires access charges to:

3) Pass through infrastructure cost savings resulting from technological innovations to the infrastructure (WP4) to freight and passenger operators via lower track access charges and ultimately to freight and passenger users. Not all infrastructure cost savings are passed through, only the proportion which is variable with traffic as this reflects the change to marginal costs of running traffic.
4) Redistribute infrastructure cost savings to freight operators if freight operators utilise track friendly vehicles.

The first point is important because if rail freight (or indeed rail transport in general) is to become more competitive, the end user cost needs to fall in response to a fall in the industry costs, including in the costs of the infrastructure manager. As such there needs to be mechanism to redistribute infrastructure cost savings to elements of the industry further down the production chain. The second point reflects the need to compensate operators of track friendly vehicles for the infrastructure benefits that using these vehicles yield. This may actually be essential for incentivising the adoption of track friendly vehicles as without changes to access charges, it may not be in the operator’s financial interest to adopt the technology. Much freight traffic is currently unprofitable, so simply raising its profitability may be sufficient to improve long run freight mode share.

Therefore access charges play two roles. First they help to realise the benefits of infrastructure cost reductions, in terms of passing these through to final users and thus enhancing the rail proposition (reducing end user price). Second they provide incentives for adoption of new vehicle technology which benefits the railway system as a whole, by allowing benefits that accrue to the infrastructure manager to be shared with the operator, through a reduction in track access charges. Access charges can therefore ensure that there is a financial business case for each industry participant, for example ensuring that there is a benefit to operators from adopting track friendly bogies, an innovation which without differentiated track access charges would primarily benefit infrastructure managers.

6.2.2 Approach to access charge variation in SUSTRAIL project

The principle that access charges should reflect the infrastructure damage (and thus cost) incurred from running a train service, implies that the whole cost saving of any infrastructure cost reduction should be fully reflected in changes in access charges. So if infrastructure costs decrease 5% across all vehicle types as a result of the SUSTRAIL infrastructure innovations, then access charges should fall 5% for all services. This effectively means that the whole of the saving relating to the proportion of cost variable with traffic is passed through to the operators of train services (both passenger and freight). This simply reflects that the cost to the infrastructure manager of remedy damage from a train service has fallen. Such a mechanism allows the proportion of infrastructure cost recovered from charges to remain the same before and after the innovations.

Implication: With respect to *Infrastructure* innovations, the proportionate change in infrastructure cost will be reflected in the same proportionate change in access charges relative to the base case.

With respect to infrastructure cost savings arising from innovations to the vehicle, the principle that access charges should reflect the damage (and thus cost) caused to the infrastructure from running the service implies that 100% of the infrastructure cost reduction should be passed through to operators as a reduction in access charges. However this reduction should be specific to those vehicles that do the lower amount of damage (as opposed to being applied to all vehicles).

Implication: With respect to *Vehicle* innovations the absolute change in infrastructure costs resulting from running the less damaging vehicles should be passed to the operators of those vehicles.

The above two strategies to adjust track access charges ensures that, with respect to infrastructure improvements, the cost recovery rate for the infrastructure manager remains the same and with respect to vehicle improvements, that operators pay to reflect the damage that they cause to the infrastructure.

Following the LCC analysis reported in D5.1 and aggregated to case study routes in D5.2, and some subsequent bespoke engineering damage simulation of the vehicle on the track undertaken in SUSTRAIL WP3, the access charge reductions (relative to the base vehicle(s)) are those shown in Table 6.1.

Table 6.1 Access charge reduction from base in each of the scenarios

	SUSTRAIL 0 – vehicle improvement	**SUSTRAIL 1 – vehicle and track improvement**	**SUSTRAIL 2 – vehicle track and speed improvement**
Vehicles within the SUSTRAIL vehicle class	10.4%	17.4%	15.2%
Other vehicles	0%	6.9%	4.8%

There is a distinction in Table 6.1 between the SUSTRAIL vehicle and other vehicles. All vehicles benefit from the track improvements (which reduce the level of infrastructure access charges). In addition, the SUSTRAIL vehicle requires a further discount because it does less damage to the track than the base vehicle.

With respect to running freight trains at higher speed, this can be expected to reduce conflicts with other traffic (which, at least on intercity lines, tend to run closer to line speed). Given SUSTRAIL is considering innovations which may allow freight trains to travel close to line speed, then there is a question about whether there should be an incentive over and above any final user benefit (i.e. travel time savings) through an access charge. Effectively by running at line speed, there may be additional space in the time table to run an additional service which has a value to the user of that path (not necessarily by a freight operator, perhaps by a passenger operator instead). Task 5.2.3 is looking at valuing this scarcity. We could consider a suitable reduction in charges if an operator ran at line speed (as they are requiring less pathing time). However scarcity charging is a complex and context specific issue and so it would be questionable how generalizable our judgement would be. Instead we will consider a scenario in the cost benefit analysis for the British Case Study where we reallocate the capacity benefit from the operator which benefits from the path being freed up to the freight operator which speeds up their service (proxying for a full transfer via a suitable scarcity charge).

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

SUSTRAIL

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D5.3: access charge final report Annex 1

Developing improved understanding of the relative cost of damage mechanisms through integrating engineering simulation and statistical modelling approaches

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Table of contents

Note on the Structure of the document

This annex is divided into two parts. In part I we first set out the originally proposed description of work (DOW) for Sub-Task 5.3.1 and explain why subsequent developments between writing the SUSTRAIL proposal and commencing the work led to a change in the research undertaken. The remainder of the document, starts with Part II.A, and is structured as a working paper outlining the rationale for and implementation of a new approach to estimating the relative cost of different damage mechanisms on the rail network utilising data from the Swedish rail infrastructure manager, Trafikverket. This working paper has been submitted to the Institute of Mechanical Engineers Stephenson Conference: Research for Railways. Earlier versions of this paper have also been published in Rail Professional[1]. Further econometric work, carried out since the submission of that paper, and forming the full implementation of the second stage of the methodology, is included as Part II.B.

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[1] Smith, A.S.J., Wheat, P.E., Iwnicki, S. and Odolinski, K (2014), 'What are the costs of an extra service?', Rail Professional, February 2014, Issue 199, pp. 79-81.

Part I: Proposed description of work and reasons for re-directing the research

Part I is structured into two sections. Section 1.1 sets out the original proposed DOW and the reasons for changing the direction of the research. Section 1.2 contains a short literature review setting out the developments in the literature that supports the conclusion that the original research question had been superseded by subsequent research.

1. The proposed research in the description of work

A key question for rail infrastructure managers (IMs) concerns the different damage levels caused by different vehicles on the rail network and, in turn, the relative marginal costs incurred. This information is important particularly where IMs wish to differentiate track access charges by vehicle types.

It was intended at the time of writing the SUSTRAIL DOW to carry out new analysis to inform the engineering formula used by the British Office of Rail Regulation (ORR) for allocating costs to vehicles based on the amount of vertical track damage that they do. Britain had (and still has) the most sophisticated approach to differentiated track access charges (with respect to wear and tear damage mechanisms) in Europe and it was envisaged that seeking to improve this methodology further would be useful therefore in both the British and wider European context.

The proposed approach was to combine the outputs of engineering simulation models with statistical modelling. The former would provide relative damage estimates for a large variety of vehicle/track combinations based on detailed models of the track and vehicle characteristics. The predicted damage estimates from the engineering models would then be used as the dependent variable for a second stage statistical model which will seek to summarise the key drivers of damage (in its different forms). The statistical model would not be as detailed as the underlying engineering simulation modelling, and would provide a means of translating case specific estimates in to a transferable equation that is suitable for charging purposes. This “simplified” set of drivers of damage would then be compared against the approach used by ORR, and potentially be used to update that approach.

However, between writing the SUSTRAIL DOW and starting the project it was noted that considerable new research had been carried out with regard to understanding the relative damage caused by different vehicles on the network (see section 2 for a literature review). It was therefore determined that the research frontier had shifted, with the more important challenge being to understand the relative cost of different damage mechanisms; with the damage mechanisms themselves being relatively well understood.

A new approach, in the same spirit as the original DOW, was therefore developed. This approach again uses a two stage methodology to generate damage estimates and then use these predictions in a second stage statistical method. However the aim now is focused on understanding the relative cost of different damage mechanisms and combinations of damage types. The next section sets out the literature review to show the developments in the literature that supports the conclusion that the original research question had been superseded by subsequent research. The remainder of the document then sets out the new research question and its implementation using Swedish data.

2. Literature review on relative damage of different vehicle types

The main role of the track is to support and guide the railway vehicle. The forces between the vehicle and the track as are carried through the wheel-rail interface and include vertical support, lateral guidance, acceleration and braking. The role of the supporting structure under the rails is to distribute these loads evenly and to provide continuous support through track features such as curves, switches, gradients, changes in ground conditions etc.

If the support structure fails to provide this continuous support then the forces at the wheel rail interface will show greater peak values and this in turn will result in increased forces on the vehicle and on the track and substructure and on the sub components within these system and on levels of noise and vibration. These will result in different forms of damage.

2.1 Key damage mechanisms for railway infrastructure

The key damage mechanisms are summarised below in Boxes 1-3.

Box 1: Track settlement	
Caused by:	Unsteady wheel-rail forces from passing vehicles (in turn influenced by track irregularity).
Effect:	Deterioration in track condition (increased amplitude of irregularities – often characterised by the standard deviation).
Factors:	Axle load, unsprung mass and speed, track construction, quality and condition.
Remediation:	Ballast tamping.
Calculation method:	Various empirical measures have been used, most use vertical wheel-rail force raised to a power.

Box 2: Rolling contact fatigue of rails	
Caused by:	Lateral, vertical and longitudinal wheel-rail forces, contact stress.
Effect:	Cracking of rail leading to possible failure.
Factors:	Vehicle suspension design (especially yaw stiffness) rail material properties, track design (e.g. cant deficiency).
Remediation:	Rail grinding, rail replacement.
Calculation method:	Two methods currently used: 1) Based on shakedown which defines a stress limit below which fatigue is unlikely. 2) A measure of energy dissipated in the contact patch (usually known as 'T gamma') which can be weighted to indicate the likelihood of fatigue rather than wear damage.

Box 3: Rail wear

Caused by:	Lateral, vertical and longitudinal wheel-rail forces.
Effect:	Changing rail-wheel contact leading to reduced performance.
Factors:	Wheel profile, rail profile, vehicle suspension design rail material, lubrication, traffic (type and mix).
Remediation:	Renewal.
Calculation method:	Material removal can be predicted by energy dissipation in the contact patch or by use of the force and the sliding distance (the Archard wear model).

2.2 Approaches used by ORR to set variable access charges (up to and including control period 4 – 1st April 2009 to 31st March 2014)

As noted above, in Britain train operators pay a variable access charge based on the volume of traffic they run on their network, and also the type of vehicle used (since the vehicle type affects the amount of damage done and in turn the marginal cost). The Variable Usage Charge (VUC) recovers operating, maintenance and renewal costs that vary with traffic. These include costs associated with signalling, civils (underbridges, embankments etc.) and track. Track VUC accounts for more than 80% of the VUC and includes maintenance and renewals costs of the track system. The VUC of any vehicle type is determined by its 'track friendliness'. For each vehicle type a 'track friendliness score' is calculated and used to apportion costs. The four key vehicle characteristics that inform the 'track friendliness score' are axle load, operating speed, unsprung mass and bogie primary yaw stiffness.

The approach used by the ORR and Network Rail in the UK for charging combines 'Top-down' and 'Bottom-up' approaches:

a) The sum of money to be recovered is determined by a top-down assessment of the variability of maintenance and renewals.
b) This sum is allocated to the vehicle fleet using a bottom-up model of marginal costs by vehicle type.

The method used during control period 4 (1st April 2009 to 31st March 2014) for evaluating the damage caused by a single vehicle was based on the equivalent gross tonne miles (EGTM) operated by the vehicle. EGTM are calculated by factoring the gross tonne miles (GTM) by various vehicle properties. See CATRIN Deliverable D1 for further details[2]. A separate EGTM calculation is made for track and for structures costs.

$$\text{EGTM} = K\ Ct\ A^{0.49}\ S^{0.64}\ USM^{0.19}\ \text{GTM} \qquad \text{(for track)}$$

and

$$\text{EGTM} = L\ Ct\ A^{3.83}\ S^{1.52}\ \text{GTM} \qquad \text{(for structures)}$$

where: K is a constant

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[2] http://www.diva-portal.org/smash/get/diva2:745886/FULLTEXT01.pdf; page 37-53.

Ct	is 0.89 for loco hauled passenger stock and multiple units and 1 for all other vehicles
S	is the operating speed [mph]
A	is the axle load [tonnes]
USM	is the unsprung mass [kg/axle]
GTM	is gross tonne miles [Tonne. Miles]

These values were derived by fitting regression relationships to a large amount of data from damage models. As ORR notes, the above formula for vertical track damage was based on analysis carried out more than ten years ago (see ORR, 2013). A number of weaknesses have been identified in this method. The main engineering issues are:

- As the EGTM calculation is based only on vertical forces, rolling contact fatigue is not accounted for in the distribution to vehicles despite the fact that it is the cause of major maintenance and renewal expenditure (currently 19% of the NR maintenance and renewal budget).
- Rail head wear, axle spacing, wheel profile are also not properly accounted for.
- Varying track quality is not accounted for in the EGTM calculation.
- Vehicle behaviour in worn rather than new conditions is not included.
- Calibration is based on 1999 data.

2.3 New approaches developed during the 2013 Periodic review (PR13) for implementation in control period 5 (1st April 2014-31st March 2019)

As a part of PR13 for CP5, Serco were commissioned to undertake a review of the three components of the VUC – track, structures and signalling. The review suggested minor changes to the structures and signalling components of VUC. However more significant changes were suggested for the track component of VUC. A hybrid formula based on axle load, operating speed and unsprung mass was defined as:

$$\textit{Relative damage (per axle.mile)} = 0.473.e0.133A + 0.015.S.U - 0.009.S - 0.284.U - 0.442$$

where: A = Axle load (tonnes), within the range: 5 to 25 tonnes
S = Operating speed (mph), within the range: 25 to 100 mph
U = Unsprung mass (tonnes / axle), within the range: 1 to 3 tonnes

The hybrid formula is considered to be more appropriate than the power formula mentioned in the previous section because of its higher degree of fit and stronger correlation to the damage data. The power formula has a weaker correlation to the data, particularly at higher relative damage values. Therefore, it was recommended that the hybrid formula is used in the CP5 VUC apportionment process. The Serco review mentions that the results obtained with new formulae show that damage is more sensitive to axle load and unsprung mass and less sensitive to vehicle speed, compared with the existing method. This would result in the vehicles with a high axle load or unsprung mass attracting a greater share of the variable usage costs than in CP4 and vehicles with a high operating speed would attract a smaller share, all other things being equal. In general, it is most probable that heavy freight traffic will attract more cost and high speed trains will attract less cost[3].

The new charges, based on the new research, were implemented in control period 5, though with some phasing, given the substantial increases in charges facing freight operators, particularly in respect of the transportation of some commodities (see ORR, 2013).

Part II: Write up of research undertaken

This section is divided into two sections. Section II.A is in the form of a paper submitted to the Institute of Mechanical Engineers Stephenson Conference: Research for Railways (submitted in September 2014). Additional appendices are also added to this paper to provide further details of the data and approach beyond what was considered appropriate for the paper. Section II.A sets out only stage 1 of a two stage methodology, since at the time of submission the data was not available to run the second stage. Section II.B reports the results of the second stage modelling and concludes.

Part II. A Estimating the damage and marginal cost of different vehicle types on rail infrastructure: combining economic and engineering approaches

Abstract

EU legislation requires that European infrastructure managers set access charges based on the marginal cost of running trains on their networks. Two methods have been used in the literature for this purpose. Top-down methods relate actual costs to traffic volumes. Bottom-up methods use engineering models to simulate damage and then translate damage into costs based on assumptions about interventions and their unit costs. Whilst top down methods produce sensible results for marginal cost overall, they have struggled to differentiate between traffic types. The challenge for bottom-up approaches is how to translate damage into cost, with numerous assumptions being required which may be invalid.

This paper proposes a new, two stage approach to estimating the marginal cost of rail infrastructure usage. The first stage uses engineering models to simulate damage caused by vehicles on the network. The second stage seeks to establish a statistical relationship between actual costs and damage. It is thus possible to convert damage estimates into costs using actual cost data, rather than through a set of potentially invalid assumptions as in previous approaches.

Only the first stage is implemented in this paper. We show that it possible to produce total (annualised) damage measures for three damage mechanisms on five actual track sections in Sweden. Once extended, it will be possible to model the relationship between damage and actual costs for the first time; and thus better understand the relative costs of the different damage mechanisms and in turn inform the level and structure of track access charges.

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[3] See: VTISM Analysis to Inform the Allocation of Variable Usage Costs to Individual Vehicles by Serco http://orr.gov.uk/__data/assets/pdf_file/0016/1186/serco-vuc-report-review-july-2013.pdf.

1. Introduction

European policy since the mid-1990s has emphasised the promotion of within-mode competition as a way of revitalising the fortunes of Europe's railways. Progressively freight and international passenger services have been opened up to competition. The proposals contained in the European Commission's Fourth Railway package (European Commission, 2013) for further reforms of Europe's railways, mean that, once enacted, it will be compulsory to introduce competitive tendering for passenger services run under public service contracts and open access for commercial services across the whole of Europe. Vertical separation of infrastructure and operations or, at least, fair access to infrastructure and transparent prices for access, is seen by the Commission as a key enabler of competition in the sector.

The above developments mean that understanding the cost, and in particular, the marginal (infrastructure) cost, of running an extra service on the network has become more important than ever. Existing legislation requires that charges for access to the infrastructure must be based on "costs directly incurred as a result of operating the train service". This can be interpreted as what economists would call the short-run marginal (or incremental) cost imposed on the infrastructure by the service running on the network. This paper focuses on one element of short-run marginal cost, namely the additional maintenance and renewal cost required to rectify the incremental damage caused a train service (the marginal wear and tear cost).

Of course, the need to estimate marginal cost of infrastructure use is not merely for the purpose of meeting EU legislation. It is important from the purpose of economic efficiency (in terms of making best use of the existing network) that train operators pay at least the short-run marginal cost of running trains on the network. Further, track access charges that vary according to the different damage and cost imposed by different vehicles, should ensure that the "right" vehicles are run on the network and potentially that new rolling stock designs are developed that reduce whole system costs (operator and infrastructure managers costs).

The previous literature, and practice by bodies responsible for charging, contains three approaches for estimating marginal costs of traffic and also different types of traffic: cost allocation methods; statistical approaches; bottom-up engineering methods. In practice the approaches used by charging setting bodies can be a hybrid of approaches, such as that used by the British Office of Rail Regulation (ORR). However, each of the approaches has significant drawbacks. The contribution of this paper is to propose an alternative, two-stage approach that combines engineering and statistical approaches in a way that seeks to combine the best features of both; and thus overcome some of the weaknesses of previous approaches.

The remainder of the paper is structured as follows. In section 2 we explain the previous approaches used to estimate marginal rail infrastructure costs and their weaknesses. The proposed methodology is set out in section 3 and the data used for the empirical work outlined in section 4. Section 5 presents the results and section 6 concludes. Full details of the engineering simulations for one of the track sections are provided in Appendix 1 for reference.

It should be noted that at this stage of the research we have only been able to implement stage 1 of the methodology. This is because we do not yet have sufficient data to implement the second stage, though this is anticipated soon. This conference paper therefore reports and discusses the methodology and the first stage results. The second stage will be implemented post submission of this deliverable. The data needed was requested from Trafikverket in

September and it is expected to be received towards the end of October. It is therefore expected that the full analysis, including the second stage modelling results, will be added to the deliverable in December 2014.

2. Previous approaches

To summarise briefly, there are two methods for producing estimates of marginal costs (Wheat and Smith, 2008). Top-down methods relate actual costs to traffic volumes, controlling for characteristics of the infrastructure. Bottom-up methods can be characterised as using some form of engineering model to estimate the damage inflicted by different types of vehicle on the network. Then assumptions can be made about the intervention / remediation required to deal with that damage, combined with estimates of unit costs of that remediation activity, to give the marginal cost estimates. These approaches are summarised in Figure 1. A "third" method, the so-called cost allocation method, can be thought of as a hybrid that utilises engineering judgement and econometric evidence and other rules of thumb to establish the variability of different cost categories. This approach is therefore not discussed further.

Figure 1: Alternative approaches for estimating marginal costs

- Method 1: engineering approach
    - Simulate damage done by traffic (engineering model)
    - Determine action need to remedy damage (e.g. tamping)
    - Activity volume * Unit cost of activity = (marginal) Cost
- Method 2: top down statistical approach
    - Relate actual costs to passenger and freight tonne-km (regression)
    - E.g. Log Cost = a + b* Log Passtonne + c * Freight tonne
    - Compute marginal costs from the parameter estimates (the a and b) from that model

Both methods have strengths and weaknesses. The advantage of top-down methods is that they use actual cost data. Their weakness lies in the fact that it is likely to be very hard to capture the complexity of factors that will affect the relationship between traffic and cost, and in particular, it has proved difficult to get any sensible estimates of the relative cost of passenger and freight vehicles. The bottom-up method is very good at capturing complexity and it is possible to model and gain estimates of the relative damage of different vehicle types. The problem is how then to translate these damage estimates into cost.

It is worth noting, more precisely, why there is a difficulty in getting from damage to cost in bottom-up approaches. First, traffic results in different types of damage. In practice, one vehicle may cause more of one type of damage and less of another, thus meaning that information is needed on the relative cost of the different types of damage to obtain estimates of relative marginal cost. This leads to a second problem, namely that assumptions are needed on what type of activity and how much of it, are needed to rectify the damage done. This potentially requires a very detailed model or alternatively simplifying assumptions are needed which might be wrong.

Added complexities include the fact that the mix of damage types will affect what activity should be undertaken (e.g. some traffic types might cause damage but at the same time alleviate the need for other forms of remediation, such as rail grinding) and the fact that some damage mechanisms lead to more maintenance activity, whilst others result in more renewal (and the costs of these can be very different). Finally it is hard to estimate unit costs of activities as these will depend on, inter alia, the location, the nature of the job, the length of possession and the scale of the activity.

The research question therefore is as follows: how can we obtain better estimates of the relative cost of different damage mechanisms (which in turn can then help estimate the relative marginal cost of different vehicle types).

In terms of its relation to other approaches, in the past ORR has used a top-down cost allocation approach, based on engineering judgement, to determine the general level of cost variability, and then used an engineering formulae to allocate costs to vehicles based on their relative damage (vertical forces only). Since then Network Rail has developed its bottom-up cost modelling approaches (its infrastructure cost model (ICM) model, which in turn is based on the Vehicle Track Interaction Strategic Model (VTISM)) to estimate marginal costs from the bottom up). This approach measures the overall variability of costs with respect to traffic. Engineering approaches, based on both vertical and horizontal forces, are then used to allocate that element of costs that is deemed variable down to individual vehicles (see, ORR, 2013). This approach means that Britain, unlike other European countries, has highly differentiated charges, by vehicle, which should incentivise the use of more track friendly vehicles.

At the same time, top-down econometric methods relating actual costs to traffic volumes, controlling for other factors have been extensively used and the results used by the European Commission (see, for example, Johansson and Nilsson (2004), Wheat et. al. 2009 for a summary, and Andersson et. al., 2012 for subsequent developments in modelling of renewals costs). These studies have covered a range of European countries, and suggest that the marginal cost of rail infrastructure maintenance is in the region of 20-35% of maintenance costs (or up to 45% for heavily used sections). Wheat et. al. (2009) found that the available evidence was much less strong for renewals, though suggested an indicative overall cost variability proportion of around 35% of renewal costs. More recent evidence has put this at a higher level; at approximately 55% (Andersson et. al., 2009). As noted above, these methods have been useful in determining the extent of cost variability with traffic in general, but less effective at allocating to types of traffic or vehicle. It is worth further noting that the engineering based bottom-up approach used by Network Rail puts the variability proportion at less than 10% which is out of line with the top-down econometric evidence from across Europe.

Our proposed approach is therefore positioned within the existing literature and would particularly enhance ORR’s approach to allocating variable costs to vehicle by providing new evidence on the relative cost of different damage mechanisms, in turn leading to better estimates of the relative marginal cost of different vehicle types. The approach could also be used to determine absolute marginal cost and cost variability levels to compare against the results of top-down and other engineering models.

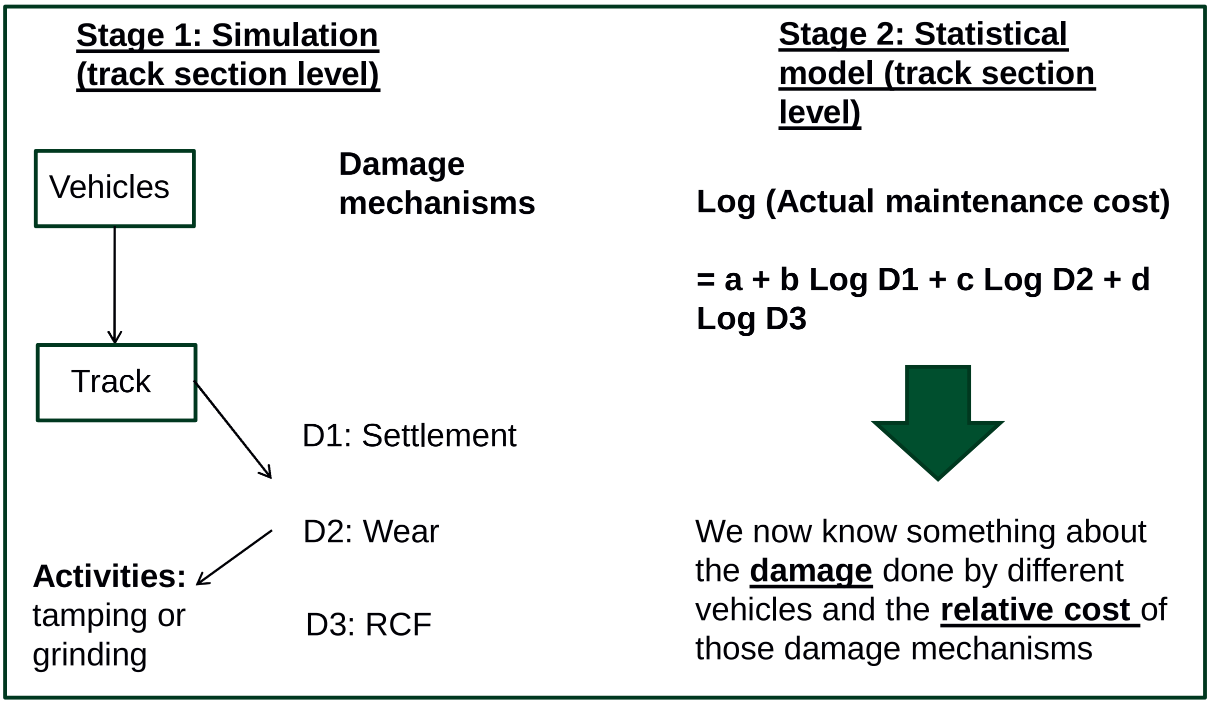
3. Methodology

Our proposed method essentially consists of two stages. The first stage involves an engineering simulation exercise in which traffic (of certain vehicles and mixes of vehicles) is run down a network of known characteristics, to produce estimates of the resulting damage (denote these D1, D2, and D3, to represent the three main damage mechanisms: settlement, wear and rolling contact fatigue). For this exercise we choose actual track sections from Sweden where we have data on the maintenance and renewal costs, the traffic volumes and the infrastructure characteristics. The second stage involves establishing a statistical relationship between actual costs (maintenance and or renewal) for actual track sections on a network (in our case the Swedish network) and damage. The approach is summarised in Figure 2 below.

The three damage mechanisms are defined as follows. Wear of the rail is a natural process in which material is removed from the head and/or the gauge corner of the rail when railway vehicles run. The rate of removal is affected by the forces and contact conditions. Severe wear can change the cross sectional profile of the rail, resulting in a change of the running surface seen by the wheel. Rolling contact fatigue (RCF) occurs if the rail surface is subjected to repeated plastic deformation as is often caused by repeated wheel passages.

The 'Tgamma' value provides a measure of the wear and RCF performance of the vehicle. Tgamma is the product of the tangential or creep forces and the slippage or creepage in the contact patch between wheel and rail. Tgamma combined with a non-linear damage function produces a RCF damage index as shown in 3. This index is then used to interpret whether the vehicle is damaging the track due to wear, RCF or a combination of both.

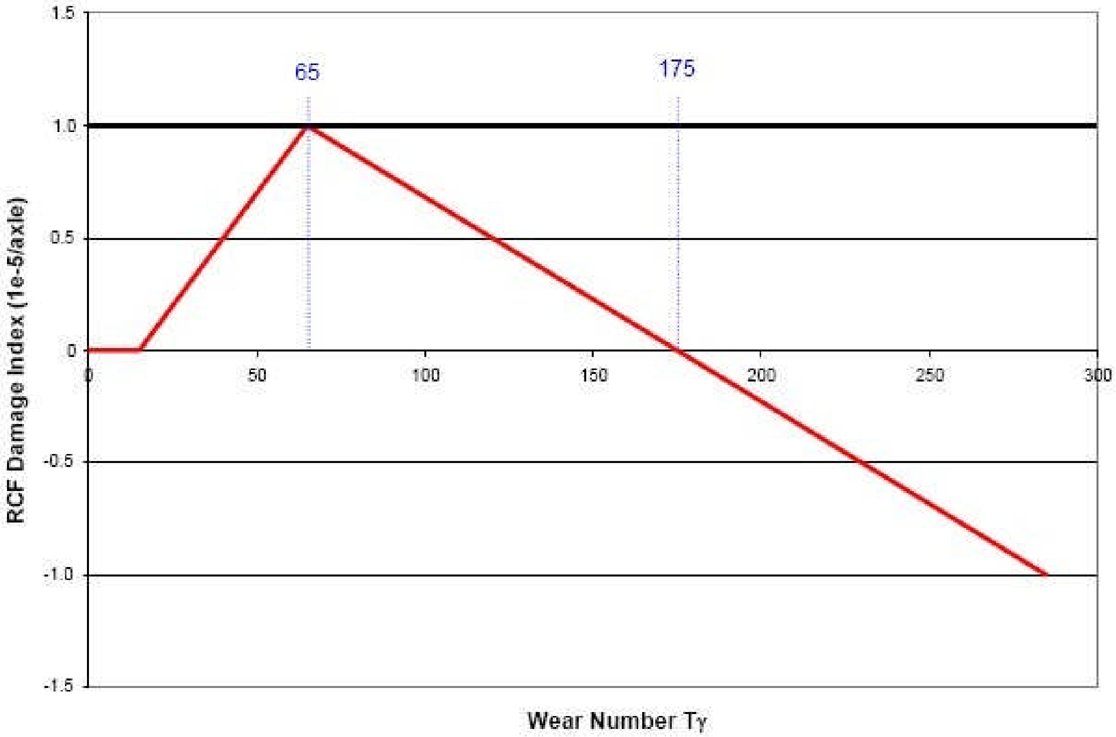
Figure 2: Overview of the methodology



With reference to 3, as Tgamma increase from 0 to 15 N, no RCF damage is generated as there is insufficient energy to initiate RCF cracks. As Tgamma increase from 15 to 65 N, the probability of RCF incitation increase, to a maximum of 1 at a Tgamma value of 65 N. As Tgamma increase further from 65 to 175 N, the level of energy is such that the dominant form of surface damage is wear (rather than crack initiation), therefore the probability of RCF damage decreases as wear increases. Negative values of RCF damage indicate values of Tgamma greater than 175 N, resulting in wear and no RCF initiation. The units of the RCF damage index are 10-5 per axle. This indicates that for a damage index of 1, 100000 (One hundred thousand) axle passes would result in RCF initiation.

Finally, track settlement may be defined as the sinking of the track (in the vertical plane) into the ballast under a variety of conditions. A number of models have historically been used to predict track settlement. Initially the Technical University of Munich (TUM) model and the Sato model were considered. It is assumed that the settlement is going to be proportional to the vertical force on the wheelset.

Figure 3: Relationship between wear number (Tγ) and RCF damage index



Estimates of the relative cost of different damage mechanisms can be estimated from the parameters in this second stage regression (the b, c and d parameters in Box 2), which in turn allows us to estimate the relative cost of different vehicles. Of course, a more complex relationship could be assumed in the second stage statistical model, for example to include interactions between damage types (e.g. D1*D2). The detailed assumptions for stage 1 of the approach, as they apply in practice, are set out in section 5, after the description of the data. As noted in the introduction, stage 2 of the approach is not implemented in this paper due to lack of data at this time.

Full details of the engineering modelling approach for one track section is provided in Appendix 1.

4. Data

There are four main aspects to the dataset, which has been provided by the Swedish Transport Administration (*Trafikverket*). These are, for the damage simulations, data on track alignment and vehicle characteristics. Secondly, for the second stage modelling, data on costs (maintenance and renewals), traffic volumes and infrastructure characteristics.

So far the analysis has focussed on five track sections. Data for another one hundred sections has been requested but has not been received in time for inclusion in this conference paper. The additional data points will be used in subsequent analysis to implement the second stage.

4.1 Vehicle data

Three vehicle types have been modelled running down the selected five sections (see Table 1). These include two types of freight locomotives (with associated wagons) and one EMU. The data provided by Trafikverket revealed the generic type of vehicles and their usage on the network. However, the information was not sufficiently detailed to identify the exact vehicle. Hence generic freight and EMU vehicle types from the EU funded research project, INNOTRACK[4], were used. These types are considered to represent typical freight and EMU vehicles running on the EU network. In future work it is hoped to obtain more detailed information on the exact vehicles running on the Swedish network.

The vehicle models were described in terms of mass properties, geometry, axle load, unsprung mass, wheel radius and suspension characteristics. The VAMPIRE simulation package uses the model description to generate equations of motion for the vehicle which it then solves with the track input. Once the simulations are completed, outputs are available for wheel-rail forces vehicle motions and can be used to estimate damage.

4.2 Track data

Track alignment data were obtained using a track geometry coach which measures the curvature, cross level, vertical irregularity, lateral irregularity and gauge at fixed intervals of 25cm. This data was then used to create VAMPIRE track input files for the chosen track sections. An example of the track data for section 629 is shown in Figure 4. The five graphs represent:

1. Cross level versus Distance along the track
2. Curvature versus Distance along the track
3. Lateral Irregularity versus Distance along the track
4. Vertical Irregularity versus Distance along the track
5. Gauge Variation versus Distance along the track

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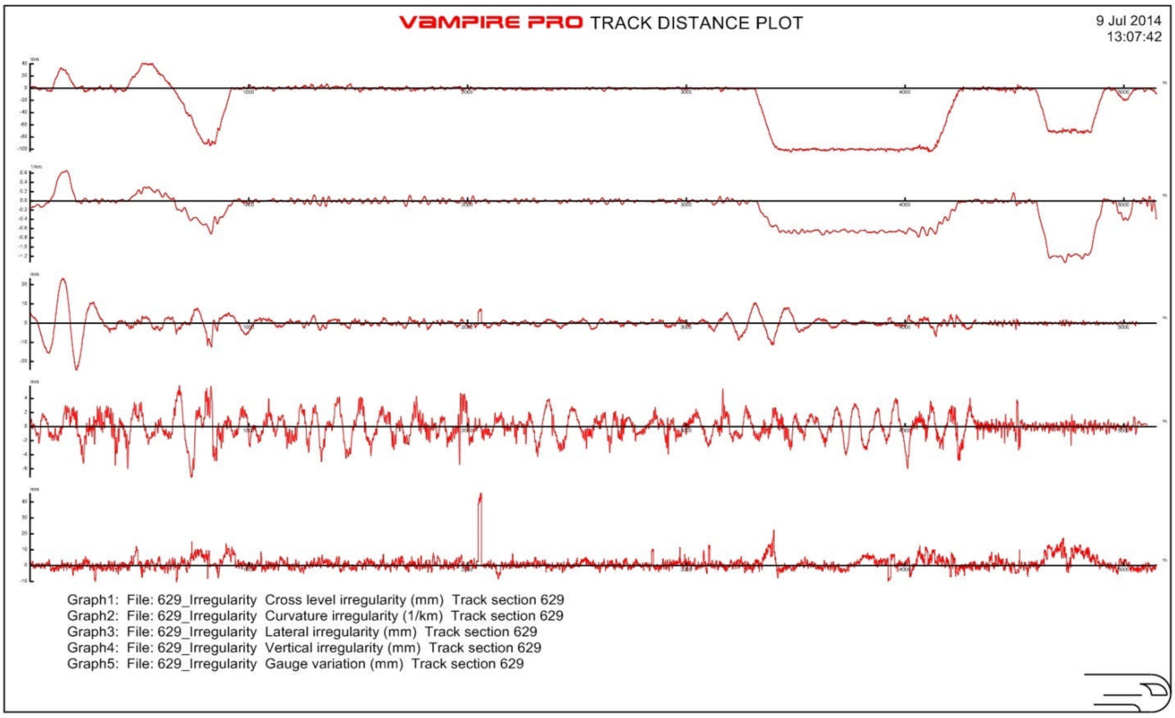
[4] http://www.innotrack.net/article/presentation

Table 1: The vehicles running on each track section

Track Sections	Vehicle ID	Type
326	RC2	Loco
	RC4	Loco
	4-axle Wagon	Wagon
	2-axle Wagon	Wagon
629	RC2	Loco
	RC4	Loco
	4-axle Wagon	Wagon
	2-axle Wagon	Wagon
652	X12	EMU
	X14	EMU
654	X12	EMU
	X14	EMU
821	X11	EMU
	X31	EMU

Figure 4: Track alignment data for track section 629



VAMPIRE Plot

4.3 Second stage data: costs, traffic and track characteristics

Costs for maintenance and renewals are collected in Sweden at the track section level. Included in these costs are activities conducted to maintain the railway assets as well as replacement and refurbishments to restore the assets to original condition. Snow removal is defined as maintenance in Sweden, though these costs are excluded in our data set. Renewal activities are not as frequent as maintenance, and a renewal cost is only observed for one of the track sections (see Table 2).

The simulation models produce an overall estimate of damage per tonne-km for each vehicle type. It is therefore necessary to scale up these measures based on the volume and mix of traffic that is actually running on the network. Traffic data include the declared train kilometres, weight (gross tonnes), number of wagons, and train length for different types of locomotives or EMUs/DMUs. The data is summarised in Table 3.

Table 2 – Costs, SEK

Track section no.	Maintenance costs	Renewal costs
326	5 757 077	132 707
629	323 503	0
652	15 609 488	0
654	8 735 644	0
821	3 566 033	0

In the second stage it is also important to recognise that the cost of addressing different levels of damage will depend on the characteristics of the infrastructure. Additional data has therefore also been collected on measures such as rail weight and linespeed (these are not shown to keep the discussion tractable). Full details are provided in Appendix 2.

Table 3 – Traffic data

	Train-km			*Tonne-km*		
Track section no.	Passenger trains	Freight trains	Empty trains and service trains	Passenger trains	Freight trains	Empty trains and service trains
326	8 150	212 521	15 247	1 676 878	192 837 314	1 208 129
629	18	2 983	95	2 810	684 166	5 502
652	285 707	15 728	22 586	38 554 466	15 262 308	3 442 515
654	312 434	5 368	3 404	33 160 000	5 327 958	338 685
821	325 744	16 927	53 390	53 677 213	14 306 152	8 709 709

5. Results and discussion

The output from the simulation runs are the vertical track force and 'Tgamma', which has been described earlier. The vertical track force was used to calculate a damage index, which is the vertical force raised to the power 1.21. This damage index is then used to calculate track settlement. Tgamma was used to calculate wear and RCF damage. All damages for each track section were measured per gross tonne-km. See Appendix 1 for further details.

It should be noted that damage is estimated at a number of points along the section (that is, each section is split up into segments covering 40 or 200 metres for wear/RCF and settlement respectively). Thus it is necessary to produce a measure of overall damage for each of the three damage types over the whole section. In the case of wear and RCF these are the summations of the damage over each of the segments. In the case of settlement, an average measure is taken, as a summation would not make sense from an engineering perspective.

The summary damage measures per gross-tonne km are then scaled up based on the total annual gross tonne-km run by each of the vehicle types in Table 1 in order to produce an annual total estimated damage. It is this measure that can then be related to annual costs in the second stage of the modelling. However, a mix of other vehicle types has also run on these track sections accounting for a small proportion of the total gross tonne-km. The damage, wear and RCF from these vehicle types are assumed to be proportionate to the damage measures caused by the vehicle types in Table 1. We have therefore scaled up the measures with respect to the total tonne-km run on the sections. The summary, total damage measures are shown in Table 4 below[5]. For further details of the scaling up assumptions see Appendix 2.

The damage measures in Table 4 are thus summary, total simulated damage measures per section, per year. It should therefore now be possible, once the same modelling has been carried out for more track sections, to estimate a relationship between these damage measures and actual costs on those sections. This second stage will enable us to understand the relative cost of different damage mechanisms and also how the different damage types and the cost of correction interact with each other to affect overall cost. This new information on the relative cost of damage, based on actual reported cost measures, will be an important contribution to the literature, where currently the link between damage and costs relies on a set of assumptions that may not be valid.

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[5] Note the results in this table differ slightly from those submitted to the Stephenson Conference due to small changes in the approach to scaling up the damage measures to reflect the total traffic running on the section.

Table 4 – Total settlement, wear and RCF

Track section no.	Vehicle	Loading condition	Settlement	Wear	RCF
629	RC2	Laden	8 124 944	241 185 202	779 506
	RC4	Laden	12 224 247	359 302 285	1 130 643
	Wagon 1	Tare	84 876	1 760 971 694	689 436
		Laden	51 855 441	806 124 839	6 170 866
	Wagon 2	Tare	6 484	5 819 123	61 751
		Laden	592 918	4 485 641	50 996
	Other	Tare/Laden	11 545 155	503 358 037	1 407 044
	Total		84 434 065	3 681 246 822	10 290 242
326	RC2	Laden	1 062 205 791	42 806 064 383	61 939 846
	RC4	Laden	1 084 876 192	43 449 915 719	61 865 695
	Wagon 1	Tare	338 937 865	2 833 678 900	30 219 139
		Laden	20 793 210 944	330 970 869 899	2 518 502 686
	Wagon 2	Tare	1 100 101 751	3 942 329 362	13 278 398
		Laden	3 685 347 475	8 826 016 918	60 725 290
	Other	Tare/Laden	3 363 990 468	51 881 304 524	329 214 667
	Total		31 428 670 486	484 710 179 705	3 075 745 722
821	X11	Tare	6 769 439	11 957 134 380	33 596 643
	X11	Laden	30 477 723	42 540 754 012	107 525 747
	X31	Tare	39 931 083	71 292 886 957	198 891 518
	X31	Laden	238 622 178	336 159 732 011	846 669 702
	Other	Tare/Laden	275 666 389	318 566 454 424	812 143 205
	Total		591 466 811	780 516 961 784	1 998 826 815
654	X12/14	Tare	0	0	0
	X12/14	Laden	793 106 283	9 911 293 329 729	370 551 152
	Other	Tare/Laden	734 645 658	8 764 365 897 263	358 274 066
	Total		1 527 751 941	18 675 659 226 991	728 825 218
652	X12/14	Tare	18 938 296	1 877 652 983	14 033 850
	X12/14	Laden	1 560 901 574	90 945 803 045	940 090 049
	Other	Tare/Laden	3 193 816 442	421 837 633 064	1 321 158 708
	Total		4 773 656 311	514 661 089 091	2 275 282 607

6. Conclusions

This paper proposes and implements the first stage of a new approach to estimating the marginal cost of rail infrastructure usage. The approach fills an important gap between the modelling of damage – which is well understood – to obtaining measures of marginal cost, where currently the relative cost of different damage mechanisms is not well understood. The approach combines engineering and statistical approaches in a way that seeks to combine the best features of both; and thus overcome some of the weaknesses of previous approaches.

