Methodology to Calculate Variable Usage Charges for Control Period 4

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EXECUTIVE SUMMARY

TTCI(UK) Ltd., under contract to Network Rail, has continued to develop the methodology for calculating variable usage charges for track access. This report reviews the existing methodology before describing a new methodology. The new methodology accounts for the variable usage costs arising from tangential forces between the wheel and the rail. Sensitivity studies on both the existing and new methodologies are described. Detail is given on applying the new methodology to routes rather than the network in total. This report builds on earlier work[1] and leads to a final set of proposed variable usage charges for Control Period 4 (CP4). These charges are published separately.

The sensitivity study shows the existing methodology, based on vertical forces, is very sensitive to the assumptions used to derive the charging formulae. The new methodology, in contrast, is relatively insensitive to its assumptions.

A full revision of the existing methodology is recommended. This should result in state-of-the-art damage models calibrated to the latest service data. The review and calibration should be fully documented and traceable. The revision should be completed in time for Control Period 5.

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1 INTRODUCTION AND OBJECTIVES

TTCI(UK) Ltd., under contract to Network Rail, has continued to develop the methodology for calculating variable usage charges for track access. This report reviews the existing methodology before describing a new methodology. The new methodology accounts for the variable usage costs arising from tangential forces between the wheel and the rail. Sensitivity studies on both the existing and new methodologies are described. Detail is given on applying the new methodology to routes rather than the network in total. This report builds on earlier work[1] and leads to a final set of proposed variable usage charges for Control Period 4 (CP4). These charges are published separately.

Section 2 is a review of the existing methodology used to calculate variable usage charges. The intention is to give an overview and to identify any changes that can be justified for CP4. A complete revision of the existing methodology is outside the scope of this report.

Section 3 describes the proposed new methodology, which still uses the existing methodology for a proportion of track costs. It introduces a new method for calculating variable usage charges to recover the costs of damage caused by tangential forces. Tangential forces are responsible for rail wear, rolling contact fatigue and squat defects. Variable usage costs arising from these forces are approximately 10% of the track variable usage costs and a similar magnitude to structures variable usage costs.

Section 4 describes an approach to route-based variable usage charging as an alternative to the existing charging based on total network traffic and costs. The new methodology can be applied the network totals, but there are further advantages of applying it to specific routes.

Section 5 presents conclusions. Comments and questions on the earlier work have been received in writing from stakeholders. These, together with responses, are listed in Appendix A.

2 REVIEW OF EXISTING METHODOLOGY

In 1999, the Office of the Rail Regulator commissioned a review of the proposed access charging methodology for Control Period 1.[2] That review noted that variable usage costs were separated into the following four headings:

1. Track
2. Structures
3. Signalling
4. Electrification

The model used for track and structures costs was the most advanced. The variable part of the signalling costs was small and was lumped in with track costs for charging purposes. The variable usage charge for electrification was combined with the charge for traction. Signalling and electrification charges are not discussed any further in this report. No changes to the handling of signalling and electrification charges are proposed.

Subsections 2.1 and 2.2 describe the methodologies used for recovering the variable usage costs from existing track and structure. Subsection 2.3 describes methodologies used in other railways, and subsection 2.4 presents a sensitivity study on the choice of methodology.

2.1 Track

The methodology for track that has been used since the start of Control Period 1 is based on the British Rail Research, Mini-MARPAS track deterioration models.[3] There are seven basic track damage submodels:

1. Rail Maintenance
2. Rail Life
3. Sleeper Life
4. Track Geometry Maintenance
5. Ballast Life
6. Switch & Crossing
7. Track Inspection

Each model calculates damage from a specified traffic. The units of damage may be a volume of work or the proportion of an asset's life consumed. Damage is converted into cost using unit cost data for the various types of work (e.g. re-railing, inspection).

Theoretically, the Mini-MARPAS models could be used to calculate usage charges directly. This would be the so-called bottom-up approach. Costs could be calculated for a base case. The marginal cost of a small increase in the number of a particular vehicle could also be calculated. This would give the marginal cost of operating one more of that particular vehicle.

The charges resulting from this bottom-up approach depend on the unit costs used and the validity of the track deterioration models. There is no guarantee that the sum of the individual vehicle usage charges would equal the total variable usage cost for the network. An alternative is a top-down approach.

In the top-down approach, formulae are used to calculate the equivalent damage caused by an individual vehicle. The equivalent damage allows one vehicle to be compared directly with another. A factor to convert damage to cost is derived by calibrating the total equivalent damage from all vehicles operating on the network with the total variable usage cost that is to be recovered. Once calibrated, the conversion factor is used to convert any individual vehicle's equivalent damage to its cost, and hence, variable usage charge.

The advantage of the top-down approach is that it guarantees to recover the total variable usage cost. It does so by apportioning this cost between the vehicles depending on their propensity to generate damage. The formulae used to calculate damage are still based on the Mini-MARPAS models.

Equation 1 shows the formula currently used to calculate the equivalent damage for track related costs.

$$\text{Equivalent Track Damage} = C_t\, A^{0.49}\, S^{0.64}\, \text{USM}^{0.19}\, \text{GTM} \qquad (1)$$

where C_t is 0.89 for loco-hauled passenger stock and multiple units, and 1 for all other vehicles, A is the axle load (tonnes), S is the operating speed (miles/hour), and USM is the unsprung mass (kg/axle). Further factors are applied for freight wagons to account for coal spillage and suspension types.

The coefficients and exponents in Equation 1 were derived from a parametric study using Mini-MARPAS. Results were calculated for many combinations of speed, axle load, and unsprung mass. Power law relationships were then fitted to these results.

It should be noted that the axle load exponent in Equation 1 is effectively 1.49 since expanding the gross tonne mile term gives Equation 2:

$$\text{GTM} = A \times \text{number of axles} \times \text{miles operated} \qquad (2)$$

As detailed in the 1999 ORR review[2], the methodology for track costs makes several simplifying assumptions. In summary it ignores the effects of:

- Tangential wheel-rail forces generated in curving, which require knowledge of wheel and rail profiles, curvature, and cant. Inclusion of these effects is one of the principal changes proposed for Control Period 4.
- Wheel flats and out-of-roundness. Incentives are given to train operators outside the variable usage charge to minimise these types of wheel defects.

- Axle spacing, although a factor is included in the structures methodology (see subsection 2.2).
- The design of vehicle's secondary suspension (except in a simplified way). This may affect vehicles' propensity to cause cyclic top track damage.
- Lateral forces and the shift in vertical forces due to cant deficiency in curves.

The service data available at the time was used to calibrate the models. The introduction of new methods of renewal, maintenance and inspection, and new materials has meant the historical service data is no longer relevant. Rail failure statistics, for example, have changed in recent years. A recalibration of the existing methodology is required.

In addition, the coefficients and exponents in Equation 1 appear to have been derived for part of the former London North Eastern Zone of Railtrack. There is an underlying assumption that these are valid for the network in general.

2.2 Structures

The existing methodology for recovering the variable usage costs from structures is the same as that for track, except a different formula for damage is used. For structures, Equation 3 is used:

$$\text{Equivalent Structures Damage} = C_t\, A^{3.83}\, S^{1.52}\, \text{GTM} \qquad (3)$$

where C_t is 1.20 for two-axle freight wagons, and 1 for all other vehicles, A is the axle load (tonnes), S is the operating speed (miles/hour).

Equations 1 and 3 show that the axle load and speed exponents are higher for structures compared to track damage.

It can also be seen that the unsprung mass term is not present in the damage formula for structures. This is because the dynamic forces that are a function of unsprung mass are attenuated by bridge superstructure before they reach the bridge structure and cause damage.

2.3 Alternative Methodologies

Alternative methodologies have been investigated to give continued assurance that the existing equivalent damage formulae are valid. In particular, alternative values for the axle load, speed, and unsprung mass terms in Equations 1 and 3 have been studied.

2.3.1 Track

In a former Railway Group Standard,[4] a definition was given for Equivalent Million Gross Tonnes per Annum (EMGTPA). The definition is based on one given by the International Union of Railways (UIC).[5] EMGTPA is used today to specify design, maintenance, renewal, and inspection of Network Rail's track. Since EMGTPA is a method for combining the effects of speed, axle load, and vehicle type to determine the volume of work required, it is also relevant to the cost of that work.

Equation 4 gives the formula for EMGTPA.

$$\text{EMGTPA} = S' \; K \; \text{MGTPA} \qquad (4)$$

where S' is a speed factor and K is a factor to account for different axle loads.

Tables 1 and 2 show the speed factors used by Railway Group Standards (RGS) and the UIC, respectively.

Table 1. Speed Factors from Railway Group Standards

Speed (mph)	Factor
Up to 40	1.00
41 - 50	1.10
51 - 60	1.20
61 - 75	1.35
76 – 100	1.55
101 – 125	1.60
126 – 140	1.80

Table 2. Speed Factors from UIC

Speed (kph)	Speed (mph)	Factor
Up to 60	Up to 37	1.00
61 - 80	38 – 50	1.05
81 - 100	51 – 62	1.15
101 - 130	63 – 81	1.25
131 - 160	82 – 99	1.35
161 - 200	100 – 124	1.40
201 - 250	125 – 155	1.45
More than 250	More than 155	1,50

Figure 1 shows the factors from Tables 1 and 2 plotted on linear axes. The RGS factor of 1.60 for the speed band 101 to 125 mph has been replaced with 1.70. The RGS value is a long way from the trend formed by the other values and is assumed an error.

Figure 1 also shows logarithmic trends fitted to the data points. The exponents for these trends are 0.47 and 0.28 for the RGS and the UIC, respectively. The reason for the difference in the two standards is unknown.

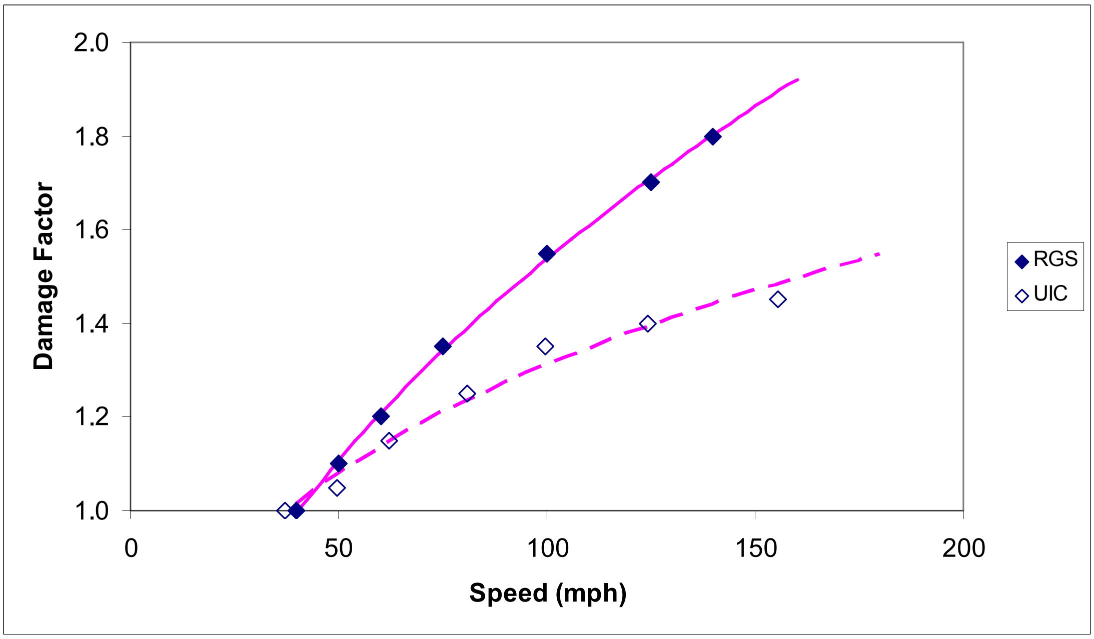

Figure 1. Speed Factors from Railway Group Standards and UIC Code

Öberg and Andersson[6] have recently described a model for determining the effect of traffic on track costs. They reviewed 21 track deterioration models before producing their own model. Thus, the Öberg and Andersson model may be considered as the state-of-the-art in track deterioration modelling. It was developed for the track and operations in Sweden. These are similar enough to those on Network Rail controlled infrastructure for the model to be applicable here.