A new dataset is utilised, comprising detailed information on individual track sections of the Swedish network. This data includes information, at the section level, on track alignment and actual maintenance and renewal costs, as well as information on the vehicle volumes and types running on those sections.

Through testing this approach out on five sections, we conclude that, as expected, it is possible and indeed relatively straight forward to model the damage resulting from running vehicles on the network. We have further shown, however, that is possible to produce summary, total (annualised) damage measures for each of the three damage mechanisms. Once the approach is extended to an increased number of track sections, as planned, it will then be possible to explore the relationship between these damage measures and actual costs for the first time; and thus better understand the relative costs of the different damage mechanisms. Such information will be highly valuable to academics, the industry and policy makers as it will allow the cost implications of different technologies to be more clearly assessed. Further, from a track access charge perspective, the approach will permit improved estimation of the relative cost of different vehicle types, allowing more cost reflective charges for different vehicles on the network. In turn, more cost reflective access charges should incentivise the development and use of more track friendly vehicles.

There are a number of aspects to the research where assumptions have been used, for example, concerning the precise nature of the vehicles running on the network (we could identify passenger versus freight vehicles, and locomotive versus EMU, but had to use generic types for these rather than the actual vehicle characteristics). It has also been assumed that the damage caused by one vehicle is independent of the damage caused by other vehicles, and that the damage measures from one vehicle run can be scaled up in a simply manner. These are limiting but pragmatic and sensible assumptions; however, relaxing them would be interesting and useful for future research. Validation of the damage estimates, as compared to actual measurements would also be a useful addition if the necessary information can be obtained.

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Part II. B Implementation of Stage 2 of the methodology

1. Introduction

At the time of submitting the draft deliverable it had not been possible to carry out the second stage modelling approach due to delays in receiving data. The necessary data has now been received from Trafikverket.

As an indication, based only on the five sections that had been modelled at that date, Figure 5 suggested a reasonably clear relationship between total damage (the sum of the three damage measures) and maintenance costs (in natural logarithms). Table 5 also indicated that there is a high degree of correlation between the variables. This relationship was indicative but suggested that the modelling approach had produced sensible measures of damage that appeared to be related to cost, as expected.

Figure 5: Maintenance costs and combined measure of total damage, wear and RCF per track section

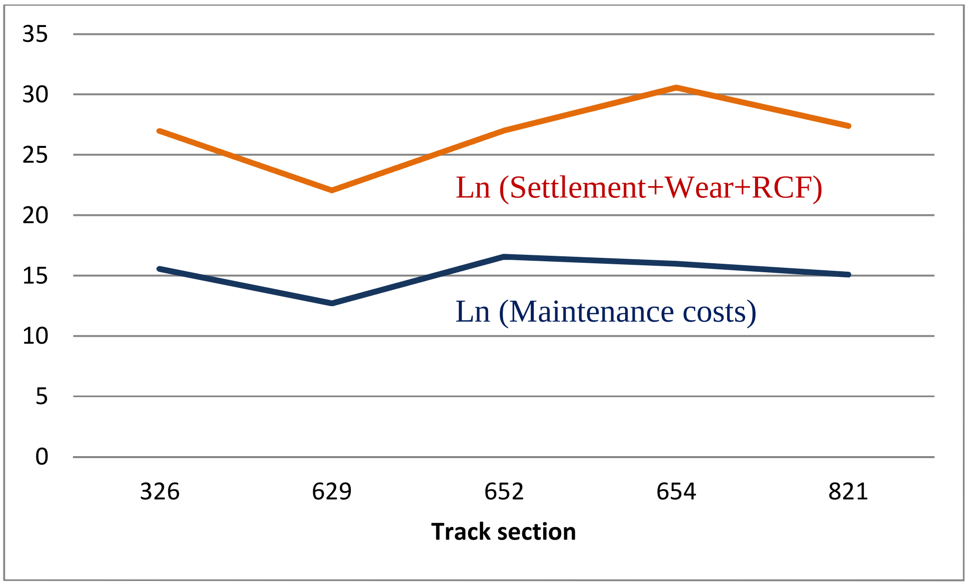

Table 5: Correlation coefficients between damage measures and maintenance cost

	Ln(Maintenance cost)
Ln(Settlement)	0.76
Ln(Wear)	0.83
Ln(RCF)	0.89
Ln(Settlement+Wear+RCF)	0.83

The remainder of this section sets out the results of the second stage modelling carried out since the submission of the draft deliverable.

2. Data and overview of the approach

As described in Part II. A, the first stage engineering simulation model produces damage estimates, which initially were reported for five track sections. It has now been possible to carry out engineering simulations for 45 sections. In stage 2 of the methodology, the objective is to relate the maintenance (and also renewal) costs to these damage estimates. In carrying out this exercise it is important to control for factors such as the length of section and the characteristics of the section, as this could affect the cost of rectifying damage, quite apart from the damage itself (this control is akin to including track length and traffic volumes, alongside track characteristics variables in the rail infrastructure marginal cost studies in the wider literature (for example, Wheat, Smith and Nash, 2009). In terms of a priori expectations, there may be scale economies which, for a given level of damage, reduce the cost of rectification; likewise, rectification costs may be different depending on the track standards required for different levels of permitted linespeed.

The descriptive statistics for the available variables are shown in Table 6. The last column in the table indicates the number of observations with zero values, showing that a majority of the track sections did not have a renewal cost in 2012. Tables 2-4 show the correlation matrix for the available variables.

Table 6: Descriptive statistics

	Obs.	Mean	Std. Dev	Min	Max	No. of zeros
MaintC	45	11 710 759	8 533 885	323 503	35 307 461	0
RenwC	45	11 604 054	67 459 659	0	453 142 803	25
M&R	45	23 314 812	70 368 666	323 503	480 456 207	0
Wear*	45	44 229 209	166 599 095	310	1 064 240 828	0
RCF*	45	6 603	9 706	6	45 474	0
Settlement*	45	47 902	64 058	45	322 782	0
Totdamage*	45	44 283 714	166 590 909	3 777	1 064 254 678	0
Ton_km	45	370 560 930	471 715 298	703 385	2 487 231 414	0
TgtDEN	45	6 665 663	6 162 461	46 839	22 719 570	0
Route_km	45	56	37	4	150	0
Track_km	45	71	48	8	248	0
RatioTLRL	45	1	1	1	5	0
Rail_age	45	21	11	2	48	0
Rail_w	45	52	5	42	60	0
Sleeper_age	45	21	12	2	49	0
Curv_km	45	17	11	1	46	0
Curvcl12_km	45	2	3	0	11	4
Curvcl13_km	45	5	6	0	23	2
Curvcl14_km	45	7	7	0	32	1

Bridge_km	45	1	1	0	8	0
Struct_km	45	1	3	0	22	0
Qualave	45	2	1	0	4	0
Switch_km	45	2	1	0	7	0
Switch_age	45	22	12	0	48	1
No switches	45	96	74	10	355	0
Ballast_age	45	22	13	0	49	1
D.Elect	45	1	0	0	1	0

Definition of variables:

MaintC = Maintenance costs

RenwC = Renewal costs

M&R = Maintenance + renewal costs

Wear* = wear/1 000 000

RCF* = RCF/1 000 000

Settlement* = Settlement/1 000 000

Totdam* = (Wear + RCF + Damage)/1 000 000

Ton_km = Tonnes km

TgtDEN = Tonnes km/Route km

Route_km = Route km

Track_km = Track km

RatioTLRL = Track km/Route km

Rail_age = Average rail age

Rail_w = Average rail weight kg

Sleeper_age = Average sleeper age

Curv_km = Track curvature km

Curvcl12_km = Track curvature with absolute value of radius $\in [0,450)$

Curvcl13_km = Track curvature with radius $\in [0,600)$

Curvcl14_km = Track curvature with radius $\in [0,800)$

Bridge_km = Track length of bridges, km

Struct_km = Track length of structures (tunnels and bridges), km

Qualave = Average quality class; note a high value of average quality class implies a low speed line

Switch_km = Track length of switches, km

Switch_age = Average age of switches

No switches = Number of switches

Ballast_age = Average age of ballast

D.Elect = Dummy variable indicating electrified track section

3. Model specification and estimation results

We estimate three different models as set out in Table 7. Data is transformed by dividing by the sample mean prior to taking logs. We can therefore interpret the first order coefficients in the estimation results as elasticities at the sample mean.

Table 7: Models

Model no.	Model	Dep. variable
1	Cobb-Douglas	Maintenance
2	Restricted Translog	Maintenance
3	Restricted Translog	Maintenance and renewals

In model 1 we only include the damage measures (Wear, RCF and Settlement) as explanatory variables. We start with a translog model:

$$lnC_i = \alpha + \beta_1 lnWear_i + \beta_{11}(lnWear_i)^2 + \beta_2 lnRCF_i + \beta_{22}(lnRCF_i)^2 + \beta_3 lnSettlement_i + \beta_{33}(lnSettlement_i)^2 + \beta_{13}(lnWEAR_i \cdot lnSettlement_i) + \beta_{12}(lnWEAR_i \cdot lnRCF_i) + \beta_{23}(lnRCF_i \cdot lnSettlement_i) + \varepsilon_i, \quad (1)$$

and test the Cobb-Douglas restrictions:

$$\beta_{11} = \beta_{22} = \beta_{33} = \beta_{12} = \beta_{13} = \beta_{23} = 0, \quad (2)$$

Based on an F-test we cannot reject the following null hypothesis:

$$\beta_{11} = \beta_{12} = \beta_{13} = 0, \quad (3)$$

which means that we can exclude the squared wear variable and the cross products between wear and other variables. However, the first order coefficients for RCF and Settlement are not significant in this restricted translog model, so the elasticites are not significant at the sample mean. For this reason the remaining second order terms were dropped. Since we are seeking to illustrate the method, and are working with a relatively small sample size, we consider that the use of a Cobb-Douglas model is reasonable. The estimation results are presented in Table 8.

Table 8: Estimation results, model 1

	Coef.	Std. Err.	T	P>t	[95% Conf.	Interval]
Constant	16.4467	0.1746	94.18	0.000	16.0940	16.7994
Wear	0.0670	0.0441	1.52	0.137	-0.0221	0.1560
Rcf	0.0023	0.0930	0.02	0.981	-0.1856	0.1902
Settlement	0.2401	0.0881	2.72	0.009	0.0622	0.4181

R^2=0.3787, Adj. R^2=0.3333, Mean VIF=2.08

We test if the coefficients are significantly different from each other. The coefficients for wear and settlement are significantly different at the 10 per cent level, i.e. we reject the null hypothesis (however, the coefficient for wear is not significant). See results from the F-tests in Table 9.

Table 9: F-tests for difference between damage coefficients, model 1

Null hypothesis	Prob>F
Wear - RCF = 0	0.583
Wear - Settlement = 0	0.080
RCF - Settlement = 0	0.164

In model 2 we include route length and average quality class as control variables. We start with a full translog model and test the Cobb-Douglas restrictions.

Most of the second order terms were insignificant and were dropped from the model. The parameter estimate for the interaction variable between RCF and route length is significant and negative, as is the first order coefficient for RCF. This suggests that an increasing RCF interacted with route length decreases the maintenance costs, which seems implausible. We therefore exclude this variable, and the first order coefficient for RCF is then no longer statistically significant (though remains negative). We also drop the interaction variable between Qualave and Wear on the basis that the first order coefficient for Qualave is not significant (p-value =0.79). This results in a first order coefficient for Qualave that is nearly significant at the 10 per cent level (p-value=0.112). The estimations results from the final model are presented in Table 10.

The parameter estimate for the interaction variable between Settlement and Qualave is significant and negative in model 2. This shows that the maintenance cost for settlement damage is lower when the requirements on track geometry standard are lower. Note that a higher value for the variable Qualave indicates lower track standard requirements and lower linespeeds, which also explains the negative first order coefficient for Qualave.

Table 10: Estimation results, model 2

	Coef.	Std. Err.	t	P>t	[95% Conf.	Interval]
Constant	16.3307	0.1669	97.83	0.000	15.9925	16.6689
Wear	0.0434	0.0399	1.09	0.283	-0.0374	0.1242
Rcf	-0.0509	0.0851	-0.60	0.553	-0.2234	0.1216
Settlement	0.1972	0.0824	2.39	0.022	0.0301	0.3642
Route tl	0.3193	0.1546	2.06	0.046	0.0060	0.6327
Qualave	-0.5089	0.3122	-1.63	0.112	-1.1415	0.1237
Settlement*Qualave	-0.3646	0.1348	-2.70	0.010	-0.6378	-0.0914
Qualave^2	-0.3712	0.1803	-2.06	0.047	-0.7365	-0.0058

Model 2c: R^2=0.5560, Adj. R^2=0.4720, Mean VIF=3.18

We test if the coefficients for the damage measures are statistically different in model 2. The results are presented in Table 11, showing that the coefficients for wear and settlement are significantly different at the 10 per cent level. This is almost the case for the difference between RCF and Settlement.

Table 11: F-tests for difference between damage coefficients, model 2

Null hypothesis	Prob>F
Wear - RCF = 0	0.376
Wear - Settlement = 0	0.093
RCF - Settlement = 0	0.106

The conclusion from models 1 and 2 is that it is important to control for the size of the section and also the characteristics of the infrastructure (e.g. the quality class variable, which principally reflects the permitted linespeed on the section). As noted earlier, there may be scale economies which, for a given level of damage, reduce the cost of rectification; likewise, rectification costs may be different depending on the track standards required for different levels of permitted linespeed. That said, in both models 1 and 2, and particularly in model 2, it is hard to obtain statistically significant estimates of the cost elasticity with respect to the different damage mechanisms. The settlement elasticity is the largest in absolute terms and is statistically significant at the 1% and 5% levels in models 1 and 2 respectively. In model 1 the wear coefficient is close to being significant at the 10% level, but the RCF coefficient is highly insignificant. In model 2 both the wear and RCF coefficients are highly insignificant and the RCF coefficient is wrong sign (though statistically insignificant as noted). The coefficient on settlement is fairly stable between the two models.

The problem of not being able to obtain statistically significant estimates of the different traffic types may result from only having 45 observations (this being the maximum that could be carried out for this project). We note that the previous literature relating costs to traffic has likewise struggled to obtain statistically significant elasticities for different traffic types.

Since the model includes only maintenance costs, it is not entirely surprising that only settlement damage is significant in the model, since tamping is the remediation action for settlement (and this cost is included in maintenance). By contrast, rail replacement is the remediation action for wear and rolling contact fatigue (which is a renewal cost), though grinding and re-profiling may also occur which should be included in maintenance costs. Whilst in principle renewal costs can also be included in this methodology, in practice, as we are working at track section level, many of the sections have zero renewals costs. We therefore do not report a model with the dependent variable constructed based on the sum of maintenance and renewal costs (though we did estimate such a model and it produced results very similar to the maintenance only model). A corner solution approach, as set out in Andersson, Smith, Wikberg and Wheat (2012) is needed for renewals at section level, and such an approach is beyond the scope of the current study.

4. Computation of relative marginal costs

The marginal cost is calculated by multiplying the average cost for each track section by the cost elasticity for that section:

$$MC_i^j = \widehat{AC}_i^j \cdot \hat{\gamma}_i^j \tag{4}$$

where $j = wear, RCF\ or\ damage$, i denotes the track section number and $\hat{\gamma}_i^j$ is the cost elasticity with respect to the *jth* damage mechanism, evaluated for each section. Since we use model 1, which is a Cobb-Douglas specification, the elasticities are the same for each section. We use the predicted average costs, which is the fitted cost divided by total Wear, RCF or Settlement:

$$\widehat{AC}_i^j = \hat{C}_i / Total\ damage_i^j \tag{5}$$

$\hat{C}_i$, as specified in eq. (6), derives from the double-log specification of our model that assumes normally distributed residuals (see Munduch et al. 2002, and Wheat and Smith 2008).

$$\hat{C}_i = \exp(\ln(C_i) - \hat{\varepsilon}_i + 0.5\hat{\sigma}^2) \tag{6}$$

Table 12: Average costs, ÖRE (=SEK/100)

	Variable	Obs.	Mean	Std. Dev.	Min	Max
Model 1:	Wear	45	0.052	0.325	0.000	2.185
	RCF	45	3.885	17.140	0.043	114.358
	Settlement	45	0.270	0.765	0.008	4.561
Model 2:	Wear	45	0.080	0.517	0.000	3.471
	RCF	45	5.135	26.965	0.059	181.656
	Settlement	45	0.399	1.793	0.007	12.079

Table 13: Average Marginal costs ÖRE (=SEK/100)

	Variable	Obs	Mean	Std. Dev.	Min	Max
Model 1:	Wear	45	0.003	0.022	0.000	0.146
	RCF	45	0.009	0.039	0.000	0.261
	Settlement	45	0.065	0.184	0.002	1.095
Model 2:	Wear	45	0.003	0.022	0.000	0.151
	RCF	45	-0.262	1.374	-9.254	-0.003
	Settlement	45	0.053	0.202	-0.008	1.333

* These are based on the average of the marginal costs computed for each track section

Since the elasticities in model 1 were all positive, we use model 1 to draw conclusions. The results suggest that settlement is the most costly damage mechanism, with a marginal cost that is just over seven times that of rolling contact fatigue and twenty-one times that of wear. RCF damage is in turn three times more costly, per unit of damage, than wear. As noted earlier, in interpreting these findings it is important to remember that the estimation is based on 45 sections and not all the parameter estimates were statistically significant. Further, as noted, the dependent variable only includes maintenance. If renewal had been included in the model, thus permitting a more complete comparison of relative costs, it is likely that the relative damage costs would be very different.

It is possible, in principle, to cross-validate these results against other estimates. For example, rough estimates of different deterioration mechanisms' share of track maintenance and track renewal costs were used in bottom up-approach to estimate costs for different vehicle characteristics in Öberg et al. (2007). The estimates were given by the Swedish Rail Administration and relate to the whole railway network. The Swedish Rail Administration states that 25 per cent of the costs are attributed to track settlement deterioration, 40 per cent to wear + RCF, and 35 per cent to deterioration of other components. These are not directly comparable to our study, which focuses on maintenance only. Since our intention in this work is merely to illustrate the approach, we do not take this comparison further. In subsequent work we would seek to expand the sample size and then make a fuller comparison of this method with alternative methods.

This is, to our knowledge, the first time that the relative cost of damage mechanisms has been estimated in this way, based on a combination of engineering simulations, combined with actual cost data. As noted earlier, whilst engineering models are adept at estimating damage, the challenges is to convert damage into cost. The traditional ”bottom-up” approaches faces many problems, since an assessment needs to be made of the remediation activity that will be done, and its timing, and then the unit cost of these activities. Depending on the nature of the network, and the combination of the damage types, these estimates could vary widely. The advantage of our top-down approach is that it uses actual cost data to derive relative marginal costs.

Table 14 provides a simple illustration of how this approach might be useful. For three vehicle types, running on a given network, estimates of damage can be obtained. The problem noted in previous approaches is that whilst these relative damage measures can be predicted with reasonable accuracy based on simulation models, it is then not clear what the relative costs will be. The latter is important for infrastructure managers to know and, given European legislation, to support track access charging regimes differentiated by vehicle.

The different vehicles in Table 14 produce different amounts of the different types of damage mechanisms; some resulting in more of one type of damage and less of other types. This situation therefore creates a problem as it is therefore not clear which vehicle results in the highest incremental cost which, as noted, is important for charging purposes. One might be able to produce a summary measure indicating the total level of damage (the fourth column in the table). Since the units are not directly comparable, this measure is not terribly meaningful. The final column of the Table however shows that, by using the relative marginal costs coming out of model 1, reported above, we can constructed a weighted damage measure, weighted according the relative marginal cost. Since settlement is the most damaging mechanism, according to model 1, then vehicle 2 has by far the highest cost weighted damage index, and thus would attract a higher access charge. Of course, as noted, we are not claiming that this is a definitive result, for the reasons set out earlier, but put this forward to demonstrate the potential power of the approach.

Table 14: Illustration of the outputs of the methodology

	Wear	RCF	Settlement	Simple Sum of Damage Measures	Cost-weighted Damage Index
Vehicle 1**	10	20	15	45	385
Vehicle 2	5	25	25	55	605
Vehicle 3	20	5	10	35	245
Relative marginal cost (Wear = 1.00)*	1	3	21		

* This is based on the results of model 1, with the marginal cost of wear normalised to unity.

** The damage numbers are simply created for the purpose of the illustration for three hypothetical vehicle types.

5. Conclusions

This paper fills an important gap in the literature concerning the translation of damage measures into measures of the cost of remediation of damage. It does so by combining engineering simulation models (stage 1), which are well understood, with top down econometric methods linking cost and damage (stage 2). This second stage is the first time a relationship between actual, cost and damage has been attempted using track section data. The approach has been implemented using Swedish data. The combination of these two approaches provides a new methodology for comparing the relative cost of damage done by different vehicles on rail infrastructure, which in turn can be used to inform track access charges differentiated by vehicle-type.

We consider that our research has demonstrated the feasibility of the approach. Whilst the time taken to undertake the engineering simulations is not trivial it is also not prohibitive. The econometric results indicate that it is possible to obtain sensible relationships between cost and the different damage mechanisms; though the statistical significance of some of the findings has been limited in this case by the relatively small sample size. Bringing together then, information on damage and relative cost of the different damage mechanisms, is potentially a powerful means of obtaining cost information that can be used to produce vehicle-differentiated track access charges. The principal advantage of this approach, compared to existing methods, is that it is Since it is based on actual cost data on actual track sections, as opposed to assumptions about the remedial work done and the unit costs of those activities; these assumptions can be potentially hard to justify and are highly uncertain.

We find that settlement is the most costly of the three damage mechanisms, followed by RCF and then wear, with settlement being approximately seven times more costly that RCF and RCF approximately three times more costly than wear. As noted we caveat this finding because of the relatively small sample and the fact that we have only been able to include maintenance costs in the approach. Taken at face value, this result suggests that vehicles resulting in more settlement and RCF damage should attract higher track access charges, though of course the results are only indicative.

Whilst the approach has been shown to be feasible, we offer some comments about future research. Further work might focus on generating more observations, exploiting panel data. This approach should be feasible using Swedish data, though it would be a significant research project. The approach is in principle applicable to many European railways where track section data is available, though again we do not claim that the approach is straightforward or trivial. That said, given that previous approaches rely in any case on engineering simulations, which is the most time consuming aspect of the work, we consider that the econometric second stage has a potential to contribute greatly to better understanding of the relative marginal cost of different vehicle types (and indeed different vehicle types running on different types of infrastructure); particularly in view of the well established problem with existing approaches to translating damage into cost.

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Appendix 1: Detailed description of engineering simulations for one track section (section 629)

Introduction

As part of the SUSTRAIL project engineering simulations of selected track and vehicle types have been undertaken. These simulations have been used to provide an estimation of the relative damage for a variety of vehicle/track combinations which can then be used in a statistical model to summarise the key drivers of damage.

Track sections with predominantly freight or passenger traffic were chosen for this analysis and track data was obtained from measuring vehicles. Models of the main vehicles running on these sections were adapted from generic models and set up in vehicle dynamics simulation package VAMPIRE.

The track sections were chosen from Sweden and vehicles running on them are shown in the table below.

Traffic	Track Section	Vehicle ID	Vehicle Type
Freight	629	RC2, RC4	BoBo Loco
	326	RC2, RC4	BoBo Loco
Passenger	821	X11, X31	EMU
	654	X12, X14	EMU
	652	X12, X14	EMU

A number of modelling techniques in combination with computer simulation packages can be used to estimate different damage mechanisms. The damage mechanisms of interest are rail wear, rail rolling contact fatigue and track settlement. The determining factors behind the mechanisms are the vertical and lateral wheel-rail forces and the energy dissipation at the surface of the rail. In order to make an accurate prediction of damages a detailed description of the track and the vehicles is required. This includes details of the masses and geometries of the vehicle and its suspension and the track design and irregularities.

Damage Mechanisms

1.1 Wear and Rolling Contact Fatigue

Wear of the rail is a natural process in which material is removed from the head and/or the gauge corner of the rail when railway vehicles run. The rate of removal is affected by the forces and contact conditions. Severe wear can change the cross sectional profile of the rail, resulting in a change of the running surface seen by the wheel.

Rolling contact fatigue (RCF) occurs if the rail surface is subjected to repeated plastic deformation as is often caused by repeated wheel passages.

1.2 'Tgamma'

The 'Tgamma' value provides a measure of the wear and RCF performance of the vehicle. Tgamma is the product of the tangential or creep forces and the slippage or creepage in the contact patch between wheel and rail. Tgamma combined with a non-linear damage function produces a RCF damage index as shown in Figure 1. This index is then used to interpret whether the vehicle is damaging the track due to wear, RCF or a combination of both.

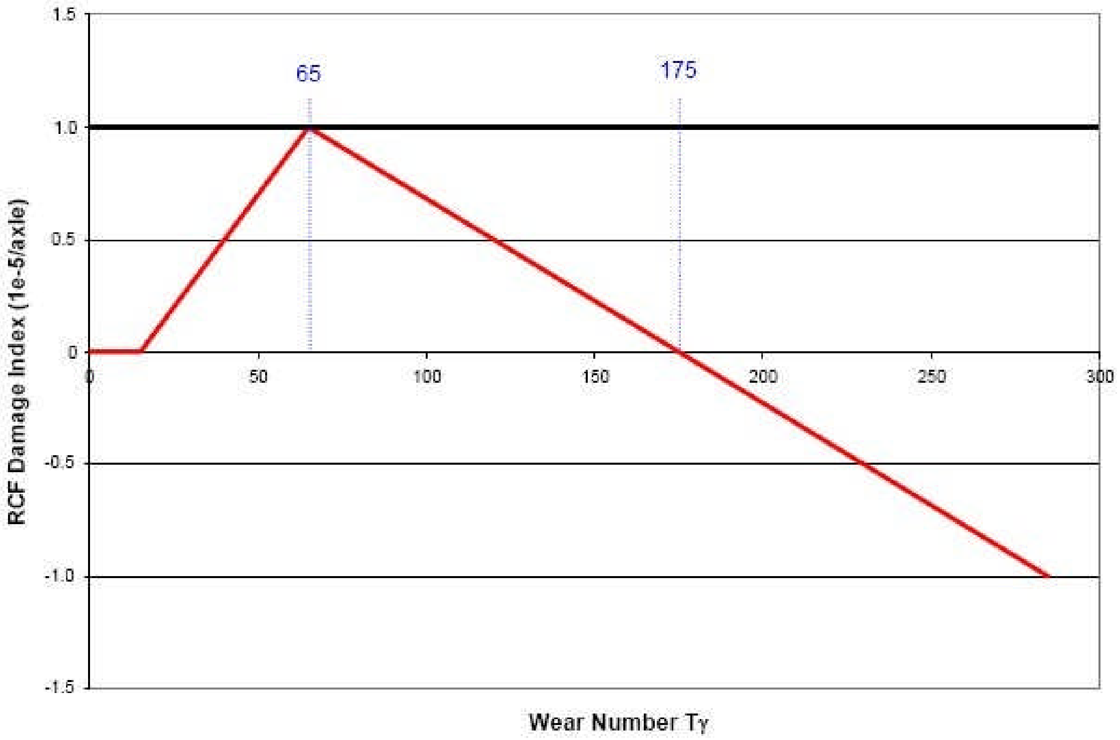


Figure 1: Relationship between wear number (Tγ) and RCF damage index

With reference to Figure 1,

- As Tgamma increase from 0 to 15 N, no RCF damage is generated as there is insufficient energy to initiate RCF cracks.
- As Tgamma increase from 15 to 65 N, the probability of RCF incitation increase, to a maximum of 1 at a Tgamma value of 65 N.
- As Tgamma increase further from 65 to 175 N, the level of energy is such that the dominant form of surface damage is wear (rather than crack initiation), therefore the probability of RCF damage decreases as wear increases.
- Negative values of RCF damage indicate values of Tgamma greater than 175 N, resulting in wear and no RCF initiation.

- The units of the RCF damage index are 10-5 per axle. This indicates that for a damage index of 1, 100000 (One hundred thousand) axle passes would result in RCF initiation.

1.3 Track Settlement

Track settlement may be defined as the sinking of the track (in the vertical plane) into the ballast under a variety of conditions. A number of models have historically been used to predict track settlement. Initially the Technical University of Munich (TUM) model and the Sato model were considered. However after investigation another method adapted from TUM was used. This method has been used earlier to estimate track settlement where the calculation of the ballast pressure has not been necessary. Instead of calculating the ballast pressure, this method incorporates vertical force on the wheelset to calculate the settlement.

	TUM model	Adapted method
Ballast settlement (mm)	$A\ p\ \ln \Delta N + B\ p^{1.21} \ln N$	$A'\ Q^{1.21} \log N$

Where:

N = number of axles passes

p = ballast pressure

Q = Vertical force at the wheelset

A, B and A' are constants.

Case Study: Track Section 629

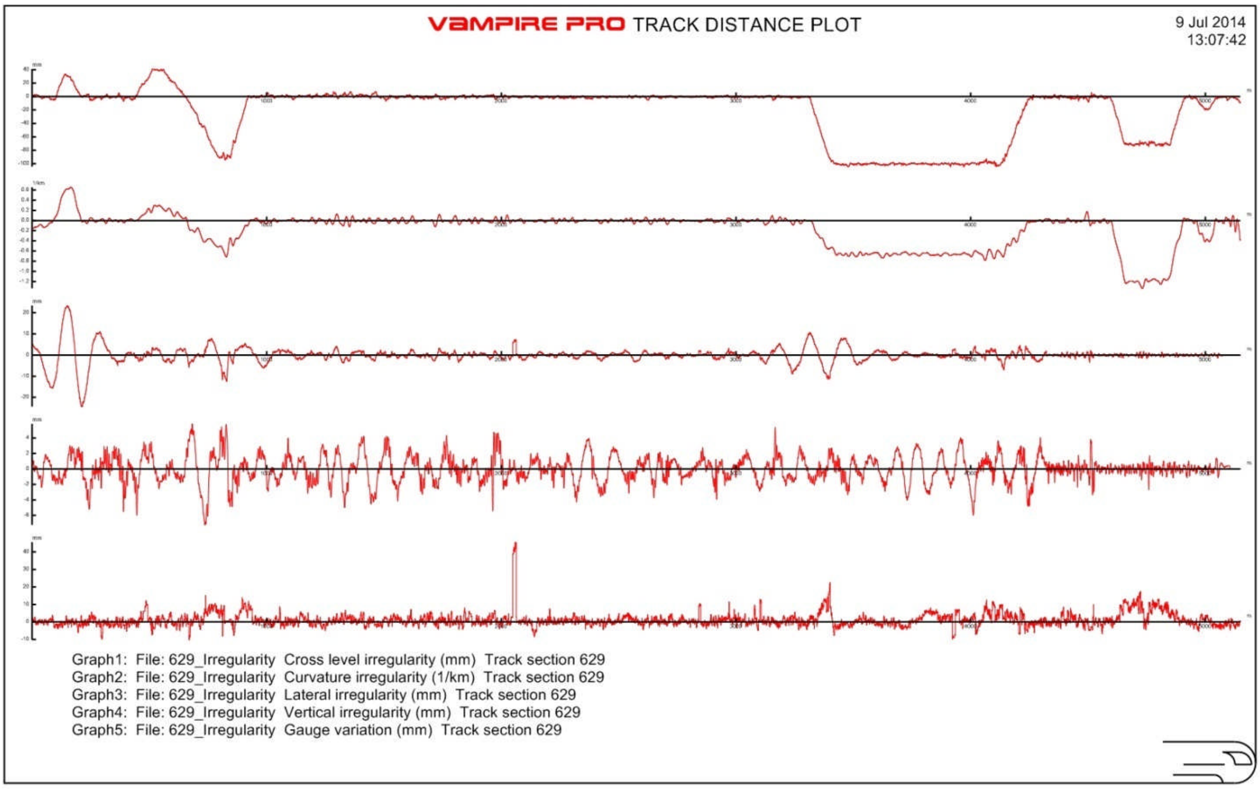
1.4 Track data

A case study based on track section 629 in Sweden has been set up to establish a method for estimation of track damage. This route is dominated by freight traffic which is 80% of the total traffic-km run. The length of the track was estimated to be 5.1 km from the track geometry data.

The track quality data were provided by VTI (originally supplied by Trafikverket) for section 629. The data were obtained using a track geometry recording coach which measures distance, curvature, cross level, vertical irregularity, lateral irregularity and gauge. This track data was then used as input data for the simulation. The track data for track section 629 is shown in Figure 2. The five graphs represent

1. Cross level versus Distance along the track
2. Curvature versus Distance along the track
3. Lateral Irregularity versus Distance along the track
4. Vertical Irregularity versus Distance along the track

5. Gauge Variation versus Distance along the track



VAMPIRE Plot

Figure 2: Track geometry data for Section 629

1.5 Vehicle models

The vehicle models were described in terms of mass properties, geometry, axle load, unsprung mass, wheel radius and suspension characteristics. The Vampire simulation package uses the model description to generate equations of motion for the vehicle which it then solves with the track input. Once the simulation is complete outputs are available for wheel-rail forces vehicle motions and can be used to estimate damage.

Vehicle	Vehicle type	Freight traffic km	Sum of axle load [ton]	Axles per vehicle	Max Speed [km/h]
RC2	BoBo Loco	990.23	76.8	4	135
RC4	BoBo Loco	1455.51	78.0	4	135
Wagon 1	Bogie type 1	-	102.0	4	-
Wagon 2	Bogie type 2	-	45.0	2	-

Results

The outputs from the simulations were Tgamma number and peak forces on each wheel or wheelset. Tgamma number was then used to calculate wear and RCF damage.

Table 1 shows the Tgamma number at each wheel of RC2 vehicle for every 40m distance. From these values a total Tgamma is calculated which is then converted into a wear measure. Total wear is calculated and then averaged over the length of the track to arrive to gross wear per tonne-km.

Table 1: Wear calculation for RC2

Start (m)	**Left wheel 1**	**Left wheel 2**	**Left wheel 3**	**Left wheel 4**	**Right wheel 1**	**Right wheel 2**	**Right wheel 3**	**Right wheel 4**	**Total**	**Wear**
0	19.488	7.163	15.565	8.314	35.105	5.748	26.43	5.881	123.694	0
40	26.682	5.965	26.926	7.03	71.314	5.454	72.856	5.406	221.633	8865.32
80	135.464	6.487	4.001	5.085	79.574	9.113	5.88	4.643	250.247	10009.88
120	75.931	9.26	73.655	11.438	92.581	12.05	91.188	14.016	380.119	15204.76
160	202.581	28.709	83.761	20.39	305.3	28.617	244.43	12.542	926.33	37053.2
200	2.584	5.497	75.634	5.324	2.143	7.952	63.957	7.289	170.38	6815.2
240	3.708	3.432	4.689	4.976	4.091	4.154	4.249	6.412	35.711	0
280	20.898	4.457	4.236	6.319	4.33	4.689	4.158	5.301	54.388	0
320	2.65	3.189	3.702	5.21	3.07	2.61	4.037	3.959	28.427	0
360	3.702	4.259	4.534	4.999	3.787	3.552	4.375	5.444	34.652	0
400	4.63	4.97	4.02	4.83	5.025	4.836	4.052	7.401	39.764	0
440	99.869	7.729	21.119	8.339	127.002	9.359	60.169	7.618	341.204	13648.16
480	89.505	8.432	3.064	2.684	131.445	11.181	3.056	3.692	253.059	10122.36
520	67.581	5.803	68.64	5.711	65.384	6.855	54.004	7.903	281.881	11275.24
560	50.395	5.509	86.644	5.858	144.236	5.843	58.138	7.608	364.231	14569.24
600	3.913	4.689	89.441	7.426	4.108	6.414	218.17	10.049	344.21	13768.4
640	229.413	4.798	14.311	5.684	17.299	5.907	87.998	7.656	373.066	14922.64

680	161.383	8.643	5.392	12.717	74.367	6.772	5.18	5.64	280.094	11203.76
720	149.442	13.437	72.879	15.15	95.178	10.208	77.325	10.931	444.55	17782
760	136.297	8.531	100.54	9.338	94.709	6.9	82.719	7.166	446.2	17848
800	339.074	8.721	350.914	10.066	144.623	11.042	150.253	12.151	1026.844	41073.76
840	105.412	12.339	144.538	13.413	69.832	30.975	146.201	15.326	538.036	21521.44
880	9.443	6.376	140.329	17.13	10.91	5.663	102.248	12.178	304.277	12171.08

Table 2 shows the maximum vertical force on each wheelset of RC2 vehicle for every 200m distance. From these values a damage index is calculated which is then summed together to obtain a total damage index per 200m section. Average damage is calculated from these values and converted into gross damage per tonne-km.

Table 2: Settlement damage calculation for RC2

LADEN (Total Axleload = 76.8; No. of axles = 4)									
	Max peak force per wheelset				Damage Index				
Start (m)	WS1	WS2	WS3	WS4	WS1	WS2	WS3	WS4	Total
0	-135.051	-159.402	-160.244	-159.374	378.3575	462.3996	465.3567	462.3013	1768.415
200	-81.162	-80.487	-81.114	-82.745	204.3228	202.2684	204.1766	209.1547	819.9225
400	-126.801	-127.508	-126.762	-129.125	350.573	352.9395	350.4425	358.3625	1412.317
600	-149.05	-149.906	-151.454	-151.175	426.3161	429.2803	434.65	433.6814	1723.928
800	-127.323	-114.855	-124.675	-116.055	352.32	311.015	343.4734	314.9512	1321.76
1000	-161.372	-160.901	-161.523	-159.974	469.3233	467.6663	469.8547	464.4081	1871.252
1200	-166.083	-167.274	-166.029	-167.758	485.9521	490.1719	485.7609	491.8886	1953.773
1400	-168.583	-167.85	-168.184	-168.984	494.8171	492.215	493.4004	496.2416	1976.674
1600	-128.202	-127.492	-127.516	-126.649	355.2652	352.8859	352.9663	350.0646	1411.182
1800	-116.611	-119.073	-116.803	-119.074	316.7779	324.8883	317.4091	324.8916	1283.967
2000	-87.022	-112.289	-113.928	-111.947	222.306	302.6272	307.9803	301.5123	1134.426
2200	-152.662	-153.218	-152.128	-153.288	438.8483	440.783	436.9916	441.0267	1757.65
2400	-171.324	-171.056	-170.907	-168.895	504.5684	503.6135	503.0827	495.9254	2007.19

Table 3 contains measures of the three damage mechanisms for track section 629 for each vehicle type.

Table 3: Results for different damage mechanisms

Track Section	Vehicle	Loading condition	Damage per tonne-km	Wear per tonne-km	RCF per tonne-km
629	RC2	Laden	103.81	3081.7	9.96
	RC4	Laden	104.98	3085.7	9.71
	Wagon 1	Tare	20.51	425533.1	166.6
		Laden	128.57	1998.7	15.3
	Wagon 2	Tare	24.12	21645.9	229.7
		Laden	124.29	940.3	10.69

Vehicle models for RC2 and RC4 locomotives were run on this track route and the results for track settlement for each vehicle are shown as a percentage distribution in Figure 3 and Figure 4 represents the percentage of actual damage caused by the two locos. As RC4 makes a larger proportion of traffic on this route, it causes more settlement as seen in Figure 3. From the data available it was estimated that in a fixed period of time 192 RC2 locos are operational on this track section whereas in this same period 282 RC4 locos carry freight on this route.

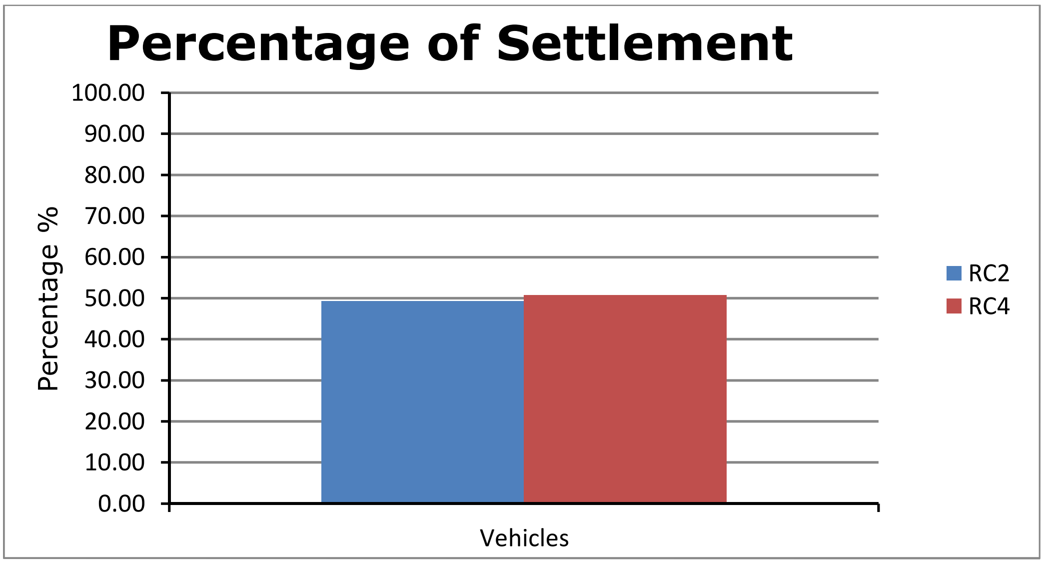


Figure 3: Percentage distribution of Settlement by actual damage by Locomotives

Figure 4 represents the percentage of settlement per ton of axle load for the locos. RC4 is a later version of the RC2 loco and is slightly less damaging to the rail compared to the RC2 even though the RC2 has a lower axle load.

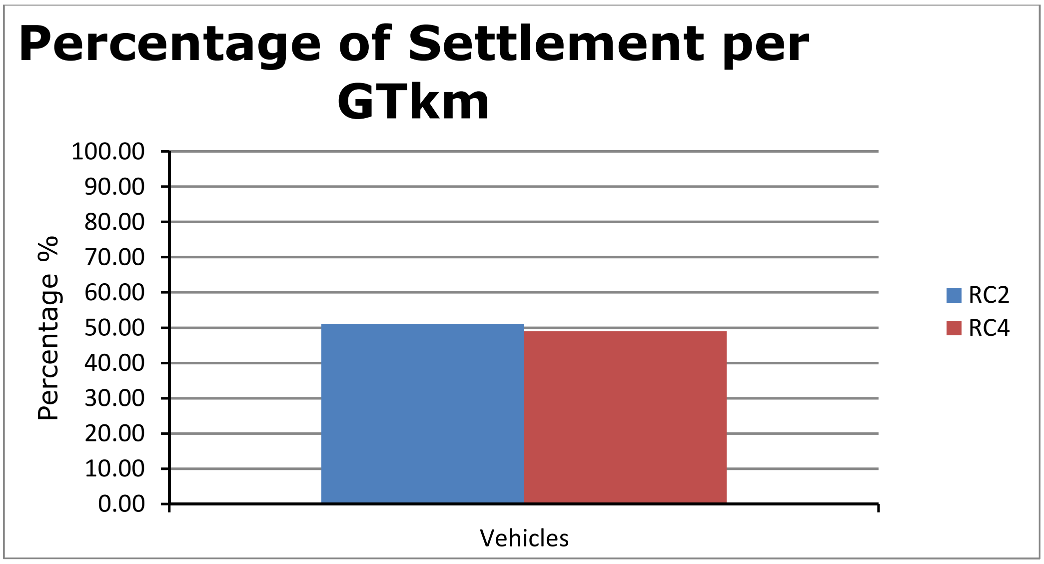


Figure 4: Percentage distribution of Settlement per ton of axle load by Locomotives

A comparison of the damage caused two kinds of wagon was also carried out. Figure 5 and Figure 6 show the settlement damage by the different wagons operating on this section of track. As can be expected a laden wagon causes more settlement compared to a tare wagon. There is no significant difference in the percentage of damage per GTkm caused by the wagons with different bogie types.

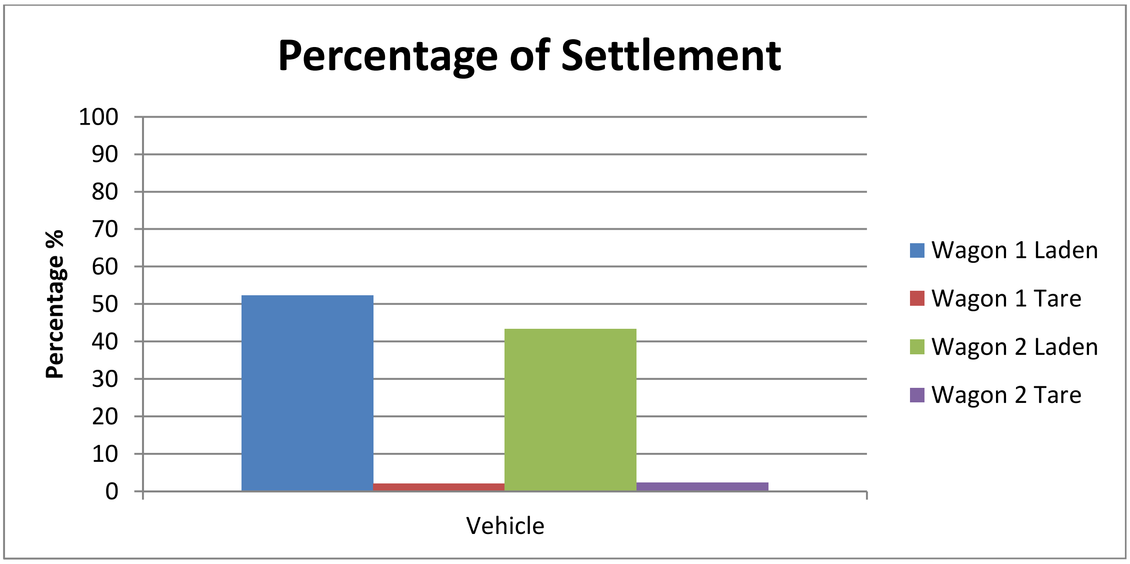


Figure 5: Percentage distribution of Settlement by actual damage by Wagons

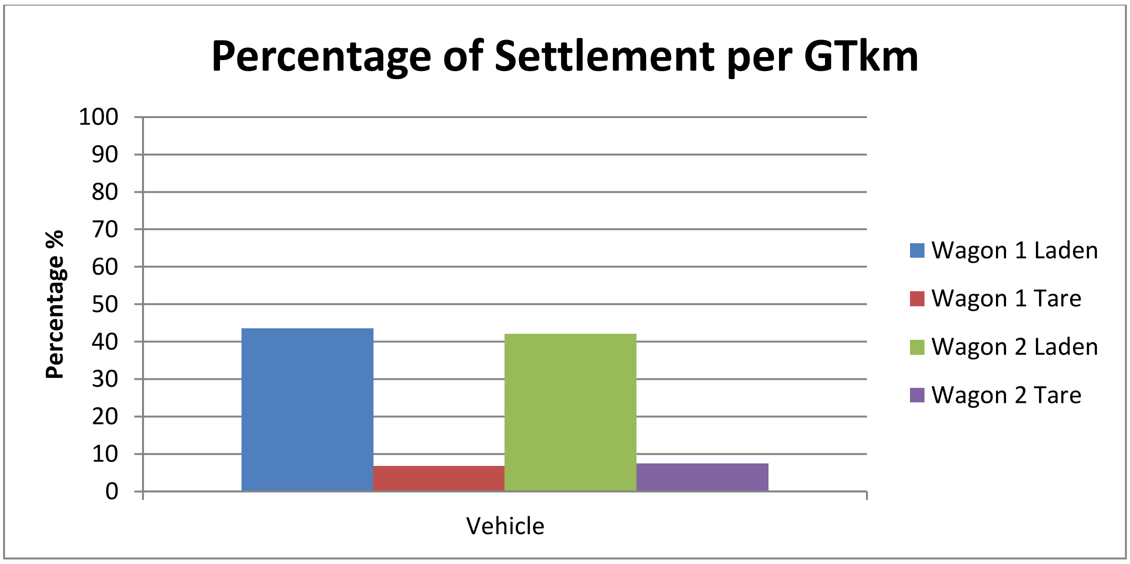


Figure 6: Percentage distribution of Settlement per ton of axle load by Wagons

Figure 7 and Figure 8 represents damage on the rails due to RCF and wear by RC2. Figure 5 shows the distribution of the Tgamma and RCF Indices along the track. Negative values of RCF Index imply a large amount of wear. This can be seen in the section of track between 4500m to 5000m where Tgamma values are very high (meaning greater wear). Figure 8 shows the percentage of track where high wear, RCF or a combination of both occurs. Both RC2 and RC4 cause similar levels of wear and RCF damage.

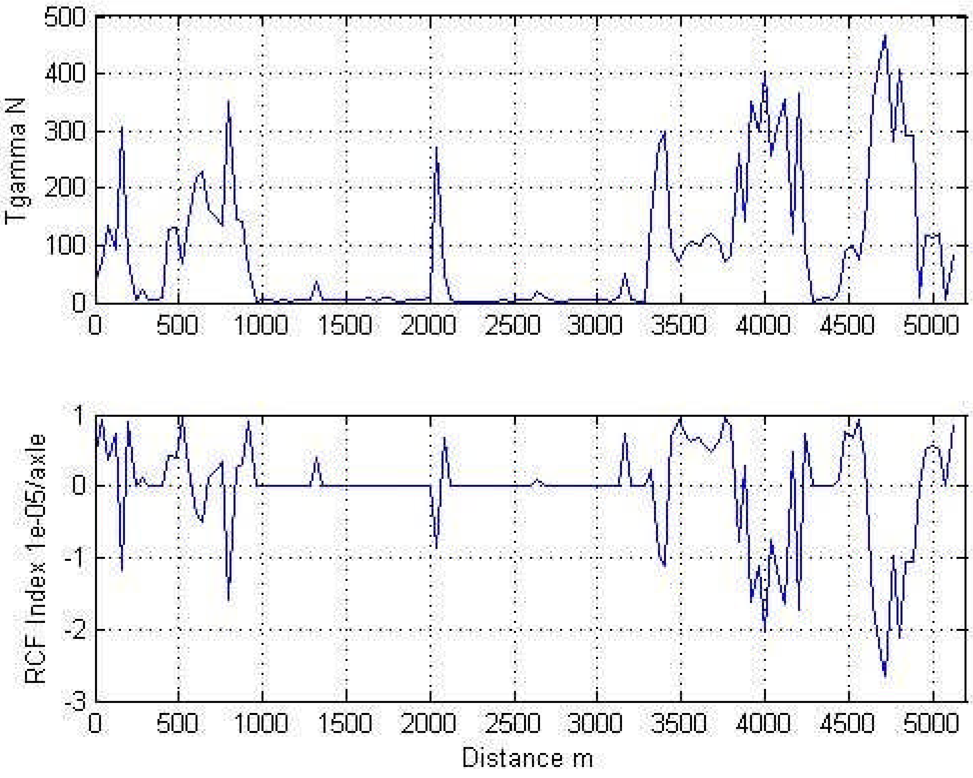


Figure 7: Tgamma and RCF Index for Section 629

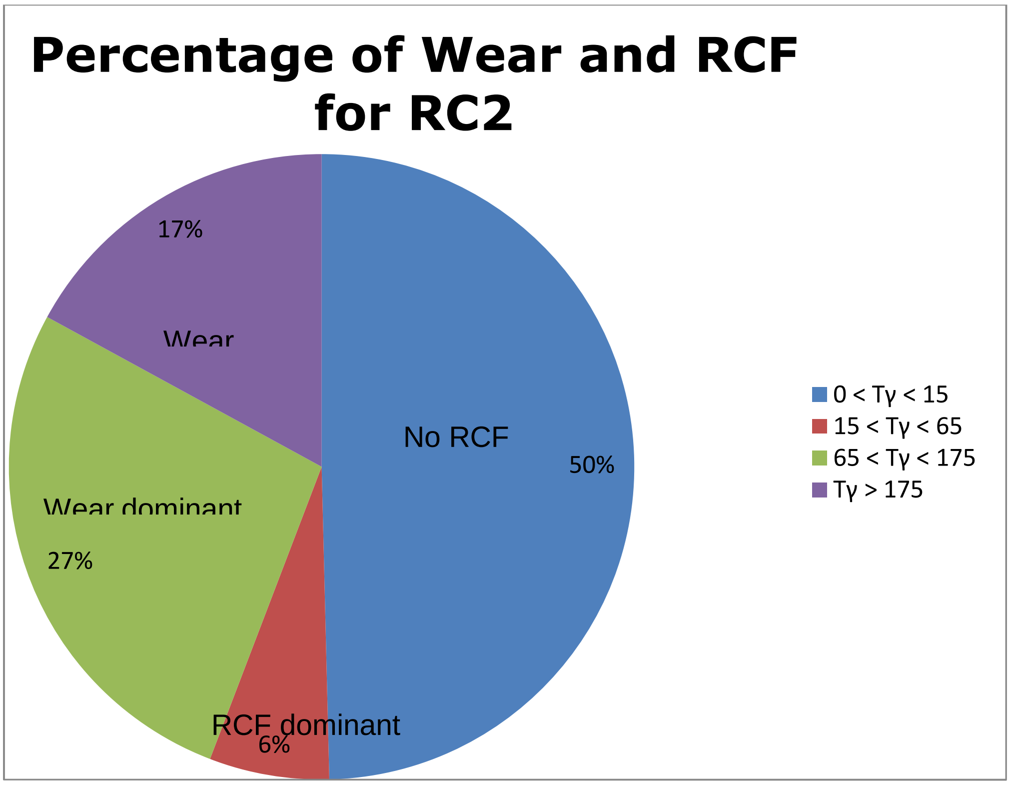


Figure 8: Percentage distribution of Wear and RCF by RC2

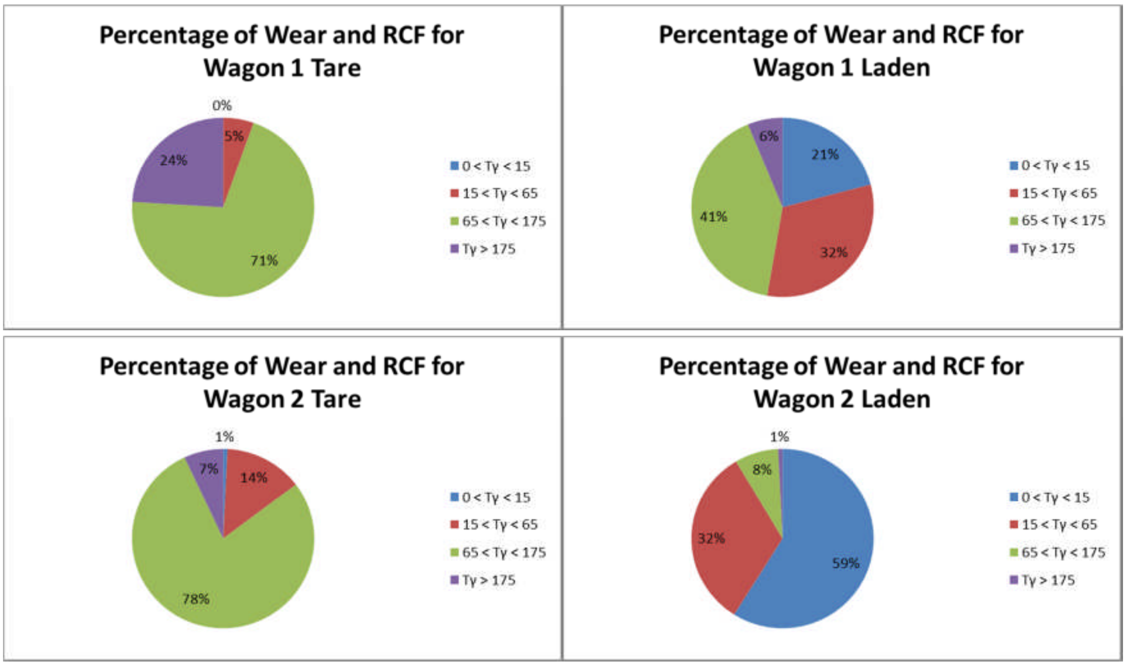


Figure 9: Percentage distribution of Wear and RCF by Wagons

Figure 9 shows the percentage distribution of wear and RCF damage by the two-axle and the four-axle wagon.

Conclusions

A model to estimate the costs due to this damage needs to be chosen and applied. From these simulations it is seen that the locomotives RC2 and RC4 cause a similar level of track settlement, rail wear and rail RCF damage per gross ton-km. The two wagons considered lead to similar amount of track settlements. Track settlement however depends on the payload on these wagons. A tare wagon is less damaging than a laden wagon as the vertical forces at the wheelset are lower. Rail wear and rail RCF damages are however different for both wagons as they have dissimilar bogie configuration. Rail wear is the dominant form of damage for wagon 1 in tare and laden condition. Propensity for rail RCF is higher for a laden wagon when compared to a tare wagon.

Appendix 2: Data and scaling up method

This appendix is divided into two sections. In the first section we list the infrastructure characteristics data that has been collected for inclusion in the second stage model selection process, but is not described in the summary of the approach in Part II.A above. In the second section we provide further detail on the scaling up of damage measures from the runs of vehicles that we have carried out, to take account of all traffic running on the sections.

1. Track characteristic data collected

The Swedish railway network is divided into about 260 track sections. The characteristics of the sections vary quite a lot since they have a long history and were not defined on a specific set of criteria. Moreover, the traffic volume as well as the type of traffic running on the sections vary, which results in differences in various aspects of the sections (for example requirements on track standard and amount of maintenance and renewal activities carried out).

The characteristics of the infrastructure data has been collected from Trafikverket's track information system. The information is available at a detailed level. For example, the age and weight information is presented for rails with lengths stretching from 10 metres to several kilometres. We therefore use a weighted measure to describe the data at the track section level. Weighted means and weighted standard deviations are used for rail age, rail weight and linespeed in the tables below.

Table: Track length, rail age and weight

	Track length	*Rail age*				*Rail weight*			
Track section no.	Total	Mean*	St. dev.*	Min	Max	Mean*	St. dev.*	Min	Max
326	118 842	11.06	3.94	1	57	58.67	4.48	34	60
629	9 178	45.69	6.62	4	49	49.31	2.08	43	50
652	42 018	48.08	6.67	3	57	43.17	1.08	41	50
654	43 623	35.27	14.23	1	63	47.09	4.58	32	50
821	31 287	16.95	0.47	3	22	49.51	2.02	41	50

* Weighted using share of total track length

The weighed means of rail age differ considerably between the sections; a difference which is also reflected in the weighted means of rail weight as old rails are usually replaced with heavier rail.

Table: Linespeed

Track Section no.	Mean*	St. dev.*	Min	Max
326	93.04	11.11	40	110
629	123.57	14.70	90	130
652	104.01	15.89	40	110
654	101.47	11.87	50	110
821 – A**	126.74	26.54	60	160
821 – B**	134.08	26.95	60	160
821 – S**	143.41	27.54	60	160

* Weighted, ** Linespeed depends on the vehicle type, where A=locomotives with stiff boogies, B=most passenger trains, S=vehicles with body tilting (passenger train X2). These linespeeds do not vary for the other track sections.

Intervals of the absolute radius of the curves are used to describe the curvature of the track sections. Metres of curved track and share of total track lengths are found in the table below. Track section no. 326 has the largest share of sharp curves with 16.4 per cent of the total track length having a radius below 600, while the corresponding share is below 6.6 per cent for the other track sections.

Table: Curvature

Track metres of different radius intervals, with share of total track length in parentheses

Track section no.	[0, 300]	[301,450]	[451,600]	[601,800]	[801,1500]	[1501,9 999]	10 000+
326	2056	9019	8405	2616	5992	2847	210
	(1.7 %)	*(7.6 %)*	*(7.1 %)*	*(2.2 %)*	*(5.0 %)*	*(2.4 %)*	*(0.2 %)*
629	0	0	0	0	946	129	76
	(0.0 %)	*(0.0 %)*	*(0.0 %)*	*(0.0 %)*	*(10.3 %)*	*(1.4 %)*	*(0.8 %)*
652	133	311	0	975	1946	6228	60
	(0.3 %)	*(0.7 %)*	*(0.0 %)*	*(2.3 %)*	*(4.6 %)*	*(14.8 %)*	*(0.1 %)*
654	523	751	1608	727	1491	2543	0
	(1.2 %)	*(1.7 %)*	*(3.7 %)*	*(1.7 %)*	*(1.7 %)*	*(3.4 %)*	*(0.0 %)*
821	645	545	376	727	1810	1466	41
	(2.1 %)	*(1.7 %)*	*(1.2 %)*	*(2.3 %)*	*(5.8 %)*	*(4.7 %)*	*(0.1 %)*

2. Scaling up assumptions

The simulation runs do not include all the different types of vehicles running on each track section. Hence, we have an additional share of ton-km from other vehicles to consider when calculating the total damage on each track section. The damage caused by these vehicles is assumed to be proportionate to the damage caused by the vehicle types in the simulation runs. We therefore calculate the share of ton-km for each vehicle type in the simulation and use their respective damage measure to estimate the damage caused by vehicles not included in the simulation runs. The calculations for track section 326 and the damage measure RCF is used as an example. More specifically this calculation assumes that, for example, 79 per cent of the ton-km of other vehicle types (not included in the simulation runs) has the same RCF per ton-km as wagon 1 (laden).

Table: Example of damage calculations, track section 326

Vehicle	Loading condition	Ton-km	Share	RCF per ton-km	RCF	RCF other vehicles
RC2	Laden	7 820 688	4%	7.92	61 939 846	7 424 458
RC4	Laden	7 951 889	4%	7.78	61 865 695	7 415 570
Wagon 1	Tare	3 021 914	2%	10.00	30 219 139	3 622 236
	Laden	141 488 915	79%	17.80	2 518 502 686	301 881 904
Wagon 2	Tare	5 419 754	3%	2.45	13 278 398	1 591 624
	Laden	13 031 178	7%	4.66	60 725 290	7 278 875
Other vehicle types	Tare/Laden	21 424 103	-	-	-	-
Total	-	200 158 441	-	-	2 746 531 055	329 214 667

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

SUSTRAIL

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1. INTRODUCTION

A principle in Sweden is that transports should pay its socio-economic costs. This principle became important for the Swedish railway system with the vertical separation of train operations and rail infrastructure management in 1988, which thus preceded the decision by the European Commission (see directive (Dir. 91/440)). Directive 2001/14 establishes the charging principles of infrastructure, which led to Swedish legislation (Järnvägslag (2004:519)) stating that track access charges should be set according to the direct cost of running a vehicle on the tracks. In Sweden, research on the cost incurred by an extra vehicle on the tracks has resulted in charges based on marginal costs for maintenance, operation, accidents and emissions. The marginal cost of noise has been studied by Ögren and Swärdh (2012), but is not a part of the track access charges. Likewise, marginal costs for track renewals, estimated by Andersson and Björklund (2012) and Andersson et al. (2012), is not included in the track access charges.

2. MAINTENANCE COSTS

Research on the marginal maintenance wear and tear costs in Sweden started with the paper by Johansson and Nilsson (2004) who used econometric estimation techniques on panel data for years 1994-1996. The methodology can be referred to as a top-down approach, which estimates a cost function (often with a double-log functional form) using historical data. With traffic volume included in the cost function, the cost elasticity with respect to traffic is derived. The marginal cost is then calculated as the product of average costs and the cost elasticity. This approach was used by Andersson (2006, 2007 and 2008), which formed the basis for the track access charges for maintenance wear and tear costs in Sweden.

Track access charges have been based on a weighted marginal cost (1) for the entire railway network. Equation (1) is also used in other econometric studies of marginal costs for maintenance, operations[1] and renewals in Sweden (the studies are summarized in table 1).

$$MC^w = \sum_{it}\left[MC_{it} \cdot \frac{TGTKM_{it}}{\sum_{it} TGTKM_{it}}\right] \qquad (1)$$

where MC= marginal cost, TGTKM = total gross tonne-kilometre, *i* = track section number and *t* = time.

The weighted marginal maintenance wear and tear cost in Andersson (2008) was calculated - and thus charged - for a gross tonne-kilometre, irrespective of the type of vehicle the gross tonne-kilometre belonged to. However, in a case study by Anderson (2009) - within the sixth framework programme Cost Allocation of Transport Infrastructure Cost (CATRIN) - a Box-Cox model was estimated with freight and passenger traffic included as separate outputs in

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[1] Total train-km - instead of total gross tonne-km - is used when calculating the weighted marginal operation cost

the cost function. The estimations resulted in significantly different cost elasticities, with a mean cost elasticity of 0.18 for passenger traffic and 0.05 for freight traffic; an unexpected result for track engineers in Sweden, since the implied marginal cost for freight were substantially lower than for passenger (see Table 4.2 in the main D5.3).

Engineering models, which can be referred to as a bottom-up approach, was used in Öberg (2006) and later extended in Öberg et al. (2007). The bottom-up approaches establishes a relationship between traffic and damage (wear and tear) on the infrastructure, with a focus on the forces created between tracks and vehicles, i.e. the vehicle’s ride behaviour. A unit cost for the activities required to remedy the damage are often used in the second stage of the model (Wheat and Smith 2008). As different types of vehicles have different ride behaviours, these approaches have been sought as a possibility to differentiate the track access charges by vehicle type. One motive is to create incentives for using vehicles that inflict less wear and tear on the tracks. The engineering model by Öberg et al. (2007) considers four different track deterioration mechanisms: deterioration of track geometry, component fatigue, wear of rails and rolling contact fatigue. Simulations on the forces creating these different deteriorations are used to evaluate how increased axle loads and ride behaviour of a vehicle damage the tracks. The marginal cost of traffic is then based on an assessment of the share of maintenance costs that each deterioration mechanism is responsible for. The results from the deterioration models show that axle load have a significant role in track deterioration and that a fixed bogie increases wear of rails and rolling contact fatigue. Hence, based on the results from the engineering model and the cost assessment, Öberg et al. (2007) suggests differentiated track charges by vehicle types/characteristics, with a larger share of the costs attributed to freight traffic. Moreover, they show that passenger locomotives should bear a larger share of the costs compared to multiple-unit trains.

Returning to the top-down approach, Wheat et al. (2009) suggested a different type of differentiation, with cost elasticities varying between different traffic usage levels. The recommended cost elasticity for low density lines (less than 3 million tonne-km/track-km) is 0.2, for medium density lines (between 3-10 million tonne-km/track-km) it is 0.3 and 0.45 for high density lines (over 10 million tonne-km/track-km). Yet another type of differentiation was studied by Wikberg (2013) on Swedish data from three studies on marginal costs for operation, maintenance and renewals. The objective was to evaluate the possibility of differentiating marginal costs with respect to track sections and corridors (which implicitly can result in a differentiation with respect to traffic levels). Negative marginal costs were found for a number of track sections and corridors. A section- or corridor specific track access charge based on these estimation results was therefore not recommended. However, Wikberg (2013) found that track sections consisting mainly of station areas had significantly higher marginal maintenance costs, together with low density sections. Track sections with high traffic density had higher marginal costs for operation, while the marginal renewal costs were lower for these sections. It should be noted that these estimations were based on different sample periods, with maintenance, operations and renewals based on periods 1999-2002, 1999-2006 and 1999-2009 respectively.

3. OPERATION COSTS

Turning to operation costs, the track access charges are based on estimations by Grenestam and Uhrberg (2010) who had access to operation costs at the track section level for years 1999-2006. About 80 per cent of the costs are due to snow removal. Though, only 35 percent of the total operation costs were registered for different track sections. The authors note that a large part of the operation costs not booked at track section level is costs for traffic management/control centres. They find a mean cost elasticity of 0.18, which can be compared to the results in Andersson (2006) with a mean cost elasticity of 0.37. These findings differ substantially from the results in Andersson (2007), with a mean cost elasticity of -0.014 . The suggested explanation for negative cost elasticities (also present in the study by Grenestam and Uhrberg 2010) is train passages sweeping snow off the tracks, which thus have a negative effect on costs up to a certain traffic volume. A very high traffic density will increase the need for quick snow removal and de-icing, which is more costly with high capacity usage. Neither Andersson (2007) nor Grenestam and Uhrberg (2010) include variables capturing variations in weather in their models, which might explain some of the differences in results when using the same model on different sample periods.

4. RENEWAL COSTS

Renewal costs were estimated within the aggregate of renewals and maintenance costs in Andersson (2007) using a standard econometric cost function treatment. This resulted in an insignificant cost elasticity. The lumpy and cyclical nature of renewals makes this kind of model specification challenging, and this approach requires sufficient variation in the data and sufficient variables to characterised the infrastructure, to yield appropriate results. A different approach is used in Andersson and Björklund (2012). They use survival analysis on track renewals costs (i.e. only the rails, sleepers and ballast costs). They calculate the marginal track renewal costs as the change in present values of renewal costs due to a premature renewal caused by increased traffic volumes. They find a weighted average marginal cost of SEK 0.0021 per gross tonne-km.

A different approach is used in Andersson et al. (2012), in which corner-solution models are estimated using data on 190 track sections over 11 years. The cost variable is again track (only) renewal cost. The preferred two-part model (originally proposed by Cragg 1971) consists of a selection equation (probability of renewal) and an outcome equation (quality of renewal), which results in a weighted marginal cost of SEK 0.009 per gross tonne-km with an cost elasticity of 0.55. This is notably higher than SEK 0.0021, and Anderson and Björklund (2012) stress that they use an average cost estimate for track segments, while observation specific costs at a more aggregate level (track section level) are used in the other study.

The Andersson et al (2012) also provided elasticity estimates for track sections with different characteristics as shown in Table 2. This demonstrates that the elasticity of renewals cost with respect to traffic is increasing with traffic density, which is intuitive, given we would expect traffic relate costs to increase as a proportion of total cost with more traffic. It also shows that improving track capability (measured by rail weight) decreases marginal cost per tonne-km and the older the track, the higher the impact of traffic i.e. greater marginal cost associated with older track (measured by switch age in this case).

Table 1 - Previous marginal maintenance, operation and/or renewal cost studies on Swedish data

Studies	Cost category	Output	Data type	Functional form	Mean cost elasticity w.r.t. output
Johansson and Nilsson (2004)	Maintenance	Gross tonnes	Panel data, pooled OLS	Translog	0.17
Andersson (2006)	Maintenance	Gross tonnes	Paneld data, pooled OLS	Double log, quadratic terms	0.21
	Operation	Trains	Paneld data, pooled OLS	Double log, quadratic terms	0.37
	Maintenance and renewals	Gross tonnes	Paneld data, pooled OLS	Double log, quadratic terms	0.26
Andersson (2007)	Maintenance	Gross tonnes	Panel data, fixed effects	Double log, quadratic and cubic terms	0.27
	Operation	Trains	Panel data, fixed effects	Double log, quadratic and cubic terms	-0.014
	Maintenance and renewals	Gross tonnes	Panel data, fixed effects	Double log with quadratic and cubic	0.133
Andersson (2008)	Maintenance	Gross tonnes	Panel data, fixed effects	Double log, quadratic and cubic terms + renewal dummy	0.26
	Operation	Trains	Panel data, fixed effects	Double log, quadratic and cubic terms + renewal dummy	-0.04
Grenestam and Uhrberg (2010)	Operation	Trains	Panel data, fixed effects	Double log, quadratic term	0.182

Studies	Cost category	Output	Data type	Functional form	Mean cost elasticity w.r.t. output
Andersson and Björklund (2012)	Renewals	Gross tonnes	Panel data, survival analysis	log-likelihood, no higher order terms	-0.3[a]
Andersson et al (2012)	Renewals	Gross tonnes	Panel data, corner solution models	double log in outcome equation, no higher order terms	0.55

[a] Elasticity of expected life time with respect to traffic volume

Table 2 Variations in marginal costs and elasticities by rail weight, switch age and tonnage density

	Marginal cost (SEK per Gross Tonne-km)	Elasticity	Number of observations
Rail weight (kg)			
<45	0.077	0.602	249
45–55	0.02	0.548	1014
>55	0.007	0.523	396
Switch age (years)			
0–10	0.006	0.586	191
11–20	0.013	0.536	683
21–30	0.028	0.544	538
>30	0.067	0.573	251
Tonnage	(mtgt)		
0–5	0.038	0.575	995
6–10	0.008	0.525	266
11–20	0.006	0.514	255
>20	0.007	0.487	146

Reproduced from Table 5 in Andersson et al (2012)

5. ORGANISATIONAL REFORMS

While the above mention cost studies have focused on cost elasticities with respect to traffic, there have been organisational reforms of rail infrastructure management during the last two decades which affects the cost structure of rail infrastructure management. In 1998, the production unit was separated from the administrative unit which created a client-contractor relationship. A further reform was made in 2002 when competitive tendering of maintenance contracts was introduced. The exposure of railway maintenance to competition was gradual. In 2012, 95 per cent of the railway network was tendered in competition. The impact of competitive tendering in rail maintenance in Sweden is studied by Odolinski and Smith (2014), using pooled data at contract area level. The estimated cost function included freight and passenger traffic as separate outputs, and the estimated cost elasticity for freight traffic was 0.13 and 0.035 for passenger traffic , a difference which is more in line with the results from the engineering models by Öberg et al. (2007). However, the study used another cost base compared to previous studies on marginal costs; activities that traditionally have been considered as operation is now a part of the maintenance contracts, including snow removal which furthermore was defined as maintenance in 2007 by the Swedish Rail Administration.

Considering the organisational reforms, new estimations might change the marginal infrastructure costs. Further research on marginal costs in Sweden is ongoing. The government commissioned the Swedish National Road and Transport Research Institute (VTI) in 2012 to update and develop knowledge about the socio-economic costs of transport. Results are to be reported in November 2014.

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

SUSTRAIL

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ABSTRACT

Determining the marginal wear and tear costs from traffic is important in railways given the need for infrastructure managers to base charges for traffic access on the costs incurred to the infrastructure from doing so. Further there is less evidence on infrastructure renewals costs than maintenance costs. In this paper we show that it is possible to estimate sensible marginal costs by seven traffic types for wear and tear to railway infrastructure measured as the sum of maintenance and renewal cost, which has to date been difficult due to lack of data both on the disaggregated traffic measures and sufficient observations to pick up such intricate partial effects. We use data for the Swiss railway network. We consider the most appropriate functional form for the model by advancing beyond the common Translog cost function through estimation of a model with Box-Cox transformed explanatory variables. This issue has found some traction in this empirical literature since adopting a Box-Cox model has been a pragmatic way to avoid counter intuitive marginal cost distributions when using Translog models which have been found in nearly all previous studies in Europe. Our innovation here is to apply an appropriate estimation routine which specifically acknowledges second order terms as opposed to previous applications which actually did not nest the Translog as a special case. Given that we find that the null hypothesis that the Translog form can be rejected we conclude there is a valid statistical motivation for the use of the Box-Cox model in this case. Our findings on the sensibility of incorporating traffic types is important in terms of the extent to which econometric analysis can be used to inform the relative damages of different traffic types to offer a benchmark for the findings from more detailed engineering models, which are not without their own assumptions, particularly with respect to translating damage into cost.

1. INTRODUCTION

There now exists a large body of empirical research in Europe examining the marginal infrastructure wear and tear costs from running traffic on railway networks. This has been primarily driven by the need for countries of the European Union to charge access to railway infrastructure on the basis of ‘incremental cost’, which can broadly interpreted as the marginal cost to the infrastructure manager of accommodating the extra train movement.

This econometric literature has provided some useful results in terms of the extent to which railway maintenance and renewal costs vary with traffic, with a general finding that the variable cost of maintenance increases with intensity of usage (from 20% at low densities to 45% at high densities) and the finding that renewal costs appear slightly more variable than maintenance (Wheat et al, 2009). It should be noted that there is much less empirical evidence on the cost variability of the sum of maintenance and renewals expenditure vis-à-vis maintenance only expenditure. For example the work undertaken in the FP7 CATRIN project contained only two studies for maintenance and renewal costs, but six for maintenance only costs and as such there was much uncertainty related to the recommended cost variability of the renewal category (35%).This study provides new evidence on this important combined cost category.

However there remains a number of limitations with the results from the existing literature. Two such (inter-related) issues are the subject of this paper. Firstly, much work has been undertaken looking at the differences between results from double-log models e.g. Translog, and Box-Cox models, with the former found to give counter intuitive variations in cost elasticities and marginal costs across the network. In particular Translog models tend to yield falling cost elasticities with respect to usage even when the level of quality of the network is held fixed. This is odd given that the quality of the network is held fixed when deriving this relationship as it would seem fixed costs should be fixed, but variable cost increasing as usage increases imply an increasing elasticity. Importantly, when elasticities are converted to marginal cost, the marginal cost curve (again for a given asset quality) is an extreme ‘L shape’ implying, lightly used lines have very high marginal costs, but any other usage levels have close to zero marginal cost. This is clearly at odds with accepted analysis such as the results of bottom-up engineering analysis (e.g. Iwnicki et al, 2009) (however engineering models are not without their own assumptions, particularly with respect to translating damage into cost).

What is not clear is why Box-Cox models yield such different results, which are fortunately more intuitive. Both the Box-Cox model (with interaction terms) and the Translog model are second order approximations to a cost function. Such degree of approximation is often thought to be very ‘flexible’. As such it is not clear why they should give such dramatically different estimates. One loose end that this paper seeks to determine is the extent to which a simplifying approach used in previous research actually influenced the rejection of the Translog hypothesis. In particular because of the manner to which the Box-Cox transformation was applied to the second order terms, the models estimated in past studies did not nest the Translog and thus any testing of restrictions on the Box-Cox parameters to see if we can reject the Translog restriction is invalid. In this paper we correct for this issue and produce a true likelihood ratio test of the null of the Translog against an alternative Box-Cox parameter value. This is important since rejecting the null gives us a basis for preferring the (intuitive) results from the Box-Cox against the (counter intuitive) results from the double log Translog model.

A second issue is the extent to which the econometric approach can provide evidence on the relative damages (per gross tonne) of different traffic types. This is important for two reasons. The first is the need for a high level understanding of what traffic does most damage relative to others (per gross tonne). This is very useful for strategic decision making. The second is the policy need to incentivise the use of more track friendly vehicles to minimise whole system costs. While it is unlikely that the econometric approach could ever get to a level of disaggregation between vehicles which would discriminate with respect to specific vehicle characteristics (such as unsprung mass), the greater the degree of robust disaggregation available from econometric models improves the estimate of variable cost from each group that can then be distributed between vehicles in the group by engineering models. This is a useful goal, given the degree of arbitrariness with engineering analysis and the difficulty in translating damage into cost (see work under Sub-task 5.3.1 in this project (Smith et al, 2014)).

In this paper we disaggregate traffic into seven types, of which four are passenger traffic and three are freight. We show that such a model provides estimates of marginal costs that are not without justification. These in turn can be used as benchmarks for relative damage analysis from engineering models or used for charging purposes in their own right.

The structure of this paper is as follows. Section 2 outlines the model formulation and discusses the approach to test the Translog restriction within the Box-Cox framework. Section 3 outlines the data used in the study and Section 4 reports the model selection and parameter estimates. Section 5 analyses the results in greater detail, in particular examining the estimated average and distribution of cost elasticity and marginal costs with respect to different traffic types. Section 6 concludes.

2. MODEL FORMULATION

The model is an econometric cost function maintenance and renewal activities for track sections in Switzerland. As such cost is conceptually a function of the level of output and level of input prices. In line with the received empirical literature (see Wheat et al, 2009) (and available data), we assume the price of inputs are the same for all track sections and such variation over time is absorbed into time dummy variables. Further, and also in line with received empirical studies, we distinguish between the length of track sections (N) and the density of traffic running along it (Q), which maybe a vector if there are multiple traffic types considered. Finally we include variables which characterise the physical attributes and capabilities of the infrastructure (denoted Z). Finally, Swiss railways is organised into 24 regions and so we include dummy variables to account for unobserved heterogeneity (the indicator region for a given zone is denoted r).

As such the cost function can be represented as:

$$C_{it} = f(N_{it}, \boldsymbol{Q_{it}}, \boldsymbol{Z_i}, d_t, r_i) \text{ i=1,…,N and t=1,…, T} \quad (1)$$

A form for f(.) is required. For reasons described in the introduction the Box-Cox formulation has gain credence in the relevant empirical literature recently. Importantly the Box-Cox transform nests the log transform as a special (restricted case).

However the following section discusses a common mistake that can be made when implementing Box-Cox models with second order terms and a mistake which was widely implemented in previous work, notably the CATRIN project work (with the exception of Gaudry and Quinet, 2009).

2.1 Second order terms in Box-Cox models[1]

Consider a simple model involving cost (denoted C) and usage e.g. tonne-km (denoted Q). Let C* and Q* denote C and Q respectively transformed by the Box-Cox transformation and x* be a generic variable, x, transformed by the Box-Cox transformation. The Box-Cox transform has the parameter λ (BCT parameter) and for completeness:

$$x^* = \frac{x^{\lambda} + 1}{\lambda} \tag{2}$$

Firstly, the correct second order model (as given in Shin and Ying (1994) for example) is:

$$C^* = \beta_0 + \beta_1 Q^* + \beta_2 (Q^*)^2 \tag{3}$$

However in the past when off-the-shelf routines available in packages such as STATA have been used the following is estimated:

$$C^* = \beta_0 + \beta_1 Q^* + \beta_2 (Q^2)^* \tag{4}$$

Now consider the case when $\lambda \to 0$. Then $x^* \to \ln x$, implying for (3)

$$\ln C = \beta_0 + \beta_1 \ln Q + \beta_2 (\ln Q)^2 \tag{3b}$$

Which is simply the Translog special case. However in (4), β_1 and β_2 are not separately identified for the following reason

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[1] The authors are grateful for discussions with Marc Gaudry relating to these issues. All errors are the responsibility of the authors however.

$$\begin{aligned}\ln C &= \beta_0 + \beta_1 \ln Q + \beta_2 \ln\left(Q^2\right)\\ \ln C &= \beta_0 + \beta_1 \ln Q + \beta_2 2\ln(Q)\\ \ln C &= \beta_0 + (\beta_1 + 2\beta_2)\ln Q\end{aligned} \tag{4b}$$

Therefore the Translog is not nested in the commonly estimated model (4). There remains an issue as to what the (4) actually represents for cases when $\lambda \neq 0$ and indeed, whether it is identified i.e. whether the parameter estimates are unique.

The following discussion is aimed at understanding the implications of the specification in (4) in terms of its usefulness for modelling infrastructure costs.

2.2 The power invariance property of Box Cox models

The following is a key result for the Box Cox Transformation (BCT) known as the invariance to power transformations (Gaudry and Laferrierre, 1989):

$$\left(x^{\gamma}\right)^* = \gamma . x^{**} \text{ where } x^{**} = \frac{x^{\gamma\lambda} - 1}{\gamma\lambda} \tag{5}$$

Proof

$$\left(x^{\gamma}\right)^* = \frac{\left(x^{\gamma}\right)^{\lambda} - 1}{\lambda} = \gamma\left(\frac{x^{\gamma\lambda} - 1}{\gamma\lambda}\right) = \gamma . x^{**}$$

As an example consider the square case:

$$\left(x^{2}\right)^* = \frac{\left(x^{2}\right)^{\lambda} - 1}{\lambda} = 2\left(\frac{x^{2\lambda} - 1}{2\lambda}\right) = 2 . x^{**} \tag{6}$$

Note this is what is being implemented when squared terms are included using off-the-shelf routines.

The implication is that including x^2 alongside x, is the same as including x twice but each with different Box-Cox transformations. In particular the BCT parameters are related, one is half the other and the linear coefficients (betas) are related, one is half the other. As such there is an issue of identification for these models. This result led Gaudry and Quinet (2009, Table 4) in the CATRIN work to exclude squared interactions from their modelling. Interestingly they also excluded them from their T-log variant too. This is logical since when $\lambda \to 0$ (4b) clearly shows the identification issues.

The reason that packages such as STATA can estimate Box-Cox models like (4) is that common Box-Cox transforms are applied to all explanatory variables. This was the approach in all the studies in the CATRIN project except Guadry and Quient (2009).