The Öberg and Andersson model consists of three terms to account for:

1. Track settlement, which drives tamping costs, etc.
2. Component fatigue, which drives renewal costs for rails, sleepers, etc.
3. Rail wear and RCF, which drive grinding and rail renewal costs.

Terms 1 and 2 include a dynamic vertical force parameter that can be assumed proportional to speed. For both terms, the dynamic vertical force parameter is raised to the power 3.0. For the settlement term, this power comes from collaborative European railway research. For the fatigue term, this power is typical of the relationship between applied stress and fatigue life of welded metal components. Since the wear and RCF term does not include a speed factor (although some assumption about speed in curves must be made) and the other terms include a static force parameter, the overall effect of speed will be an exponent somewhat less than 3.0.

Table 3 summarises the speed exponents used by the various sources described above. Clearly, there is a wide variation, and this can be expected to have a significant effect on the variable usage charges for high- and low-speed vehicles. The results of a sensitivity study on the speed exponent are presented in subsection 2.4.1.

Table 3. Summary of Speed Exponents

Source	Exponent
ORR Variable Usage Charging	0.64
Railway Group Standards EMGTPA	0.47
UIC Code 714	0.28
Öberg and Andersson	Up to 3.0

Railway Group Standards and the UIC Code have a similar approach to the factor K that accounts for axle load. In both cases, it depends on the mix of traffic, but it typically varies linearly with axle load. Thus, the exponent used by these standards is typically 1.0.

Öberg and Andersson raise the total vertical force (static plus dynamic) to a value of 3.0 for the settlement and component fatigue factors in their model. Thus, the effective exponent for the static axle load is somewhat less than 3.0.

Table 4 summarises the exponents used for axle load. In each case, the formula for damage includes a gross tonnage factor that has the effect of increasing the axle load exponent by 1.0

Table 4. Summary of Axle Load Exponents

Source	Exponent	Exponent including Gross Tonnage
ORR Variable Usage Charging	0.49	1.49
Railway Group Standards EMGTPA	1.00	2.00
UIC Code 714	1.00	2.00
Öberg and Andersson	Up to 3.0	Up to 4.0

Again, there is a wide variation, and this can be expected to have a significant effect on the variable usage charges for high axle load vehicles. The results of a sensitivity study on the axle load exponent are presented in subsection 2.4.2.

Railway Group Standards and the UIC Code use the factor K to account for differences in unsprung mass between certain types of vehicles. For freight vehicles designed to give low track forces (typically by reducing the unsprung mass), the factor is reduced by 0.1.

For axles that are powered, and whose mass is therefore increased by the mass of the motor or gearbox, an additional factor is included. In the RGS, this factor increases linearly with the power of the motor used to drive the axle. The UIC Code does not distinguish between motors with different power. Instead, it applies a factor to all powered axles to account for the increase in unsprung mass. The constant factor is in the middle of the range used by the RGS.

Öberg and Andersson recommend using computerised vehicle dynamic models to determine the effect of unsprung mass on dynamic forces. In the absence of such models, the suggested high frequency dynamic forces depend on the square root of unsprung mass. Since unsprung mass only affects one of the components of force in the Öberg and Andersson model, the effective exponent will be somewhat less than 0.5.

Table 5 summarises the unsprung mass exponents used by the various sources described above. The results of a sensitivity study on the unsprung mass exponent are presented in subsection 2.4.3.

Table 5. Summary of Unsprung Mass Exponents

Source	**Exponent**
ORR Variable Usage Charging	0.19
Railway Group Standards EMGTPA	1.00
Öberg and Andersson	Up to 0.5

2.3.2 Structures

Equation 3, which is used for allocating the variable cost of structures, has axle load raised to the power 3.83. When the axle load component of gross tonne miles is included, the exponent becomes 4.83. Fatigue damage in steel bridges is typically dependent on stress raised to the power 3.0.[7] The exponent for concrete and masonry bridges is not well defined. There may not even be a logarithmic relationship between damage and axle load for these types of structures. If it is assumed that stress range in a steel bridge member is proportional to axle load, then the axle load exponent in Equation 3 would be expected to be around 2.0. The value of 3.83 seems high. A sensitivity study on the effect of this value is presented in subsection 2.4.4.

In general, stress range in a member of a steel bridge is not directly proportional to axle load. It also depends on the spacing between axle loads. Thus, the equivalent damage formula for structures could be improved by including a term for axle spacing. The approximation appears to have been made that (except for the 2-axle freight wagon) the variation in axle spacing is insignificant for vehicles operating on Network Rail controller infrastructure.

The current speed exponent in the equivalent damage formula for structures (Equation 3) is 1.52. This is consistent with AREMA guidelines[8] for speed limits on bridges. Formulae for setting speed limits use exponents of 1.0 and 2.0 for concrete and steel bridges respectively.

2.4 Sensitivity to Damage Model Assumptions

2.4.1 Speed Exponent

The current formula for equivalent track damage, Equation 1, raises speed to the power 0.64. Figure 2 shows the effect on passenger vehicles of changing this exponent to 0.28 and 2.0. Two values are plotted for each of the 117 different types of passenger locomotives, coaches, and multiple units. One value is the percentage change in variable usage charge when the speed exponent is reduced from the base case value of 0.64 to 0.28. The second value is the percentage change when the exponent is increased to 2.0. Thus, the scatter in results indicates the sensitivity of the charge to the speed exponent. Higher sensitivity produces more scatter.

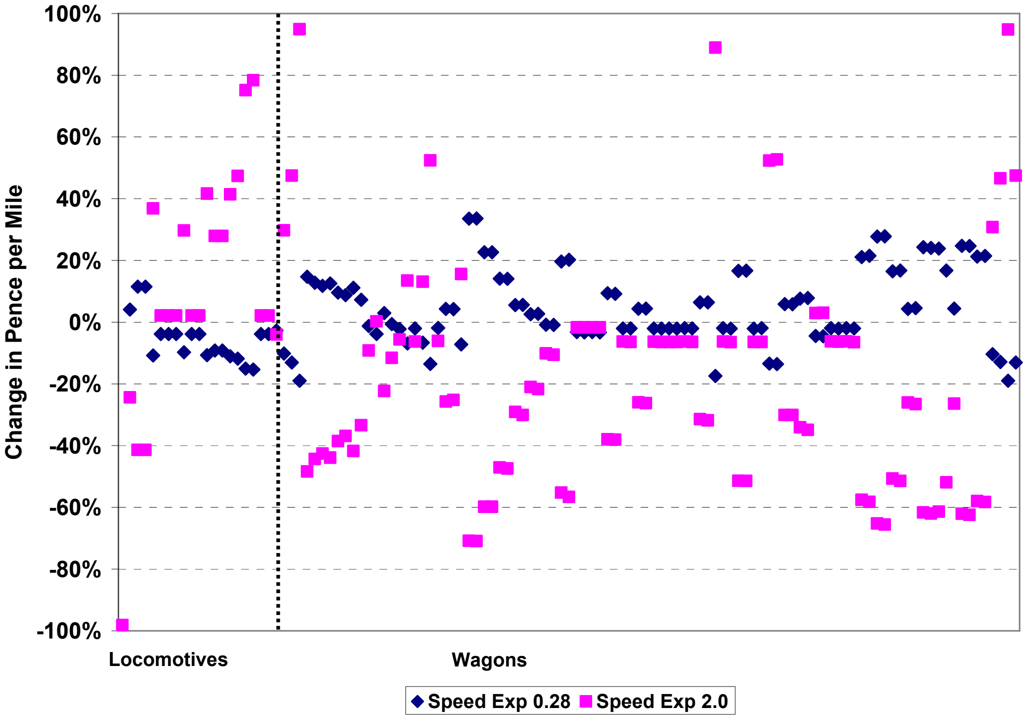

Figure 2. Effect of Track Speed Exponent on Passenger Vehicle Variable Usage Charges

Figure 2 shows that increasing the speed exponent in the equivalent track damage formula generally increases the variable usage charge for passenger locomotives and reduces it for other passenger vehicles. The opposite happens when the exponent is reduced.

The variable usage charge tends to increase for high-speed vehicles when the exponent is increased because they are being increasingly penalised for their high speeds.

Variable usage charges are clearly very sensitive to the value of the speed exponent. For the highest and lowest speed vehicles, the usage charge can change by almost 100% with alternative (and reasonable) values of the speed exponent. For the majority of passenger vehicles, the charges can vary between +30% and -60%.

Figures 3 and 4 show the effect on empty and loaded freight vehicles, respectively, of changing the speed exponent in the equivalent track damage formula. Figure 3 shows a data point for each of the 293 different combinations of freight locomotive and commodity, and a data point for each of the 1720 combinations of empty freight wagon and commodity. Figure 4 shows a data point for each of the 1190 combinations of loaded freight wagon and commodity. Note that freight locomotive results are shown only with the empty wagon results (Figure 3).

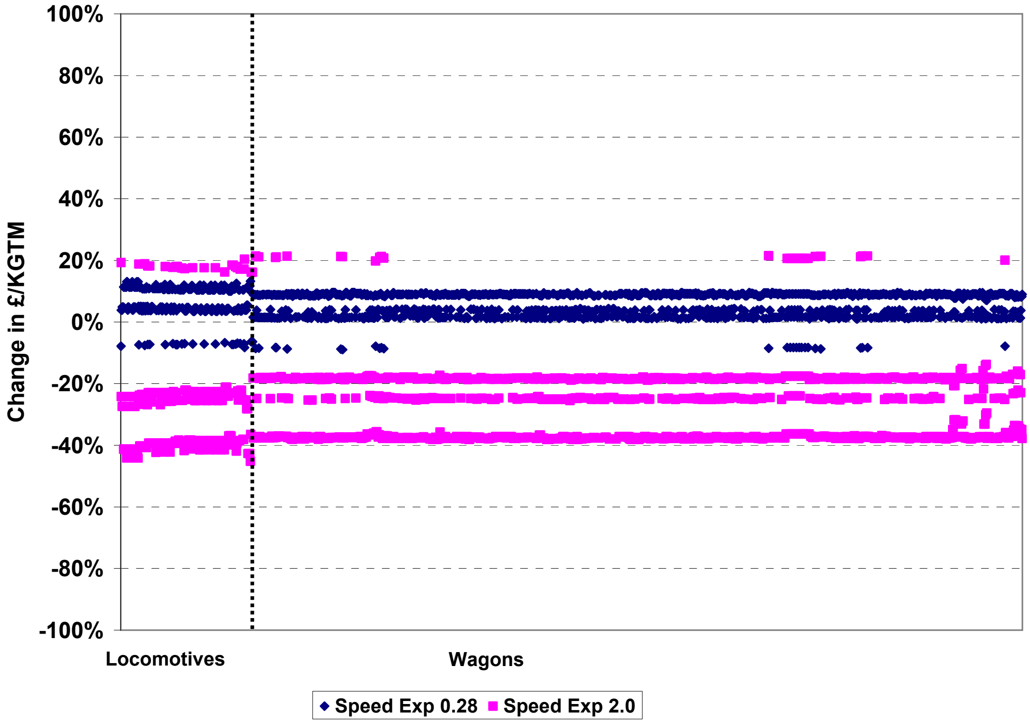

Figure 3. Effect of Track Speed Exponent on Empty Freight Vehicle Variable Usage Charges

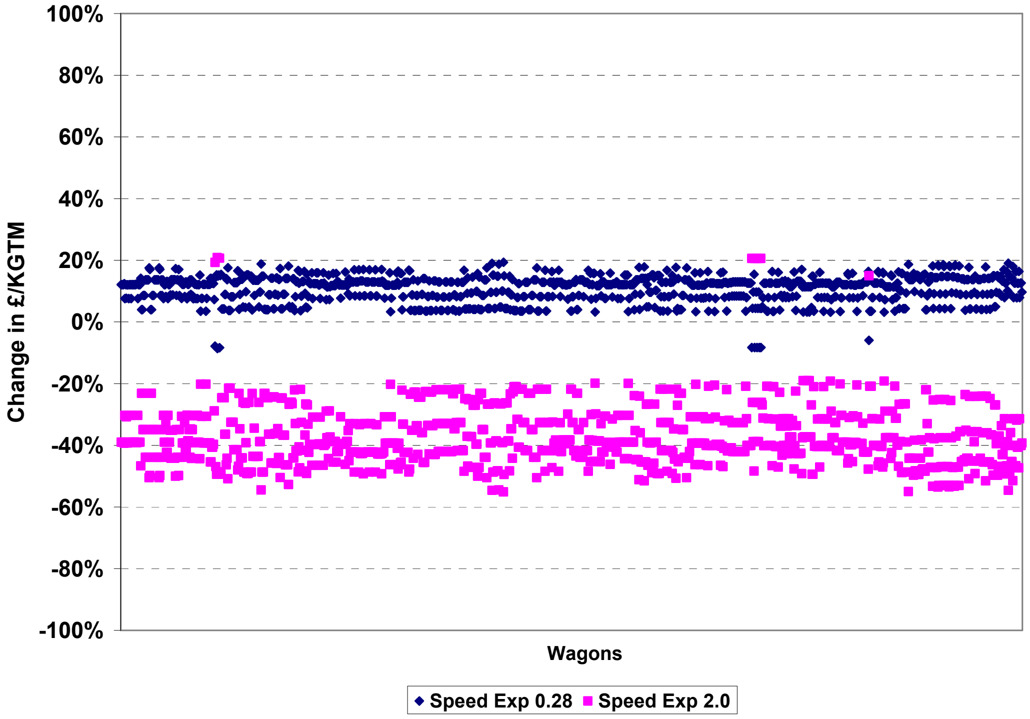

Figure 4. Effect of Track Speed Exponent on Loaded Freight Vehicle Variable Usage Charges

Figures 3 and 4 show that increasing the speed exponent in the equivalent track damage formula generally reduces freight vehicle variable usage charges. This is because freight vehicles generally operate at lower speeds than passenger vehicles. Thus, increasing the significance of speed penalises the high-speed vehicles to the benefit of the slower speed freight vehicles.