The implication of the above indicates that only the model as articulated in (3) nests the Tlog. Further we can also say that nothing above indicates that including the squared terms adds flexibility to the BC model and in particular moves it to a second order Taylor series type approximation to an arbitrary cost function.

Finally in this section note that this applies only to squares of variables and not to interactions. The same results do not apply to interaction terms i.e.

$$(xy)^* = \frac{(xy)^{\lambda} - 1}{\lambda} \neq \left(\frac{x^{\lambda} - 1}{\lambda}\right)\left(\frac{y^{\lambda} - 1}{\lambda}\right) \text{ or similar} \qquad (6)$$

Gaudry and Quinet (2009) do include the interaction terms. Therefore interactions defined in the spirit of (6) do help generalise the function. This does not nest however the Translog interactions.

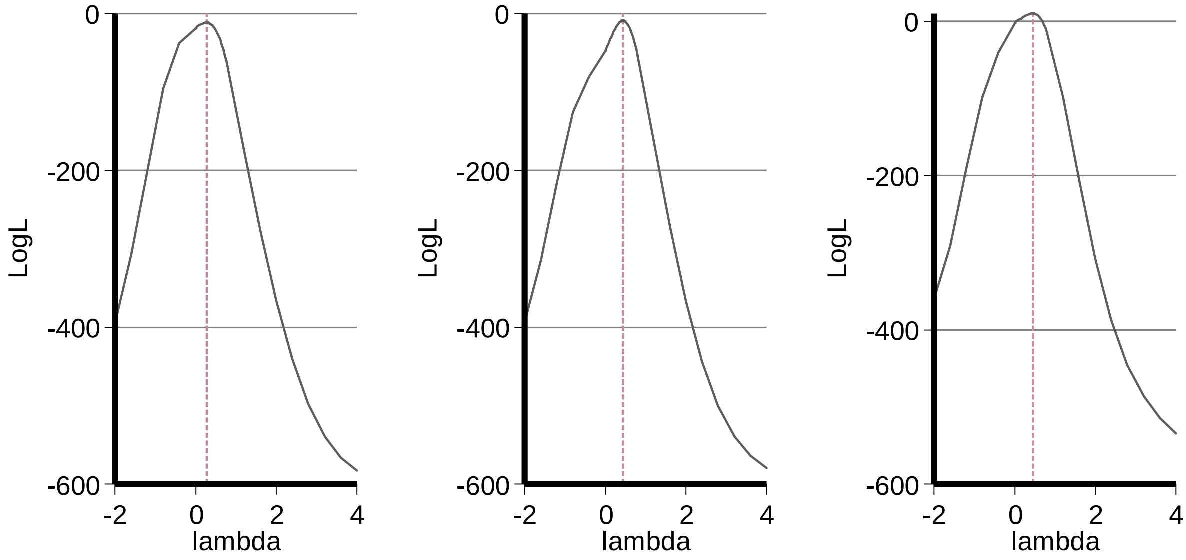
2.3 A framework to test the Translog restriction

What is sought is a relatively simple method to incorporate second order terms into Box-Cox model in the sense of (3). This can not be done using the automated routines in STATA and LIMDEP. The aim is to use of-the-shelf computing packages such as STATA and LIMDEP to estimate a Box-Cox model which nests the Translog.

To do this we restrict the Box-Cox model to have a common Box-Cox parameter for all explanatory variables and set the Box-Cox parameter for the dependant variable to be zero i.e. the log transform. These two assumptions imply that we can undertake a one dimensional grid search over the single Box-Cox parameter and yield a model which nests the Translog as a restricted case. The criteria for selecting the Box-Cox value is that which maximises the log-likelihood assuming normally distributed errors. This is in line with ML estimation of Box-Cox models in general (see Greene (2012)). Also the log-likelihood is easily available from simple OLS output. Further we can use an LR test to test the Translog restriction. Finally we note the numerical ease of this method given our experience is that there is a well-defined global maximum – see Figure 1 for examples from our empirical models.

Figure 1 Example log-likelihood functions for different values of the Box-Cox parameter

Model A Model B Model C



3. DATA

3.1 Swiss network context

The data for the estimations are provided by the Swiss national railway company (SBB), who owns most part of the Swiss national railway network, including most important national and international railway tracks.[2] The network is split in different track sections and transport nodes. Data on costs for maintenance and renewal costs as well as traffic density for the years 2003 and 2012. However, the tracks are not homogeneous; they differ in track length, rail and sleeper types, ballast, curvature, slope etc. As such, data has been obtained for each track section relating to physical information about the railway out of the SBB data system DfA (Datenbank für feste Anlagen).

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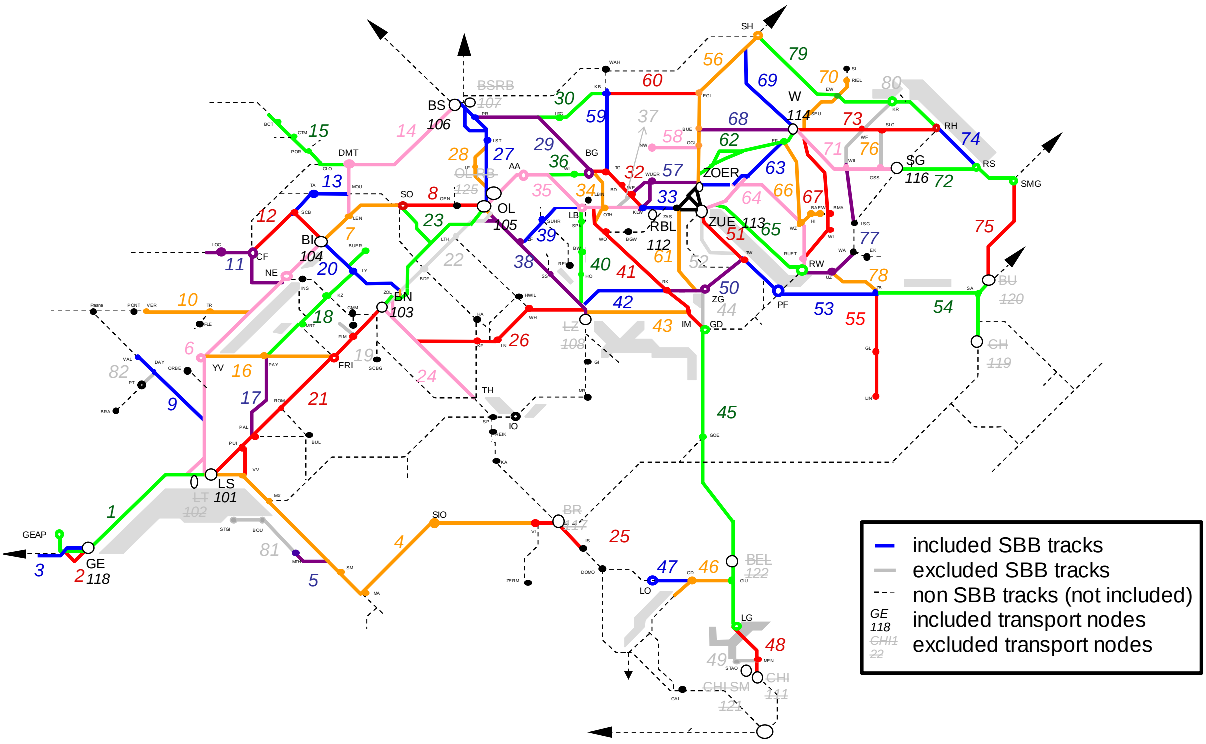
[2] Besides the SBB there exists other infrastructure owners. Private owned infrastructures often are small-gauges railroads with regional traffic. The most important infrastructure owner next to the SBB is the BLS. The BLS property includes one part of the north-south corridor through the “Lötschberg” tunnel (second most important connection for passenger and freight form Germany to Italy). All infrastructures next to the SBB infrastructure are not included in this dataset.

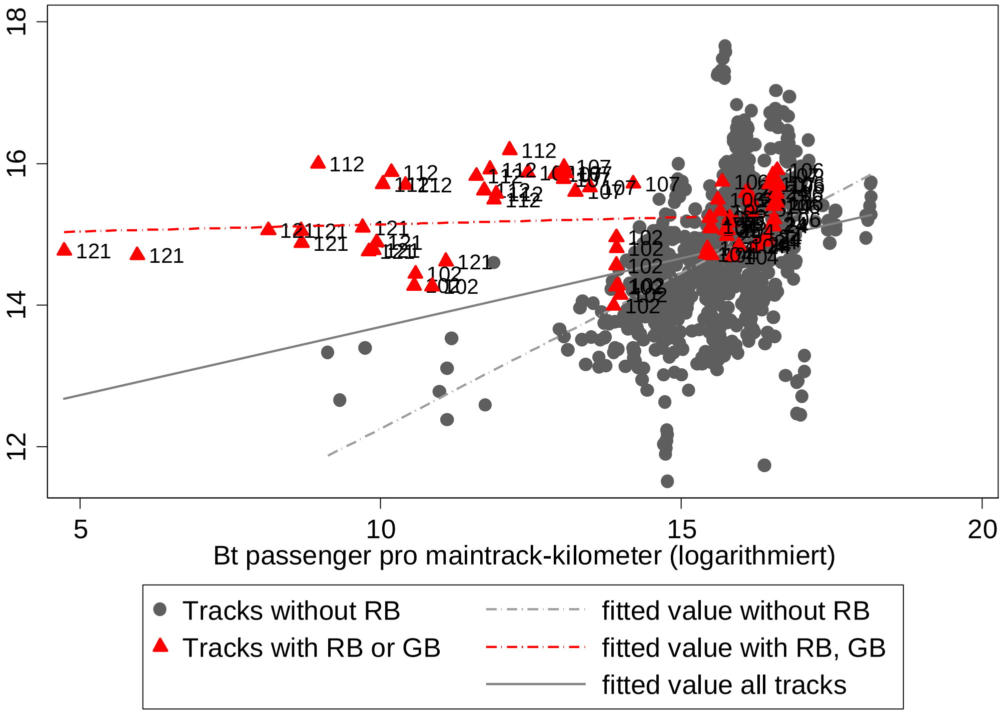
Figure 3.1 Schematic representation of the track section system with approximately 110 track sections (including junction and station nodes)



In total, we have data on 80 tracks – of which 9 are traffic nodes – in a time span from 2003 to 2012 available. Some track sections have been excluded for the following reasons:

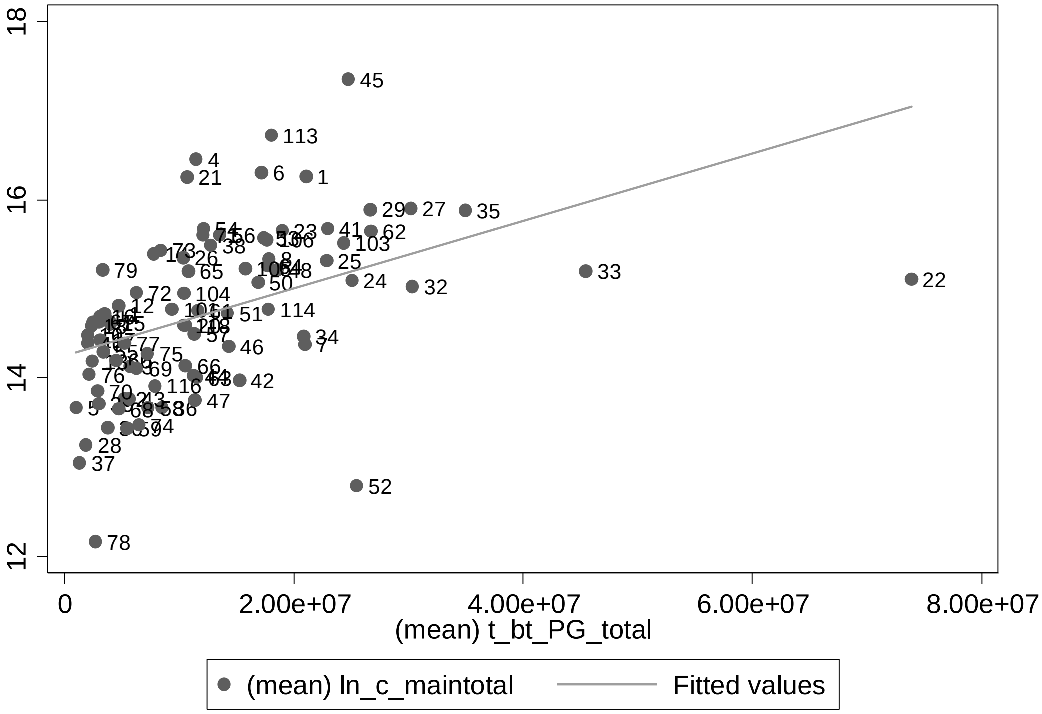
- Some tracks show missing data (for example because the ownership changed, or no more/seldom in use or only for special historic purpose)
- Some tracks are marshalling yards which have special traffic as well as special maintenance policy; Figure 3.2 shows marshalling yard tracks (no. 102, 107, 112, 121) and makes clear that these tracks are outliers

Figure 3.2 Evidence of clear outliers



- Some tracks have been excluded because they are new built tracks which leads to a totally different maintenance policy with few or no maintenance at all in the first years; Figure 3.3 shows the two tracks sections 22 and 52 which are new built tracks

Figure 3.3 Evidence of outlier observations due to very recent construction



3.2 Description of variables

This section is dedicated to the descriptions of the variables used and includes summary statistics on the main variables.

The dependent variable is total maintenance and renewal cost. We have annual data for the years spanning from 2003 to 2012. The available data is divided into four categories which failure management cost, supervision cost, maintenance cost and renewal cost. The first three categories can be seen as periodical short-term maintenance cost while the last category describes renewal cost. The four cost categories and their values are shown in the Figure 3.4 below.

Figure 3.4 Evolution of expenditure over the time series

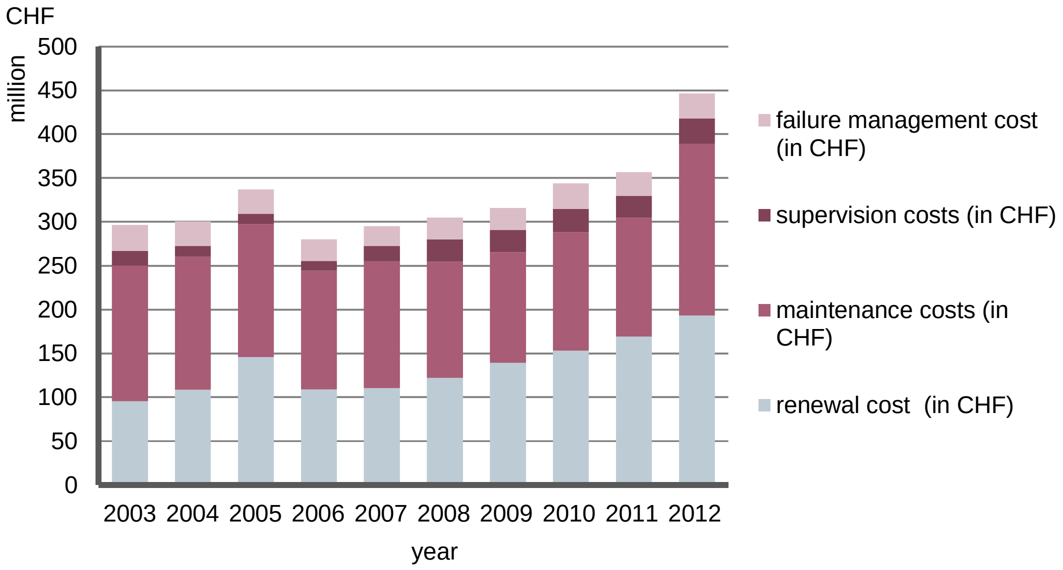


Table 3.1 shows some statistical values for total maintenance and renewal costs as well as for the four cost categories mentioned above.

Table 3.1 Breakdown of cost

Costs (in CHF)	Mean	Std. dev.	Minimum	Maximum
Total maintenance and renewal	4096505	4933082	99834	46880460
Supervision maintenance	249917	338711	7496	3509633
Failure management maintenance	335321	358461	8321	2880904
Other maintenance	1828098	1919987	59266	16279349
Renewal	1683168	2556785	0	26245112

Figure 3.5 and Table 3.2 show the main explanatory variable which is the transport data, measured in Gross Tonne KM. Data is available from 2003 to 2012 and include passenger and freight traffic (service train data are excluded). As visualised in Figure 3.5, a further disaggregation in different types of passenger and freight trains is available. The graph shows for each year two columns. The left one represents the disaggregation in different types of

passenger and freight transport, the right one summarizes the gross ton km in passenger and freight traffic.

The disaggregation in the traffic data available for this study is, to the authors' knowledge, unprecedented with respect to that used in past econometric studies. Only studies in France have had data on different traffics comprising passenger and freight (4 traffic types in their case) (e.g. Guadry and Quinet, 2009). This in turn allows the potential for this study to make genuinely unique empirical observations on the different marginal costs of different traffic types.

Figure 3.5 Traffic data over time

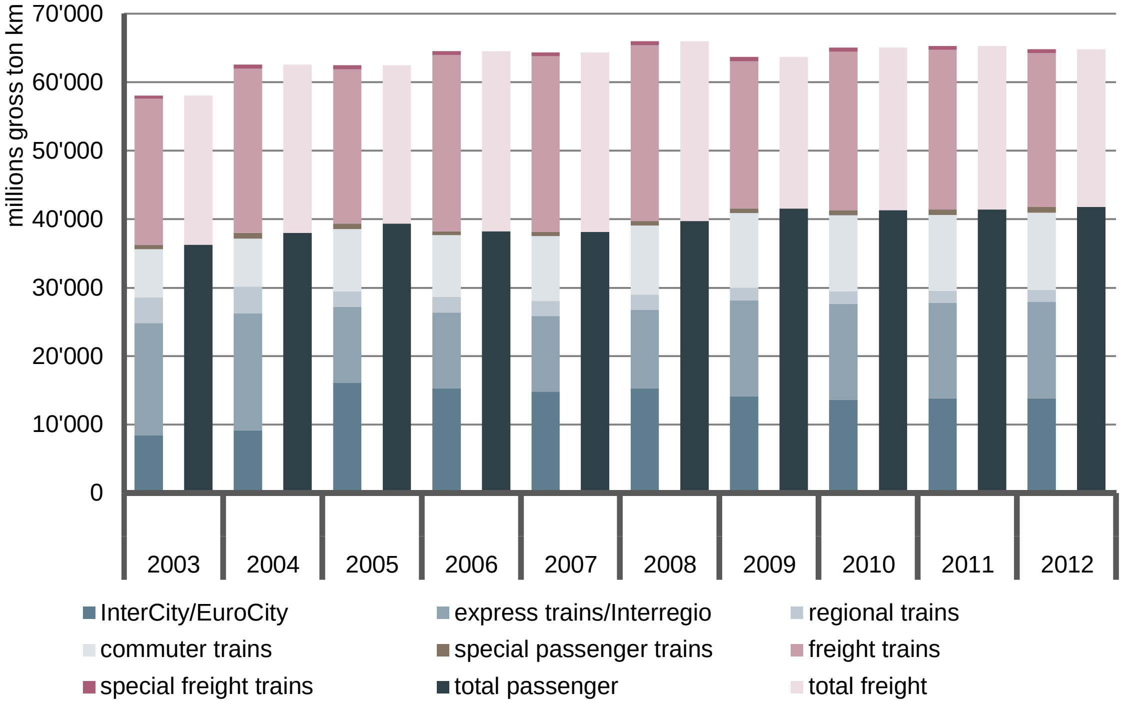


Table 3.2 statistics for the traffic variables. These variables are shown as traffic densities (gross-ton per track km).

traffic density of[3]	obs.	Mean	std. dev.	minimum	maximum
InterCity/EuroCity	800	2'246'249	3'537'881	0	18'356'096
Express trains/Interregio	800	2'518'890	3'265'948	138	17'021'012
Regional trains	800	611'819	887'982	0	4'057'344
Commuter trains	800	2'690'519	3'329'091	0	18'637'836
Special passenger trains [4]	800	185'899	210'607	0	1'225'836
Total passenger traffic	**800**	**8'253'377**	**6'646'275**	**430'562**	**42'717'236**
Freight Trains	800	3'649'018	5'003'272	0	23'077'292
Special freight trains[5]	800	138'449	143'650	48	1'323'867
Total freight traffic	**800**	**3'787'467**	**5'044'570**	**2'219**	**23'276'028**
Total traffic	**800**	**12'040'844**	**9'026'177**	**676'177**	**50'294'944**

Finally, Table 3.3 shows various infrastructure variables. Infrastructure data is available for all track sections. The infrastructure data is provided by SBB by their data system DfA (Datenbank der festen Anlagen). The DfA shows the current status of the network and contains all existing physical information about the railway network in Switzerland. Since the data system has been built only recently, there are no historical records. For this work we adopt the 2007 entries. The vast majority of these variables does not change over few years, so the decision to use the state of the year 2007 is sensible.

The chosen infrastructure variables are based both on existing literature as well as on discussions with experts from the regulator. The table below provides for all variables some statistical information.

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[3] For a detailed description of the traffic types see: For more details see SBB CFF FFS 2013, List of Infrastructure Service 2014, For ordering and execution of time tabled transport operation form 15 December 2013 to 13 December 2014, p.60ff

[4] Including "Tractor-hauled" freight trains (ex. Tractor hauled freight trains, freight trains without brake, ratio calculation, shunting train on open section of line, freight train with passenger conveyance, firefighting and rescue train, engineers' coaches, service trains without brake ratio calculation) and light engines (ex. Tractor locomotive, shunting loco on open section of line, special train locomotive, self-propelling construction trains and other service trains) For more details see SBB CFF FFS 2013, List of Infrastructure Service 2014, For ordering and execution of time tabled transport operation form 15 December 2013 to 13 December 2014, p.60ff

[5] Including Empty passenger stock train, test and measurement trains and shunting loco on open section of line. For more details see SBB CFF FFS 2013, List of Infrastructure Service 2014, For ordering and execution of time tabled transport operation form 15 December 2013 to 13 December 2014, p.60ff

There are statistical implications of including so many time invariant variables. First, this, by definition is an attempt to control for time invariant heterogeneity using measured variables (as opposed to effects – unobserved heterogeneity). The use of so many infrastructure characteristics and also 24 regional dummy variables (there are 80 track sections, so roughly 4 track sections per region), means that we strongly expect that time invariant heterogeneity is captured by these variables.

Table 3.3 Descriptions of infrastructure variables

Variable	Mean	Std. dev.	Minimum	Maximum
Track length (main track) [km]	54.081	56.709	3.862	338.493
Mean maximum speed of passenger trains (km/h)	108.329	16.513	65.681	147.261
Fraction of switch metres of total track length [%]	0.114	0.120	0.000	0.704
Fraction of bridge metres of total track length [%]	0.021	0.018	0.003	0.104
Fraction of tunnel metres of total section length [%]	0.070	0.132	0.000	0.913
Fraction of radius metres <500m [%	0.184	0.119	0.017	0.578
Fraction of slope > 2 percent [%]	0.110	0.154	0.001	0.853
Fraction of track length with noise/fire protection [%]	0.045	0.075	0.000	0.397
Supporting walls (m2) per km of track	510.753	455.397	11.123	2117.913
Fraction of sleepers with age > 25 years [%]	0.233	0.190	0.000	0.714
Fraction of platform edge of total track length [%]	0.140	0.090	0.037	0.517
Dummy for marshalling yards [0/1]	0.050	0.218	0.000	1.000
Dummy for one-track sections [0/1]	0.425	0.495	0.000	1.000

4. MODEL SELECTION

4.1 Functional form tests

Section 2.3 outlined the general form of the model. There remains an issue as to the exact model specification. In particular, the second order Box-Cox form proposed in 2.3 implies two specification search issues which need to be explored simultaneously. Firstly, in the interest of parsimony (and in some cases appropriate economic interpretation – see below) what interactions between variables need to be considered? Thus there is a general to specific testing process undertaken reported on below. To keep the starting specification manageable, we only interact and square the traffic density variables and the track length variable. This is in line with the wider literature. Secondly, and of interest to the empirical literature, we need to test whether the log transform restriction ($\lambda = 0$) can be rejected, as rejection implies the Box-Cox model adds explanatory power over the more standard double-log model.

Four models are tested between:

1) $\ln(c_{total,i}) = \alpha + \beta km^{(\lambda)} + \beta {km^{(\lambda)}}^2 + \beta bt^{(\lambda)} + \beta(bt^{(\lambda)})^2 + \beta(km^{(\lambda)}bt^{(\lambda)}) + X\mathrm{B}$

2) $\ln(c_{total,i}) = \alpha + \beta km^{(\lambda)} + \beta(km^{(\lambda)})^2 + \beta bt^{(\lambda)} + \beta(bt^{(\lambda)})^2 + X\mathrm{B}$

3) $\ln(c_{total,i}) = \alpha + \beta km^{(\lambda)} + \beta(km^{(\lambda)})^2 + \beta bt^{(\lambda)} + \beta(km^{(\lambda)}bt^{(\lambda)}) + X\mathrm{B}$

4) $\ln(c_{total,i}) = \alpha + \beta km^{(\lambda)} + \beta(km^{(\lambda)})^2 + \beta bt^{(\lambda)} + X\mathrm{B}$

Model 1 is the most general full second order model. Model 2 and 3 are single parameter restrictions of Model 1. Model 4 is a further single parameter restriction of Model 4. Overall we adopted Model 4 (and so we present Models 2 and 3 to guard against path dependency in model selection).

Table 4.1 provides model fit statistics for each of the models. Our logic for choosing Model 4 is:

1. **Model 1 versus Model 2:** LR test = 0.166 (pval=0.684)
2. **Model 1 versus Model 4:** LR test = 5.285 (pval = 0.071)
   - ➔ implies no evidence against Model 4 being selected.

However, a test of Model 1 versus Model 3 and Model 2 versus Model 4 implies rejection of the restrictions at the 5% significance level, which would indicate Model 3 is preferred (pvals of 0.022 and 0.024 respectively). However, we stay with the simple box cox model for two reason:

1) The testing has been undertaken on a model with only one traffic variable. When more traffics are included, the number of parameters to be estimated would highly increase in the models with more distinct traffic density included (densities for passenger and freight or rather seven different densities).
2) Finally, at the 1% level we cannot reject the restriction in any case.

Table 4.1 Model fit statistics

Model	LogLikelihood	df	AIC	BIC
1) Full Second order model	-8.92849	51	119.857	358.7722
2) Intermediate model	-9.01124	50	118.0225	352.2531
3) Intermediate model	-11.5466	50	123.0932	357.3238
4) Preferred bc-model	-11.5711	49	121.1422	350.6882
Model 1 with λ=0	-12.9755	51	127.9509	366.8661
Model 4 with λ=0	-18.6669	49	135.3338	364.8798

The lower entries of Table 4.1 demonstrate the rejection of the log transform restriction. For both Model 1 and Model 4, the restriction of $\lambda = 0$ is rejected at any reasonable significance level. As such we proceed with the specification as in Model 4 with a freely estimated Box-Cox parameters.

4.2 Final model selection

Finally, we use three different models for the estimations of the total maintenance and renewal costs. All three models include the same explanatory variables with the exception of different disaggregations of traffic density. In the first model, we use the total traffic density. In the second model two different densities, the density for passenger traffic and the density for freight traffic, and an interaction variable between the two kinds of traffic were included. In the third model we make the distinction between seven different kinds of traffic and include also interaction variables between each of them. The seven more distinct traffic densities were described in Section 3.2.

The three resulting models are summarised below:

Model A: traffic density for total traffic

$$lnC_{it}^{(ln)} = \beta_0 + \beta_1 km_{it}^{(\lambda)} + \beta_2 \left(km_{it}^{(\lambda)}\right)^2 + \beta_3 q_{it}^{(\lambda)} + \sum \gamma_k x_{kit}$$

Model B: distinction between passenger and freight traffic density

$$lnC_{it} = \beta_0 + \beta_1 km_{it}^{(\lambda)} + \beta_2 \left(km_{it}^{(\lambda)}\right)^2 + \beta_{P3} q_{Pit}^{(\lambda)} + \beta_{F3} q_{Fit}^{(\lambda)} + \beta_4 \left(q_{Pit}^{(\lambda)} \times q_{Git}^{(\lambda)}\right) + \sum \gamma_k x_{kit}$$

Model C: traffic density for seven different traffic types

$$lnC_{it} = \beta_0 + \beta_1 km_{it}^{(\lambda)} + + \beta_2 \left(km_{it}^{(\lambda)}\right)^2 + \sum_{N=1}^{7} \beta_{N3} q_{Nit}^{(\lambda)}$$

$$+ \sum_{M=1}^{7} \sum_{N=1}^{7} \frac{1}{2} \delta_{NM} \left(q_{Nit}^{(\lambda)} \times q_{Mit}^{(\lambda)}\right) + \sum \gamma_k x_{kit} \qquad \delta_{NM} = \delta_{MN}$$

where km = track length (in km), q = traffic density, x = control variables, and (λ) = box cox transformation.

Only track length and traffic densities were transformed. The control variables are not transformed. Also, models with more distinct traffic density contain additional interactions variables between each traffic density.

The estimation results are shown in Table 4.2.

Table 4.2 Estimation results

	Model A: total traffic		Model B: passenger and freight traffic separately		Model C: 7 different traffic types separately	
Observations	800		800		800	
λ (Lambda)	0.29148		0.44276		0.4528	
Constant	11.05199	***	11.57001	***	11.57663	***
Track length (main track) [km]	0.5146679	***	0.3152896	***	0.3075639	***
	[16.866]		[22.141]		[19.459]	
Track length (main track) squared [km2]	-0.0140013	***	-0.0064843	***	-0.0064368	***
	[-6.771]		[-10.387]		[-9.369]	
Traffic density all traffic [gt]	0.0043491	***				
	[13.199]					
Traffic density passenger traffic [gt]			0.0004626	***		
			[9.432]			
Traffic density freight traffic [gt]			0.0004876	***		
			[9.185]			
Interaction between traffic density passenger traffic [gt] and traffic density freight traffic [gt]			-0.000000106	***		
			[-5.254]			
Traffic density Intercity/Eurocity [gt]					0.0002335	***
					[3.249]	

	Model A:	Model B:	Model C:
Traffic density express trains, Interregio [gt]			0.0001209 *
			[1.690]
Traffic density regional trains [gt]			0.0001579
			[1.525]
Traffic density commuter trains [gt]			0.0002526 ***
			[3.112]
Traffic density freight trains [gt]			0.0001442
			[1.585]
Traffic density special freight trains [gt]			-0.0000111
			[-0.026]
Traffic density special passenger wagon trains [gt]			0.0008892 ***
			[3.244]
Interaction between traffic density Intercity/Eurocity [gt] and traffic density express trains, Interregio [gt]			2.37E-08 *
			[1.872]
Interaction between traffic density Intercity/Eurocity [gt] and traffic density regional trains [gt]			-0.000000108 ***
			[-3.106]
Interaction between traffic density Intercity/Eurocity [gt] and traffic density commuter trains [gt]			-5.18E-08 *
			[-1.866]
Interaction between traffic density Intercity/Eurocity [gt] and traffic density freight trains [gt]			-4.08E-08 ***
			[-2.618]
Interaction between traffic density Intercity/Eurocity [gt] and traffic density special freight trains [gt]			0.000000147
			[1.535]
Interaction between traffic density Intercity/Eurocity [gt] and traffic density special passenger trains [gt]			-9.48E-08
			[-1.458]
Interaction between traffic density express trains, Interregio [gt] and traffic density regional trains [gt]			3.78E-08
			[1.083]
Interaction between traffic density express trains, Interregio [gt] and traffic density commuter trains [gt]			3.19E-08
			[1.284]
Interaction between traffic density express trains, Interregio [gt] and traffic density freight trains [gt]			-2.43E-08
			[-1.344]
Interaction between traffic density express trains, Interregio [gt] and traffic density special freight trains [gt]			-0.000000133
			[-1.200]
Interaction between traffic density express trains, Interregio [gt] and traffic density empty wagon trains [gt]			-5.34E-08
			[-0.881]
Interaction between traffic density regional trains [gt] and traffic density commuter trains [gt]			-0.000000108 ***
			[-3.081]
Interaction between traffic density regional trains [gt] and traffic density freight trains [gt]			2.78E-08
			[0.719]
Interaction between traffic density regional trains [gt] and traffic density special freight trains [gt]			0.000000333
			[1.353]
Interaction between traffic density regional trains [gt] and traffic density special passenger trains [gt]			-0.00000023
			[-1.510]
Interaction between traffic density commuter trains [gt] and traffic density freight trains [gt]			-1.51E-08
			[-0.423]
Interaction between traffic density commuter trains [gt] and traffic density special freight trains [gt]			0.000000182
			[1.010]
Interaction between traffic density commuter trains [gt] and traffic density empty wagon trains [gt]			-0.000000178 **
			[-2.430]
Interaction between traffic density freight trains [gt] and traffic density special freight trains [gt]			0.000000089
			[0.748]
Interaction between traffic density freight trains [gt] and traffic density special passenger trains [gt]			0.000000118
			[1.151]
Interaction between traffic density special freight trains [gt] and traffic density special passenger trains [gt]			-0.000000589 *
			[-1.846]
Mean maximum speed of passenger trains (km/h)	-0.010744 ***	-0.0104584 ***	-0.009124 ***
	[-7.943]	[-7.874]	[-5.737]
Fraction of switch metres of total track length [%]	1.622483 ***	1.279797 ***	1.587011 ***
	[6.389]	[4.910]	[4.753]
Fraction of bridge metres of total track length [%]	0.4759945	0.2757196	-0.3340648
	[0.589]	[0.330]	[-0.337]
Fraction of tunnel metres of total section length [%]	0.5930194 ***	0.5758981 ***	0.3118104 **
	[4.951]	[4.530]	[2.206]
Fraction of radius metres <500m [%	0.8062883 ***	0.908459 ***	0.7209899 ***
	[4.938]	[5.482]	[3.493]
Fraction of slope > 2 percent [%]	0.1029022	0.1998629 *	0.1733615
	[1.083]	[1.960]	[1.338]
Fraction of track length with noise/fire protection [%]	0.661952 ***	1.010015 ***	1.383313 ***
	[3.008]	[4.398]	[4.679]
Supporting walls (m2) per km of track	-0.00000887	0.0000169	0.0000355
	[-0.272]	[0.511]	[0.843]
Fraction of sleepers with age > 25 years [%]	0.1658246 *	0.2007098 **	0.3774971 ***
	[1.673]	[2.043]	[3.271]
Fraction of platform edge of total track length [%]	1.470186 ***	1.51769 ***	1.177593 ***
	[5.615]	[5.734]	[3.640]
Dummy for marshalling yards [0/1]	0.1009692 **	0.0985184 *	0.107436 *

	Model A:		Model B:		Model C:	
	[2.082]		[1.948]		[1.665]	
Dummy for one-track sections [0/1]	0.1559218	***	0.196567	***	0.1999786	***
	[3.770]		[4.647]		[3.577]	
Dummies for year 2003 [0/1]	-0.2704914	***	-0.2765454	***	-0.2610682	***
	[-5.630]		[-5.851]		[-5.028]	
Dummies for year 2004 [0/1]	-0.2750879	***	-0.2814638	***	-0.2833405	***
	[-6.111]		[-6.414]		[-5.928]	
Dummies for year 2005 [0/1]	-0.171055	***	-0.1776745	***	-0.1692988	***
	[-3.654]		[-3.804]		[-3.416]	
Dummies for year 2006 [0/1]	-0.3936872	***	-0.3979404	***	-0.3779425	***
	[-8.953]		[-9.232]		[-8.659]	
Dummies for year 2007 [0/1]	-0.3509833	***	-0.3532077	***	-0.3342992	***
	[-8.140]		[-8.384]		[-7.540]	
Dummies for year 2008 [0/1]	-0.3264068	***	-0.3302354	***	-0.3216113	***
	[-7.483]		[-7.752]		[-7.344]	
Dummies for year 2009 [0/1]	-0.3296034	***	-0.3349576	***	-0.3373965	***
	[-7.227]		[-7.448]		[-7.483]	
Dummies for year 2010 [0/1]	-0.2586375	***	-0.2618067	***	-0.2600011	***
	[-5.882]		[-6.066]		[-5.968]	
Dummies for year 2011 [0/1]	-0.2251016	***	-0.2267496	***	-0.2267321	***
	[-4.917]		[-5.108]		[-5.012]	
Dummy Region Airolo [0/1]	0.1378307		0.5555344	**	1.000474	***
	[0.668]		[2.324]		[3.407]	
Dummy Region Arth-Goldau [0/1]	-0.1417543	***	-0.1846291	***	-0.1295209	*
	[-2.883]		[-3.404]		[-1.950]	
Dummy Region Basel SBB [0/1]	-0.2176437	***	-0.2363622	***	-0.1611796	**
	[-3.313]		[-3.494]		[-2.067]	
Dummy Region Bern [0/1]	-0.0161108		-0.0149999		0.0474673	
	[-0.347]		[-0.321]		[0.885]	
Dummy Region Biel / Bienne [0/1]	0.1738041	***	0.1829186	***	0.2198653	***
	[4.444]		[4.686]		[4.403]	
Dummy Region Brig [0/1]	-0.0236213		0.0401887		0.2188638	
	[-0.218]		[0.336]		[1.599]	
Dummy Region Brugg AG [0/1]	-0.0540364		-0.0947343	**	-0.0212335	
	[-1.170]		[-2.002]		[-0.376]	
Dummy Region Bülach [0/1]	0.152071	***	0.1150294	***	0.1106278	**
	[3.691]		[2.666]		[2.004]	
Dummy Region Delémont [0/1]	0.2225862	***	0.2280634	***	0.3174117	***
	[3.592]		[3.679]		[4.665]	
Dummy Region Fribourg [0/1]	0.2353448	***	0.2092165	***	0.1606008	**
	[3.513]		[3.136]		[2.066]	
Dummy Region Genève [0/1]	0.3279879	***	0.2773368	***	0.278797	***
	[5.249]		[4.586]		[3.218]	
Dummy Region Giubiasco [0/1]	-0.0764162		-0.1232188		0.0659565	
	[-0.967]		[-1.563]		[0.756]	
Dummy Region Lausanne [0/1]	0.1626858	**	0.2156321	***	0.3889783	***
	[2.253]		[2.853]		[4.066]	
Dummy Region Luzern [0/1]	0.0901117		0.1293654	**	0.256033	***
	[1.595]		[2.038]		[3.820]	
Dummy Region Neuchâtel [0/1]	0.059879		0.0512566		0.1302486	**
	[1.148]		[0.977]		[2.381]	
Dummy Region Olten [0/1]	0.0435919		0.0377339		0.106957	**
	[1.162]		[0.984]		[2.016]	
Dummy Region RB Limmattal [0/1]	-0.056176		0.0185263		-0.0605252	
	[-1.054]		[0.307]		[-0.796]	
Dummy Region Rapperswil [0/1]	-0.1624725	***	-0.1449164	***	-0.0655479	
	[-3.135]		[-2.764]		[-1.080]	
Dummy Region Sargans [0/1]	0.0709988		0.074851		0.2206241	***
	[1.141]		[1.187]		[2.775]	
Dummy Region St-Maurice [0/1]	0.4950765	***	0.5391383	***	0.4397258	***
	[4.386]		[4.741]		[3.356]	
Dummy Region St.Gallen [0/1]	0.1992117	***	0.1616743	***	0.1899516	***
	[4.567]		[3.724]		[3.587]	
Dummy Region Uebrige [0/1]	0.1048922		0.0995583		0.0227147	
	[1.339]		[1.297]		[0.247]	
Dummy Region Winterthur [0/1]	0.0047325		0.0381928		0.0599593	
	[0.119]		[0.913]		[1.198]	
Dummy Region Zürich HB [0/1]	-0.0084172		0.0365325		0.1617825	**
	[-0.168]		[0.630]		[2.012]	
Log-Likelihood	-11.90087		-8.277984		10.70598	
R2 adjusted	0.9253536		0.9258291		0.9268246	

t statistics in brackets
* p<0.1, ** p<0.05, *** p<0.01

Most estimates with respect to the key explanatory variables are as a priori expect. The most important effects are the following:

- As expected, the influence of traffic density to maintenance costs is highly significant and positive. The more traffic on a track, the higher are the maintenance and renewal costs. In the model with different traffic densities for passenger traffic and freight traffic, the estimated coefficients are quite similar. Furthermore, the model shows a significant but negative effect by the interaction variable between the two traffic densities. The higher the traffic density in one traffic type is, the smaller is the impact on the other traffic type. In the more distinct model it's getting more difficult to interpret the estimated coefficients because we included a couple of interaction variables. At least, all significant main effects are positive. But there are a couple of main effect (regional trains, freight trains and special freight trains) which aren't significant.

  In all models, track length is highly significant and has a positive effect on maintenance costs. Additional, we find negative significant effect for square terms of the track length. In other words, with increasing track length, its influence getting smaller. For the experts, the correlations in the second order term are not easy to explain. In their views, there should be no economics of scale in the track length. There's no link between length of each track and the maintenance work. The track section which is maintained differs from the track section used in our sample. It is more reasonable that the track length square explain some aspect which not integrated in the estimations. For example it could be regional aspects: short track sections are often in agglomerations, long track sections in rural regions.

- The estimated coefficients of the additional control variables (infrastructure variables) vary between the models. But their influence on maintenance costs is more or less as expected:
  - The maintenance costs are smaller the higher the mean maximal speed allowed for regional trains is. Tracks with a lower mean maximal speed are often tracks with topographical difficulties (like narrow curves tunnels etc.) or tracks across highly populated regions. All those aspects are already controlled by other infrastructure variables in the models. If there is a difference in the maximal speed of two – apart from the aspects mentioned above – identical tracks, the speed could be an evidence for the infrastructure quality (the higher the quality is, the higher is the maximal allowed speed). In this case, the negative significant effect on maintenance costs seems plausible because there is less maintenance work needed in tracks in good conditions.
  - As expected a positive and significant effect on maintenance costs have the following infrastructure aspects:
    - Fraction of switch metres of track length
    - Fraction of tunnel metres of total section length
    - Fraction of radius metres <500m
    - Fraction of track length with noise/fire protection
    - Fraction of sleepers with age > 25 years
    - Fraction of platform edge of total track length
    - Tracks with marshalling yards
- On single rail tracks, the maintenance costs are also higher than on tracks with more than one track. A possible reason for that could be that on single rail tracks no bypass exists. In this case, maintenance works get interrupted often and the maintenance works have to take place after operating hours or the track must be closed for maintenance. All this effects the costs for maintenance.

- The maintenance costs differ also in maintenance regions and years.
- For some control variable the estimated effects are slightly different between the models:
  - Fraction of slope: this variable has only in model 2 a significant impact on maintenance costs.
  - The dummy for marshalling yards is almost getting insignificant in model 3 (more distinct traffic densities)

The estimated parameters and signification levels are more or less as expected. The estimations also show similar results as previous work. All the post estimation analysis gives the right results. Because of the aggregation of the track sections in larger parts (compared with earlier work), some implausible results in similar models disappeared. Over all we reached an improvement in the model selection.

5. DERIVED COST ELASTICITY RESULTS

In this section, we explore the estimated model in terms of the implied cost elasticities with respect to traffics (by type) costs. We consider the variation of cost elasticities over the sample i.e. across track sections, and across the different model formulations i.e. different traffic disaggregation. The cost elasticity is a useful measure as it corresponds to teh proportion of cost that is found to vary with traffic. Further, in previous work (e.g. the multiple case study exercise in CATRIN (Wheat et al, 2009)) the estimates in cost elasticities were found to be more comparable across countries and so examining them provides a useful comparison with the received literature.

Overall, we find a sensible variation over the sample and we find that the elasticities are consistent across model formulations, which helps us to make the case for their use in supporting the setting of track access charges.

The elasticity of cost with respect to a generic traffic type A is given by the following expression for the Box-Cox model used in this paper:

$$\varepsilon_A = \frac{dC}{C}\frac{Q_A}{dq_A} = \frac{d\ln C}{d\ln q_A} = \frac{d\ln C}{dq_A^{(\hat{\lambda})}}(q_A^{\hat{\lambda}})$$

Note that this is a simplified version of the general elasticity formula for a Box Cox model since the dependent variable is transformed by a log transform in this paper. Given this expression and the interactions used in the modelling (which have been tested and justified in section 4), the elasticity of cost with respect to each traffic type varies with traffic density of the traffic in question and also by the traffic density of other traffic types

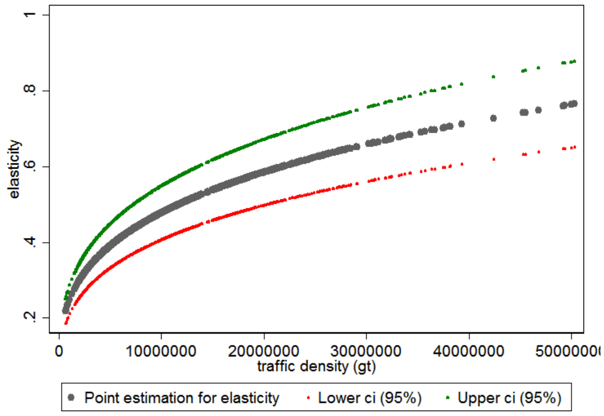
5.1 Cost elasticities by traffic type

Figure 5.1 shows the estimated cost elasticity with respect to traffic for Models A-C for each of the traffic types considered in each model. In addition, for those observations with negative cost elasticities, we plot the 95% confidence intervals, to show that the null of a positive elasticity cannot be rejected. Ultimately this results, along with the fact that most point elasticity estimates are positive, gives us reassurance that the models are economically plausible.

Intuitively, the elasticities are increasing, indicating that the percentage of costs that are variable with traffic increase with traffic levels (fixed costs are spread over more units of output).

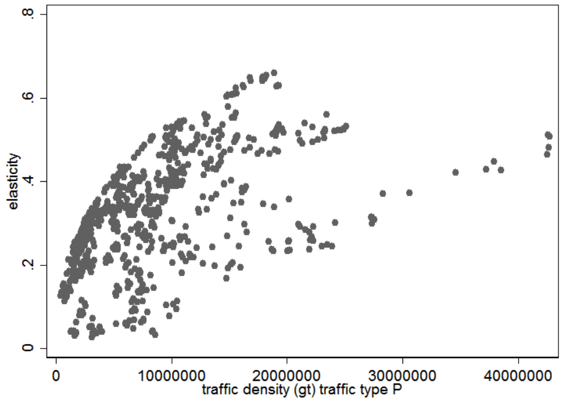
Figure 5.1 Cost elasticity with respect to traffic in each of the three models evaluated for each observation

Model A



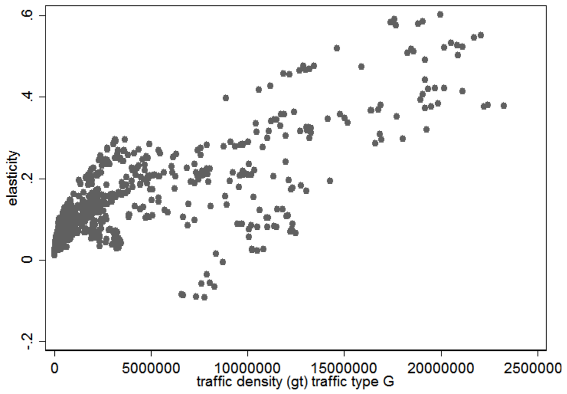
Model B

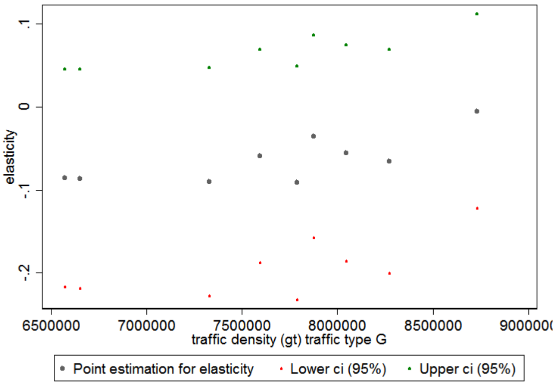
Passenger



Freight

Confidence intervals for freight elasticity if elasticity < 0



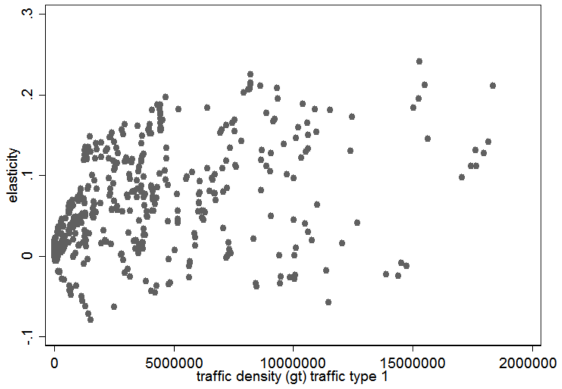


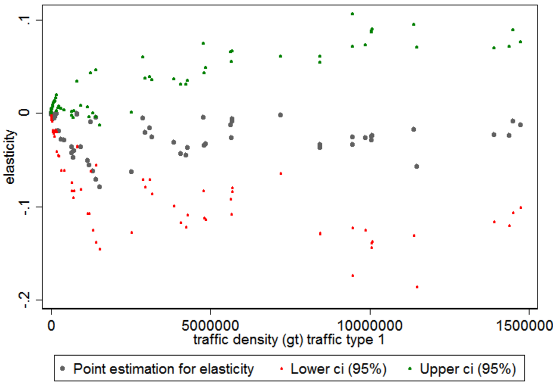
Model C

Elasticity

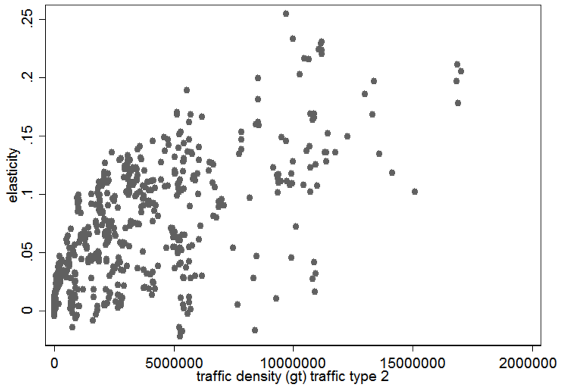
Confidence intervals for elasticity point estimates<0

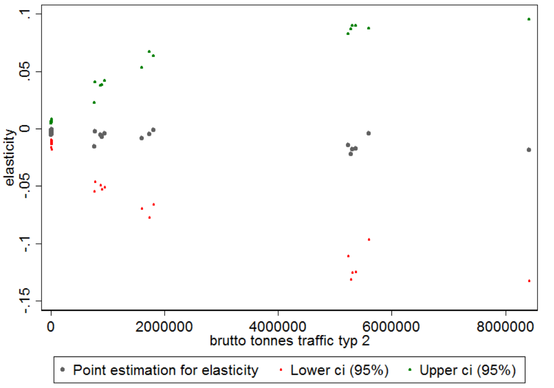
Intercity/Eurocity



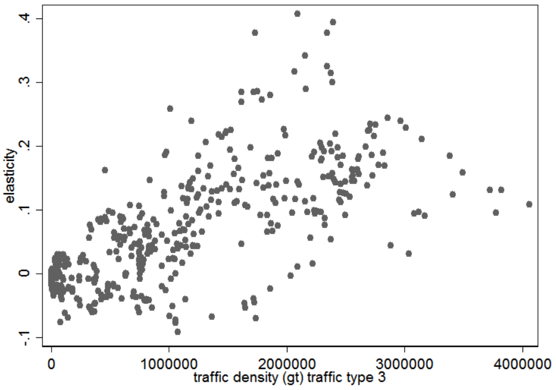


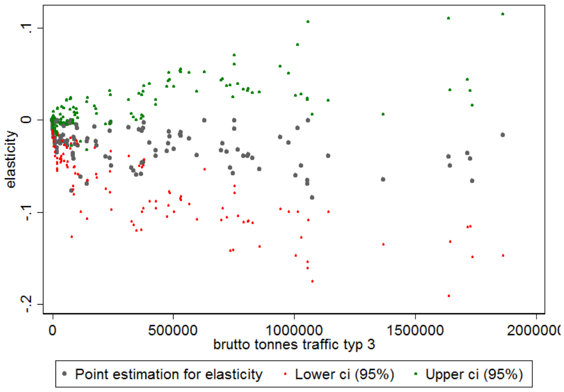
Express train, interregio, local express trains



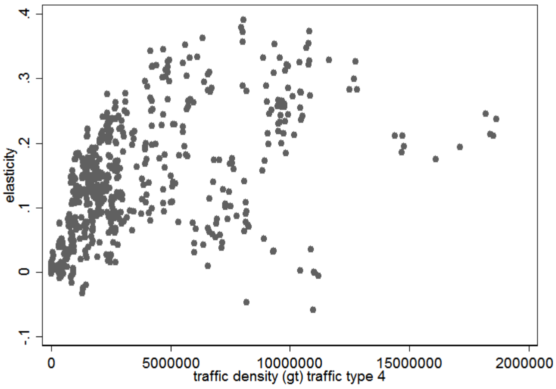


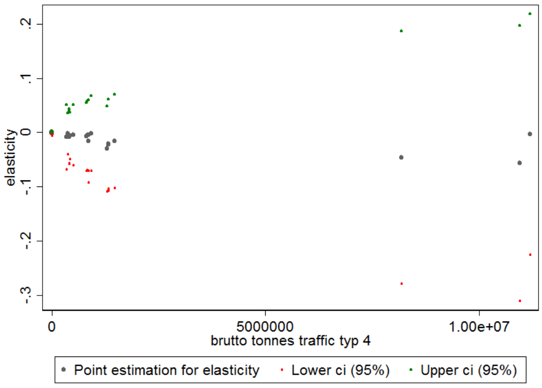
Local trains



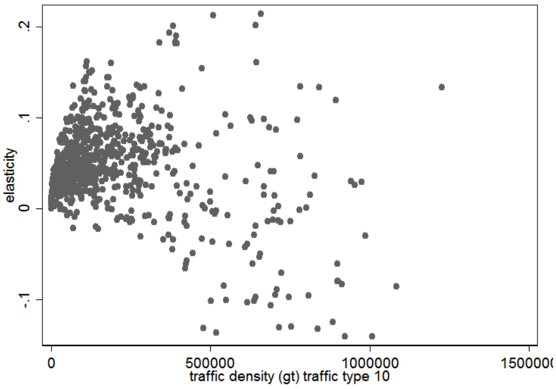


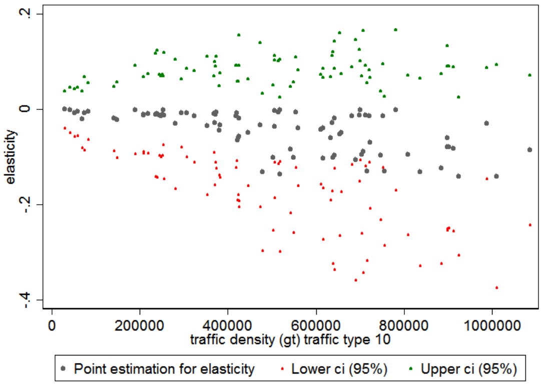
Commuter trains



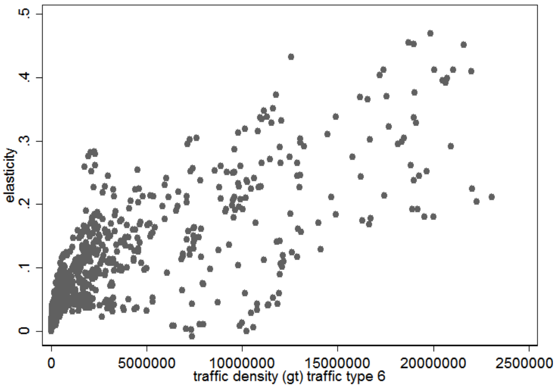


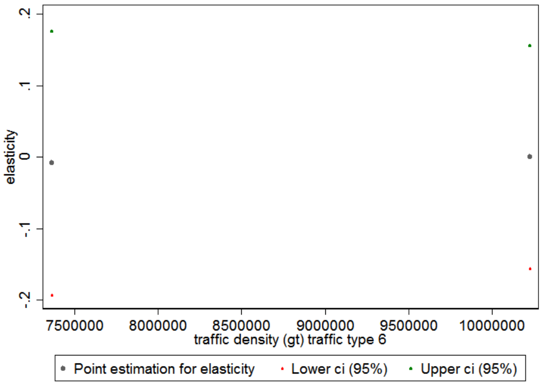
Special passenger trains



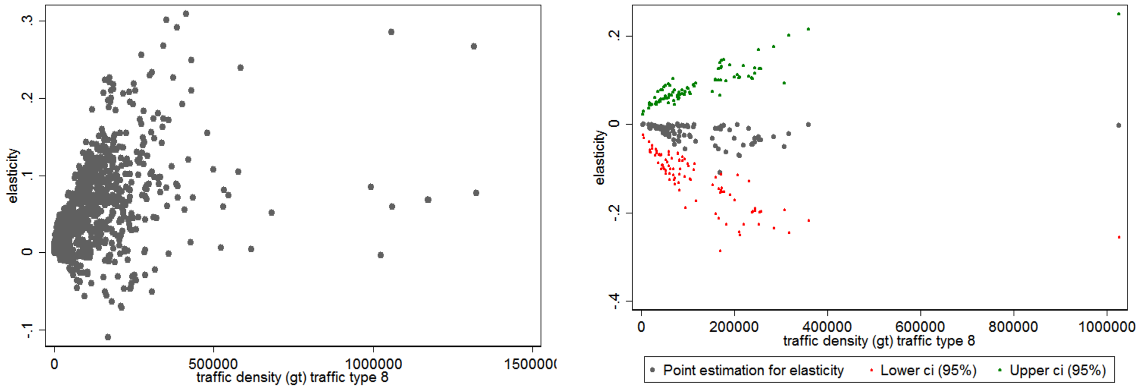


Freight trains





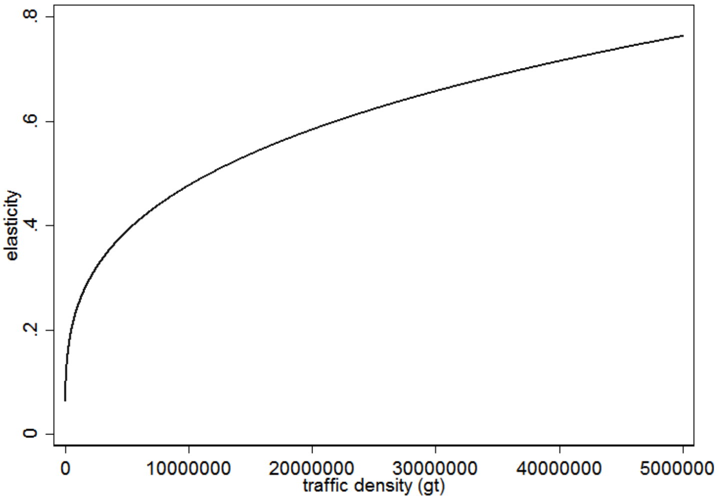
Special freight trains



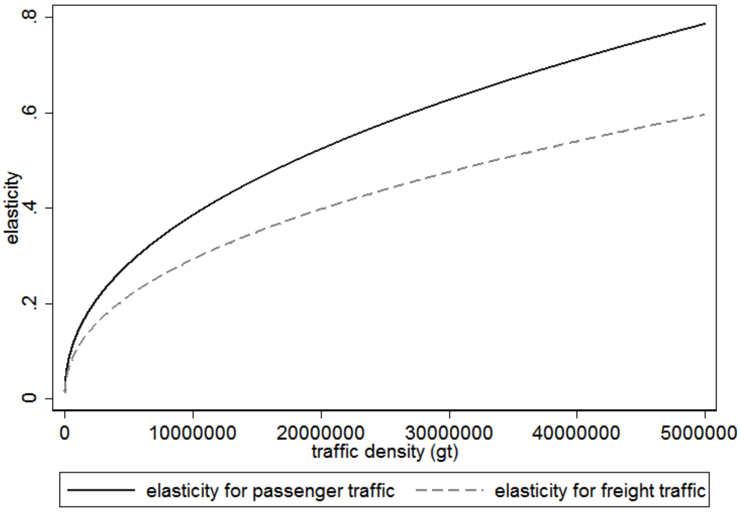
In addition to Figure 5.1, Figure 5.2 presents the cost elasticities with respect to relevant traffic types evaluated at the mean of traffic length and other traffics as appropriate. These are presented to demonstrate the underlying variation in cost elasticities holding all other things equal. What is compelling from the plots is the sensible variation in cost elasticities. We would expect increasing elasticities with traffic density, as it can be expected that traffic damage (in total) would account for a greater proportion of track damage, the greater traffic there is, all other things equal (which is the assumption in Figure 5.2).

Figure 5.2 Elasticities at the mean track length and mean level of other traffics:

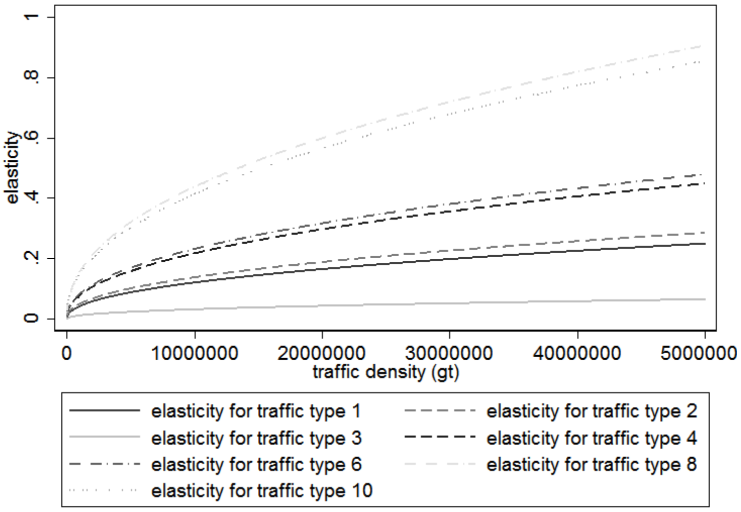
Model A:



Model B:



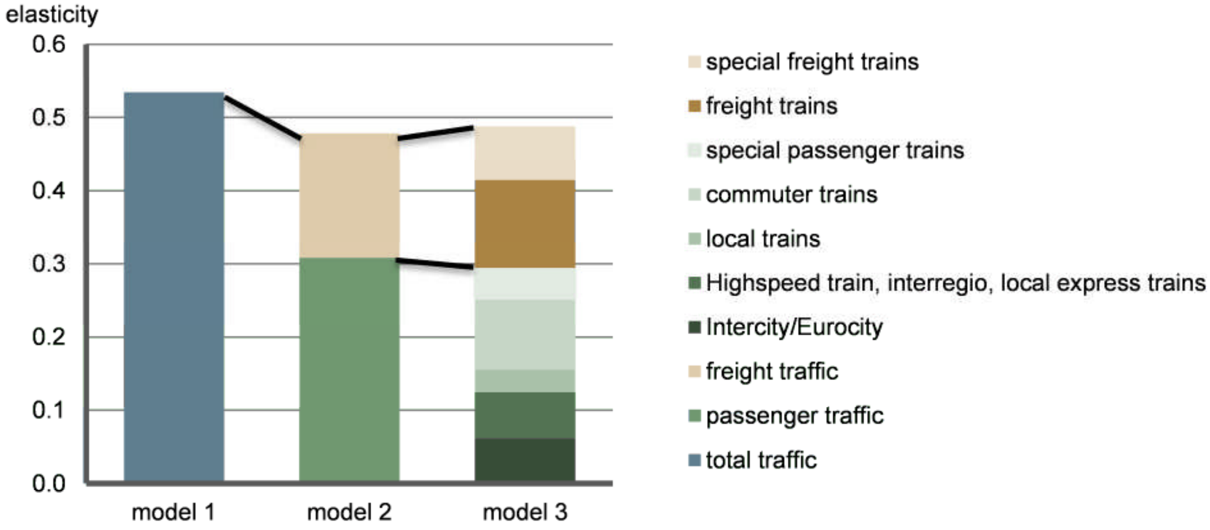
Model C



Finally, with respect to examination of the cost elasticities with traffic, Figure 5.3 summarises the elasticities from each model, by showing the sum of the elasticities across all traffics averaged over observations. Intuitively, the sum of the cost elasticities are similar across all three models as are the sum of passenger and freight from Model C, compared to Model B. This gives us reassurance that our estimations are sensible.

Overall the average cost elasticity for all traffic is found to be between 0.48 (Model B) and 0.53 (Model A). Each of these are higher than that recommended in the CATRIN work (0.35) although the CATRIN work acknowledged the lack of evidence on the combined maintenance and renewal cost category and so it is not necessarily a concern that there is a difference. The work by Andersson et al (2012) in Sweden using Corner Solutions models (see Annex 2) found an elasticity of renewals cost of 0.55, however this referred to track renewals only, which would be expected to be vary variable with usage.

Figure 5.3 Summary of cost elasticity estimates with respect to traffic across models



5.2 The impact of other traffics on elasticities

A data innovation of this study is the number of different traffic types that we have available for analysis. One interesting question to ask is how changes in the traffic mix influence the elasticity of cost with respect to traffic for a given traffic class. This is useful as it gives an indication as to whether increasing traffic on mixed lines increases cost proportionally less or more than increasing traffic on less mixed lines. Given the form of the elasticity expression, mixing traffic decreases the cost elasticity if the interaction term between traffics is negative and increases the cost elasticity is the interaction term between traffics is positive.

For model A there is only one traffic and so the discussion is not appropriate. For model B there are two traffic types (passenger and freight). The interaction term is negative and statistically significant at the 1% level. Thus we conclude that mixing passenger and freight traffic decreases both the passenger and freight cost elasticities, which in turn implies, all other things equal, marginal costs should be lower increasing traffic on mixed lines than dedicated lines. In practice all things are not equal and average costs and thus potentially marginal costs may be higher, but at least at the margin our results hold.

For model C Table 5.1 shows the signs of the interaction terms between different traffic types for those interaction terms which are statistically significant at at least the 10% level. This gives some support that mixing traffic can result in lower costs (at least at the margin, all other things equal). This might support some of the hypotheses being examined in Task 5.3.1 of SUSTRAIL, namely then mixing traffic may reduce the amount of remedial work that is needed to be undertaken for a given amount of total tonne-km. This is because different traffics have different damage characteristics and that some damage mechanisms correct the effects of other damages mechanisms.

Table 5.1 Signs of statistically significant interaction terms between different traffic types from model C

Traffic	Intercity	Express	Regional	Commuter	Special Passenger	Freight	Special Freight
Intercity							
Express	+*						
Regional	-***	Insig					
Commuter	-*	Insig	-***				
Special Passenger	Insig	Insig	Insig	-**			
Freight	-***	Insig	Insig	Insig	Insig		
Special Freight	Insig	Insig	Insig	Insig	-*	Insig	

* p<0.1, ** p<0.05, *** p<0.01

6. DERIVED MARGINAL COST RESULTS

6.1 Average MC by model and by traffic

We now discuss the estimates of the marginal maintenance and renewal costs of different traffic types in infrastructure (MC). The results are given in Table 5.1 which are computed as the average of the estimated MC for each track section, weighted by tonne-km per track section.

Table 5.1 Marginal costs for different traffic types

Model	Traffic	Marginal Costs [CHF/gtkm]	Average Costs [CHF/gtkm]	Cost ratio [in %]
Model A	Total traffic	0.00270	0.00505	0.53455
Model B	Passenger traffic	0.00251	0.00812	0.30842
	Freight traffic	0.00226	0.01332	0.16991
Model C	Intercity/Eurocity	0.00130	0.02096	0.06196
	Express train, interregio, local express trains	0.00150	0.02397	0.06247
	Local trains	0.00320	0.10459	0.03059
	Commuter trains	0.00299	0.03074	0.09714
	Freight trains	0.00164	0.01364	0.12031
	Special freight trains	0.04051	0.55307	0.07324
	Special passenger trains	0.01887	0.44707	0.04222

The marginal costs for total traffic are calculated based on model A and constitute 0.00270 CHF/gtkm. Compared to Marti et al. (2009) the marginal costs of model A are clearly higher. In the project CATRIN the estimated marginal costs for the same cost category were 0.00132 CHF/gtkm. One possible explanation is the higher aggregated track section. Because of that, there are less extreme values and outliers . Also the mapping of the costs is probably more appropriate in the higher aggregation. Compared with other international studies, the marginal costs are on a comparable level with the marginal costs in Austria (marginal costs for maintenance only: ~0.00226 CHF/gtkm) and Great Britain (marginal costs for maintenance only: ~0.00326 CHF/gtkm (Wheat et al, 2009).

With model B, we can do separated mc-calculations for passenger and freight traffic. Accordingly, a small increase in passenger traffic has about the same effect on marginal cost like a small increase in freight traffic on average. The MC for passenger is 0.00251 CHF/gtkm and for freight is about 0.00226 CHF/gtkm. Both values are slightly smaller than the MC for total traffic although this finding stemming from the slightly smaller estimated sum of elasticities for model B compared to model A. Because there are almost no international results to compare this two, at least for the cost category of maintenance and renewals together, it’s difficult to check the plausibility of the results.

Model C allows MC calculations for even more distinct traffic. The calculations show following results:

- MC for Intercity/Eurocity trains and international trains are 0.00130 CHF/gtkm and are about the same level as MC for express train, interregio and local express trains.
- Local trains and commuter trains have similar marginal costs (0.00320 CHF/gtkm compared to 0.00299 CHF/gtkm). Compared to the faster passenger trains, the MC for the slower trains are higher. There are different possible reasons for the higher MC of local and commuter trains;
  - Because of the higher amount of stops, local and commuter trains causes more damage by braking and accelerate, compared to express trains and international trains.
  - Especially commuter trains often operate in densely populated regions and on tracks with high traffic density. Both aspects make the maintenance work more difficult and more expensive (smaller opportunity windows, night work, special noise prevention etc.)
  - Different underbody: express and international trains often have better running gear which makes less damage on the tracks.
- The marginal costs for normal freight trains (95% of total freight traffic) are about 0.00164 CHF/gtkm.
- The special passenger and special freight trains have extremely high marginal costs. But theirs share in total traffic are extremely small, which explains why the results are not accurate.

The finding that local trains have higher marginal costs than intercity trains was also found by Gaudry and Quinet (2009) in France for maintenance only cost (i.e. not including renewals). They found that regional trains had marginal costs, once controlling for track quality, over twice hose of intercity long distance trains. However they also found that the Parisian local services (IdF) had average marginal costs closer to long distance which would seem at odds with the findings here relating to commuter trains (see Table 10 in Gaudry and Quinet, 2009), but of course their study was concerned with maintenance only cost and Paris is quite a unique city.

6.2 Variation in marginal costs over the sample

Figure 6.1 shows the variation in MC with traffic density for models A and B. Model A shows a plausible distribution of marginal costs. The model points to falling MC with traffic density, although it is clear that other characteristics influence MC. In particular some track sections with average tonnage density (average as measured by the mean of traffic density) have high MC. We interpret this in a positive manner, namely that the model is sufficiently flexible to allow for MC to vary with a number of factors. We have controlled for a number of factors (listed in section 3) such as maximum linespeed, curvature and gradient.

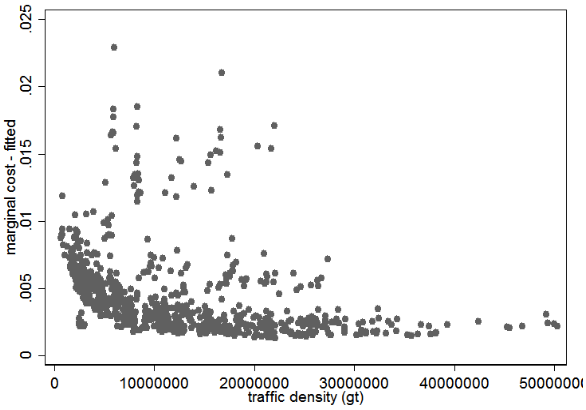
For Model B, the variation in Passenger MC is a very similar pattern to that of total traffic in Model A. The variation in Freight MC is more structured, in that at very low traffic densities MC are very high, were as at medium to high tonnage densities MC are low. It may be of concern that this is an artefact of the model functional form, and indeed such concerning findings have been found in the literature when using Double log functional forms (Wheat et al, 2009). However this functional form is more flexible and the fact that the variation in the total (Model A) and passenger traffic in this model do not appear constrained to this pattern, we do not have such concerns here and conclude this is legitimate variation in the data. It may also simply be a combination of poor predictive performance at very low tonnage levels (statistical models will always be limited at the extremes of the sample) coupled with graphical scale issue.

For the traffics examined in Model C, the individual plots of MC for each traffic type show some volatility and are not very informative. We suspect that this reflects the limits of our data and confine ourselves to discussing MC by these traffic types only in the average rather than the distribution across track sections.

Overall, the average marginal costs appear intuitive both at the total traffic, passenger and freight disaggregation and seven traffic type disaggregation (with the exception of the special passenger and freight traffics). Further the variation in MC over track sections appears sensible for Models A and B.

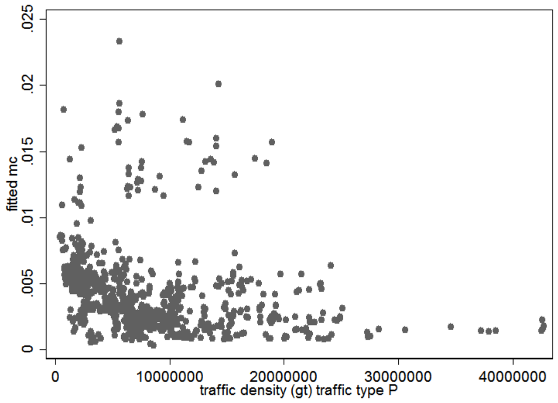
Figure 6.1 Variation in MC with traffic density from models A and B

Model A

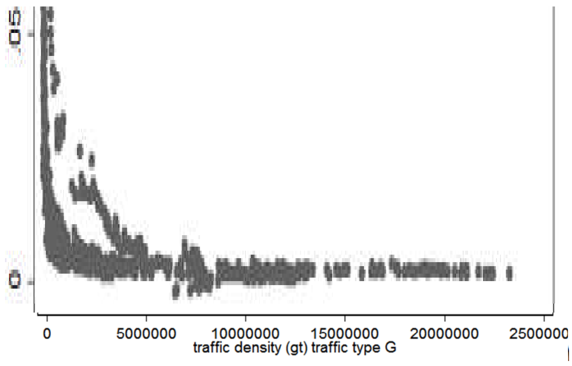


Model B

Passenger



Freight



7. CONCLUSION

In this paper we have utilised a ten year panel data set for 80 track sections in Switzerland. We have considered the combined infrastructure maintenance and renewal cost which is an under researched area. Further we have data on seven traffic types, which is unprecedented in this literature. We estimate three models for traffic aggregated into a single measure, two measures (passenger and freight) and the seven measures. We adopt a Box-Cox functional form which is very flexible and represents best practice in this literature (see Wheat et al, 2009). Further we correct the common implementation of the model to allow for the function form to truly nest the Translog model, which is a further innovation of this work.

Overall we find that the average cost elasticity with respect to all traffic is found to be between 0.48 (Model B) and 0.53 (Model A). Each of these are higher than that recommended in the CATRIN work (0.28 to 0.35) although the CATRIN work acknowledged the lack of evidence on the combined maintenance and renewal cost category and so it is not necessarily a concern that there is a difference. We also find increasing cost elasticities with traffic density which is intuitive given we would expect traffic related damage to form a greater proportion of total asset degradation for higher traffic usages, all other things equal.

Further we find evidence that mixing traffic of different types can result in lower overall cost elasticities and, all other things equal, lower marginal costs. This might support some of the hypotheses being examined in Task 5.3.1 of SUSTRAIL, namely then mixing traffic may reduce the amount of remedial work that is needed to be undertaken for a given amount of total tonne-km. This is because different traffics have different damage characteristics and that some damage mechanisms correct the effects of other damages mechanisms.

The average marginal costs appear intuitive both at the total traffic, passenger and freight disaggregation and seven traffic type disaggregation (with the exception of the special passenger and freight traffics). Further the variation in MC over track sections appears sensible for Models A and B. We find the MC for intercity and inter-regional trains are lower than for regional and commuter trains (per gross tonne-km). Freight trains have, on average, similar marginal costs per gross tonne-km than overall passenger. This is an interesting conclusion and would indicate that charges do not (on average) have to be different for passenger and freight, although there may be additional bonus or penalties for specific characteristics of vehicles that affect the relative track damage within the passenger or freight class.

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

SUSTRAIL

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ABSTRACT

This Annex reports on the work to determine the wear and tear costs of railway infrastructure in Britain. The work analyses a panel data set of up to ten zones comprising the British rail network over the period 1995/96 to 2009/10. We consider both maintenance and track renewal cost and develop a model which utilises dynamic terms within to capture both the inter relation between maintenance and renewal cost and the important evolution of renewals cost over time. We demonstrate how to compute the marginal cost with respect to traffic. We compare the results to those from the static model and find consistency between the long run elasticity and the elasticity from the static model.

1. INTRODUCTION

There now exists a large body of empirical research in Europe examining the marginal infrastructure wear and tear costs from running traffic on railway networks. This has been primarily driven by the need for countries of the European Union to charge access to railway infrastructure on the basis of ‘incremental cost’, which can broadly interpreted as the marginal cost to the infrastructure manager of accommodating the extra train movement.

This econometric literature has provided some useful results in terms of the extent to which railway maintenance and renewal costs vary with traffic, with a general finding that the variable cost of maintenance increases with intensity of usage (from 20% at low densities to 45% at high densities) and the finding that renewal costs appear slightly more variable than maintenance (Wheat et al, 2009). It should be noted that there is much less empirical evidence on the cost variability of the sum of maintenance and renewals cost vis-à-vis maintenance only cost. For example the work undertaken in the FP6 CATRIN project contained only two studies for maintenance and renewal costs, but six for maintenance only costs and as such there was much uncertainty related to the recommended cost variability of the renewal category (35%).This study provides new evidence on this important combined cost category.

This annex explores using dynamic econometric models, namely vector autoregressive models to better model both the inter-relationship between maintenance and renewals costs and the inter temporal relationship, particularly for renewals costs. This type of analysis has previously not been possible due to only relatively short panel datasets being available for analysis. This dataset is from 1995/96 to 2009/10 i.e. 15 years. We contrast the results with those from a simple pooled static model.

2. MODEL FORMULATION

The data comprises of 10 zones of the British infrastructure manager, from 1995 to 2009. We collect maintenance and renewal cost separately, as well as traffic, track length and both delay minutes and number of broken rails which proxy for the condition of the infrastructure.

The aim of the modelling is to estimate the marginal cost of traffic while simultaneously allowing for past maintenance and renewals to determine the level of current maintenance and renewals. As such we aim to capture a trade off between maintenance and renewal activities and also that undertaking previous levels of maintenance (and renewal) influence the required levels of maintenance (and renewal) today.

An accessible treatment of VAR models and associated analysis (including Impulse Response Analysis and Granger Causality used in section 5) can be found in Greene (2003, Section 19.6). The model can be represented, in its simplest form as:

$$\begin{aligned} \ln(M_{it}) &= \alpha_1 + \phi_{11}\ln(M_{it-1}) + \delta_{11}\ln\left(R_{it-1}\right) + \beta_{11}\ln(Q_{it}) + \gamma_1\ln(I_{it}) \\ \ln(R_{it}) &= \alpha_2 + \phi_{21}\ln(M_{it-1}) + \delta_{21}\ln\left(R_{it-1}\right) + \beta_{21}\ln(Q_{it}) + \gamma_2\ln(I_{it}) \end{aligned} \qquad (2.1)$$

i=1,…,N and t=2,…,T

where M is maintenance cost, R is renewal cost, Q is traffic and I is an infrastructure condition measure. By forming the model is this way we can relate todays maintenance to all previous levels of maintenance and renewals and traffic (since because the current year's maintenance is related to last year's maintenance and this in turn is related to the previous years, implicitly todays maintenance is related to maintenance in all previous time periods). We can then use "Impulse Response Analysis" to understand (forecast) how future maintenance or renewal cost will evolve if there is an increase or decrease in one of the costs in the present time period.

2.1 Deriving the elasticity of cost with respect to traffic – short run and long run

We can also derive the relevant cost elasticity and thus marginal cost with respect to traffic changes. The concepts of short run and long run are relevant here given that there are feedbacks in the model that mean maintenance and renewal costs do not fully adjust to a change in traffic in a single time period.

The **short run elasticity** of cost with respect to traffic refers to the proportional impact on cost in the current time period from a 1% increase in traffic. Using the model in (2.1), it is given simply as

$$\varepsilon_{MQ}^{S} = \frac{\partial lnM_{it}}{\partial lnQ_{it}} = \beta_{11}$$

for maintenance cost and $\varepsilon_{RQ}^{S} = \beta_{21}$ for renewals cost.

However, the inclusion of lagged terms for maintenance and renewals cost in each equation means that the full impact on maintenance and renewals cost is not realised until further into the future. The **long run elasticity** of cost with respect to traffic captures the proportional impact of cost once all the impacts over time are traced through the model. In the model in (2.1) the long run elasticity can be calculated by considering the long run equilibrium. Equilibrium is whether the maintenance and renewal cost variables have no tendency to change. That is $M_{it} = M_{it-1} = M_i^*$ and $R_{it} = R_{it-1} = R_i^*$.For the maintenance equation:

$$\ln(M_i^*) = \alpha_1 + \phi_{11}\ln(M_i^*) + \delta_{11}\ln(R_i^*) + \beta_{11}\ln(Q_i) + \gamma_1\ln(I_i)$$

Rearranging:

$$\ln(M_i^*) = \frac{\alpha_1}{(1-\phi_{11})} + \frac{\delta_{11}}{(1-\phi_{11})}\ln(R_i^*) + \frac{\beta_{11}}{(1-\phi_{11})}\ln(Q_i) + \frac{\gamma_1}{(1-\phi_{11})}\ln(I_i) \qquad (2.2)$$

This implies[1]:

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[1] This is a simplification. In reality there will be a secondary impact in each equation arising from responses to the change in traffic in the other equation. However such an effect is, in this empirical implementation, small, and so for this study it is ignored when computing the long run elasticity.

$$\varepsilon_{MQ}^{L} = \frac{\partial lnM_i^*}{\partial lnQ_i} = \frac{\beta_{11}}{(1-\phi_{11})}$$

And the equivalent for renewals cost is

$$\varepsilon_{RQ}^{L} = \frac{\beta_{21}}{(1-\phi_{21})}$$

2.2 Comparison of this approach with the existing literature

The majority of the literature to date has not considered explicit dynamic relationships between maintenance and renewals cost. See the Deliverable 8 in the FP6 project CATRIN (Wheat et al, 2009) and the main body of Deliverable D5.3 in this project for a survey. Smith (2012) did consider an ad hoc adjustment to renewals expenditure (based on the rate of physical track renewals) to smooth out renewals costs specifically for the British operator in an international study involving 13 railways. However the most comprehensive study which considered dynamic and inter relations between maintenance and renewals expenditure is Andersson (2008) for Sweden.

Andersson (2008) considered data of a different form to this study. In particular data was only available for four years, but for each year there were 185 track sections available for analysis. This is clearly a short fat panel as opposed to the long thin panel available for this study. As such the modelling approach is different. Andersson modelled maintenance costs, but included as an explanatory variable an indicator for whether there was a planned future renewal. Andersson found a negative relationship between current maintenance cost and the indicator as to whether a large renewal was imminent. The explanation is that maintenance expenditure is temporarily reduced in anticipation of a renewal. In a further model Andersson considers including a lag of the maintenance cost variable in the specification ($\ln(M_{it-1})$ in equation (2.1)). He finds that this is statistically significant and the coefficient is negative. Andersson considers this to represent a tendency of the system towards a steady state, but this result implies a short run elasticity greater than the long run as defined in section 2.1 above (and such a result is reported in Andersson). This seems odd as it could be expected that the infrastructure manager would take time to react to shocks in the system be these from external factors captured by the model error or by changes in the exogenous variables (notably traffic).

Overall, the analysis in this Annex is different to the Andersson (2008) analysis primarily since the dataset structure is different, which allows for a much more flexibility in terms of capturing dynamics in the model. However this dataset is smaller in terms of total observations relative to the Andersson dataset and also, given the geographical aggregation, will have different patterns of variation within which may yield different results.

3. DATA

The data comprises 10 zones of the British infrastructure manager, from 1995 to 2009. We collect maintenance and renewal cost separately, as well as traffic, track length and both infrastructure manager caused delay minutes and number of broken rails which proxy for the condition of the infrastructure.