Freight vehicle variable usage charges are sensitive to the exponent of speed used in the equivalent track-damage formula. They can change by +20% to -50% of the current value when alternative and reasonable exponents are used.

Table 6 shows the net effect of changing the speed exponent on the variable charges to the passenger and freight sectors. The base-case usage charges shown in Table 6 are the totals for the passenger and freight sectors over the whole network.

Table 6. Net Effect of Track Speed Exponent on Variable Usage Charges (£k/year)

	Track Speed Exponent		
	0.28	0.64 Base Case	2.0
Passenger	168,442	178,692	214,040
Freight	104,757	94,507	59,159

Table 6 shows that the track speed exponent has a significant impact on charges. Choosing a value at the top or bottom of the range changes the balance of charges made by each traffic sector.

2.4.2 Axle Load Exponent

The value of the axle load exponent in the existing equivalent track-damage formula is 0.49. Figures 5, 6, and 7, respectively, show the effects of changing this value to 1.0 and 2.0 for passenger, empty freight, and loaded freight vehicles.

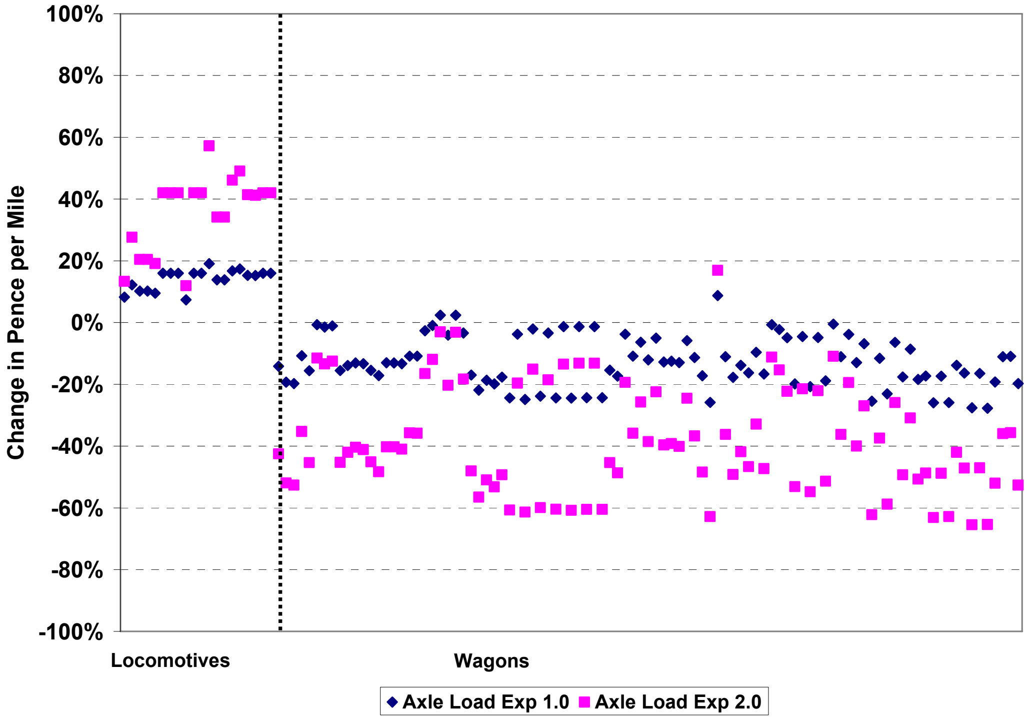

Figure 5. Effect of Track Axle Load Exponent on Passenger Vehicle Variable Usage Charges

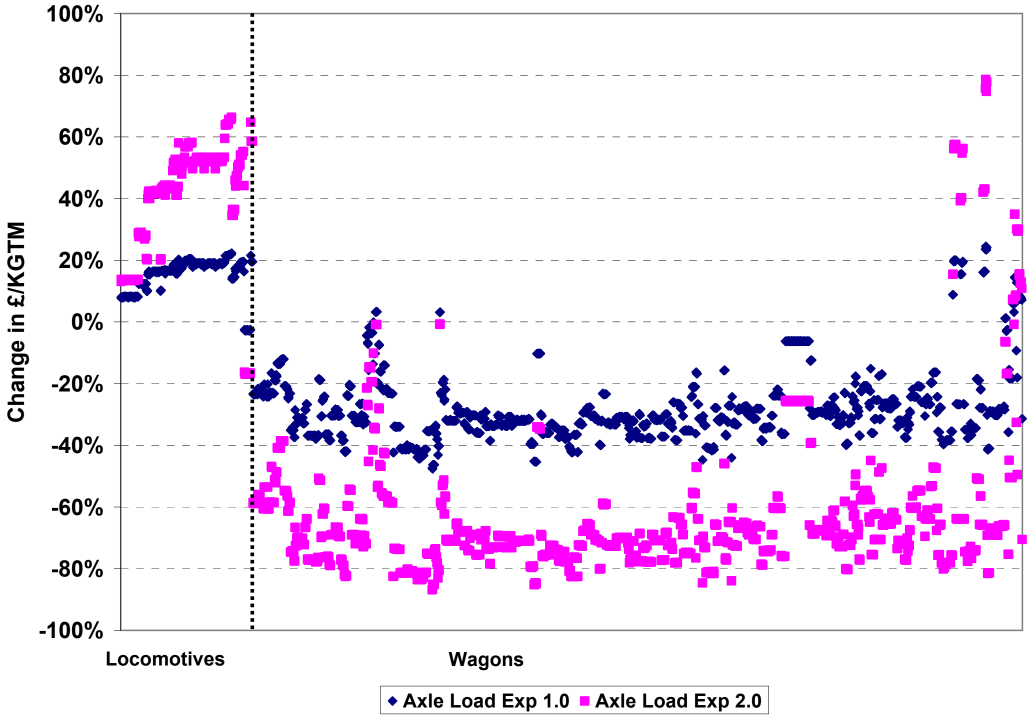

Figure 6. Effect of Track Axle Load Exponent on Empty Freight Vehicle Variable Usage Charges

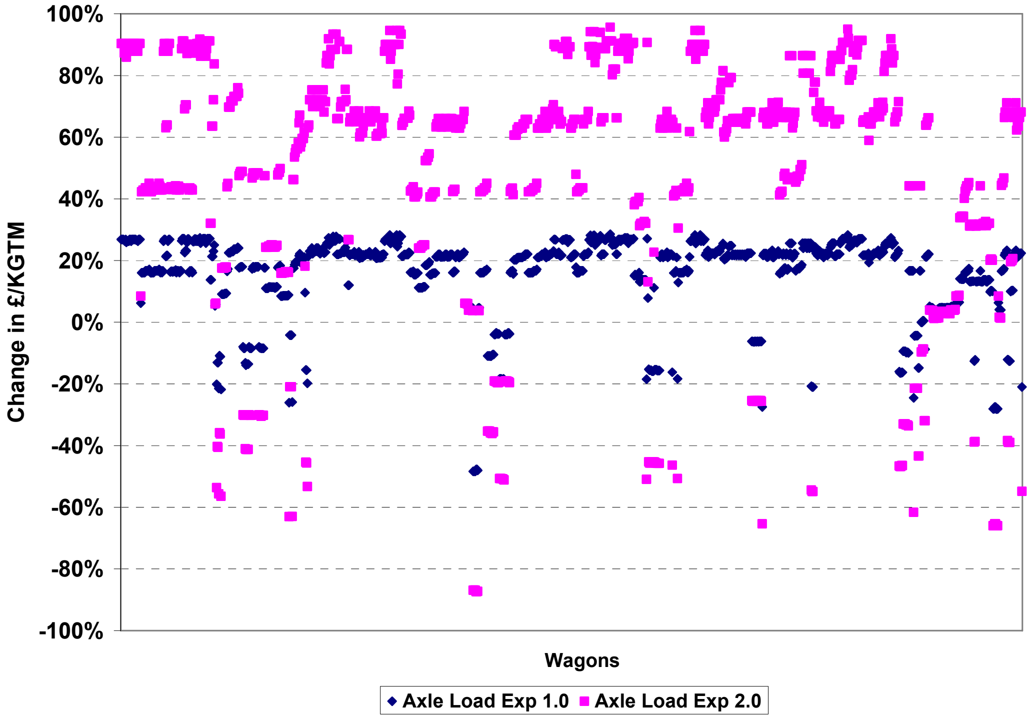

Figure 7. Effect of Track Axle load Exponent on Loaded Freight Vehicle Variable Usage Charges

Figure 5 shows that increasing the value of the axle load exponent in the equivalent track damage formula increases the variable usage charge for passenger locomotives and generally reduces it for other passenger vehicles. Figures 6 and 7 show the same is true for freight locomotives and loaded freight wagons. Figure 6 shows the effect on empty freight wagons is to generally reduce variable usage charges.

Increasing the significance of axle load can be expected to increase variable usage charges for heavy axle load vehicles. The alternative values of the axle load exponent used here are not unreasonable. They result in 10% to 60% increases in charges for locomotives. Charges for passenger coaches and multiple units can be up to 60% lower.

Freight wagon charges show the greatest sensitivity to the axle load exponent in the equivalent track-damage formula. Empty freight wagons, because of their low axle loads, generally benefit from increasing the value of the exponent. The reduction in variable usage charge can be as much as 80% when the exponent is raised to 2.0.

The variable usage charges for loaded freight wagons generally increase significantly when the axle load exponent is increased. The increase can be as much as 100%. The exceptions are certain combinations of wagon types and commodity that even in the loaded condition have low axle loads (e.g. Domestic Automotive).

Table 7 shows the net effect of changing the axle load exponent on the variable charges to the passenger and freight sectors. Clearly, the choice of track axle-load exponent has a significant impact on the balance of charges.

Table 7. Net Effect of Track Axle load Exponent on Variable Usage Charges (£k/year)

	Track Axle load Exponent		
	0.49 Base Case	**1.0**	**2.0**
Passenger	178,692	166,010	135,155
Freight	94,507	107,189	138,044

2.4.3 Unsprung Mass Exponent

The unsprung mass exponent in the current equivalent track-damage formula is 0.19. Variable usage charges have been recalculated with the exponent changed to 0.5 and 1.0. Figure 8 shows the effect on passenger vehicles.