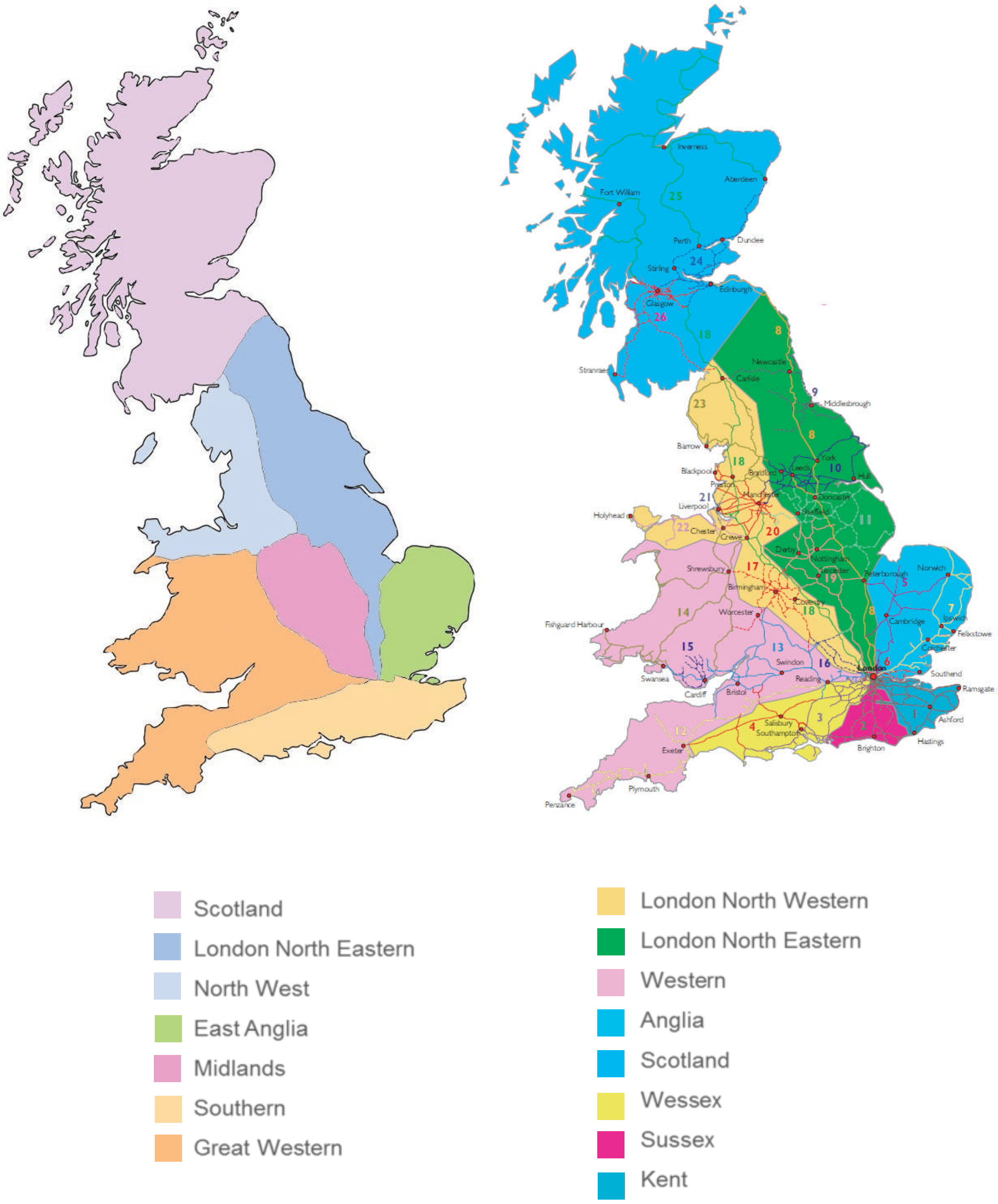
Given the length of the panel, we have developed the data from a number of sources. The first was the database compiled for the work by Kennedy and Smith (2004). This included data from 1995 to 2002 and was sourced from the British infrastructure manager (see Kennedy and Smith (2004) for more details). 2003-2009 represents an update to this database. Table 3.1 summarises the sources of this data.

Table 3.1 Sources of data for the updated years

Data	**Source**
Cost data	Network Rail Annual Returns
Traffic data	Database for 2005/06 used in Wheat and Smith (2008) provided by Network Rail, Network Rail Annual Returns and Statement 13 zones traffic baselines for 2008/09
Delay minutes and number of broken rails	Network Rail Annual Returns

An additional consideration is that the geographical zonal structure has changed post 2004/05 (inclusive). As such, after matching up similar zones between the two time periods, there are 11 zones in an unbalanced panel (4 zones continue throughout the whole period, 3 other zones in the early period and 4 other zones in the later period). Further work could consider the sensitivity of results to the exact specification of the panel in terms of which zones to dove-tail into others and which to consider as ‘new’ zones, however the approach taken here is justified based on the obvious mappings between zones.

Figure 3.1 British zonal structure pre (left) and post (right) 2004/05



4. MODEL SELECTION

We estimate a dynamic VAR model with maintenance and renewal costs as two dependent (or endogenous) variables and track length, traffic, delay minutes and number of broken rails as exogenous explanatory variables. In addition we include a time trend which is piecewise linear. In particular we have a linear trend up to the year 2000/01 and then a separate linear trend from 2001/02 onwards. We also allow for a shift in costs at the year 2001/02. This is included to model the cost shock associated with the aftermath of the Hatfield train derailment accident in October 2000 which had major impacts in terms of sudden increases in maintenance and renewals cost of the infrastructure manager.

A remaining issue concerns the number of lags of the endogenous variables to be included within each equation. This means, what should be the choice of the number of lagged maintenance and renewal cost terms (t-1, t-2 etc) on the right hand side of each equation? There are advantages and disadvantages of including more terms. From a model flexibility perspective (the ability of the model to describe the underlying cost relationship) more terms are preferred. However the more terms that are included, the more years of data have to be dropped from the regressions. To explain, consider the model in (2.1) which contains only one time period lag for each cost variable (t-1). It is necessary to drop the first year of data for all zones (which for those zones starting midway through the panel, means dropping the first year that they actually appear for that zone specifically), since at time t=1, the lag t-1 does not have any data associated with it (t=1-1=0 is outside the dataset). Similarly if we have two lags (t-2) we have to drop the first two years worth of data. Given the unbalanced nature of the panel (some zones only having 6 years of data), too many lags can seriously reduce the number of observations to be used for analysis.

One final consideration is that the model estimates are only unbiased if there is no serial correlation within the error structure of the model[2]. In practice this means that the residuals in the regressions cannot be serially correlated. Such serial correlation can be removed by increasing the number of lags of the endogenous variables within the model. Thus we choose the lag length as the minimum required to eliminate serial correlation in the residuals. Using LM tests for models of increasing lag lengths, it is found that a minimum lag length of 2 is required to fail to reject the null hypothesis of no serial correlation. Thus we adopt the lag length of 2.

The model is estimated by equation by equation ordinary least squares. This means that OLS is applied to each equation in turn. Table 4.1 reports the results of the estimations. We discuss the implications of these estimates in the following three sections.

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[2] In static models serial correlation is not a major problem (it affects the precision of estimators rather than results in bias). However in dynamic models, the presence of a lagged dependent variable implies that a serially correlated error structure creates correlation between the lagged dependent variable and the error within the model, resulting in biased estimates using ordinary least squares techniques. As such serial correlation needs to be removed from the model errors and this can be accomplished by adding in more lags of the dependent variables.

Table 4.1 Estimation results from the two cost equations
Sample (adjusted): 1997 2009
Included observations: 89 after adjustments
Standard errors in ( ) & t-statistics in [ ]

	MAIN	REN
MAIN(-1)	0.958499	-0.396322
	(0.08895)	(0.36214)
	[10.7752]	[-1.09441]
MAIN(-2)	-0.314884	0.572373
	(0.09023)	(0.36734)
	[-3.48973]	[1.55817]
REN(-1)	0.050179	0.590991
	(0.03055)	(0.12439)
	[1.64230]	[4.75123]
REN(-2)	-0.019890	-0.105415
	(0.03288)	(0.13385)
	[-0.60495]	[-0.78756]
C	1.504456	4.641055
	(0.90022)	(3.66481)
	[1.67122]	[1.26638]
ALLTMD	0.268976	0.277425
	(0.06088)	(0.24783)
	[4.41839]	[1.11942]
TRACK	0.306465	0.481337
	(0.05690)	(0.23164)
	[5.38598]	[2.07792]
DELAY	-0.045872	-0.423381
	(0.03989)	(0.16239)
	[-1.15000]	[-2.60719]
BRAIL	0.003407	-0.077957
	(0.02926)	(0.11912)
	[0.11645]	[-0.65446]
YEAR>2000	0.386361	0.226173
	(0.11234)	(0.45736)
	[3.43906]	[0.49452]
T*(YEAR>2000)	-0.037906	0.012140
	(0.00786)	(0.03200)
	[-4.82319]	[0.37944]
T*(YEAR<2001)	-0.012122	0.044597
	(0.01697)	(0.06909)
	[-0.71429]	[0.64552]
R-squared	0.969559	0.793047

5. IMPULSE RESPONSE ANALYSIS AND GRANGER CAUSALITY

To understand the estimation results, we first review how the estimated model characterises the dynamics associated with maintenance and renewals cost. This is important since these dynamics inform how traffic influences current and future costs, the subject of section 6.

Impulse response analysis (IRA) is a graphical representation as to how maintenance or renewals costs respond over time to changes in a base time period (time=1). The IRA for this model is given in Figure 5.1. To understand the nature of IRA, consider for example the top left hand panel of Figure 5.1 which shows how maintenance cost responds to a one standard deviation variation in error in the maintenance equation. This can be thought of as a ‘shock’ to the maintenance equation (and could come from changes in traffic for example or through a random shock via the error). The x-axis of all the charts represent time periods (in this case years). In a static model the graph would only be non-zero for time=1, after that period a shock in time=1 has no impact on further maintenance expenditures. However because the models are dynamic, the impact of an increase in maintenance expenditure in time=1 has a further impact in time=2, 3, 4 etc.

We first describe the implications of the IRA for each cost category (top left and bottom right) with respect to itself and then describe the cross influences between them (bottom left and top right).

5.1 The evolution of maintenance and renewals expenditure

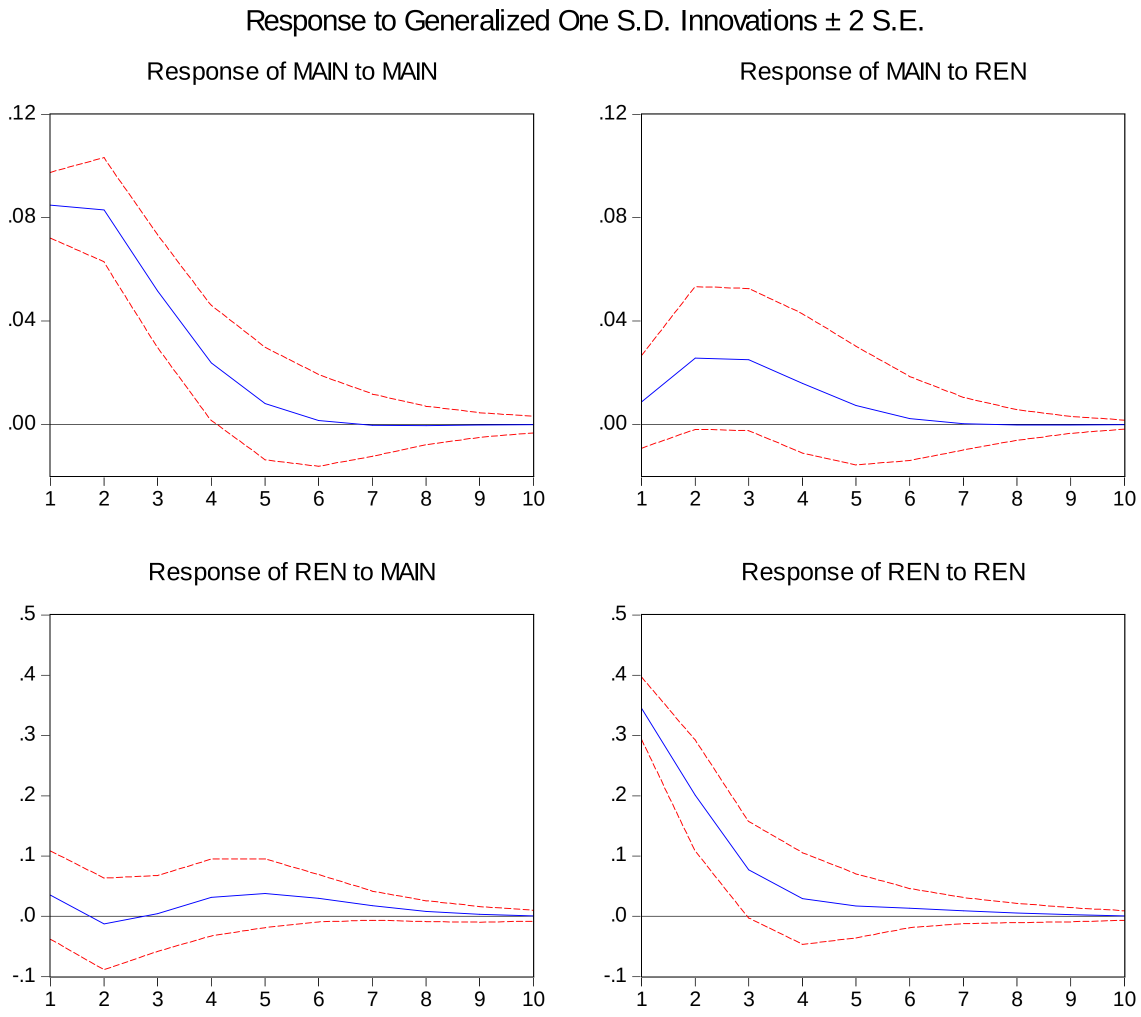
Given that the lagged maintenance terms (MAIN(-1) and MAIN(-2)) in the maintenance equation are statistically significantly different from zero (the t-stats are greater than 2 in absolute values), there is evidence for intertemporal relationships between maintenance costs. Similarly there is evidence for intertemporal relationships between renewals costs given the statistical significance of the REN(-1) parameter estimate in the renewals equation.

The IRA plots in Figure 5.1 show the nature of the relationship. Both maintenance and renewals costs have the same shape of relationship (again top left and bottom right in Figure 5.1). For maintenance cost, increases in maintenance in one year result in a similar increase in the second year (the value for time=1 and time=2 are roughly equal). Then, after year 6, the impact of the original increase in maintenance cost has dissipated. For renewals cost, there is less persistency in time=2, and instead a gradual reduction in the impact of a renewals shock.

These results seem to reflect that, in reality, there tend to be periods of higher than average maintenance and renewals expenditure. Thus a high maintenance cost in one year is likely to be followed by another high maintenance cost and similarly for renewals. It also indicates that there is a lagged response in maintenance and renewals expenditure to changes in external factors, be these captured in the error in the model or due to changes in the levels of the exogenous variables (e.g. traffic). Thus it takes time for the infrastructure manger to change expenditures on maintenance and renewals in response to traffic growth. This result is in contrast to the result in Andersson (2008) which found that the long response is to dampen the short run response i.e. infrastructure managers ‘over react’ to changes in traffic in the immediate period in that model.

What the results do not show is a subsequent ‘holiday’ period for maintenance and renewals cost. That is, a period of high maintenance cost could be thought to proceed a period of lower than average cost levels. If this was indicated by the model then we would expect some negative entries in the plots for the higher time periods. This could be due to limits in the panel length (compounded by the break in the panel at 2003/04 for some zones) which prevent the inclusion (and significant parameter estimation) of higher order lags.

Figure 5.1 Impulse response analysis for maintenance and renewals costs



In contrast to the significant relationship between current maintenance cost (or renewals cost) and past maintenance cost (or renewals cost), the IRA indicates that there is only a weak impact on maintenance and renewals costs in response to changes in renewals and maintenance costs respectively (the bottom left and top right plots in Figure 5.1). The response of renewals cost to maintenance cost changes is particularly minor and the confidence interval (red lines) for the effect clearly span zero impact for all time periods. The response of maintenance to renewals is a little more marked with evidence of a lagged positive impact (c.f. maximum impact in time periods 2 and 3) and the associated interval estimate (the red lines nearly are above 0 indicating weak statistical significance of this relationship). This pattern could be explained by renewal activity reducing the short term need for maintenance however for this to be a convincing explanation we would expect to see a negative initial impact on maintenance cost from an increase in renewals cost (as undertaking renewals activity means less maintenance is temporarily undertaken) which we do not see in the data. This is in contrast to the significant result in Andersson (2008) who found that future large renewals reduced current maintenance cost.

We can formally test whether knowing past values of renewals/maintenance cost helps to better predict current (or future) maintenance/renewals cost respectively. In econometrics such a concept is known as 'Granger Causality'. The tests involve determining if the lagged dynamic terms of the opposite cost variable (so lagged renewals terms in the maintenance equation for example) are jointly statistically significant (the null hypothesis is that they are not). The tests for both the maintenance and renewals cost equations are given in Table 5.2. In both cases we cannot reject the null hypothesis, indicating that there is no evidence that either renewals or maintenance cost Granger Causes maintenance or renewals cost respectively. An alternative way to put this is that there is no evidence of a relationship between the two cost categories. This is surprising given that, at the margin, one would expect some trade-off between the two activities. Of course failure to reject the null hypothesis does not mean that the null is true and once we develop the panel data set further (see the Conclusion), we may find evidence for such a cross relationship.

Table 5.2 Granger Causality Tests

VAR Granger Causality/Block Exogeneity Wald Tests
Date: 07/24/15 Time: 15:11
Sample: 1995 2009
Included observations: 89

Dependent variable: MAIN

Excluded	Chi-sq	df	Prob.
REN	3.045594	2	0.2181

Dependent variable: REN

Excluded	Chi-sq	df	Prob.
MAIN	2.448689	2	0.2940

6. DERIVED COST ELASTICITY RESULTS

We now turn to the implied cost elasticities with respect to traffic. These are summarised in Table 6.1. In addition to the results for the separate maintenance and renewal cost categories, the short and long run elasticities are presented for a single equation combined cost model (the sum of maintenance and renewal cost). The final column presents the results from a static model (no lagged terms) for each of the cost categories. The parameter estimates associated with these models are presented in Appendix A and the elasticities are included in Table 6.1 for comparator purposes.

For both cost categories the short run elasticities are roughly the same, 0.27 and 0.28 for maintenance and renewal costs respectively. 0.27 implies that a 1% increase in traffic results in a 0.27% increase in maintenance cost in the same time period. The long run elasticities are, as expected, higher at 0.75 and 0.54 for maintenance and renewal costs respectively, although the renewal elasticity is not statistically significant. These seem high particularly the maintenance elasticity when compared to other evidence. The consensus from the CATRIN project (Wheat et al, 2009) was that for medium traffic density lines/zones, the elasticity of cost with respect to traffic is 0.3. For renewals there was less evidence, but a figure of 0.35 was proposed. Wheat and Smith (2008), specifically for Britain found an elasticity in their preferred model of 0.378 for maintenance cost only when they analysed a cross section of data for the year 2005/06. However this was high relative to some of the other model specifications. Therefore 0.75 from this model looks very high, particularly given that the maintenance costs considered contain most cost elements (in contrast Wheat and Smith (2008) only considered permanent way and signalling and telecoms which are expected to be most influenced by traffic).

However, it would appear that these higher elasticities are not an artefact of the dynamic functional form, as similar elasticities are yielded from the static variants of the models (no lagged dependent terms). The underlying reason for the higher elasticities is not clear. It could be due to the aggregate nature of the zones in this study. Indeed the Swiss case study in this project (D5.3 Annex 3) does provide some supporting evidence that aggregating to a higher geographical level does increase the estimated elasticity. Alternatively it could be due to the reliance on data which varies considerably over time in the presence of a cost shock, attributed to the fallout from the Hatfield accident, which may have had some unexpected influence in these results. However the inclusion of a relatively flexile time trend would have been thought to compensate for the majority of this effect. Finally, the model does not include a large number of infrastructure characteristics. In particular there are no variables which capture the operational capability of the lines, such as the maximum permitted linespeed or the maximum permitted axel load. The latter maybe an important controlling factor given that the traffic variable does not reflect weight of trains.

Table 6.1 Estimated cost elasticities with respect to traffic [all statistically significant at the 5% level except *]

Cost Category	**Dynamic Model Short Run**	**Dynamic Model Long Run**	**Static Model**
Maintenance	0.27	0.75	0.68
Renewal	0.28*	0.54*	0.72
Combined	0.29	0.82	0.70

* Not statistically significant from zero at 5% level.

7. DERIVED MARGINAL COST RESULTS

Marginal cost is computed for each zone in each year as the product of the relevant cost elasticity and the average cost per train-km. This simply follows from the fact that a cost elasticity is the ratio of marginal cost and average cost. Table 7.1 summarises the marginal cost estimates for each cost category (with the static and combined cost models as comparators). These are averages across all zones and years weighted by train-km as is standard in the empirical literature[3].

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[3] Such averaging ensures that charging this average to all traffic yields the same revenue as charging traffic in each zone, in each year, a unique marginal cost.

Table 7.1 Average marginal costs from each model in 2009/10 prices (£ per train km)

Cost Category	**Dynamic Model Short Run**	**Dynamic Model Long Run**	**Static Model**
Maintenance	0.621	1.724	1.563
Renewal	0.410	0.790	1.054
Combined	1.091	3.084	2.633

The maintenance marginal costs are greater than those reported in Wheat and Smith (2008) for three reasons. Firstly, the cost based is 2009/10 rather than 2005/06, implying a 2005/06 price base figure of £1.48 per train km for the long run maintenance marginal cost, which compares to £1.01 per train km in Wheat and Smith model VI. Secondly, the estimated elasticities are greater than Wheat and Smith (2008) (and the Wheat and Smith model VI referred to above had variable elasticity formulation). Thirdly, average costs are higher primarily because the cost elements in this modelling are broader than in the Wheat and Smith analysis.

A remaining issue arises with respect to which marginal cost – “short run” or “long run” – should be used for charging purposes. It is important to realise that the distinction between short run and long run in this context is not the same as that used in the economics pricing literature. Here it relates to the difference between instantaneous (within period) response and subsequent ‘equilibrium’ (long run) response. In the pricing literature, short run is when at least one factor of production is fixed (in this context railway infrastructure) and in the long run all factors can adjust to optimal levels. However given the length of the data set at our disposal it is doubtful that the ‘long run’ response is really reflecting the movement to optimal capital response given traffic, particularly given the IRA indicates that most of the majority of the response is realised within 5 years. As such using the Long Run marginal cost seems the most appropriate reflection of incremental cost of additional traffic.[4]

Overall, perhaps the most important message from this work is that the static approach does not seem to be systematically over or under estimating incremental marginal cost when contrasted to a more flexible approach.

8. CONCLUSION

This annex has presented an analysis of zonal data over 15 years for the British network. A dynamic analysis using a Vector Autoregressive (VAR) model has been undertaken. This is the first example of such a modelling approach applied to modelling the marginal infrastructure wear and tear cost of traffic.

The potential benefits of this approach over the static approaches to date include:

- Explicit modelling of the maintenance/renewal cost trade-off

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[4] Even though it is argued both short run and long run are consistent with incremental cost, there is still a choice between the two. The argument for using the long run estimate is similar to the argument for charging for renewals cost elements of cost. In particular running trains today causes a change in the cost profile for the infrastructure manager going forward into the future and this needs to be quantified. The short run marginal cost would only capture the first year of this profile change. This is only the author’s view and further views on this would be useful should the dynamic approach be taken forward to other studies.

- Explicit modelling of year on year budgetary constraints
- The distinction between instantaneous response (short run) to extra traffic versus longer term changes

In this implementation it has been demonstrated that there is support in the data for a dynamic data structure over the static data structure, although using this particular data set, the empirical benefits over the static approach are not obvious in terms of specifically informing marginal cost estimates, given that the marginal cost results are similar. It could be deemed reassuring that the static approach does provide a useful approach for estimating marginal cost of infrastructure wear and tear with respect to traffic. This should be verified with reference to other data sets. However, going forward, further consideration should also be given as to how understating of dynamic response to traffic changes can be used to enhance infrastructure charges.

The approach can be developed in a number of ways. Firstly in terms of data:

- For the British case study the data can be updated to nearer the present day. The zonal structure as of 2004/05 has continued and so such an extension will result in a large gain in the number of time periods per zone which in turn could yield large empirical benefits.
- For Britain, data on tonne-km should be collected as this better represents the engineering drivers of track damage when compared to simply having train-km
- Finally, specifically for the British case study, the model currently contains only four ‘exogenous’ variables; traffic, track length, number of broken rails and infrastructure manager cause delay minutes (as well as a specification of a time trend). These variables have some limits as to the extent to which they fully describe the cost drivers in the railway. Supplementing these variables with others such as the average maximum axel load of the tracks, the age of the tracks and average maximum line speed may better isolate that component of cost which varies with traffic holding all other things equal
- More generally, these techniques are suitable for panel data sets with many time periods. Such data sets are being collected such as in Switzerland where the data is available for 10 years (see Annex 3 of this deliverable). Therefore these techniques should be applied to more widely.
- The longer the panel, the more likely that a full picture of the trade-offs over time between costs can be quantified.

Secondly, there are some remaining statistical issues:

- The current model ignores the panel nature of the dataset. Panel data techniques should be explored in further work to account for unobserved heterogeneity in the modelling
- While the panel is long relative to other panels used in this empirical literature, it is still not long from the perspective of invoking statistical results which rely on a large number of time periods (large T asymptotics). This presents difficulties in estimation of panel data models (due to the dynamic terms) and it is likely that such analysis will require GMM estimation techniques such as Arellano and Bond (1991).
- However both statistical developments in the two previous bullets require sufficient data to produce precise estimates and at present the data do not seem to support such sophisticated analysis (based on the author’s initial work). This suggests the primary concern should be to continue to develop the datasets and then choose the most feasible statistical technique.

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APPENDIX A – COMPARATOR MODELS

Dynamic Model – Sum of maintenance and track renewal cost

Sample (adjusted): 1997 2009
Periods included: 13
Cross-sections included: 11
Total panel (unbalanced) observations: 89

	Coefficient	Std. Error	t-Statistic	Prob.
C	3.003784	1.347186	2.229673	0.0286
TOT(-1)	0.703589	0.122489	5.744105	0.0000
TOT(-2)	-0.059456	0.121897	-0.487754	0.6271
ALLTMD	0.292659	0.088520	3.306115	0.0014
TRACK	0.385135	0.080783	4.767547	0.0000
DELAY	-0.182659	0.062478	-2.923592	0.0045
BRAIL	-0.021530	0.045566	-0.472510	0.6379
YEAR>2000	0.328992	0.168406	1.953561	0.0543
T*(YEAR>2000)	-0.021438	0.012019	-1.783706	0.0783
T*(YEAR<2001)	0.008610	0.024678	0.348906	0.7281

R-squared	0.940544	Mean dependent var	18.92141
Adjusted R-squared	0.933770	S.D. dependent var	0.514961
S.E. of regression	0.132526	Akaike info criterion	-1.098549
Sum squared resid	1.387484	Schwarz criterion	-0.818926
Log likelihood	58.88541	Hannan-Quinn criter.	-0.985841
F-statistic	138.8569	Durbin-Watson stat	2.037882
Prob(F-statistic)	0.000000		

Maintenance cost static model

Dependent Variable: MAIN
Method: Panel Least Squares
Date: 07/27/15 Time: 13:59
Sample: 1995 2009
Periods included: 15
Cross-sections included: 11
Total panel (unbalanced) observations: 111

	Coefficient	Std. Error	t-Statistic	Prob.
C	6.142446	1.161408	5.288793	0.0000
ALLTMD	0.682803	0.075560	9.036516	0.0000
TRACK	0.939766	0.040974	22.93562	0.0000
DELAY	-0.181044	0.052613	-3.441077	0.0008
BRAIL	0.032255	0.042947	0.751027	0.4543
YEAR>2000	0.547961	0.109375	5.009920	0.0000
T*(YEAR>2000)	-0.067429	0.010509	-6.416194	0.0000
T*(YEAR<2001)	-0.055343	0.013929	-3.973176	0.0001

R-squared	0.894950	Mean dependent var	18.42332
Adjusted R-squared	0.887811	S.D. dependent var	0.451108
S.E. of regression	0.151097	Akaike info criterion	-0.872445
Sum squared resid	2.351526	Schwarz criterion	-0.677163
Log likelihood	56.42068	Hannan-Quinn criter.	-0.793225
F-statistic	125.3550	Durbin-Watson stat	0.804491
Prob(F-statistic)	0.000000		

Renewal cost static model

Dependent Variable: REN
Method: Panel Least Squares
Date: 07/27/15 Time: 13:59
Sample: 1995 2009
Periods included: 15
Cross-sections included: 11
Total panel (unbalanced) observations: 111

	Coefficient	Std. Error	t-Statistic	Prob.
C	4.915326	3.077776	1.597038	0.1133
ALLTMD	0.721062	0.200238	3.601027	0.0005
TRACK	1.249224	0.108583	11.50479	0.0000
DELAY	-0.372981	0.139425	-2.675129	0.0087
BRAIL	-0.039694	0.113812	-0.348772	0.7280
YEAR>2000	0.919080	0.289848	3.170899	0.0020
T*(YEAR>2000)	-0.013627	0.027850	-0.489289	0.6257
T*(YEAR<2001)	0.098187	0.036913	2.659995	0.0091

R-squared	0.695711	Mean dependent var	17.84026
Adjusted R-squared	0.675031	S.D. dependent var	0.702405
S.E. of regression	0.400413	Akaike info criterion	1.076704
Sum squared resid	16.51407	Schwarz criterion	1.271986
Log likelihood	-51.75708	Hannan-Quinn criter.	1.155924
F-statistic	33.64194	Durbin-Watson stat	0.910485
Prob(F-statistic)	0.000000		