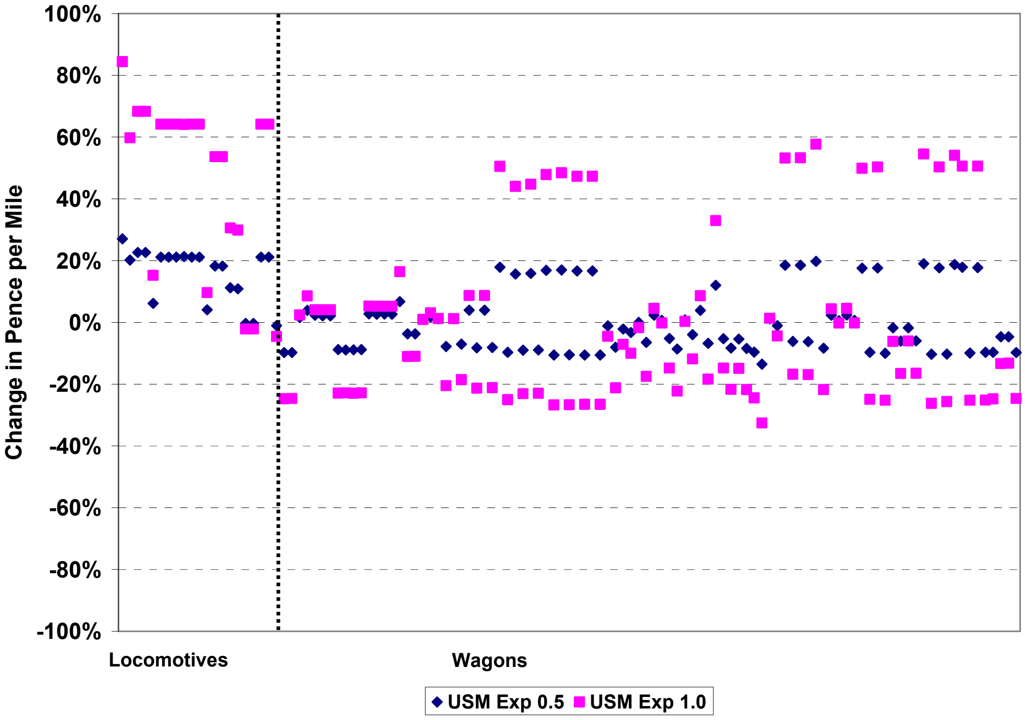

Figure 8. Effect of Unsprung Mass Exponent on Passenger Vehicle Variable Usage Charges

Figure 8 shows that increasing the unsprung mass exponent increases the variable usage charges for passenger locomotives. This is due to the relatively high unsprung mass of those locomotives. With a linear dependency on unsprung mass, which is not unreasonable, the variable usage charges for passenger locomotives could increase by up to 70%.

The effect of the unsprung mass exponent on passenger multiple unit vehicles depends on whether the vehicle has powered or unpowered axles. For powered axles the unsprung mass is relatively high and charges increase if the significance of unsprung mass is increased. For unpowered axles the opposite is true.

Figures 9 and 10 show the effect of increasing the unsprung mass exponent on empty and loaded freight vehicles respectively.

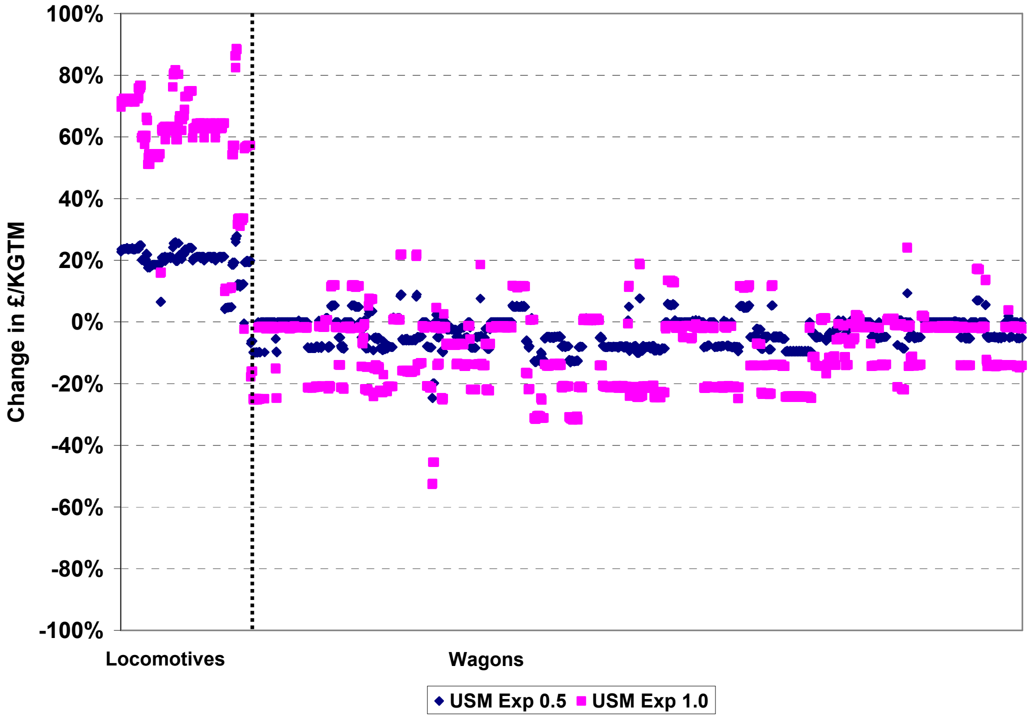

Figure 9. Effect of Unsprung Mass Exponent on Empty Freight Vehicle Variable Usage Charges

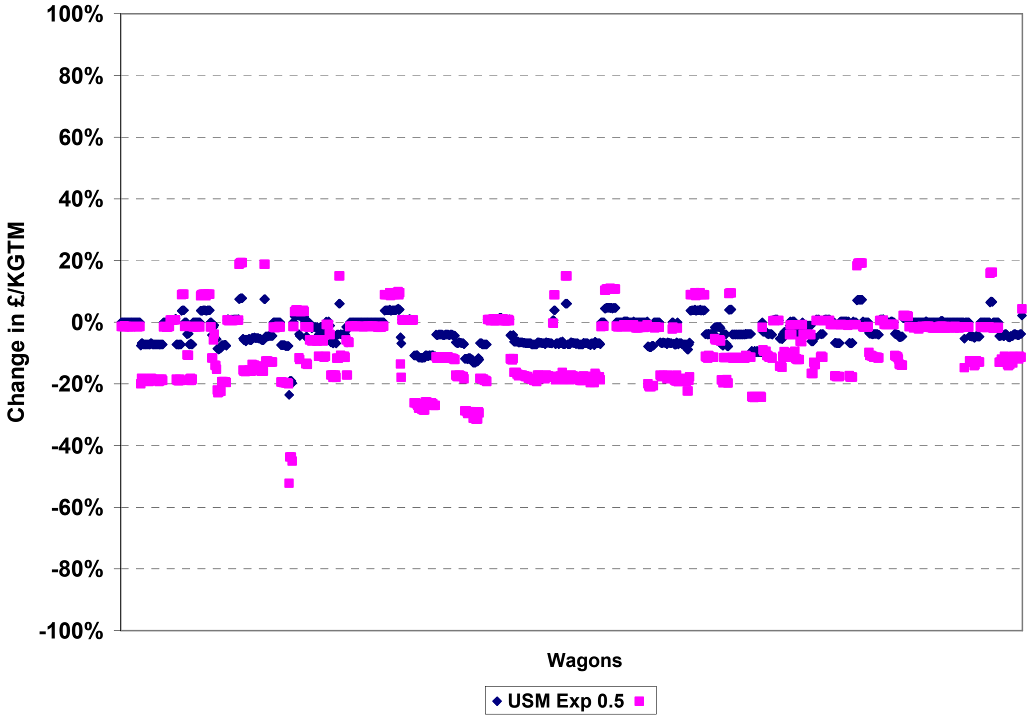

Figure 10. Effect of Unsprung Mass Exponent on Loaded Freight Vehicle Variable Usage Charges

Figure 9 shows that, due to their relatively high unsprung masses, charges for freight locomotives generally increase when the unsprung mass exponent is increased. The increases are similar to those for passenger locomotives.

Figure 9 and 10 show the variable usage charges for freight wagons generally reduce when the significance of the unsprung mass is increased. This is because they typically have a lower than average unsprung mass. For freight wagons with a higher than average unsprung mass, charges increase when the unsprung mass exponent is increased.

Increasing the unsprung mass exponent to 1.0, giving a linear dependency on unsprung mass, can change freight wagon variable usage charges by +20% to -30%.

Table 8 shows the net effect of changing the unsprung mass exponent on the variable charges to the passenger and freight sectors. Clearly, the choice of unsprung mass exponent has an effect on charges, although it is not as significant as the effects of the speed and axle load exponents.

Table 8. Net Effect of Unsprung Mass Exponent on Variable Usage Charges (£k/year)

	Unsprung Mass Exponent		
	0.19 **Base Case**	**0.5**	**1.0**
Passenger	178,692	177,438	174,759
Freight	94,507	95,762	98,440

2.4.4 Structures

The equivalent damage formula for structures (Equation 3) currently raises axle load to the power 3.83. Variable usage charges have been recalculated with this exponent changed to 2.0 and 3.0. The effect on passenger vehicle charges was found to be relatively small (between +10% and -10%). The effect is less than that for the axle load exponent in the equivalent track damage formula because variable structures costs are only approximately 10% of variable track costs.

A similar result was found for freight locomotives and empty freight wagons. When the axle load exponent in the structures equivalent damage formula was reduced, the variable usage charges for empty freight wagons generally increased. The increase was less than 10% for an exponent of 2.0.

The greatest sensitivity to the structures axle load exponent was found to be with the variable usage charges for loaded freight wagons. Figure 11 shows the change varied between +10% and -20%.

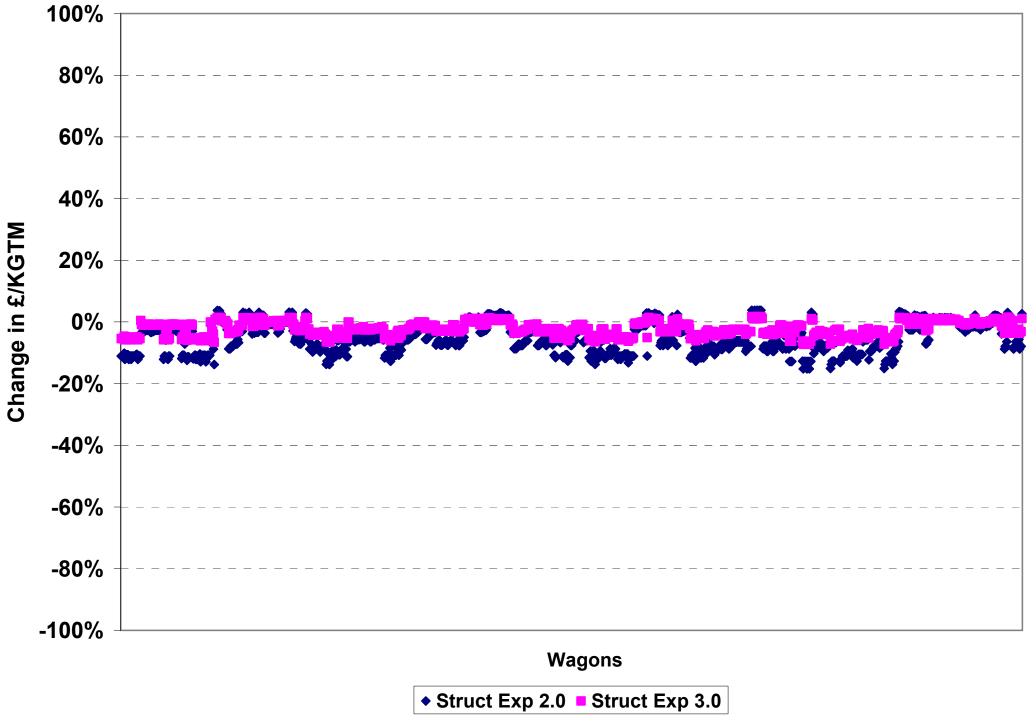

Figure 11. Effect of Structures Axle load Exponent on Loaded Freight Vehicle Variable Usage Charges

Table 9 shows the net effect of changing the structures axle load exponent on the variable charges to the passenger and freight sectors. Clearly, the choice of structures axle load exponent has an effect on charges, although it is not as significant as the effects of the track speed and axle load exponents.

Table 9. Net Effect of Structures Axle load Exponent on Variable Usage Charges (£k/year)

	Structures Axle load Exponent		
	2.0	3.0	3.83 Base Case
Passenger	183,690	180,986	178,692
Freight	89,509	92,213	94,507

2.5 Sensitivity Summary

Table 10 summarises the results of the sensitivity study.

Table 10. Summary of Sensitivity Results

Exponent	Base Case	Range Tested	Range of Effect
Track speed	0.64	0.28 to 2.0	-100% to 90%
Track axle load	0.49	0.49 to 2.0	-85% to 90%
Track unsprung mass	0.19	0.19 to 1.0	-50% to 90%
Structures axle load	3.83	2.0 to 3.83	-15% to 5%

2.6 Recommendations

The sensitivity study has shown how variable usage charges are strongly affected by the values of the exponents in the equivalent damage formula for track. The speed exponent in the equivalent track-damage formula lies in the middle of a range of reasonable alternative values. Although the value should be reviewed in the future, there are no strong arguments to change it at present.

The exponents used for axle load and unsprung mass in the equivalent track-damage formula are low in comparison to other published sources. TTCI recommends that they be changed after a full review of the charging methodology for vertical forces.

It has not been possible to trace fully the derivation of the existing equivalent damage formulae for track and structures. A thorough review of the methodology for calculating variable usage charges due to damage from vertical forces is recommended. The review should consider methodologies and models used by other railway administrations. It should result in a set of charges that are fully auditable. Sensitivity studies should be performed to test that assumptions do not have a significant effect on the results.

The recommended review to the existing charging methodology would require:

- a literature survey,
- analysis of maintenance and renewal costs,
- track and structures deterioration model development,
- parametric studies,
- development of new equivalent damage formulae,
- sensitivity studies,
- re-calculation of variable usage charges, and
- documentation.

It is reasonable to expect this to be completed in time for Control Period 5.

3 PROPOSED NEW METHODOLOGY

In recent years, the industry has recognised the importance of rail grinding and ongoing rail renewal to deal with rail surface damage. The cost of this work is significant and is currently included in the general track costs recovered through the variable usage charge for track. To make usage charges more cost reflective and to incentivise train operators to use vehicles that reduce rail surface damage Network Rail proposes to introduce a term to account for rail surface damage in the methodology for calculating variable usage charges.

Rail-surface damage costs arise due to rail wear, rolling contact fatigue, and squat defects. These costs have been estimated by considering each line item in the track maintenance and renewals budgets. Table 11 shows the results of this analysis. The costs shown in Table 11 are network totals, after the Office of Rail Regulation cost reduction targets have been applied.

Table 11. Rail Surface Damage Costs (CP4 Year 1)

	Total	RCF	Squats	Wear	Other
	Plain Line Renewals				
Percentage		2.57%	1.35%	3.91%	92.17%
Cost (£k/year)	530,631	13,622	7,140	20,762	489,108
	S&C Renewals				
Percentage		5.15%	0.00%	7.69%	87.16%
Cost (£k/year)	181,415	9,348	0	13,943	158,124
	Maintenance and Inspection				
Percentage		5.10%	2.79%	1.05%	91.06%
Cost (£k/year)	470,774	24,031	13,128	4,940	428,675
	Totals				
Percentage		3.97%	1.71%	3.35%	90.96%
Cost (£k/year)	1,182,821	47,001	20,268	39,645	1,075,907

Thus, 92.17% of plain line renewals costs, 87.16% of S&C renewals costs and 91.06% of track maintenance costs will be handled using the existing methodology (i.e. using Equation 1). The rail surface damage costs will be handled with the new methodology described in subsection 3.1.

Structures costs, which amount to £371,320 k/year, will continue to be handled with the existing methodology (i.e. using Equation 3). Signalling costs are £121,620 k/year. The variable part of these will continue to be added to the track costs for variable usage charging.

The annual cost of rail surface damage from Table 11 is £106.9M. Approximately £73M of this total is assumed to be variable with traffic. Network Rail's Infrastructure Cost Model (ICM) calculates the variable costs for the various types of asset. Table 12 shows the results from the ICM in March 2008.

Thus, the variable costs of rail surface damage (£73M/year) are approximately 30% of the total variable track costs.

Table 12. Variable Usage Costs from ICM March 2008

Asset	£M/year
Track	243.4
Structures	23.0
Signalling	6.8

3.1 Rail Surface Damage Methodology

Rail surface damage has been shown to be a function of the tangential forces (T) and creepages (γ) between the wheel and the rail.[9] This function depends on the curving performance of a vehicle and cannot be expressed as a simple relationship with vehicle properties. Thus, the equivalent of Equations 1 and 3 for tangential forces is:

$$\text{Equivalent Rail Surface Damage} = \text{f}(T\gamma)\ \text{VM} \qquad (4)$$

where VM is the miles travelled by a vehicle.

The function f($T\gamma$) is derived in Appendix B. It only needs to be calculated once for each type of vehicle operating on the network. The function combines the surface cracking and wear damage produced by a vehicle.

Equation 4 is applied to each of several bands of curvature and the results are weighted by the length of track in each band. Table 13 shows the curve distribution for Network Rail controlled infrastructure that has been used to calculate rail surface damage costs. The data is interpolated from the percentage points on the cumulative distribution of curvature taken from Network Rail's ICM. The ICM gives cumulative percentages of track for curve radii 800, 1500, and 2500m.

Table 13. Curve Distribution for Network Rail Controlled Infrastructure

Radius (m)	Track (km)
0–300	83
301-500	332
501-700	775
701-900	1872
901-1100	1187
1101-1300	1187
1301-1600	1187
1601-2000	1878
2001-2400	1712
2401-2800	1712
2801-3500	1712
3501-5000	4280
More than 5000	11088
Total:	29094

Equation 4 is applied to the steady-state $T\gamma$ from all wheels on the high rail before summing to give the total damage for the vehicle. For the purpose of calculating variable usage charges for Control Period 4, all vehicles operating on the network have been assumed to be represented by one of the curving classes shown in Table 14. Computer models have been used to determine the $T\gamma$ produced by each curving class for the central curve radius in each band shown in Table 13.

Table 14. Curving Classes Used to Determine $T\gamma$

Curving Class	Operator	Vehicle Mass * (tonne)	Primary Yaw Stiffness * (MNm/mrad)	Description
2Axle_empty	Freight			2 axle wagon
2Axle_loaded	Freight			2 axle wagon
3Piece_empty	Freight			Wagon with 3-piece bogies
3Piece_loaded	Freight			Wagon with 3-piece bogies
Artic2_80	Passenger			Eurostar trailer coach
Artic3	Passenger			Eurostar powered trailer
Class60	Freight			Co-Co locomotive
Class66	Freight			Co-Co locomotive with steering linkages
Coach_8	Passenger	45	8	Bogied coach or multiple unit
Coach_12_30	Passenger	30	12	Bogied coach or multiple unit
Coach_12_40	Passenger	40	12	Bogied coach or multiple unit
Coach_12_50	Passenger	50	12	Bogied coach or multiple unit
Coach_12_60	Passenger	60	12	Bogied coach or multiple unit
Coach_15_40	Passenger	40	15	Bogied coach or multiple unit
Coach_16_30	Passenger	30	16	Bogied coach or multiple unit
Coach_16_40	Passenger	40	16	Bogied coach or multiple unit
Coach_16_50	Passenger	50	16	Bogied coach or multiple unit
Coach_23_30	Passenger	30	23	Bogied coach or multiple unit
Coach_23_40	Passenger	40	23	Bogied coach or multiple unit
Coach_23_50	Passenger	50	23	Bogied coach or multiple unit
Coach_24_30	Passenger	30	24	Bogied coach or multiple unit
Coach_24_40	Passenger	40	24	Bogied coach or multiple unit
Coach_24_50	Passenger	50	24	Bogied coach or multiple unit
Coach_48_40	Passenger	40	48	Bogied coach or multiple unit
Coach_48_50	Passenger	50	48	Bogied coach or multiple unit
Coach_48_60	Passenger	60	48	Bogied coach or multiple unit
Coach_50_40	Passenger	40	50	Bogied coach or multiple unit
Coach_50_50	Passenger	50	50	Bogied coach or multiple unit
Coach_50_60	Passenger	60	50	Bogied coach or multiple unit
Coach_64_30	Passenger	30	64	Bogied coach or multiple unit
Coach_64_40	Passenger	40	64	Bogied coach or multiple unit
Coach_64_50	Passenger	50	64	Bogied coach or multiple unit
Coach_64_60	Passenger	60	64	Bogied coach or multiple unit
Coach_80_30	Passenger	30	80	Bogied coach or multiple unit
Coach_80_40	Passenger	40	80	Bogied coach or multiple unit
Coach_80_50	Passenger	50	80	Bogied coach or multiple unit
Coach_100_40	Passenger	40	100	Bogied coach or multiple unit
Coach_128_30	Passenger	30	128	Bogied coach or multiple unit
Coach_128_40	Passenger	40	128	Bogied coach or multiple unit
Coach_128_50	Passenger	50	128	Bogied coach or multiple unit
Tilting_50_50	Passenger	50	50	Tilting coach or multiple unit
Loco2_50	Passenger			Bo-Bo locomotive
Loco3_50	Passenger			Co-Co locomotive
NACO_empty	Freight			Empty wagon with swing motion bogies
NACO_loaded	Freight			Loaded wagon with swing motion bogies
Pacer_10	Passenger			2-axle
Shunter				3-axle
Y25_empty	Freight			Empty wagon with Y25 bogies
Y25_loaded	Freight			Loaded wagon with Y25 bogies

* Vehicle mass and primary yaw stiffness values are given only when necessary to distinguish between vehicle types.

All passenger vehicles, except those that tilt, are assumed to operate with a cant deficiency of 40mm. Tilting passenger vehicles are handled as special cases. All freight vehicles, except those whose maximum speed are 45mph, are assumed to operate at balance speed. Freight vehicles limited to 45mph are assumed to operate with 20mm cant excess.

The values of cant deficiency and excess were obtained from an analysis of cant, curvature, and line speed on Network Rail controlled infrastructure. Figure 12 shows the distribution of cant deficiency for the network assuming vehicles can reach the local line speed. The average of this distribution is approximately 40mm.

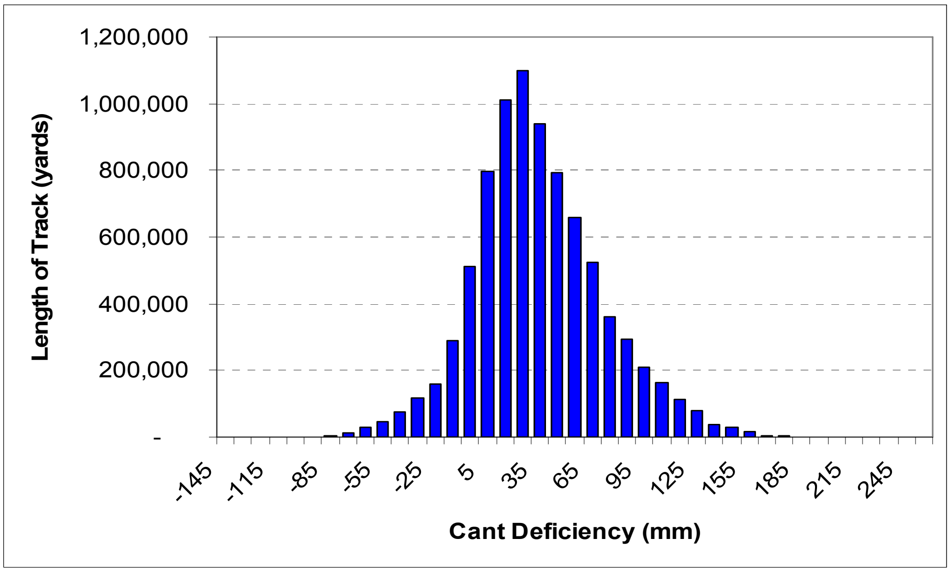

Figure 12. Distribution of Cant Deficiency Assuming Local Line Speed

Figure 13 shows the distribution of cant deficiency on the network assuming the maximum speed is limited to 60mph. The average of this distribution is approximately zero.