Combined cost (maintenance and renewal cost) static model

```
Dependent Variable: TOT
Method: Panel Least Squares
Date: 07/29/15   Time: 16:24
Sample: 1995 2009
Periods included: 15
Cross-sections included: 11
Total panel (unbalanced) observations: 111
==============================================================================
                         Coefficient    Std. Error    t-Statistic    Prob.
==============================================================================

         C                 6.691624      1.428223      4.685279      0.0000
       ALLTMD              0.702740      0.092919      7.562913      0.0000
        TRACK              1.043771      0.050387      20.71500      0.0000
        DELAY             -0.273846      0.064700     -4.232576      0.0001
        BRAIL              0.001289      0.052814      0.024412      0.9806
      YEAR>2000            0.644228      0.134502      4.789712      0.0000
    T*(YEAR>2000)         -0.044801      0.012924     -3.466615      0.0008
    T*(YEAR<2001)         -0.002531      0.017129     -0.147768      0.8828
==============================================================================
R-squared                  0.872353   Mean dependent var          18.89205
Adjusted R-squared         0.863678   S.D. dependent var          0.503250
S.E. of regression         0.185809   Akaike info criterion      -0.458848
Sum squared resid          3.556087   Schwarz criterion          -0.263567
Log likelihood             33.46608   Hannan-Quinn criter.       -0.379628
F-statistic                100.5586   Durbin-Watson stat          0.605466
Prob(F-statistic)          0.000000
==============================================================================
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The sustainable freight railway: Designing the freight vehicle – track system for higher delivered tonnage with improved availability at reduced cost

SUSTRAIL

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D5.3: access charge final report Annex 5

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Table of contents

1. INTRODUCTION

The aim of this work was to understand what impact (or not) different access charge regimes already in place within Europe have had on the behaviour of various industry players and how changes to these regimes, particularly in respect of differentiation by vehicle-type, would influence future behaviour. Differentiation by wagon type is of particular interest in the context of SUSTRAIL, and so this has been the focus of this work.

We have sought to achieve the above aim by:

- Reviewing the literature on track access charges and their effects;
- conducting desk research into the context of the European rail freight wagon market;
- reviewing network management statements for the track access charging practices of member-state railways; and
- conducting interviews with key industry members to explore the experiences of differentiated track access charges in the market (such as in Britain and Austria).

The following three sections deal with each of these areas of research in turn. We then reach our conclusions.

2. LITERATURE REVIEW

The current rules for the calculation of track access charges are set out in Directive 2001/14, and provide for charges to be based on the direct cost of operating the train services.

They may include:

- Wear and tear
- Congestion
- Scarcity charges
- Environmental costs (if charged other modes)
- Non-discriminatory mark-ups

The recast of the first railway package (Directive 2012/34) proposes to introduce more detailed guidance on how these costs are to be calculated in the form of an implementation act, as well as requiring differentiation of charges according to noise (primarily to address the issue of freight wagons with cast iron brake blocks) and to provide for lower charges for locomotives fitted with ECTS.

A considerable amount of research has been undertaken into the variability of costs according to characteristics of the vehicles involved. It is well established that wear and tear costs vary more closely with gross tonne km than with vehicle or train km (Wheat et al, 2009), whilst models exist to predict the impact of vehicle characteristics such as speed, axleload and unsprung mass. The capacity a train takes up depends largely on its speed relative to that of other trains on the line, whilst obviously environmental costs vary by type of vehicle and particularly between diesel and electric traction. Yet it will be seen in section 4 that many infrastructure managers do not differentiate by any of these factors in their charges.

It may be partly for this reason that we have found very little existing literature on the impact of differentiated charges on choice of vehicle. Most previous studies (e.g. Matthews et al, 2009) concentrate on the impact of the level of charges rather than its structure. An exception is Nash et al (2014), which finds that the highly differentiated British charges have failed to encourage more track friendly vehicles, with vehicles in fact becoming heavier and less track friendly over time. However, this study solely examines the British passenger sector, which has some particular characteristics. In particular British rolling stock generally is not suitable for use outside Britain due to differences in loading gauge and platform height, and almost all passenger services are operated by franchisees, typically on 7-10 year contracts, giving them a relatively short time horizon and discouraging taking decisions on the basis of life cycle costs. In general freight operators have no such limitations to their time horizons, and a better second hand market, although the presence of relatively short contracts for freight haulage may also be expected to lead to risk averse operators leasing wagons on relatively short term contacts which may again discourage looking at full life cycle costs.

3. THE EUROPEAN RAIL FREIGHT WAGON MARKET

The most comprehensive source of international information on the context of the European rail freight wagon market comes from reports compiled by SCI Verkehr, and whilst these are generally only available at a cost, some figures are reported in their online summary document (SCI/VERKEHR 2013). The European market for rail freight wagons remains at historically low levels, but is forecast to grow at just less than 3% per annum – being driven by withdrawal of life expired vehicles. Globally, open wagons are the most important type, though growing containerization and transport of fuel is driving growth in flat wagons and tank wagons. Globally, approx. 45% of wagons are owned by incumbent operators, down from 55% in 2010. Traditionally, wagon manufacturers have tended to focus on serving their domestic market and/or a single continent, but the growth of Chinese manufacturers is leading to this position changing; for example, Chinese manufacturers are serving Africa, South America, Australia and Asia, as well as making tentative steps into the European market.

As an example, the principal wagon suppliers in the UK, according to Network Rail, are:

- AAE;
- Axiom Rail;
- ERMEWA Group;
- GE Capital;
- NACCO;
- VTG;
- WH Davis.

These are a mix of leasing companies and manufacturers.

In addition, ASTRA, based in Romania, is a significant manufacturer of standard wagons for the European market, and Arval Fauvet, based in France, is a significant manufacturer of container wagons. According to SCI, the three largest wagon manufacturers comprise less than 50% of the market, and the majority of standard wagons are manufactured in Eastern Europe. SCI provide a list of manufacturers, but full details of their report are only available on payment for their full report.

4. REVIEW OF CURRENT CHARGE DIFFERENTIATION PRACTICE

Table 1 provides a summary of track access charging components in different member states. Because our main interest is in differentiation by vehicle type, information on usage-related charges is presented in greater detail than for other charging components, but we also note any charging components relating to capacity used that would encourage adoption of rolling stock which reduced the capacity used by freight trains (by faster running or better acceleration and braking).

It can be seen that practices vary markedly across Europe and that relatively few member states have implemented track access charges differentiated by locomotive or wagon type; principally Austria and Britain. Indeed many countries (including France and Germany) do not even charge according to gross vehicle weight. Sweden’s track access charges include an emission component (based on fuel consumption) and, since 2012, Germany’s train path charge for freight traffic includes a component to take account of the noise-related impact of train operation. Some member states, such as Czech Republic, have plans to introduce rules for differentiating charges according to noise emissions (it is envisaged that the system will require identifying all individual vehicles in the train to check their parameters with reference to a vehicle register, which is currently under development). The Czech Republic also has plans to introduce charges differentiated between trains hauled by a locomotive with ETCS and trains hauled by locomotives without ETCS.

Similarly few countries have any way of charging for capacity that takes account of the amount of capacity used. One interesting example is the Italian system, which does charge train planning costs according to the difference in speed of the train in question and the optimal speed for the track section concerned.

Other differentiations that do exist in several member states, but which are less relevant for our purposes, relate to different time periods and different classifications of track infrastructure.

As mentioned above, the two countries with the most interesting degrees of differentiation according to the vehicle in question are Austria and Britain. In Austria, the Usage Dependent Fee, based on train km, is differentiated according to the type of traction unit (locomotive) used. The traction units have been classified into three categories, depending on the wear and tear they impose on the infrastructure. Traction units causing high abrasion, in essence, attract a surcharge whilst traction units causing less abrasion attract a discount (the third category of traction unit, being associated with ‘average’ levels of abrasion, attracts neither a surcharge nor a discount).

Table 4.1 Charging Structures and Basis of charges in Selected EU States

Country	**Charge Type**	**Basis of Charge**	**Charge Type**	**Basis of Charge**	**Charge Type**	**Basis of Charge**
Austria	Usage-related fee	a function of train km; based on cost of operation and differentiated by route categories and traffic type,	weight-dependent fee	a function of GTkm	wear-dependent fee	a function of traction unit factor, differentiated into 3 categories
	Congestion-dependent fee	supplement for congested infrastructure	Infrastructure optimisation incentive			
Belgium	Train path Line charge	a function of the path, the train, the priority, environmental impact, gross weight, time slot and speed	Train path installation charge	a function of the installation, the train, the importance of the installation and time spent occupying the installation	Administrative cost	
Britain	Variable usage charge	Charge which differs per vehicle determined engineering modelling	Coal spillage Charge		Freight only Line Charge	
	Freight Specific Charge		Capacity Charge			
Bulgaria	Track Access Charge	a function of train km and gross ton km, independent of the type of train and track/route section				
	Charge for requested but unused capacity					
Czech Republic	Track Access Charge	a function of train km and gross ton km, independent of the type of train and track/route section				
	Capacity charge	Possibility of price set by auction	Low Noise Bonus	differentiated by vehicle-type)	ETCS Discount	

Country	Charge Type	Basis of Charge	Charge Type	Basis of Charge	Charge Type	Basis of Charge
Denmark	Infrastructure charge	a function of tonne km, length of line and weight of the train				
	Environmental subsidy		Bridge charges	for crossing the Great Belt and Oresund		
France	running charge	A function of train km, differentiated by freight and different categories of passenger train				
	reservation charge	differentiated by passenger/freight, line category and line speed	Freight compensation		Special investment charges	
Germany	Usage based charge component	determined by Train Path Product and Route Category- including 4 different freight train path products)				
	Charge for requested but unused					
Netherlands	Train Path Charge	a function of train km, differentiated by weight categories	HSL (High Speed Line) Levy	a function of train km		
	Reservation Levy (Charge for requested but unused capacity)		Surcharge for Scarcity of Capacity (per train path subject to competing calls on its use)			
Portugal	charges for essential services	a function of train km, differentiated by track section, type of service and traction unit				

Country	Charge Type	Basis of Charge	Charge Type	Basis of Charge	Charge Type	Basis of Charge
	charges for unused requested capacity	a function of the period of pre-notification of the non-use and the volume of unused paths	Reservation charge (for ad hoc requests, differentiated by passenger and freight)			
Spain	Initial Charge	flat fees per train-km, differentiated into three types of freight train				
	Capacity Reservation Charge					
Sweden	Track charge	based on gross tonne km, with differential rates for freight and passenger trains	Train Path Charge	based on km, and set at three different levels		
	Reservation Charge		Passage Charge	for freight crossing the Oresund Bridge and for trains entering and exiting Stockholm, Goteborg and Malmo at certain times	Emissions Charge	based on engine type and fuel usage
Switzerland (SBB)	Minimum Price					
	Low Noise Bonus	differentiated by wheel-size and brake-type	ETCS Discount			

Source: 2015 Network Statements, via www.railnet.eu

Note: Where The Basis for Charge entry is blank this implies that the Network Statement did not provide such justification

In Britain, there is a highly detailed differentiation of the Variable Usage Charge by vehicle type and commodity carried. The vehicle-type component is based on a function of the vehicle’s tear weight, number of axles, unsprung mass, yaw stiffness, the maximum or operating speed, Ride Force Count, and Operating Weight. The Ride Force Count is a metric that has been developed to provide a quantitative assessment of the ‘track friendliness’ of a wagon’s suspension/bogie type, following vehicle dynamics modelling. Using this metric enables adjustments to be made to charges to reflect the relative ‘track friendliness’ of the suspension/bogie type. As Network Rail explain, “the purpose of this adjustment is to incentivise the use of ‘track friendly’ suspension/bogie types which will result in lower infrastructure costs. This adjustment ranges from a reduction of 14.2 per cent to an increase of 9.8 per cent” (Network Rail, 2014). The use of the Ride Force Count methodology was introduced in 2014, replacing a previous, more subjective, methodology which allocated a freight wagon to a ‘suspension band’ based on a qualitative description of the wagon’s suspension/bogie type.

The explanation for differentiating by commodity carried is that “the operating speed and operating weight of a freight vehicle can vary materially depending on the commodity type being transported” (Network Rail, 2014). The list of commodity types used for charging purposes is as follows:

- Biomass;
- Chemicals;
- Coal Electricity Supply Industry (ESI);
- Coal Other;
- Construction Materials;
- Domestic Automotive;
- Domestic Intermodal;
- Domestic Waste;
- Engineering Haulage;
- Enterprise
- European Automotive;
- European Conventional;
- European Intermodal;
- General Merchandise;
- Industrial Minerals;
- Iron Ore;
- Mail and Premium Logistics;
- Petroleum;
- Royal Mail;
- Steel.

The above differentiations result in a price list table which runs to more than 2000 rows. The differentiation according to Ride Force Count results in the very worst vehicles paying charges that are 14% higher than the base charge (a 1.14 ratio) and the very best vehicles paying charges that are 12% lower than the base charge (a 0.88 ratio).

The scheme for incentivising low noise wagons in Germany works as follows. As part of the TSI, all new wagons since 2003 have had composite brake blocks. These prevent roughing of the wheels and reduce noise and wear and tear. DB Netz wishes to encourage retro fitting of the 90% of wagons that are older than this. This is being achieved by a bonus /malus scheme whereby noisy wagons pay a premium of 1% rising to 1.25% in 2014, 2% in 2015, 2.5% in 2018 and 3% in 2019. What will happen in 2020 is not clear; noisy wagons may be banned. The charges are based on what is needed to finance the scheme rather than on the cost of noise.

These are used for DB Netz to pay a premium to railway undertakings for operating quiet trains. A quiet train currently has 80% quiet vehicles (will be 100% in 2017). This is straightforward for block trains but a problem for wagonload services.

Also the state pays a premium to the wagon owner (only 45% of wagons hauled by DB Schenker are owned by them). Foreign wagons are eligible provided that they run at least a minimum distance in Germany and have not already received funding in another country (Switzerland has a similar scheme).

Both payments amount to around 850 euros per wagon p.a.. This pays the capital cost but not the increased maintenance cost of a quiet wagon. It is intended that near complete retro fitting will be achieved but the threat of an ultimate ban is also an incentive.

5. INTERVIEW FINDINGS

5.1 Introduction

The survey sought to explore the motivations behind wagon design and the extent to which financial incentives, such as may be provided by differentiated track access charges, have influenced designs and purchasing and leasing decisions in the past and could influence designs, purchasing and leasing decisions in the future. In all, 16 interviews were conducted with a mix of key industry players, encompassing operating companies, leasing companies and manufacturers, infrastructure managers and regulators, and government officers. Ten of the interviews were with industry players in Britain, 3 with industry players in Bulgaria and a further three with other European industry players.

5.2 Composition and Ownership of the Vehicle Fleet

We asked our interviewees about the composition of the vehicle fleet. It is estimated that there are approximately 700,000 wagons in the fleet across the whole of Europe, though only approximately 500,000 of these are actually in operation. Of the 500,000, it is estimated that approximately 300,000 are owned by the freight operating companies, with the remaining 200,000 wagons being approximately equally split between those which are owned by leasing companies and those which are owned by the end user. Then, most of the 200,000 wagons which are not in operation (but which have a ‘book value’) are thought to belong to the freight operating companies.

In Britain, it is estimated that there are approximately 30,000 wagons. Of these, approximately 23,000 are owned by the freight operators themselves, whilst the remaining approximately 7000 are owned by leasing companies, banks, or end-users (industry or individuals), collectively referred to as ‘Keepers’ and represented by the Private Wagon Federation (PWF). The largest of the leasing companies accounts for some 2000of these 7000 wagons. In Europe, it is thought that the percentage of wagons that are not owned by freight operating companies is higher (approximately 40% cf 23%); and they also have a representative body – UIP.

One of the British operators we interviewed explained to us the variety of vehicles that go to make up their fleet. Overall, they have approx. 100 locos, of which 71 are class 60, and approx. 1300 wagons. The wagon fleet comprises the following (numbers are approximate):

- 220 coal hoppers;
- 200 boxes (used for scrap, waste away or aggregates);
- 170 60 foot container flats;

- 130 biomass hoppers;
- 100 bogie bolsters (which carry steel in a steelworks, but which are not authorised for external use);
- 50 100-tonne tankers;
- 40 aggregate hoppers; and
- A selection of other wagon-types.

The vast majority of these wagons are leased, either on a ‘wet’ or a ‘dry’ lease (either one that includes maintenance or one that doesn’t). It was explained that there isn’t that much choice between leasing companies; “the original ROSCOs are not as interested in freight as they used to be… they see freight as being millions whereas passenger is billions and passenger is underwritten by Government”. The practice of ‘lease-back’ was explained to us, whereby the operator borrows in order to purchase its own kit, and then sells it to the leasing companies and then leases it back. This serves to repay the borrowings, and “unblocks the process a bit”. Most operators enter into what are called operating leases, whereby the majority of the risk of the asset remains with the leasing company, who negotiate various lengths of lease, ranging between 5 and 20 years. With the lease-back arrangement, the decision about what vehicle to procure remains with the operator.

One of our interviewees explained that leases can range from as short as 3 months through to ten years, depending on the sector and the state of the economy (and associated sense of confidence). For example, he explained, that the cement sector tends to be keen to have the security of a longer lease, whilst the building aggregates sector tends to be more keen to have the flexibility of a shorter lease; whilst when business confidence is higher, the length of contract would tend to be longer (for fear that, at any contracts end, that customer may lose access to their leased vehicles).

It was explained to us that OBB Cargo own most of their vehicles, whilst the private operators in Austria would tend to lease their vehicles. DB are said to own about half of their wagons (but note they carry a lot of international traffic, so some of the wagons they haul may be owned overseas), but this is probably unusual, given that, as EWS, they were instrumental in re-opening the Thrall Europa works in York for the purpose of building their own wagons. Freightliner, for their heavy haul business, bought wagons built by IRS in Romania and Greenbrier in Poland, and GBRF have also sourced their vehicles from Poland and Romania.

Interestingly, one of our interviewees explained that as they have entered the market to haul biomass, they have begun to speculate and take IPR out on the design of wagons. Getting a 3rd party to design them on their behalf, they seek, as part of the deal, to have the IPR transferred through to them. Biomass is an interesting commodity, in so far as it is less dense, so, the design challenge was to carry more volume over the same buffer length.

We asked our interviewees about the possible effect of the ownership model on the incentives track access charges could have. There was a strong sense that a lot of the incentives are common, irrespective of whether the wagons are owned or leased by those operating them. It comes down to a choice of financing model, either borrowing money to purchase and having to cover the repayments, or asking a leasing company to do the deal for you and having to cover the lease rates. Some of our British interviewees pointed out that both producers and leasing companies are keen to understand track access charging because they want their wagons to have the maximum life. So on the one hand, “they don’t want Network Rail chucking them off the network for having non track-friendly bogies but, on the other hand, they don’t want to have the most expensive wagon that then nobody will lease”.

Our British interviewees felt that, increasingly, there has been a movement towards leasing as leasing companies are looking at long term stable cash-flow, some of them are co-owned by banks and they have access to the cheapest finance. A lot of the leasing companies are multinational, operating across rail and other markets (such as airline equipment) to spread their risks. The biggest of the rail freight wagon leasing companies is VTG who are multinational, and they work across Europe, though they cannot use wagons between Britain and Europe because the railways are different sizes (in fact, vehicles designed for Britain can be used in Europe, but vehicles designed for Europe cannot be used in Britain).

5.3 Interoperability and Decisions about the Vehicle Fleet

We asked our interviewees about interoperability. Every vehicle manufactured for the European market could, during its life, end up being based in multiple countries, except for those manufactured for the British market. Every single freight wagon that is manufactured now, either for mainland Europe or for the UK, has to be in accordance with the TSI (as introduced in January 2007). There are, however, certain derogations for the UK because the loading gauge is smaller than in Europe and, consequently, a mainland European wagon cannot operate in the UK. One of the benefits of compliance with the TSI is that it results in automatic acceptance of that wagon by the various member state national approval bodies and national safety authorities.

But whilst there is interoperability of wagons across mainland Europe, each of the member state governments are different, and each of the member-state infrastructure managers have different models on how they maintain their track and how they structure their track access charges. So before a leasing company or freight operator embraces a wagon design that may be beneficial in terms of track access charges in, for example, Germany, they must consider that this wagon may go on to be used in a number of other European countries where its design has no or fewer such benefits in relation to the track access charges in those other countries. This consideration must weaken any incentive effect.

One of our interviewees raised the issue of the ‘go-anywhere’ wagon. Because of differences in the infrastructure, the ‘go-anywhere’ wagon would not be the same for Britain as it would be in continental Europe. Britain has a smaller loading gage but permits 25.4 tonne axle loads, whilst in Europe, generally, there is a lower weight restriction per axle. So if you are building a wagon in Europe, you would tend to have a lower axle load and a bigger wagon, whereas in Britain you would tend to have a higher axle load and a smaller wagon. Consequently, they argued that, “in Britain, you don’t say: ‘I’m going to buy a wagon and it needs to be able to go anywhere’ (because, as politicians might say, that improves its residual value); you would actually do it the other way round, you would say: ‘where do I want my wagon to go? What’s the commercial reason I’m building it for, and how am I going to optimise it to do whatever that is?’ So if it was moving coal in the UK, you would make sure that you can carry as much coal as possible, in every train and therefore minimise the number of trains you're going to operate, because that's your biggest cost… if however you were wanting to move car parts across Europe including the UK, then you would design something to do that, which may well be close to the TSI wagon." Whilst British operations are not completely disinterested in Europe as there are some vehicles that are designed for running through the tunnel, there are a set of engineering issues that are distinctly different, which are always going to be there.

It was explained to us that wagons are designed to last for peak cycles, through a number of maintenance and overhaul cycles but subject to how many kilometres or miles they do a year. This is then usually converted into a number of years; typically 30-40 years. However, wagons actually tend to last a lot longer, and it is not unusual to see wagons that are 40 or 50 years old in operation. Indeed, our Bulgarian interviewees highlighted that much of the fleet there is in excess of 30 years old, and much of it second-hand.

It was explained to us that where they are broadly compatible with contemporary wagons, the presence of these old, fully depreciated wagons in the market enables the leasing companies to combine the old with the new and hold down the daily lease rates for their customers; and in doing so, they gain a competitive edge over their competitor leasing companies. Were there to be more innovation in the wagon design, however, this practice may prove more difficult.

It was explained that, currently, the European wagon market is at an all-time low. In order for the fleet to remain the same age, there should be orders for approximately 10-12,000 per year but, at present, orders are running at less than this and so the fleet is ageing. In Britain, where the main manufacturers supplying wagons are Astra, Greenbryer and WH Davies, very few new wagons have been supplied in the past two years, and our Bulgarian interviewees indicated a similar picture.

One of our interviewees highlighted that the choice between different manufacturers of wagons is fairly limited. He suggested that his is for two principal reasons. Firstly, because the British market is essentially separate from that in mainland Europe, and secondly (and partly linked to the first point) because the British market is relatively small. So, to build a wagon for use in Britain, the manufacturer has to comply with the design requirements of the British infrastructure (essentially the different loading gauge, as compared with most of mainland Europe) and Britain's national notified technical rules, as well as the technical standards of interoperability (which apply to all EU member states), and this creates a certain degree of overhead for those designers. Added to this, the quantities being ordered are 'pretty small'; one of our interviewees indicated that whilst their parent company currently has 1800 wagons on order in Europe (and that is fairly typical of how many they would have on at any one time), his British subsidiary company have only 50 on order. Lack of choice and high price would seem to be natural consequences of these factors combined.

It was explained that whilst in some categories of wagon there is a choice – e.g. Astra and Greenbrier both manufacture hopper wagons and box wagons – for other wagon types there is only one manufacturer. For petrol wagons, Greenbrier is really the only manufacturer, as whilst Astra will offer to manufacture they have not actually manufactured any in Britain for a decade or more, so they would have to redesign and that would bring with it risks. For aluminium cement wagons, there is only one builder of those in Fellbinder, in Germany.

Another consequence of the separation of the British market from the rest of mainland Europe and the relative small quantities of wagons ordered is that, at the moment, there are only 2 track-friendly bogie designs approved for use, produced by 2 bogie manufacturers. Interestingly, it was indicated to us that one of the bogie manufacturers is rebranding their track-friendly bogie as a low-noise bogie, with a view to marketing this in mainland Europe. One of our interviewees suggested that mainland European operators will be less interested in track-friendliness because they do not understand track damage and the mainland European tracks are so much straighter and, consequently, their wagons get much less wheel wear than do British operators' wagons. On the other hand, EU legislative moves are likely to make low-noise wagons of greater interest.

Nevertheless, because manufacturing companies realise that they are having to design for a small market, this could actually be beneficial in terms of innovation. As our interviewee put it, "if they're going to put effort into the design, they might as well make it as efficient as possible". They described occasions when they have requested that the manufacturer make small modifications for them which they have readily incorporated into the design of the wagons. In mainland Europe, by way of contrast, the manufacturer wants to produce hundreds of identical wagons so that they can focus on reducing their unit cost.

5.4 Impacts Thus Far

When we asked our interviewees about what impacts differentiated track access charges have had thus far, several of them talked about the incentives for track friendly bogies. It was explained that, in Britain, bogies have been categorised into class 3, class 4, class 5, class 6 and class 7. Class 7 is "the best bogie money can buy" and the cost of one is approximately £500,000, but is only used in the passenger sector. In the freight sector, the best bogie is the class 6, which is classified as track friendly, but is not self-steering. The standard bogie that is used in Europe is something called Y25 or Epsilon-25. This is equivalent to a class 4, and it was estimated that 95% of all wagons in mainland Europe have that bogie. It is not regarded as being a good bogie but it is cheap, reliable, easy to maintain, and spare parts are widely available throughout the industry. Class 3 bogies are also in operation, but will never be approved again in the UK, and would never be approved in mainland Europe. For each of the different classes of bogie, there is little competition between different designs, but if there was then it was felt that accessing spare parts could become difficult.

Thus, one of our British interviewees stated that the track-friendly bogie incentives 'have delivered', in that you would find it quite unusual today to see a new wagon that didn't have some form of track friendly bogie fitted. So in Britain, "there is a modern expectation that this is what you do" and the trade that is being made in essence involves the cost of those bogies, the whole life costs of the wagon, and the utility to be gained from that wagon. We explored this trade-off further.

In terms of the costs, the non-track friendly bogie, the Y25, costs approximately £12,000 per bogie, whilst the track-friendly bogie, TF25 (a patent of Axiom Rail, owned by DB Schenker), costs £24,000. With two of them on a wagon, you immediately have an additional cost of £24,000 that needs to be justified. If the wagon is only doing 50,000 miles a year, you will find that it takes a long time to save that, and if it takes, for example, 50 years, then there is no point in adopting the track-friendly bogies. However, for the companies who are doing huge mileage, and in Europe it's not unusual for wagons to be doing 150,000 miles a year (especially with container traffic), then "any sort of incentive for track-friendly bogies should, in theory, cover quicker return".

There are, in any case, operational incentives toward track-friendly bogies. It was explained to us that when a manufacture promotes wagons, the unique selling points of the wagon, e.g. in terms of its whole life maintenance cost, are stressed. For an operator using the old Y25, after approx. 80,000 miles they will need to take the wagon out of service, probably for one week, in order to re-profile the wheel sets; involving a maintenance cost and a loss of revenue for that week. In contrast, wagons with the TF25 will, on average, do 150,000 miles before requiring a re-profiling. So, the maintenance costs associated with wheel re-profiling are approximately halved. It also means that the number of wheelsets required, over the life of the vehicle, should be halved, and a wheelset costs £2,500. Furthermore, with the wagon being out of service less time, it should be generating a greater revenue.

Hence, in mainland Europe, where there is no such track access charge incentive toward track-friendly bogies, the task is to demonstrate the operational benefit from this kind of innovation. This means explaining to the customer that whilst they may be faced with an additional investment cost of approx. £25,000 per wagon for the track-friendly wagon (as compared with a competitor wagon), after 4 or 5 years in service that upfront investment then becomes neutral and there follows many years of net savings. Not all of them will agree and, focusing on the lowest price possible, some will simply take the view that "what happens in the future happens in the future".

Then in terms of utility, the operator wants to be able to get as much in the train as they can, but different types of bogie will have different carrying capacity. So there is a trade-off, particularly in relation to heavy haul (aggregates for example), between having fewer wagons with bogies that can accommodate greater weights, or more wagons with bogies that can accommodate less weight.

Actually, it was suggested to us that these cost efficiency incentives - to run as few trains as possible and move the most amount of goods on them - outweigh anything that infrastructure charging is incentivising. However, one of our British interviewees expressed their frustration that one of the recent changes to track access charges in Britain is that charges on heavy freight have, on average, increased. In their view, heavy freight is exactly the sector that ought to be being incentivised, as greater payloads serve to improve network efficiency.

Several of our interviewees explained that what the vehicle-related incentives do in practice is impact on the replacement of vehicles that are at the end of their life. So in Britain, when it is becoming too expensive to keep old vehicles running, the tendency is now to replace them with the lower charge, lower track force vehicles; but the incentives are insufficient in themselves to cause the early retirement of the more track damaging vehicles. It doesn't work, for instance, like the car scrappage scheme, where there are incentives to accelerate early replacement of vehicles. So the rate of change is linked to the life of the wagon which, as mentioned above, can be anything between 30 or 50 years, depending on the wagon's mileage.

One of our British operator interviewees explained that "we're beginning to take account of the track access charges that are payable on any of these different design vehicles". Their coal hoppers and biomass hoppers all have track friendly bogies. Actually, he explained, it would have been difficult for them to have bought coal wagons without track friendly bogies; "it was a fairly unique design and the market could afford to pay their additional cost". In contrast, their container flats, the boxes and infrastructure wagons do not have track-friendly bogies, as the differential is not adequate. One problem, he went on to explain, is that the main track-friendly bogie used in Britain - the TF25 made by Axiom - Whilst being a very good design and one that is now tried and trusted, has a dominant position in the market. A competitor developed a new track friendly bogie under their coal hoppers but it was associated with a huge amount of risk; "wheels were wearing out and they didn't quite work as they were expecting… It works now, but it cost them quite dearly". Furthermore, there is quite a strong secondary lease market in wagons because wagons are used throughout Europe. Hence, a leasing company can often offer an operator a good deal on a set of 20 year old boxes on non-track-friendly bogies, as they are fully depreciated on their books. So the differential on track access charges, if you were to buy a new wagon with new bogies on, has to cover not only the cost of the new bogies but also the cost of a brand new wagon, which is going to be more expensive than a secondary lease asset that's 20 years old. But whilst the current track access charge differential on its own is probably insufficient to motivate operators to seek track-friendly wagons, there are other benefits, sometimes flow specific, that combine with the track access charge differential to provide that motivation.

One of our British interviewees referred to the impacts on the composition of the fleet as being "glacially slow". He felt that the very best bogies are not being introduced at any sort of noticeable rate and that, actually, the system is incentivising the migration to medium best, as represented by the Y25, rather than very best, as represented by the TF25. He felt that the reason for this is that the more mass produced design is cheaper, thanks to it having been produced for years on a regular production line, and there being a plentiful supply of spares and maintenance know-how. He went on to express a concern about whether the current charging regime, with its ceiling on the track charge differential of only + 12-13%,, fully charges for the impact of the most damaging vehicles (vehicles with pedestal suspensions) and thereby gives a sufficient incentive for operators to get rid of those wagons from operation. He referred to work in progress aimed at reassessing this, which may result in a whole industry cost case for early replacement for some of those vehicles. One difficulty is, however, that the whole basis of modelling track forces is not an exact science. For example, whilst it is known that the more poorly maintained the track is, the worse the impact of the vehicle on it is, in practice there is a lot of rounding up and averaging. One solution could be to put a sensor on the track and measure exactly what the forces are, but it was not known whether such sensors exist. Nevertheless, he did comment that slow as it may be, the system is "successful in that it's driving now some quite sophisticated thinking about fleet replacement".

Our Austrian interviewee explained that their vehicle-based differentiation related not to the wagon but to the locomotion itself. He explained that this is because whilst it is known that wear and tear is related to the specifics of the train acting on the infrastructure, it is not known how the composition of the train does this, and so the focus falls on the locomotive. The differentiation, he explained, “is very low and just a factor of 0.0263 minus 0.0237”, depending on whether the locomotive is “track-destroying” or “track-saving”. Because the incentive is small, it has not had a great impact. Their idea is to make it more expensive for some types of vehicles but, he explained, “we are not vehicle driven; our idea is more asset driven”.

One of our British interviewees observed that design of wagons in France “has not moved on at all”, and that SNCF Freight volumes are dropping off dreadfully. “they don’t seem to be as incentivised over there”, he went on, “and I do think we’re further ahead than most of the freight operators elsewhere in terms of track-friendliness; there are certainly far more wagons as a proportion of the British fleet that have track friendly bogies than there are in mainland Europe”. It could, he speculated, be to do with the track charging incentives, but it also could be that there is simply less innovation because there is little competition in the market.

On a macro-scale you would say that operators, wagon manufacturers have responded to charges by broadly making their equipment more track-friendly and by recognising that if they use more track-friendly kits, it would be cheaper for them, so, on a macro-scale then I think that that’s happened. On a, “oh, I’m moving some stuff so tarmac on Wednesday, what wagons can I find?” There will be 54 different parameters that go into that

Moving away from consideration of track-friendliness, another of our British interviewees referred to the coal spillage charge and its impacts. They observed that it has resulted in investments by operators to clean the equipment, but that it has not led to the infrastructure manager doing anything differently, such as investing to mitigate the impacts of coal spillage, and the fear is that this will mean that, next time, the costs will rise. This can be explained, as whilst the approx. £5-10 million generated by the coal spillage charge is a substantial sum for operators to pay, it is minor in relation to the infrastructure manager’s overall maintenance budget. The interviewee questioned whether this, therefore, represented an incentive or, actually a tax on that traffic.

We asked a manufacturer whether they ever have their customers come to them asking if they could have a wagon design that enables them to reduce their track access charge. He stated clearly that this is not the sort of conversation that they have ever had. However, he also said that their customers who own or operate wagons that are mainly for use in Britain always insist on a track friendly bogie, Except where they require simple wagons for track infrastructure work (such as a box wagon that will only do 15,000 miles per year, because with that mileage, the track access charge would never save you the money that it costs to make the investment for the track friendly bogie).

The interviews with Bulgarian operators found a range of views on the level of discount needed to promote the use of track friendly bogies. Estimates varied from 5-10% to 30-40%.

5.5 Incentives toward Higher Speeds

We asked our interviewees about the potential impacts on choice of rolling stock of charges that incentivised running trains at faster speeds, for example to improve capacity utilisation.

One of our British interviewees speculated that the first thing that would happen would be that the infrastructure manager would run their models and prove that faster freight trains would cause more track damage, leading to a higher overall charge payment. In fact, this is what the EU regulation would require, as track access charges must be based on direct costs. They went on to suggest that, if a freight operator was thinking about investing in high-speed bogies, then they would want to understand that if that created capacity then they would get some of it. They also explained some of the complexities in relation to speed and capacity. For instance, there is a choice to be made between speeding up freight, which often runs at a comparable speed with passenger, or slowing down intercity, which, they suggested, would probably do more for capacity but would have other negatives. “You’re probably not going to get freight running at 125, 140, so it’s not on the fast lines; so it remains on the slow lines and the achievable speed on those routes is often limited by the stopping passenger services. Also, there is some question as to whether faster freight trains would really speed things up in a way that would free-up capacity, or whether the trains would just go faster between the loops? There would need to be a change in the way the network is managed to deliver it”. Nevertheless, they felt that there is a good case for doing some work to look at putting some incentives on bogie types or wagon dynamics, but it would be complicated to incentivise it through a charge.

One of our operator interviewees was broadly in favour of incentivising speed increases up to 75 m/h. He explained that they tend to have wagons that either do 75 or 60, and that, in the UK, most of the diesel locos to pull these wagons are limited to 75mph and still have 15- 20-30 years of life left (there are a few electric locomotives that go faster than this). He also explained that once you push above 75mph the engineering costs start to increase ‘exponentially’. Therefore, he concludes that “to look much beyond that I don’t think is worthwhile”. This said, he expressed concerns about attempting to incentivise this via track access charges. If, for example, there was a charge discount for running faster, but by running faster the vehicles impose greater damage on the tracks, increasing the track-damage related component of the charge, it would be difficult to understand how these two factors balance; and the worry would be that if you, as an operator, run faster, then the charge payment would be higher. Also, he felt that “the business case around getting locos to pull those wagons at faster speeds is probably a very difficult one to make.”

More generally, it was argued that there are great difficulties with incentivising many things all at once; “we’ve ended up with too many incentives, incentives are pulling in different directions, incentives which aren’t reflecting people’s natural priorities and which, therefore, are effectively a tax”. Instead, it was suggested identifying the one or two real priorities that should be being driven, and focusing on them. It is also important to then leave them in place or, at least, strongly sign-post the nature of future changes, as it requires a long time to allow the market to conduct the research, build and deliver the new vehicles, and for those vehicles to have a life in which they can expect to return on capital

Another of our British operator interviewees echoed this, arguing that the current system of track access charges is hugely overly complicated, does not allow them to finesse what they do, and that, ultimately, “it’s just a lot of money that’s going from us to Network Rail, and I wouldn’t even claim to understand some of it”. He went on that “it was almost becoming too complicated to work out how you would price your contracts to customers; and what does a lorry have to pay? It pays just road tax, and it knows what that is”.

Our Austrian interviewee observed that they did not feel that the Austrian charging formula was viewed as being too complex, but that operators “usually don’t look at the formula itself, they look more at the height of the fee”. Having said this, it was noted that track charges were reduced in 2009 and 2011, with a view to making rail more attractive, but that train kilometres per year have remained relatively constant; the difference is that the trains, especially freight trains, are heavier now.

Another of our interviewees stated that he would fully support speeding up freight, and asserted that this would be achievable by using track-friendly bogies, with better suspension systems. “Those bogies are capable of speeds higher than they are allowed to operate today, and if they were approved to go at those higher speeds, it would be a huge added value to the whole industry”. Incentivising this through track access charges, he felt, may help this, but it would also require better arrangements for sharing the infrastructure with passenger services, because at present freight always has to give way to passenger.

5.6 Further Innovations

It was explained to us that there are a lot of discussions about noise, and that the EU is interested in introducing noise differentiated charging. Noise testing of vehicles was introduced as part of TSI, and our interviewee argued that, in their tests, they had discovered that noise levels are not to do with braking or track friendliness of the wagon as such, but depend on the condition of the track and the weather conditions. He suggested that, “unless you go for rubber wheels, or something of that nature, which at the moment I wouldn’t trust, you’re not going to be able to reduce the noise level”. However, the track-friendly bogies are, in continental Europe, now starting to be marketed as noise-friendly, on the basis that if it is track friendly then it must be noise friendly. However, in their view the link between track-friendliness and noise-friendliness is crucially associated with track condition and weather, and they are deeply sceptical about the benefits of seeking to incentivise this through charging (except for those people who live near the track).

Further innovations in relation to payloads were highlighted. Firstly, it was explained to us that in continental Europe, the maximum load weight of the wagon is 90 tonnes, where as in Britain it is 102 tonnes. Whilst the explanation for this is generally that all of the civil built structures and bridges in Europe cannot handle the extra weight, our interviewee dismissed this and argued that lifting this restriction on continental European wagons would represent a big breakthrough for the industry. In the absence of this, manufacturers and designers can increase the payload by trying to reduce the tare weight of the wagon, One of the manufacturers stated that Britain does embrace innovation and that their British customers are more susceptible to embrace innovation and be prepared to pay for it, where as in mainland Europe it is more cut-throat. However, he also said that “there’s many other things that this industry can do and it just doesn’t, because of the red tape and the bureaucracy and everything else”. Another interviewee referred to the problems of implementing EU legislation, stemming from there being so many differences between Britain and mainland Europe in terms of engineering and all sorts of other procedural aspects.

One of our operator interviewees argued strongly that there is too much focus on fine-tuning the track access charging regime, and far too little attention given to strategic thinking. For instance, they argued that focus should be placed on the commodities that rail freight deal with and what GDP they are generating, and their importance to the national economy, rather than continually re-working track access charges.

Another interviewee added a further note of caution. He suggested that it may not be good for the industry to be too incentivised into purchasing new vehicles because then you start to want to make the older wagons obsolete, which then means forcing operators to scrap them. This would then reduce the scope for leasing companies to discount their lease rates by combining a mix of newer vehicles and older, fully depreciated, vehicles. Lease rates would, therefore, rise making it more difficult for rail to compete with road (its main competitor).

The comparison was made with the very different way in which the US wagon market operates. In Europe, vehicle-owners make their wagons last as long as possible. In America, their business model involves scrapping wagons after 10 or 15 years, irrespective of whether it works or not (apparently to reduce the risks and uncertainties associated with increasing costs over time). Consequently, the markets are more stable there, and more healthy for the wagon manufacturers

6. CONCLUSIONS

The country with the most highly differentiated track access charges by type of vehicle is Britain, and it appears that even the relatively modest differentiation now in place is sufficient to influence purchasers of new vehicles intended to run in Britain to fit track friendly bogies. The current charge differentials are not in general high enough to lead to premature retirement of existing vehicles. However, were the ‘central’ charge to be raised (as was discussed during the most recent review of track access charges during 2013) then the differential either side of the central charge would be greater, probably providing a greater incentive to retire the least track-friendly wagons early and/or to invest in the ‘most’ track-friendly bogies. Of course, this would be likely to have knock-on consequences for operator costs and the overall competitive position between rail and road freight.