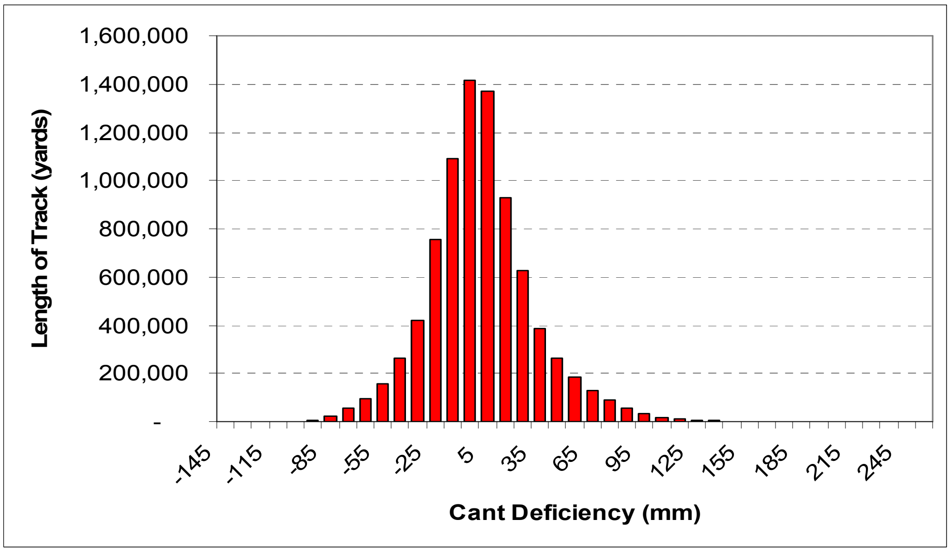

Figure 13. Distribution of Cant Deficiency Assuming 60mph Maximum Speed

Figure 14 shows the distribution of cant deficiency on the network assuming the maximum speed is limited to 45mph. The average of this distribution is approximately -20mm.

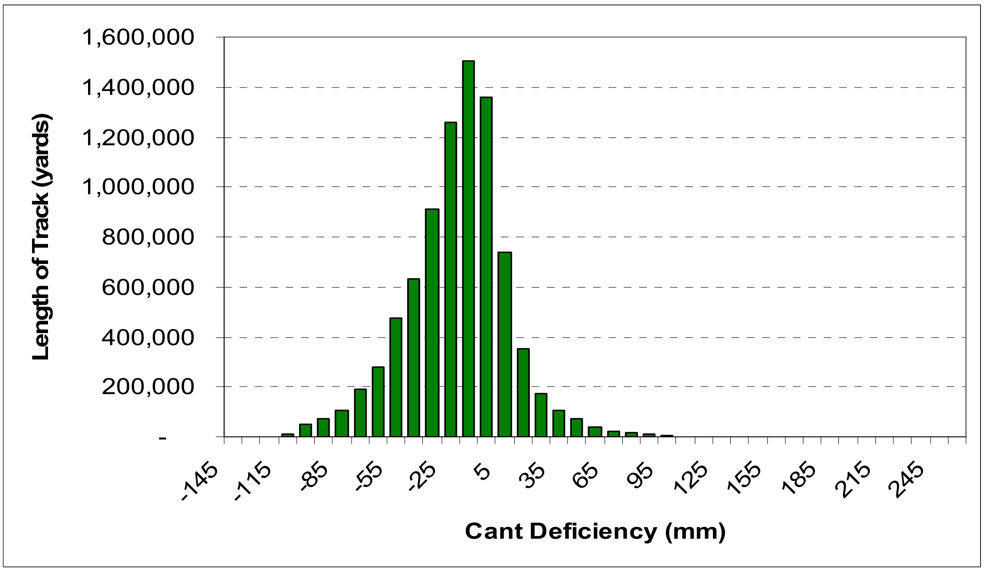

Figure 14. Distribution of Cant Deficiency Assuming 45mph Maximum Speed

The results of a sensitivity test on the assumed value of cant deficiency are presented in subsection 3.2.2.

Network Rail standards[10] require all curves with radius less than or equal to 1500m to have the gauge face of the high rail lubricated. Gauge face contact does not usually occur for curves with radius greater than 1500m at the cant deficiencies used in these simulations. Thus, in the calculation of $T\gamma$ the coefficient of friction between the wheel and the rail is assumed to be 0.4 at all contact points except the gauge face of the high rail where it is assumed 0.2. The results of a sensitivity study into the effect of lubrication are presented in subsection 3.2.3.

Measured semi-worn rail profiles are used in the calculation of $T\gamma$. Table 15 shows the profile names for each of the four different ranges of curvature.

Table 15. Rail Profile Names

Curve Radius (m)	High Rail	Low Rail
Up to 750	0-750-H.ban	0-750-L.ban
751 to 1500	750-1500-H.ban	750-1500-L.ban
1501 to 3000	1500-3000-H.ban	1500-3000-L.ban
More than 3000	0m-H.ban	0m-L.ban

Measured semi-worn wheel profiles are used in the calculation of $T\gamma$. Table 16 shows the profile names for the wheel profiles used for different types of vehicle.

Table 16. Wheel Profile Names

Vehicle Type	Profile	Left Wheel	Right Wheel
Passenger	Worn P8	F_mod_L.whl	F_mod_R.whl
Freight	Worn P5	P5_20001009-0131.whl	P5_20001009-0131.whl
Freight	Worn P10	P10_20040826-0061.whl	P10_20040826-0061.whl

All wheel and rail profiles are available in electronic format from Network Rail.

All combinations of wheel and rail profiles have been analysed to check for any unusual effects introduced from their interaction. The check has been made by examining rolling radius plots for discontinuities. The calculations of $T\gamma$ are made on right-hand curves.

Subsection 3.2.4 presents the results of a sensitivity study on the choice of wheel profiles.

3.2 Sensitivity Studies

3.2.1 Rail Grinding and Renewal Costs

The rail surface-damage function derived in Appendix B converts damage to cost. It does so by considering the variable cost of grinding to remove cracks and the variable cost of rail renewal when too much material has been lost by grinding and wear. In the process, it accounts for the beneficial effects of grinding on rail life.

The assumed unit costs of grinding and rail renewal are £2,000/km and £250,000/km, respectively. The absolute values are not important for variable usage charging, but charges may be sensitive to the ratio of these values. The effect of doubling and halving the ratio of grinding to rail renewal costs has been studied.

Figure 15 shows the effect of halving and doubling the unit cost of grinding rail on passenger vehicle variable usage charges. The effect is relatively small. The absolute maximum percentage change is less than 3% from the base case.

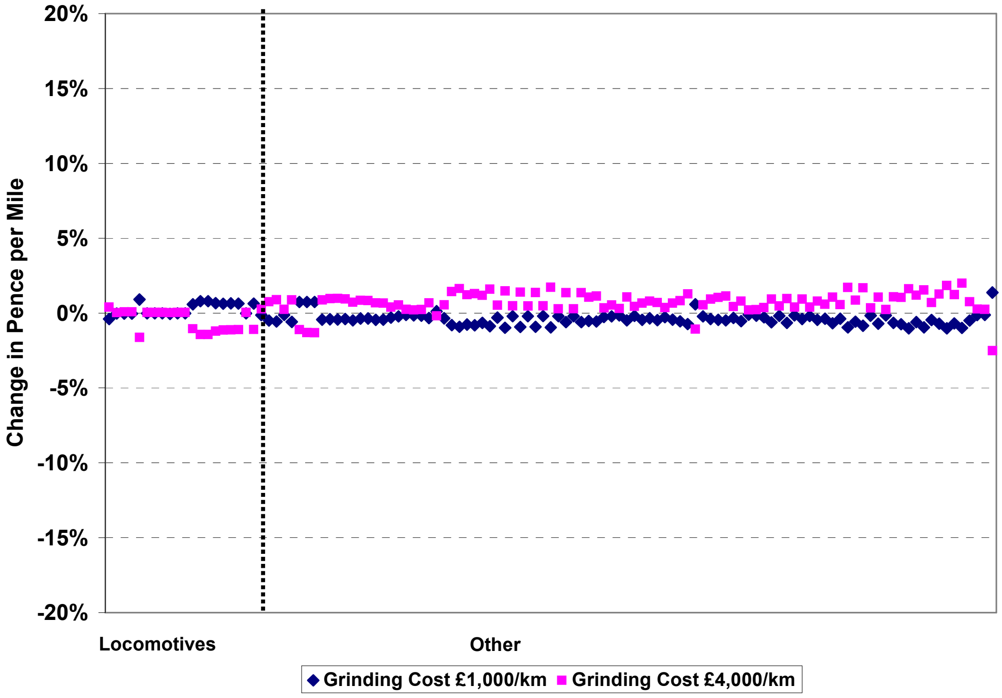

Figure 15. Effect on Passenger Vehicles of Rail Grinding Unit Cost

Similar results were found for freight vehicles. Thus, it can be concluded that the new rail-surface damage methodology is relatively insensitive to the ratio between grinding and rail renewal unit costs.

3.2.2 Cant Deficiency

In the base case, the passenger vehicles have a cant deficiency of 40mm and the freight vehicles with a maximum speed of 45mph have a cant excess of 20mm. The sensitivity to speed in curves was checked by recalculating variable usage costs assuming all vehicles operate at the balance speed.

Figure 16 shows the percentage change in variable usage costs for passenger vehicles when they are assumed to operate at balance speed in curves.

For passenger vehicles, the overall effect of reducing speed in curves is to increase the variable usage charge. Except for the first data point (which is the Class 08 shunter), the change in variable usage charge is between +6% and -5%.

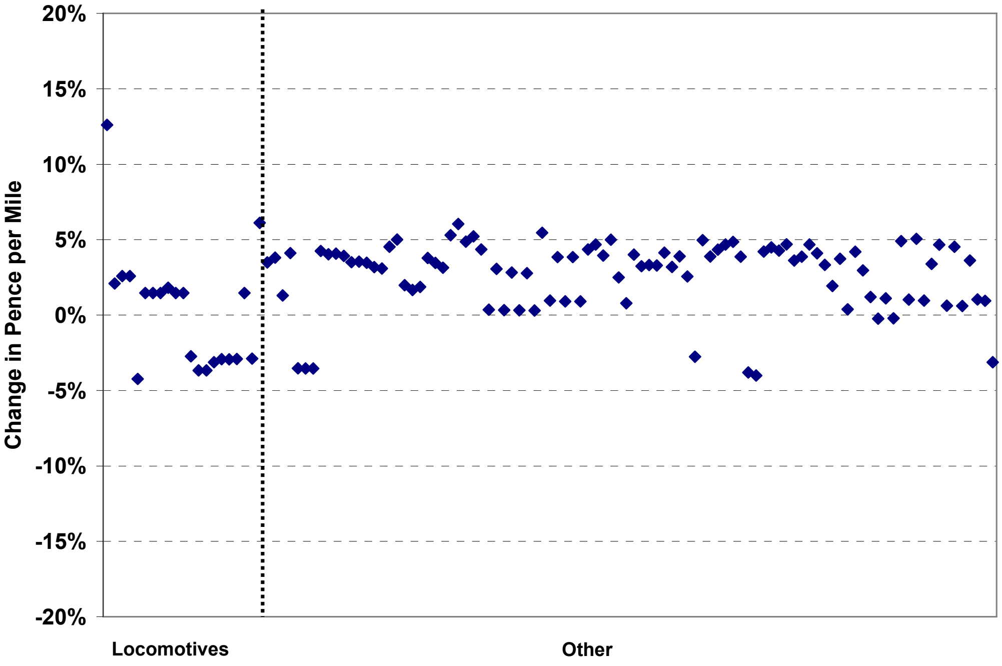

Figure 16. Effect on Passenger Vehicles of Operating at Balance Speed

Figures 17 and 18, respectively, show the percentage change in variable usage costs for empty and loaded freight vehicles.

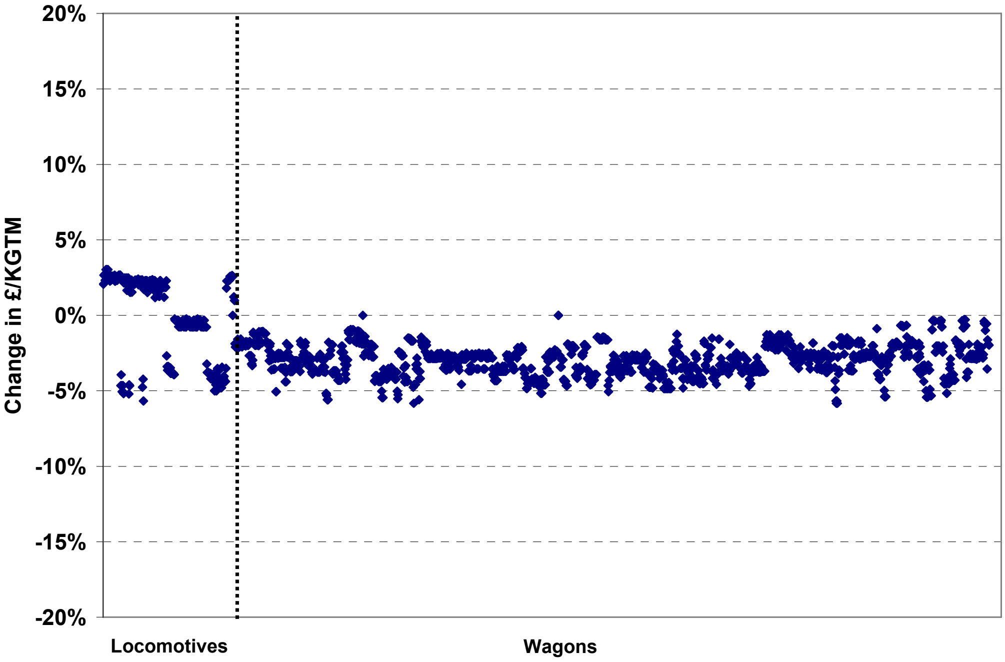

Figure 17. Effect on Empty Freight Vehicles of Operating at Balance Speed

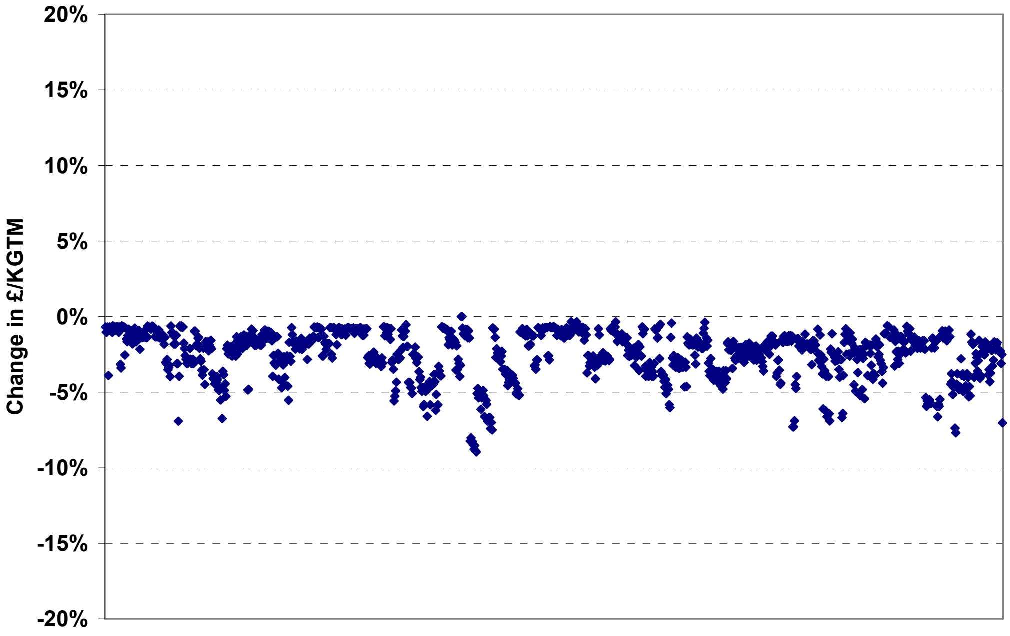

Figure 18. Effect on Loaded Freight Vehicles of Operating at Balance Speed

The effect of operating all freight trains at the balance speed in curves is generally to reduce variable usage charges. The variation for locomotives and empty wagons is between +3% and -6%. The variation for loaded wagons is between zero and -9%.

These results show that variable usage charges are not very sensitive to assumptions about operating speeds. The largest absolute variation for an individual vehicle was found to be 8%. The net effect of assuming balance speed compared to the base case would be to transfer £1.75M from freight to passenger charges. This is relatively insignificant compared to the total variable usage cost of £273M.

3.2.3 Lubrication

In the base case, the coefficient of friction is assumed to be 0.4 for all wheel-rail contact points, except the gauge face of the high rail where it is assumed to be 0.2. Variable usage charges were recalculated with the coefficient of friction changed to 0.45 at all contact points. Figure 19 shows the effect of this change on passenger locomotives, coaches, and multiple units. These results use the curve distribution for the network (as do all the other results in Section 3).

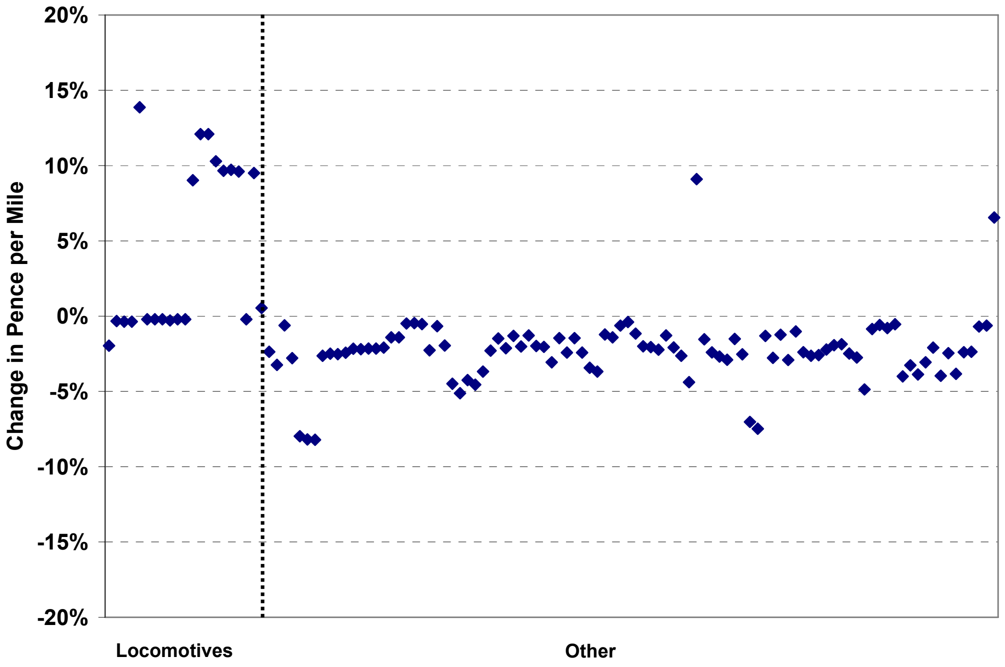

Figure 19. Effect on Passenger Vehicles of No Lubrication

Figures 20 and 21, respectively, show the effect of increasing the coefficient of friction on variable usage charges for empty and loaded freight vehicles.

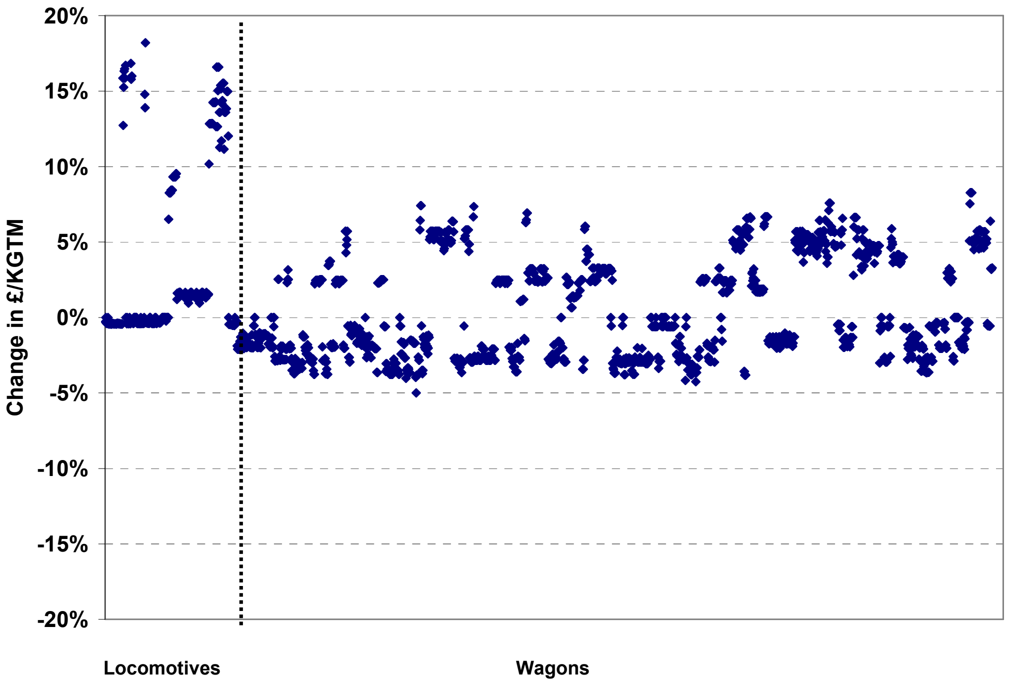

Figure 20. Effect on Empty Freight Vehicles of No Lubrication

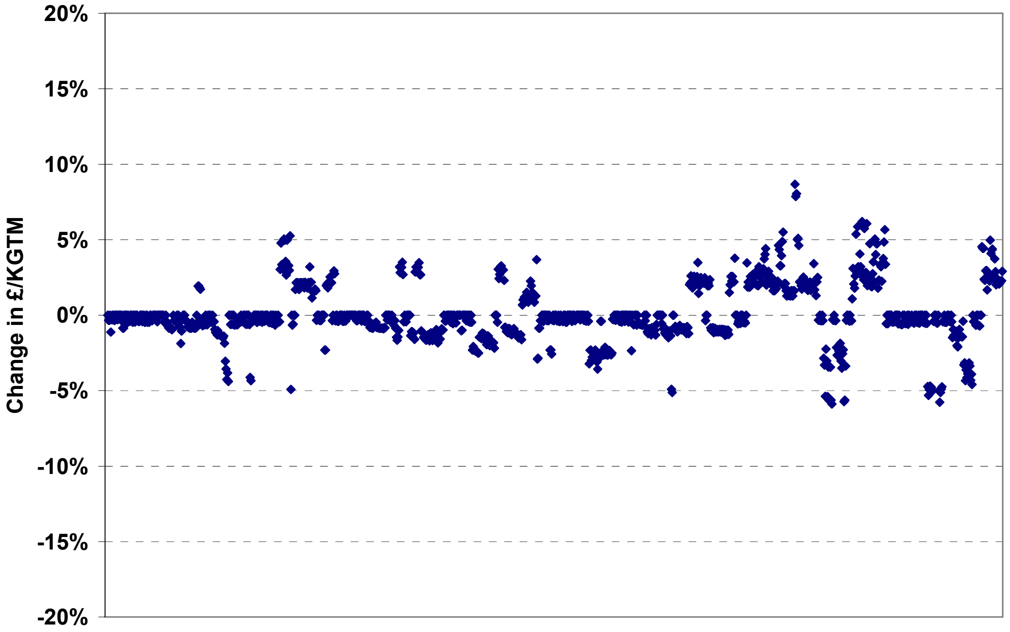

Figure 21. Effect on Loaded Freight Vehicles of No Lubrication

Figures 19 to 21 show that, with the exception of some locomotives, variable usage charges are relatively insensitive to assumptions about the coefficient of friction between the wheel and the rail. The net effect of assuming the higher values of coefficient of friction would be to transfer usage charges of £330k from passenger to freight. Again, in comparison with total variable costs of £273M, this is insignificant.

3.2.4 Wheel Profile

In the base case, the freight wagons with Y25 bogies are modelled with semi-worn P5 wheel profiles. These wagons sometimes run with P10 profiles. The variable usage costs were recalculated for all vehicles with the Y25 bogies having wheels with semi-worn P10 profiles. The effect on passenger vehicles was found to be negligible (change in p/mile less than 0.1%).

Figures 22 and 23, respectively, show the effect on empty and loaded freight vehicles of changing the wheel profiles on the Y25 bogies to semi-worn P10s.