On the continent, there is a problem in that many vehicles are intended to run in a variety of countries, either on international traffic or because they may be moved between countries in the course of their lives. There are few incentives for track friendly bogies and even those that exist are limited in effectiveness because they apply in a single country. The introduction of noise-differentiated charges, in so far as reduced noise emissions may be linked with rackfriendly bogies, may serve to increase take-up of track-friendly bogies across mainland Europe. However, the diversity of charging structures and levels found in Europe means that the impact of incentives is limited. If incentives are to be used more widely they will need to be applied consistently across countries.

The influence of revised track access charges may be limited and slow to take effect, because of the long lives of wagons, the current low level of replacement investment, the relatively small size of discounts for track friendly bogies and the risk involved in buying a more expensive wagon that will only recoup its cost if it is used for a long life. The effect of these factors might be lessened by introducing larger differentials, but if these exceeded differences in direct cost then this would be in contradiction to existing EU legislation.

There is less evidence that track access charges could readily be used to encourage speeding up of freight trains to increase track capacity. Clearly there are fears that this could lead to complex charges, with different incentives leading in different directions. It appears that the use of charging to encourage the operation of freight trains at higher speeds needs to be simple and its implications need careful thinking through.

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

SUSTRAIL

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D5.3: access charge final report Annex 5

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Table of contents

1. INFRASTRUCTURE CHARGES IN BULGARIA

1.1 Stages in the development of the system of infrastructure charges

The entry of the directives forming the First Railway Package into force created a legal basis to divide the railway system into two major players - the railway infrastructure manager and railway undertakings. Along with the other directives within the First Railway Package of the European Commission, Directive 2001/14/EC of the European Parliament and of the Council dated from 26.01.2001 defined the rules on infrastructure charges imposed on railway undertakings for using the railway networks of Member States.

In compliance with the regulations mentioned above the National Railway Infrastructure Company was established on 01.01.2002 as a state enterprise, providing access of carriers to the national rail network. The infrastructure charges are specified in Tariffs for Infrastructure Charges levied by the National Railway Infrastructure Company, which includes a charge for booking capacity and charges for passing on rail infrastructure. The procedure for imposing, collection and basic principles of their formation are regulated by the Railway Transport Act (RTA) and Ordinance № 41/27.07.2001 of the MTC for access and use of infrastructure.

With the introduction of the tariff from the beginning of 2002, the charges have been fixed according to the type of transport (freight and passenger) , the type of section (electrified /not electrified), depending on the category of railway line (e.g. major, minor, secondary, etc. network). Charges are also classified by infrastructure elements: for track, for electrical installations, overhead network, traffic management. The current tariff of infrastructure charges is characterized with no distinction between the categories of trains, both of passenger and freight. The reservation fee, in its turn, is applied only to cover the costs of train traffic planning.

In August 2004 the tariff was restructured. The amended tariff provides tthat infrastructure charges are to be differentiated for passenger trains, for empty wagons movement and isolated movement of locomotives. They are also differentiated by class and category as the charges for express trains and international trains do not depend on the category of line. There are differential charges also for freight trains and block trains of containers and vehicles that do not depend on the category of line.

Since the beginning of 2007, a new amendment to the tariff of infrastructure charges collected by the infrastructure manager has been in force The model of determining the charges for access and use of the infrastructure suggests that infrastructure charges shall be formed of fixed and variable charges.

The fixed charge reflects the cost of booking and access to infrastructure. This price refers to train-kilometer of the used route with different prices of electrified and non-electrified routes. No permanent charge is provided for the narrow-gauge lines. It is determined separately for passenger and freight transport. The variable charge shall be determined separately for passenger and freight fees and it includes:

- Use of track: per gross ton-kilometer;
- Use of electrical installations: per train-kilometer;
- Use of catenary: per to train-kilometer;
- Traffic management: per train-kilometer.

Until the end of 2012, it was only the amount of rates that changed but not the way for their determination. In the period 2002-2012 the infrastructure charges were based on marginal costs.

Decree No. 92 from 4 May 2012 of the Council of Ministers adopted "Methodology for calculation of infrastructure charges levied by the infrastructure manager." The methodology is based on Art. 35, para. 2 of the Railway Transport Act. It abolished the Tariff for infrastructure charges levied by the railway infrastructure manager approved by Decree No. 302 of the Council of Ministers from 2001. The new infrastructure charges came into force on 1 January 2013.

For the purpose of this study it it is important to examine the period since 1 January 2013 as well, when the infrastructure charge is in the form of a variable charge reflecting the actual use of railway infrastructure and the direct costs incurred in connection with using.

“Railway track and equipment”.

„Signaling and telecommunication”.

„Management of the trains movement”.

Expenditures made for maintenance of heavy road mechanization, and maintenance of switches in the stations.

1.2 Mechanism of determining infrastructure charges.

Every year, by 30 June NRIC provides to ERA information about the factual expenditures made for current maintenance of the railway infrastructure during previous year and determines the level of the track access charges for the next year.

Mark-ups, compensations and/or concessions as a result of implementation of infrastructure projects, traffic of the trains and the needs of the transport market, shall be applied in a differentiated way and for parts of network and should be announced to the public.

The period of validity of this tariff is one year (Art. 7, para.10 of Ordinance 41). The term may be shorter if Article 7, para. 14 of Ordinance 41 is applied, namely: "Based on the information in Article 7, para. 10 of Ordinance 41, Executive Director of Railway

Administration Executive Agency prepares a proposal to change the amount of infrastructure charges if necessary.

At least 3 months prior to inuring the changes of track access charges they should be announced to the public.

1.3 Analysis of the legislation related to determining and changes of infrastructure charges

The access and utilization of the railway infrastructure are treated in:

- The Law for Railway Transport (LRT), published in State Gazette,

copy 97, 28.11.2000, inure from 01.01.2002, p.9, p.4, No. 592.;

- Ordinance 41 from 27.06.2001, for access and utilization of the railway infrastructure, issued by the Minister of transport, information technologies and

communications, published in State Gazette, copy 64 from 20.07.2001, inure from 01.01.2002; copy 36 from 10.05. 2011, amended, copy 50 from 30.05.2003; inure from 01.01.2002 г.; and amended, copy 87 from 27.10.2006; and amended, copy.70 from 08.08.2008, and amended copy. 44 from 12.06.2009, inure from 01.01.2010 г.; and amended from 08.11.2011;

- The Methodology for calculation of the track access charges determines the charges for the minimum service pack and access to the railway infrastructure and is based over the direct cost of NRIC raised out of the implementation of the train service

- Tariff for track access charges levied by the infrastructure manager, approved with Decree of the Council of Ministers № 302 from 21.12.2001.

1.4 Infrastructure charges currently in effect

Based on Decree No. 1032/18.07.12 of the Director-General of National Railway Infrastructure Company, Article 7 "Charges", from 7.2 to 7.4, of the Reference Document on the Railway Network Status in Bulgaria was changed. This methodology defines the charge of the minimum package of access to railway infrastructure. The charge shall be formed on the basis of the costs of the National Railway Infrastructure Company (NRIC) arising directly as a result of the train service.

With determining the charge for using the railway infrastructure in Bulgaria, which is public property, only the amount of expenses incurred directly as a result of the train service shall be taken into account. Two types of charges are included:

- the charge of passing on the rail infrastructure, which does not depend on the type of trains and is one and the same for all tracks within the railway network;
- the charge of requested and unused capacity.

1.5 Charges of passing on the rail infrastructure

Track access charges contain two components measured in gross-tonkilometers and in train-kilometers, which render an account of the participation of the exploitation units in the implementation of the train service and direct costs made for this purpose.

Tpass. = Tg/t/km + Tt/km, BGN

where:

Tpass – charge for actual utilization of the railway infrastructure;

Tg/t/km – charge for realized gross-ton-kilometers along the route passed;
Tt/km – charge for realized train/kilometers along route passed;

The infrastructure charge of utilization (charge for the actual use of railway infrastructure) is a variable charge that depends on the kilometers actually travelled on the railway infrastructure and through which the direct costs incurred as a result of performing train service shall be reimbursed to the railway infrastructure manager.

TAC (Track access charge) is in a form of variable charges reflecting the actual utilization of the railway infrastructure and related direct costs for use of:

- „Railway track and equipment”.
- „Signaling and telecommunication”.
- „Management of the trains movement”.
- Expenditures made for maintenance of heavy road mechanization, and maintenance of switches in the stations.

The charge for train-kilometers traveled per train-kilometer regardless of the type and category of trains and the category and type of track.

Calculation of the charge for realized train/kilometers

T t/km = L*Ct/km, BGN

Where:

L – length of the route actually passed

Ct/km – infrastructure charge for train/kilometer

For gross-ton-kilometer – direct costs in ‘Railway track and equipment” and “Expenditures for maintenance of heavy road mechanization and switches in the station’s tracks” for previous year assigned to the total train work realized by the railway undertakings along the railway infrastructure, expressed in gross-ton-kilometers, for the same period.

(3)$T_{g/t/km} = \Sigma L_{ij} * Q_{ij} * C_{g/t/km}$, BGN

where:

L_{ij} – length in kilometers of j- section along the route of i-train

Q_{ij} – gross weight in tones of i-train for j-section
$C_{g/t/km}$ – infrastructure - charge for gross ton-kilometer

The charge for requested but unused capacity ensures stimulus for effective utilization of the capacity. This is a charge which covers the expenditures made by the Infrastructure Manager for maintenance of the railway network in condition allowing normal and smooth implementation of the train service in accordance with the needs of the railway operators requested and confirmed with the Yearly Timetable. The charge recovers the eligible costs for salaries determined in the direct costs under p.3.3.3. „Management of train movement”.

The charge is a variable depending on the proportion of unused but requested and confirmed with the Yearly Timetable capacity in a form of train path, expressed in train-kilometers. The stake is determined as the ratio between the eligible costs for salaries, included in the direct costs under p. 3.3.3. „Management of the train movement” for the previous year and the total train work done by the railway undertakings along the railway infrastructure, expressed in train-kilometers ,for the same period.

The charge for requested but unused capacity is calculated in trainkilometer for unused but requested and confirmed with the Yearly Timetable capacity in a form of train path. The charge does not depend on the type of the train and is equal for all railway lines of the railway network.

(4)$T_{t/km} = L * C_{t/km}$, BGN

Where:

L – length of the route actually passed

$C_{t/km}$ – infrastructure charge for train/kilometer

It should be noted that the costs are related to train operations of railway undertakings, i.e. the train operation does not include the work done as technological transport by the railway infrastructure itself according to the condition of Article 10, para. 2 of the Law for Railway Transport (LRT).

1.6 Infrastructure Charges

Table 1 shows the infrastructure charges (in EUR) since the beginning of 2013 when the dependency on the direct costs of infrastructure maintenance was introduced to define these charges.

Table 1

			Since 5.4.2014	
	2013, for freight train	2014, for freight train	For combined transportation with block-trains	For freight vehicles with block-trains
Train-kilometers	0,4194	0,4040	0,3636	0,2828
Gross-ton-kilometers	0,0019	0,0013	0,0012	0,0009
For requested but unused capacity /train-kilometer/	0,1240	0,1240	0,1240	0,1240

In 2013 freight traffic was served by 7 licensed railway undertakings. The rail freight performed is given by railway undertakings in Fig. 1 and Fig. 2 and the costs for infrastructure charges are given in Fig. 3.

Fig. 1

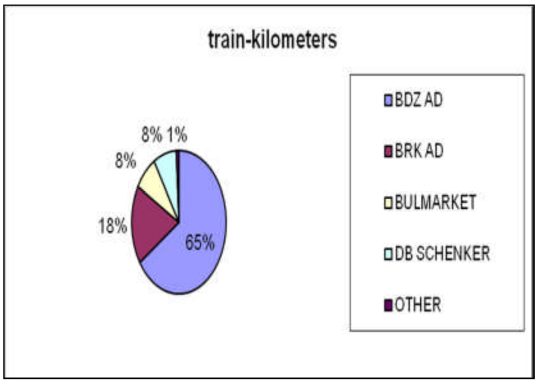


Fig. 2

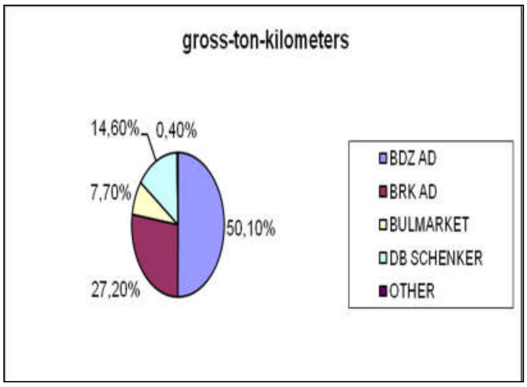
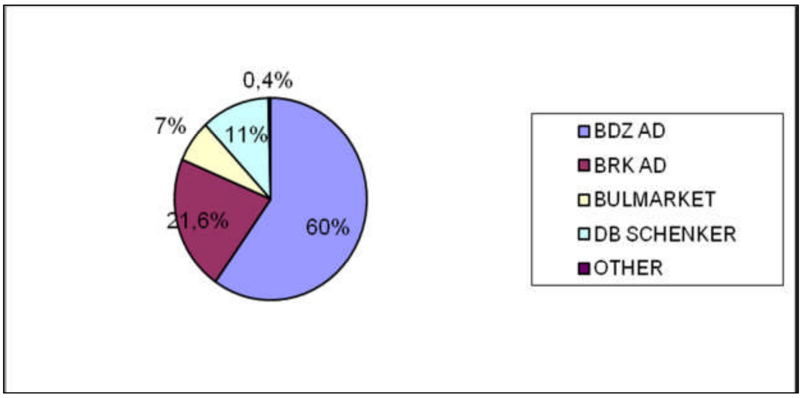
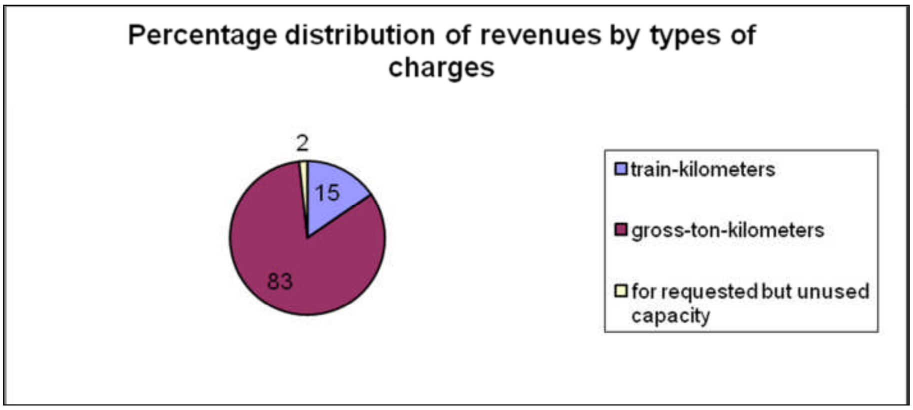


Fig. 3



As it is seen in these diagrams, the trains of BDZ are of smaller gross tonnage in comparison to the traims of BRC ("Bulgarian Railway Company" AD) and DB Schenker, so the costs for infrastructure charges are bigger. The revenues of the infrastructure manager received from freight transportation in 2013 are given by types of charges in Fig. 4. The main income is defined by the ton-kilometers transported and the penalty charge forms 2% of revenues.

Fig. 4



The amount of costs of infrastructure charges are determined for a freight train running along the corridor under examination, namely Kalotina-Sofia-Svilengrad, using a diesel locomotive and a gross tonnage of 700 tons per the length of distance traveled of 363 km. The results given in Fig. 5 are for the following cases:

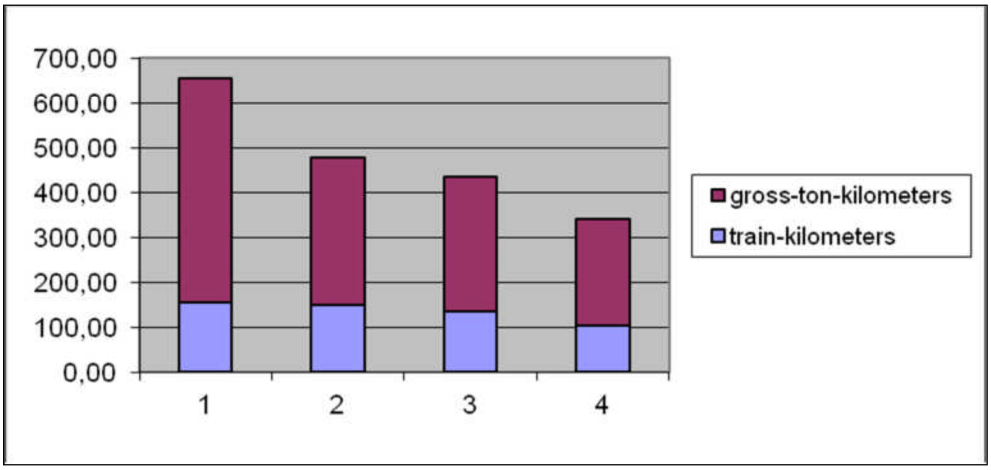
1 - Infrastructure charges for a freight train 2013

2 - Infrastructure charges for a freight train 2014

3 – Infrastructure charges for combined transportation with block-trains

4 - Infrastructure charges for freight vehicles with block-trains

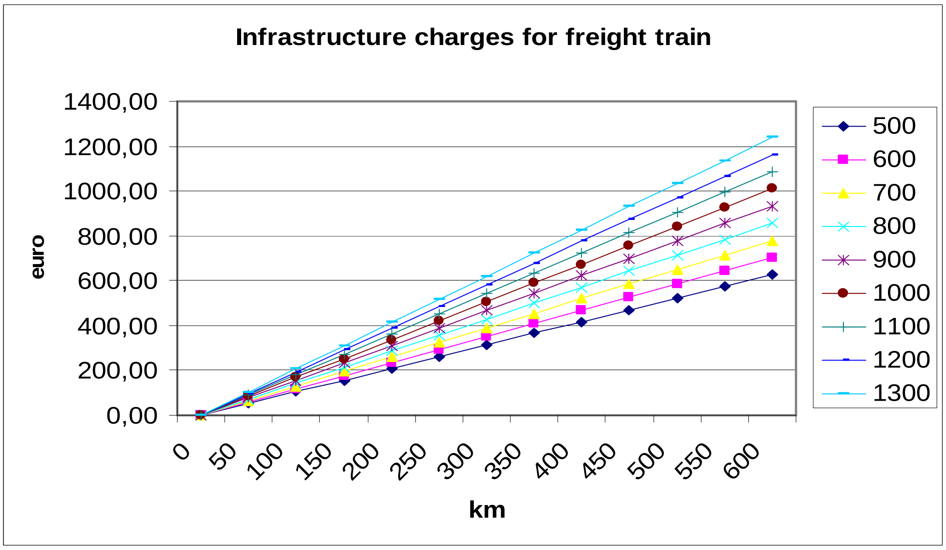
Fig. 5



As it is seen from Table 1 and Fig. 5, there was a significant reduction in the amount of charges for a year: in 2013 the costs for a train passing along this route amounted to 653 EUR, while in 2014 only 477 EUR are needed and if it is combined transportation with block-trains, the costs are 436 EUR.

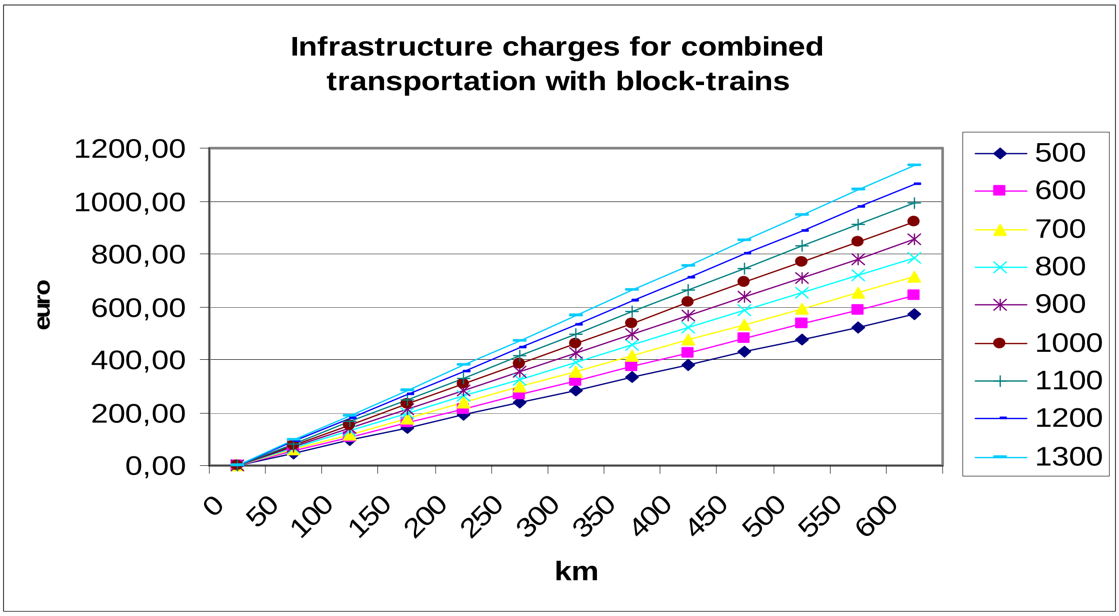
Infrastructure charges are determined factor a freight train with diesel traction for different variants of gross tonnage of the train at different length of the traction distance /Fig. 6/.

Fig. 6



Infrastructure charges per freight train for combined transportation with block-trains with diesel traction are determined for different variants of gross tonnage of the train and at different length of traction distance/Fig. 7/.

Fig. 7



2. INFRASTRUCTURE CHARGES IN OTHER NEW EU MEMBER STATES

2.1 Croatia

In accordance with the provisions of the Railway Act, the railway infrastructure manager, HŽ iinfrastructure, determines and levies charges for rail services provided. Charges are paid for the following rail services:

- minimum access package
- access to services facilities and to the services supplied in these facilities including
- track access to services facilities
- additional services
- ancillary services

Charges for the minimum access package are determined on the basis of direct costs of railway infrastructure maintenance and traffic management on railway infrastructure. Infrastructure charges are determined by taking into consideration infrastructural speed, line gradients, axle load, electrification, type and rank of the train, train mass, type of lines, number of line tracks, realized train kilometres as well as direct costs and transportation volume. HŽ Infrastruktura does not levy additional charges for the lack of or the restriction of capacities on specific railway lines, for environment protection, for capacity reservation, etc. Charges for the use of service facilities managed by HŽ Infrastruktura are determined on the basis of costs of maintaining these facilities. The charges for services provided in the service facilities provided by HŽ Infrastruktura are determined on the basis of costs incurred in the provision of these services. Charges for additional services provided by HŽ Infrastruktura are determined on the basis of costs incurred in the provision of said services. Charges for ancillary services are determined on the basis of market conditions.

There is an additional charge on train/km price for the train path with electric traction. Lines are divided into six categories and are reported by the value of the parameter line which varies from 0.3 to 1.9. A 10% additional charge to the charge for the entire train path is levied for all train paths requested in ad hoc allocation capacity procedure and 20% when a special timetable is drawn up for a train path.

2.2 Czech Republic

The tariff of access to railway infrastructure applied in Czech Republic is a collection of the charge for railway capacity allocation; the charge for using the transport infrastructure for train traffic; the charge for access to service facilities; the charge for service provided by RIA (Railway Infrastructure Administration) in connection with the train running.

The general tariff allocation of rail capacity is determined by the incoming requests and the number of required roads. The calculation of the charge for capacity of railway allocation includes the direct costs of operation of electronic operating RIA’s systems as well as the costs of other expert activities for including routes in the train schedules.

The charges for using transport infrastructure depends on its parameters: line category (E, C, R) and whether railway lines are equipped with fixed installations for electric traction; train parameters: the type of service (freight, passenger), train weight, locomotive features and energy used in terms of the environment, i.e. whether the stated emission limits, technical characteristics of the vehicle; distance passed are kept.

The method of calculating the cost of using transport infrastructure takes into account:

- Specific rules determined by the regulatory authority;

- Part of the fee to cover the cost of traffic control where train kilometers are taken as a unit of measurement;

- Part of the fee to fund the depreciation costs of infrastructure (maintaining the efficiency of transport infrastructure) where gross ton/km is taken as a unit of measurement;

- Increased fees related to gross ton/kilometers in the case of establishing a higher level of infrastructure depreciation;

- Tendency to minimize the use of drawing vehicles having internal combustion engines that do not meet the emission limits in areas where electric traction can be used.

2.3 Hungary

Two infrastructure managers function on the territory of Hungaria: MÁV Magyar Államvasutak Zártkörűen Működő Részvénytársaság (MÁV Zrt) operating as an independent railway company (Hungarian State Railway Company) and Győr-Sopron-Ebenfurti Vasút Zártkörűen Működő Részvénytársaság (GYSEV Zrt) operating as an integrated railway company.

The determination of the particular network access charges for the given timetable per year shall be based on data of the last closed business year of the infrastructure managers. Activities related to the handling of applications for railway network capacity and running of trains may be linked within basic services to two components, to the ensuring of train path and running of trains. Basic service activities provided by both infrastructure managers are the same.

Charges of ensuring of train path are constant and depend on which infrastructure the route is implemented. Charges for running of trains are accounted on the basis of effectively performed train kilometres and gross ton kilometres. The element of the fee of running of trains calculated on the basis of train kilometres shall be charged in 3 line categories and for the following train categories: passenger trains (trains of train category A, B and C), freight trains (trains of train category D) and loco trains (trains of train category E, irrespectively of line categories). The element of the fee for running of trains calculated on the basis of gross ton kilometres shall be charged irrespectively of the category of line/train. The categorisation system of the individual network elements (railway lines/line sections) is different for passenger and freight transport.

The charge for supplementary services depends on whether electric traction is used and stations charge is determined by station type and whether the station is an origin, destination or an intermediate station, etc.

2.4 Poland

Unit rates of access charges have been set up on the basis of cost directly incurred as a result of operating the train service. In particular these costs involve costs of maintenance and renewal, rail traffic management and depreciation in this part where are directly incurred as a result of operating the train service. Indirect and financial costs have been excluded from the cost base.

Unit rates of basic charges have been calculated for the following parameters:

1) railway line category, stipulated taking into account average daily traffic and permissible technical speed including permanent restrictions;

Line category was defined due to permissible technical speed respecting permanent restrictions and average daily traffic volume. It was assumed that permissible technical speed of railway line, characterizing technical standard of offered part of railway line is a weighted average of maximum speed (separately for passenger and freight trains) respecting permanent speed restrictions, calculated for railway line section. Railway line category was defined separately for passenger and freight trains as weighted average rounded to integer (downwards) from bracket <1, 5> of:

- line category resulting from with inclusion of permanent speed restrictions – weight 60%;

- line category resulting from average daily traffic of passenger and freight trains per 1 km of track – weight 40%.

2) total gross weight of a train, including weight of operating locomotives and weight of trainset, according to allocated train path on individual line sections.

For calculation of unit rates for specific line categories the reference parameters representative for above brackets of permissible technical speed for passenger and freight trains were applied. Pricing tables were developed for all passenger and freight trains; gross weights less than 900 tones – every 60 tone and for freight trains only over 900 tones – every 100 tones.

For stipulation of gross weight of a train the weight of locomotives is assumed as their weight according to allocated train path.

Reservation charge of DECREE, amounts:

1) 10% of sum of cost taken for calculation of basic charge for planned train journey on allocated train path, in case of its cancellation later than 30 days before planned date of execution;

2) 25% of sum of cost taken for calculation of basic charge for planned train journey on allocated train path, in case of its cancellation later than 72 hours before planned date of execution or when allocated train path is unused. In case of journey cancellation before date, referred to in point 1, reservation charge is not levied by PLK. Reservation charge is not levied when journey cancellation was caused by PLK or in case of exceptional situation.

During the period from 15 December 2013 to 13 December 2014, PLK awards 25% discount of basic charge for minimum access to railway infrastructure, for a journey of block train composed exclusively with wagons carrying intermodal units and/or with empty wagons designed for carriage of intermodal units.

The minimum unit rate of basic charge for minimum access to railway infrastructure amounts 75% of rate for particular category of railway line and for total gross weight of train.

2.5 Romania

The charges levied for the minimum access package and the track access to service facilities are equal to the direct costs resulting from the train operation. The infrastructure manager may set up discount systems, which can address any infrastructure user and which grant, for the specified traffic flows, limited time discounts with a view to encouraging the development of new railway services or discounts facilitating the use of some lines that are used below their capacity.

The IAC calculation methodology is based on the following charging elements:

a) distance run by the train;

b) gross train tonnage;

c) traffic type: freight or passenger;

d) traffic route;

e) class of the traffic section and its electrification systems for supplying traction current

For the moment, there are no additional charges for the cases of shortage (saturation) of infrastructure capacity or for the effects that the train operation has on the environment.

At present, CFR applies a IAC value reduced by 33% for the complete international trains, which are in transit without being processed on the CFR network.

Besides the charges for the minimum access package, charges for Track Access to Service Facilities are also levied. They include the use of the access infrastructure to terminals, the access to the marshalling yards, the train formation facilities made available by CFR и CFR’s access infrastructure to the maintenance centres or other technical facilities.

The Supply of Services includes the use of the traction power supply system. This service does not include the equivalent value of the supplied traction power. The access (commercial stops) of the RUs’ passenger trains to CFR’s stations и The access to the storage sidings in the stations and the staying of the rolling stock.

The Additional Services include:

- The traction power supply charge set down in the traction power supply contract to be separately concluded;

- The coach preheating power charge established by the supplier of low voltage power;

- The charges for the services related to dangerous goods or exceptional transports.

The charges for the telecommunication services are part of Ancillary Services.

2.6 **Slovakia**

Charges for regulated services shall be determined on the basis of variable economically eligible costs that had arisen at ŽSR directly due to the train operation and were spent on the train operation. These costs are part of total economically eligible costs after the deduction fixed cost share.

The payment system for the use of railway infrastructure can be divided into two basic categories - payment for regulated services and payments for services are not subject to price regulation.

For the purposes of charging, ŽSR lines are divided into six categories в 3 групи: Main, Minor и Other lines for passenger traffic. Charging scheme for minimum access package shall comprise charges for ordering and allocation of capacity, charges for managing and organizing of transport and charges for ensuring serviceability of railway infrastructure. Maximum charges for minimum access package for rail passenger and rail freight transport shall comprise economically eligible costs of railway infrastructure associated with the provision of management and organization of transport on railway infrastructure, railway infrastructure services and operation in accordance with Act on Railways. Those costs are connected with:

- Processing of applications on capacity allocation,
- Using switches and branches,
- Managing trains, including signalling, regulation, dispatching, co cation and provision of information on train movement,
- Other information necessary for realization or operation of transport services for which been allocated the capacity has

Charges for track access to service facilities shall be distinct for a defined category of service facilities based on type of provided services. Maximum charges for track access to service facilities within rail passenger and rail freight transport shall comprise economically eligible costs connected with services as follows:

- Use of traction current electrical supply equipment, or electrical supply equipment for trains´ pre-heating, if available
- Use of passenger stations, its premises and facilities
- Use of marshalling yards and train formation facilities or freight terminals and siding tracks.

ŽSR shall establish a price offer of supplementary shunting services and services of the technical office for railway undertakings by the product list. Determination of price for the supplementary services is not covered by a „Decree of the Slovak Railway Regulatory Authority”. Products and services not included in the Product list have to be arranged separately and shall be accounted separately as well.

Charges for the Minimum access package се състои от 3 части: Maximum charges for ordering and allocation of capacity и Maximum charges for traffic management and organization, които са в зависимост от train-km и Maximum charges for provision of rail infrastructure serviceability, която е в зависимост от gross tonne-km и се отчита coefficient allowing for travel of train with active traction rail vehicle with independent traction on electrified lines of particular category, which is **1,2** and for the other trains **1,0**. Electricity Consumption depends on train mass.

2.7 **Slovenia**

The minimum access package that all RUs with allocated train paths are entitled to use includes:

- processing the applications for train path allocation,

- using the tracks of the allocated train paths,

- using switches and crossings on the allocated train paths,

- controlling the rail traffic, which includes signaling, regulating, departures and communication with trains, as well as ensuring information on train movements,

- other information, necessary for providing services, for which the path was allocated.

The new tariff system model's Usage Fee is divided into a two-part base price, with one part charged on a per train-km basis, depending on line type and traction power type, and the other part being charged based on train weight. The charge for aceesss of train traffic is based on the train-kilometers travelled depending on the type of line (divided into 4 regional lines and 3 main rail lines/ and by the same power car (3 groups). Besides that there are Supplements and deductions in regard to the transport type that consider the gross weight of freight train and the type of passenger train. There are also fees for late cancellation or non-use of train paths, that have been allocated in procedures of the Network timetable.

The government may issue a decision that the Undertakings carrying out public service obligation in passenger carriage in domestic and cross border traffic, as well as the Managers performing public service obligation for PRI maintenance purposes, are exempt from user charges that refer to public service obligation performance.

Table 2

	Bulgaria	Croatia	Czech Republic	Hungary	Poland	Romania	Slovenia	Slovakia
Country	BG	HR	CZ	HU	PL	RO	SI	SK
Type of system	DR (direct costs)	DR	MC+ (marginal cost plus additions)		DR			Charges for regulated services shall be determined on the basis of variable economically eligible costs expended on train operation on Railway infrastructure.
Line categories		Six	Three: european, other nNational and regional	Three	Six speed categories	V	regional - 4, main rail - 3	Six
Train categories		V	V	V	V	V	V	
Freight train categories		V					V	
Pasenger train categories		V					V	
Reservation charges	Per train -Km /for requested but unused capacity/		V	V	V	V	Fees for late cancellation or non-use of train paths that have been allocated in procedures of the network timetable interim changes	V
Gross ton-Km	V		V	V		V		V
Train-Km	V	V	V	V	V	V	V	V
Per station stop			V	Per passenger 4 type, per freight 2 type	Stop time	V	For stops of freight trains and stops of passenger trains	For passenger trains - 4 types,for freight trains - 3 types
Charge for use of ET system	Per MWh	Per train-km	Per gross ton-Km	per kWh	Per train-km	V		Gross ton-Km
Remarks	For combined transportation with block-trains - 10%, of freight vehicles with block-trains - 20%				25% discount of basic charge for minimum access to railway infrastructure for a journey of block train composed exclusively with wagons carrying intermodal	The increasing coefficients for the train paths ordered or modified later, upon the request of the railway undertaking		

Table 2 presents the peculiarities with determining the infrastructure charges in the examined countries. Based on the analysis of the data given in the table, the following conclusions can be drawn:

- From the Network Statement of Romania, Hungary and Slovenia one cannot understand the principle of formation costs, which are used to determine the infrastructure charges. In Bulgaria, Croatia and Poland they are formed on the basis of the direct costs of railway infrastructure maintenance and traffic management on railway infrastructure. In Czech Republic they are based on the marginal cost plus additions, and in Slovakia the charges are determined on the basis of variable economically eligible costs expended on train operation on Railway infrastructure.

- In all countries with the exception of Bulgaria the infrastructure charges are determined according to the classification of lines.

- Only in Bulgaria and Slovakia there is not separate determination of infrastructure charges depending on the category of trains, both of passengers and freight ones.

- In Croatia and Slovenia the infrastructure charges are determined using coefficients for each category of passenger and freight trains. There are reservation charges in Hungary, Poland, Romania and Slovakia, and Bulgaria and Slovenia there are charges for non-using the requested capacity.

- In all countries the determination of infrastructure charges is based on Train-Km and in Bulgaria, Czech Republic, Hungary, Romania and Slovak Republic it depends also on Gross ton-Km.

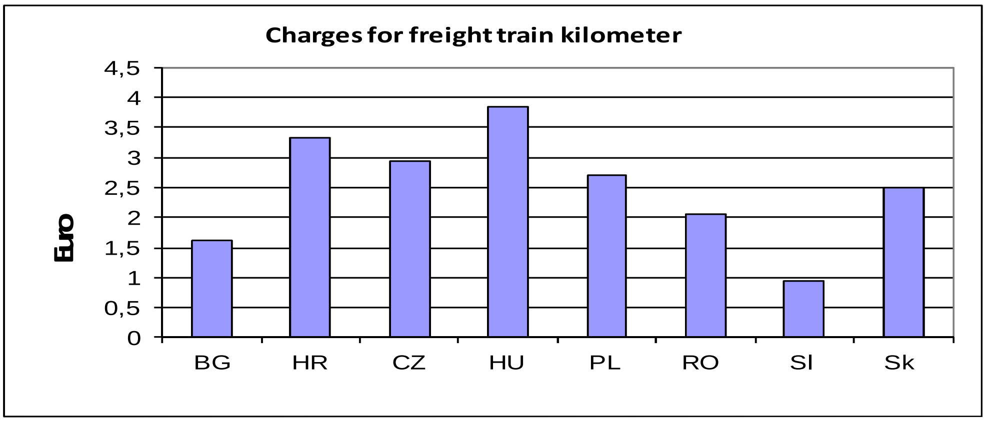
- In Bulgaria and Croatia there is no charge for trains stopping at stations (it does not refer to shunting).

- It is only in Slovenia where there is no charge in any form for using electric power but there are coefficients determined according to the traction rolling stock, which are included in determination of infrastructure charges.

- In Bulgaria and Poland there are discounts in transportation of intermodal and block trains.

The amount of infrastructure charges for a freight train of 1000 tons gross weight per 1 km running varies from 0.96 EUR in Slovenia to 3.8 EUR in Hungary (Fig./фиг.8). This amount is determined for a train with a diesel locomotive running on a main line. The size of the charge is within 2.5-3.5 EUR, with the exception of Romania where the fee is 2.07 EUR and in Bulgaria where it is 1.64 EUR

Fig. 8



The charges are most easily determined fee in Bulgaria, where they do not depend both on the category of lines and the category of trains; in Slovakia there is a calculator uploaded on the website of the infrastructure manager that gives the transport costs providing the destination and the specificity of the train.

To help carriers, they can use the Charging Information System (CIS). The web-based application provides fast information on charges related to the use of European rail infrastructure and estimates the price for the use of international train paths within minutes. It is an umbrella application for the various national rail infrastructure charging systems. .

In the recent years a reduction in the size of infrastructure charges and considering the European legislation in determining the fees in all countries has been observed.

The four systems used with determination of infrastructure charges (ICs) are classified in [6]:

- "simple system" where the size of ICs is determined depending on train-kilometer or ton-kilometer, or both, without any additional parameters –in the Republic of Bulgaria;
- "simple +" system may include additional parameters and classifications of train characteristics – in Hungary and Romania;
- with the "multiplicative system" ICs are obtained on the basis of price and other factors considering various factors to obtain the final price – in Czech Republic and Poland.
- with the "additive system" ICs are a collection of several parts, each part can be "simple", "multiplicative" or calculated by some other type of formula – in Slovakia, Slovenia and Croatia.

Under the EU legislation, Directive 2001/14/EC of the European Parliament and of the Council of 26 February 2001, CHAPTER II. INFRASTRUCTURE CHARGES. Article 9. Dicounts it can be proposed to introduce percent reduction by a factor considering the train category and to increases the size of its value depending on the type of wagons included in its composition. That means to implement the "multiplicative system" with a factor considering the category (block train) based on the systems used (in the Republic of Bulgaria it is equal to

0.9 and in Poland it is 0.75) and a coefficient taking into account the type of wagons in the composition.

3. DETERMINATION OF EFFECTIVENESS OF NEW ROLLING STOCK BY MODELLING THE LEVEL OF INFRASTRUCTURE CHARGES

3.1 Assumptions

The aim is to model the level of infrastructure charges with investing in new rolling stock by carriers (railway undertakings).

The level of investments required for the purchase of new rolling stock and reduced costs of operating the same rolling stock is important for carriers (railway undertakings) due to higher reliability.

What matters for the railway infrastructure manager matter is the level of infrastructure charges determined on the basis of direct costs of train traffic. The use of new freight vehicle leads to lower costs for operation and maintenance of the railway infrastructure thanks to better interaction with the track and therefore infrastructure charges can be reduced.

Modelling is necessary because of the changing nature of certain parameters and the lack of information about others which are important to carriers (railway undertakings) on the one hand, and to the infrastructure manager on the other.

Due to the fact that the price of the new freight vehicle is unknown, the level of infrastructure charges is modelled under various assumptions about it. The output assumption is that if a certain rail carriers (railway undertakings) invests in new freight vehicles, it should keep the operating revenue unchanged as that is on the expense of the level of infrastructure charges and reduced maintenance costs (costs of rolling stock operation and maintenance).

Modelling is done for a freight train consisting of 24 freight wagons, which after investing can be replaced by the new freight vehicles and two electric locomotives. The distance covered by the train is 147 km.

The structure of revenues and costs of the rail carriers (railway undertakings) related to such a train is given below:

1. Depreciation costs: depreciation of rolling stock – 12.94%
2. Maintenance costs – 6.47%
3. Insurance costs – 8.09%
4. Funding: financial costs for the rolling stock acquired through using credits – 18.70%
5. Power (traction) or costs of diesel fuel – 13.81%
6. Personnel costs related with train traffic – 5.47%
7. Infrastructure and slots costs (infrastructure charges) – 17.17%

8. Administrative costs – 8.26%

9. Contingency (unexpected, incidental) – 5%

10. Profit – 4.09%.

The costs are the sum of points 1 – 9 and the revenues are the sum of points 1 – 10.

The costs that depend on investments are: depreciation costs, which are not real cash but are included into the revenue rates of carriers (railway undertakings) aimed at depreciating the investments made, maintenance costs (usually a percentage of investments in rolling stock), insurance (usually a percentage of investments in rolling stock) and financial costs for rolling stock.

The purchase of a new freight vehicle will change the costs of the carriers (railway undertakings). If the approximate indicative price of the new wagon is known, it will be possible to determine the costs and revenues of the carriers (railway undertakings) per train and per train kilometer. Because the price of rolling stock cannot be known with great accuracy since it is a trade secret, the price modeling is the best approach.

The increased costs per train and per train kilometer with using the new freight vehicle can be compensated by increasing the efficiency of carriers/railway undertakings (they will have to compensate for higher costs by implementing train operations using more sparingly other resources) to keep the revenue rate. Another option is to reduce the costs for infrastructure and slots by reducing the infrastructure charges with using this type of railway vehicle. That would be logical if proved that its impact on the infrastructure will be less than of other rolling stock, i.e. operating costs for infrastructure maintenance will be less using this type of railway vehicle.

There are several approaches to determine infrastructure charges, the most used of which are: infrastructure charges based on marginal costs and infrastructure charges based on marginal costs plus supplement.

The infrastructure costs can be reduced to certain limits. The lower limit of charges is based on marginal costs. You cannot go down below this limit. The lower limit of infrastructure charges covers about 10% of the infrastructure costs. The upper limit is determined by direct costs of the railway infrastructure manager (NRIC) for direct implementation of train traffic. The direct costs have variable and fixed components (due to the fixed component they are bigger than the marginal costs) and currently cover about 20% of the costs for infrastructure. The infrastructure charges in force in the Republic of Bulgaria can be attributed to the model of determination: marginal costs plus supplement.

If the infrastructure charges are reduced and get closer to the lower limit, the National Railway Infrastructure Company needs to increase its efficiency (it should sparingly use all kinds of resources to be able to compensate for the reduced revenues of charges) or if this is not possible, the reduced revenues of charges shall be compensated by government funding: subsidies and capital transfers..

Another important prerequisite is that the charges are oriented to evaluation of the use of railway infrastructure by trains rather than freight vehicles. Reduction of infrastructure charges can be made for a train, e.g. for a block train or freight trains used for intermodal transport. If this principle is applied, reduction of infrastructure charges can be made for trains consisting entirely of freight vehicles of new type.

3.2 Modelling the level of infrastructure charges

Modelling is performed defining the range of infrastructure charges determined by the costs of railway infrastructure and published in the reference document of the railway network

The infrastructure charges currently in force in the Republic of Bulgaria are presented in the table below:

	All categories	Block-trains	Block-trains - RO-LA
Charge per kilometer gross ton	0,0025	0,0023	0,0018
Charge per train kilometer	0,7902	0,7112	0,5531
Charge per requested and unused capacity	0,2425	0,2183	0,1698

The charges calculated on the basis of the marginal costs are:

Measure	All categories
Charge per kilometer gross ton	0,0018
Charge per train kilometer	0,3206

Based on the tables given above, it is possible to determine the limits of infrastructure charges, which we will be used for modeling purposes. The limits are given in the table below:

Minimal charges based on then marginal costs	
Train kilometers	0,3206
Gross ton kilometers	0,0018
Maximal charges according to the reference document, 2013	
Train kilometers	0,8203
Gross ton kilometers	0,0038

It is assumed that the new freight vehicle price is within the range from about 60,000 EUR to about 100 000 EUR or from 120 000 BGN to 192,000 BGN. The lower limit is 60,000 EUR, as much as the price of a conventional wagon is. The freight vehicle price increases gradually at every step by 5%, and it is assumed that the carrier (railway undertaking) invests in a whole composition of new freight vehicles (24 freight vehicles in a train), and on this basis the structure of revenues and costs is defined at each step. The increased costs for the carrier (railway undertaking) related to the investment are compensated by reducing infrastructure charges. Reduced infrastructure charges are compared with the above-stated limits and if they are between the minimum and maximum values, such amount of charges is acceptable to the railway carrier (railway undertaking) and infrastructure manager.

The following table shows the results of modelling. It is seen that even at a maximum wagon price of 100,000 EUR, railway carriers (railway undertakings) can afford to invest in a whole composition of new freight vehicles provided that infrastructure charges are reduced by 32.29%. With this investment they will not lose efficiency reached so far because the increased costs of implementation of their operational activities related to investments will be compensated by lower costs for using infrastructure. In this case revenues and costs remain constant as only their structure changes and it changes as follows: depreciation costs will increase from 12.94% to 15.10%, maintenance costs will increase from 6.47% to 7.55% and the insurance costs will increase from 8.09% to 9.44%. The costs for infrastructure

With investing in whole composition of new freight vehicles at a price of 100,000 EUR per wagon, the level of infrastructure charge per wagon kilometer is 0.5554 BGN/train kilometer or 0.2840 EUR per train kilometer, and the charge of gross ton kilometer is 0.002573 BGN/ gross ton kilometer or 0.001316 EUR per gross ton kilometer.

Both charges are higher than the lower limit of 0.3206 BGN/train kilometer and 0.0018 BGN/gross ton kilometer and smaller than the upper limit of 0.8203 BGN/train kilometer and 0.0038 of gross ton kilometer.

Increase of the new wagon price	1	1,05	1,1	1,15	1,2	1,25	1,3	1,35	1,4	1,45	1,5	1,55	1,6
Output price of the new freight vehicle [BGN].	120 000	126 000	132 000	138 000	144 000	150 000	156 000	162 000	168 000	174 000	180 000	186 000	192 000
Output price of the new wagon [EUR].	61 355	64 423	67 491	70 558	73 626	76 694	79 762	82 829	85 897	88 965	92 033	95 100	98 168
Costs structure													
Depreciation costs	12,94%	13,12%	13,30%	13,48%	13,66%	13,84%	14,02%	14,20%	14,38%	14,56%	14,74%	14,92%	15,10%
Maintenance costs(M)	6,47%	6,56%	6,65%	6,74%	6,83%	6,92%	7,01%	7,10%	7,19%	7,28%	7,37%	7,46%	7,55%
Insurance costs	8,09%	8,20%	8,31%	8,43%	8,54%	8,65%	8,76%	8,87%	8,99%	9,10%	9,21%	9,32%	9,44%
Financing costs	18,70%	18,70%	18,70%	18,70%	18,70%	18,70%	18,70%	18,70%	18,70%	18,70%	18,70%	18,70%	18,70%
Energy costs	13,81%	13,81%	13,81%	13,81%	13,81%	13,81%	13,81%	13,81%	13,81%	13,81%	13,81%	13,81%	13,81%
Staff costs	5,47%	5,47%	5,47%	5,47%	5,47%	5,47%	5,47%	5,47%	5,47%	5,47%	5,47%	5,47%	5,47%
Infrastructure and slots charges	17,17%	16,71%	16,25%	15,79%	15,32%	14,86%	14,40%	13,94%	13,48%	13,01%	12,55%	12,09%	11,63%
Administrative costs	8,26%	8,30%	8,34%	8,38%	8,42%	8,46%	8,49%	8,53%	8,57%	8,61%	8,65%	8,68%	8,72%
Unexpected costs	5,00%	5,00%	5,00%	5,00%	5,00%	5,00%	5,00%	5,00%	5,00%	5,00%	5,00%	5,00%	5,00%
Profit	4,09%	4,13%	4,17%	4,22%	4,26%	4,30%	4,34%	4,38%	4,43%	4,47%	4,51%	4,55%	4,59%
	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%
	9,09%	9,13%	9,17%	9,22%	9,26%	9,30%	9,34%	9,38%	9,43%	9,47%	9,51%	9,55%	9,59%
Infrastructure charges													
Per train kilometers (BGN//train km)	0,820300	0,798229	0,776158	0,754087	0,732016	0,709944	0,687873	0,665802	0,643731	0,621660	0,599589	0,577518	0,555447
Per train kilometers (EUR//train km)	0,419413	0,408128	0,396843	0,385558	0,374274	0,362989	0,351704	0,340419	0,329134	0,317850	0,306565	0,295280	0,283995
Per gross ton kilometers (BGN/gross ton kilometer)	0,003800	0,003698	0,003596	0,003493	0,003391	0,003289	0,003187	0,003084	0,002982	0,002880	0,002778	0,002675	0,002573
Per gross ton kilometers (EUR/ gross ton kilometer)	0,001943	0,001891	0,001838	0,001786	0,001734	0,001682	0,001629	0,001577	0,001525	0,001472	0,00142	0,001368	0,001316
Percentage reduction of infrastructure charges		2,69%	5,38%	8,07%	10,76%	13,45%	16,14%	18,83%	21,52%	24,22%	26,91%	29,60%	32,29%

Fig. 9 presents the dependency of level of the infrastructure charge per train kilometer depending on the new rolling stock cost in EUR and Fig.10 shows the percentage reduction of the infrastructure charge per train kilometer depending on the new wagon cost.

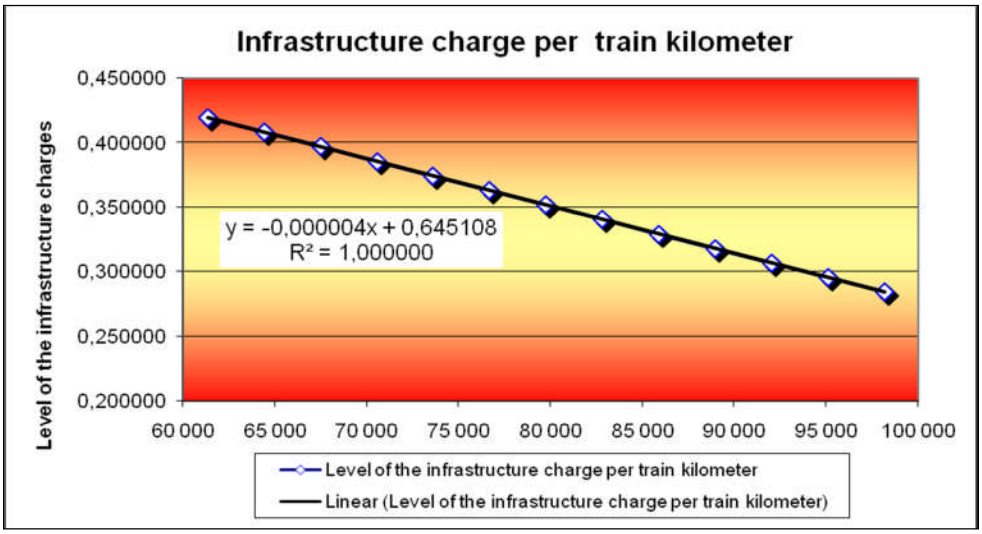


Fig.9 Level of the infrastructure charge per train kilometer depending on the new rolling stock cost [EUR]

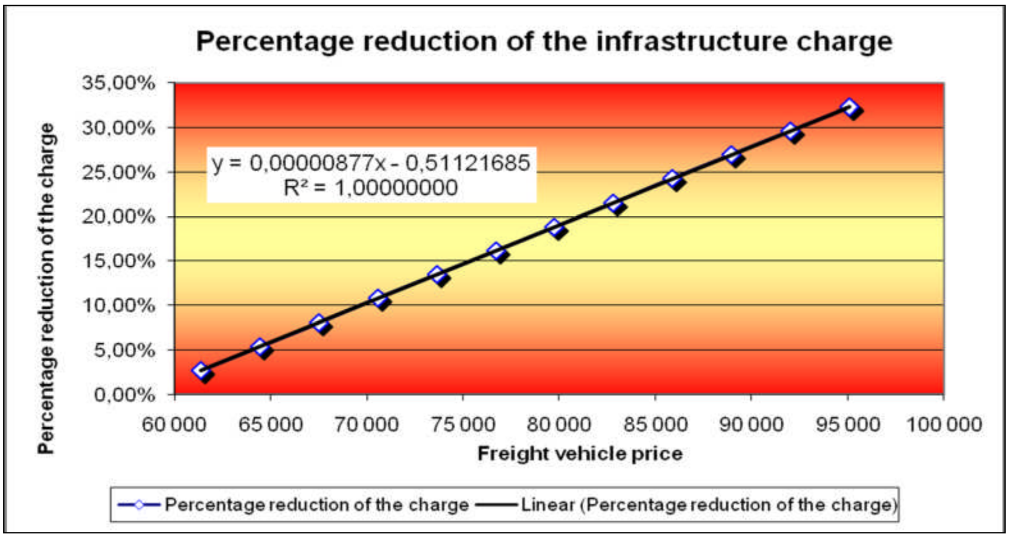


Fig.10 Percentage reduction of the infrastructure charge per train kilometer depending on the new rolling stock cost [EUR]

4. CONCLUSIONS ON THE RESULTS OF SURVEY ON ACCESS CHARGES EFFECTIVENESS

The survey made includes three of the leading companies in the rail freight sector in Bulgaria. It investigated their opinion on the system of access (infrastructure) charges, the way of determining their amount and availability of discounts given to trains consisting of track-friendly vehicles.

These companies are arranged by the quantity of fleet used and amount of freight transported /fig.1-3/: Bulgarian State Railways (BDZ) railfreight unit (BDZ Tovarni Prevozi) Ltd, BRC (“Bulgarian Railway Company” AD) and DB Shenker Rail Bulgaria. The questionnaires filled in are given as attached files.

The companies possess and use railway vehicles as follows:

1. BDZ: locomotives – 207 (electric locomotives– 90, diesel ones – 117), Wagons – 4 890, of which: open; flat; vans; and tanker

The wagons rented are 137. Approximately 40% of the total traffic is carried out with wagons owned by the Bulgarian State Railways (BDZ) railfreight unit (BDZ Tovarni Prevozi) Ltd., the rest 60% of conveyances are carried out with foreign wagons (private and of foreign railways). Depending on the structure of types of transported cargo, the operating fleet is changed. Annually about 14% -20% of the fleet in operation are subjected to Average repairs, which provide technically fit rolling stock. About 3% of the inventory fleet of the BDZ are rented wagons. The company defines the kind and type of wagons that will use.

2. BRC - Available locomotives 32 (22, 10), Wagon 391, of which all are rented or belong to customers.

Depending on the intensity of loading, the operating fleet is changed. The company work with companies RSCO, ERMEWA and GRAMPET. The lease is of different duration. The company request the type of wagons and the leasing company defines the series or we choose wagons from series available.

3. DB Shenker Rail Bulgaria – 10 (7 pieces 86 series /EA 3000/,3 pieces Class 92 /UK/), Wagon 250

All wagons belong to the company. The maintenance of rail freight vehicles for general use is performed in order to satisfy specific demands of the client. The rolling stock has to meet the common EU rules.

Related to the system of infrastructure (access) charges, all companies would prefer the previous system of charges, which included differentiation by different indicators. The complex nature of the system is considered to be no problem with using it. Related to differentiation:

- One of the companies surveyed included track category;
- Two companies include train type and category;
- All companies included the type of rolling stock depending on impact on the track;
- One of the companies included the speed, which depends on the type of rolling stock.

Only one of the companies confirmed that reduction of infrastructure charges for intermodal and block trains since April 2014 had had favorable effect on the volume of freight transported.

Related to the purchase of new freight vehicles, the practices is different for the three companies: one of them uses only rented wagons, the other one has not bought any rolling stock recently and the third one has bought only second-hand wagons. It was declared that the discounts for using different vehicles or/and track-friendly bogies, it will influence on their intention to purchase new wagons. Certification should be done according to the EU rules (as considered two of the companies) or should take into account the effect of their use proven in practice. The discount of the access charges should be per train consisting of new vehicles. Only one of the companies declared that the discount could be per wagon.

About future decisions on the composition of your fleet

The opinion on the amount of discount that could influence on the purchase of new wagons varies from 5 -50 %. Concerning the impact of access charges stimulating the traffic of trains running at higher speeds on the purchase of new railway vehicles, there is also a variety of opinions: 5 % influence; min 30% or impossibility to determine an exact percentage at present.

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