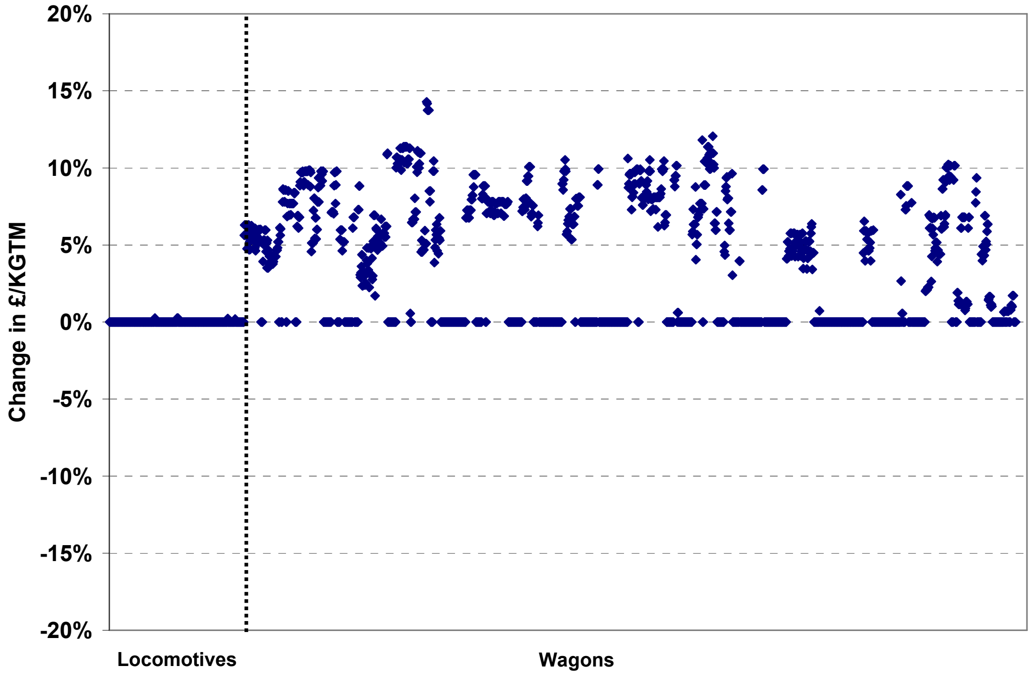

Figure 22. Effect on Empty Freight Vehicles of Y25 P10 Wheel Profiles

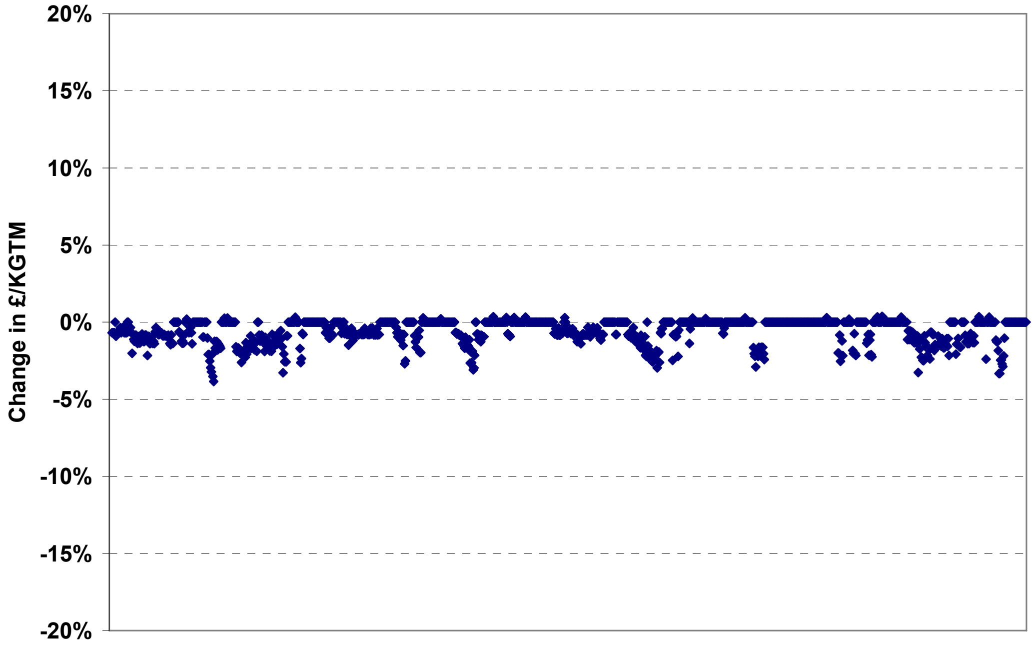

Figure 23. Effect on Loaded Freight Vehicles of Y25 P10 Wheel Profiles

Changing the wheel profile clearly makes the most difference to the vehicles whose wheels have been changed. In this example, changing the Y25 profiles from semi-worn P5 to semi-worn P10 has slightly increased the Y25 variable usage charge. The percentage increase is greater for the empty wagons compared to the loaded wagons because the charges are less for the empty wagons. The change is less than approximately 2% from the base case.

There is a smaller effect on the other vehicles even though their wheel profiles did not change. This is to compensate for the general increase in charges for the wagons with Y25 bogies.

Although it is proposed to base the usage charges on semi-worn profiles, it is recognised that some profiles, such as the WRISA2 wheel profile[11], can have a significant effect on rail surface damage. When these profiles have proven successful, the variable usage charges for vehicles using them could be suitably adjusted.

3.3 Freight Charging Categories

Freight vehicles come in many combinations of wagon body and bogie type. Primary yaw stiffness and axle spacing are still key parameters in determining curving performance, but the inclusion of friction damping and clearances in the suspension complicates the calculation of freight vehicle curving performance.

Eight categories are currently defined to overcome the complexities of freight vehicle charging for vertical forces. Table 17 shows how these categories are proposed to be mapped onto curving classes for the new rail surface damage methodology.

Table 17. Freight Vehicle Curving Classes

Category	Description	Curving Class
	Freight locomotives	Class60 for conventional 3-axle bogies Class66 for 3-axle bogies with steering linkages
1	Four-wheel (2-axle) wagon with pedestal type suspension	2Axle_empty 2Axle_loaded
2	Four-wheel (2-axle) wagon with leaf springs, friction damped	2Axle_empty 2Axle_loaded
3	Wagon equipped with three-piece bogie	3Piece_empty 3Piece_loaded
4	Bogie wagon with enhanced three-piece bogie (e.g. “swing motion” or parabolic four-wheel wagon)	NACO_empty NACO_loaded
5	Basic wagon with primary springs (e.g. Y25 suspension type)	Y25_empty Y25_loaded
6	Wagon equipped with enhanced primary springs (i.e. low track force bogies, TF25 types or “axle motion”)	Y25_empty Y25_loaded
7	Wagon equipped with enhanced primary springs and steering	No such wagons are currently in operation.

3.4 Traffic Sector Results

Table 18 shows the total variable usage charges for the passenger and freight sectors. These charges are based on the 2006/07 traffic volumes and mix of vehicle types. Table 19 shows the percentage contributions of each sector towards the total charge.

Table 18. Traffic Sector Charges (£k/year)

	Existing – Vertical Forces Only	New – Including RSD Term
Passenger	178,692	190,277
Freight	94,507	82,922
Total	273,199	273,199

Table 19. Traffic Sector Contributions (%)

	Existing – Vertical Forces Only	New – Including RSD Term
Passenger	65.4	69.6
Freight	34.6	30.4

Table 18 shows that with the assumptions stated here, the effect of introducing the new rail-surface damage term into the variable usage charges is to reduce the charges to the freight sector by approximately £11.6M/year.

Table 19 shows that this represents a swing of 4.2% of costs from the freight to the passenger sector.

4 ROUTE BASED CHARGING

Currently, variable usage charges are calculated on a network average basis. The factor to convert an individual vehicle's damage to cost is derived by comparing the total damage for the network with the total variable cost for the network.

The new methodology for including a rail-surface damage term has also been applied on a network average basis. The advantage of this approach is that it is more cost-reflective than at present, and it incentivises operators to use trains that reduce rail surface damage. The new methodology would be even better if it were route-based instead of being based on the network average. In a route-based approach, vehicles would be charged for the rail surface damage they caused on curves typical of those they normally encountered in service. The network average approach assumes that all vehicles go around every curve on the network.

Table 20 shows the six route classes defined in Network Rail's ICM. Three hundred strategic route sections (SRS), which vary from 1km to 546km in track length, are defined in the ICM.

Table 20. Infrastructure Cost Model Route Classes

Route Class
London & SE
Primary
Secondary
Rural
Freight
Non NR

Rather than have the complexity of a separate variable usage charge for each of the 300 SRSs, three curvature classes have been defined. The definitions vary by route class, as Table 21 shows. Thus, there are 15 combinations of route class and curvature class. Variable usage charges have been calculated for each of these combinations.

Table 21. Curvature Class Definitions (% of route with curve radius < 1500m)

	Curvature Class		
Route Class	**Curvy**	**Mixed**	**Straightish**
London & SE	More than 60%	26% to 60%	Less than 26%
Primary	More than 58%	18% to 58%	Less than 18%
Secondary	More than 60%	22% to 60%	Less than 23%
Rural	More than 63%	23% to 63%	Less than 22%
Freight	More than 60%	29% to 59%	Less than 29%

The reason for varying the curvature class definitions by route class is to avoid having SRSs close to the boundaries between classes. The boundaries have been chosen to lie in natural gaps in the curvature distributions for each route class (see Figures 24 through 28; a bin size of 1 percent has been used). Each SRS is considered in turn. The total length of the SRS is added to the bin that corresponds to the percentage of track in that SRS that has a curve radius less than 1500m. The y-axis is then the total length of SRSs that fall in each percentage bin.

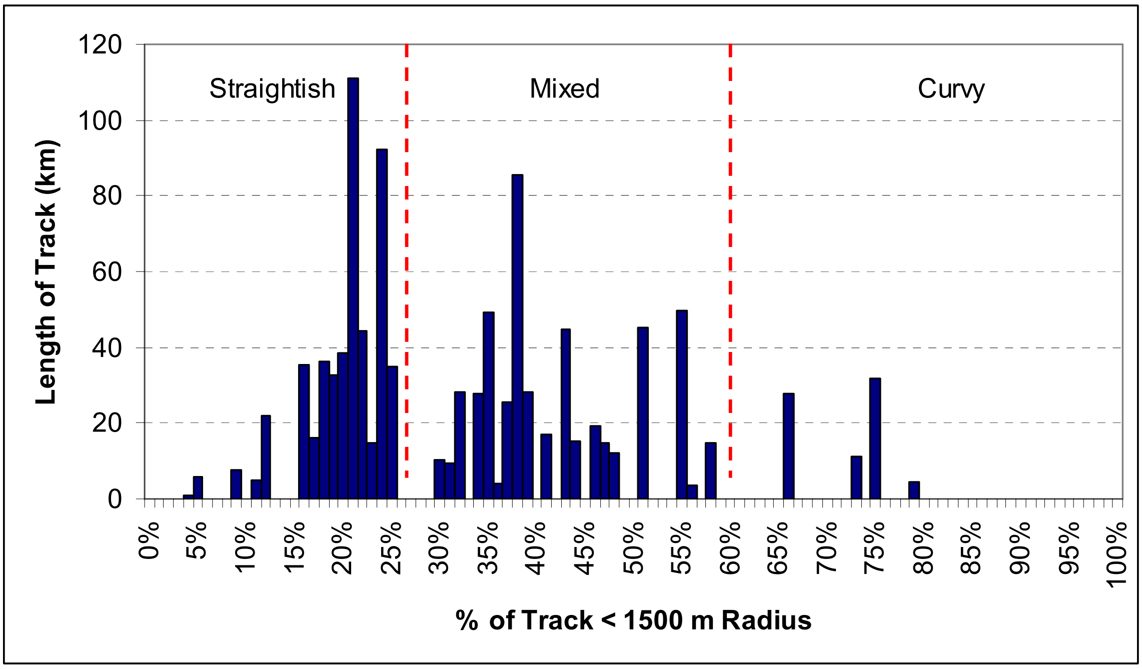

Figure 24. Distribution of Curvature in London & SE Classes

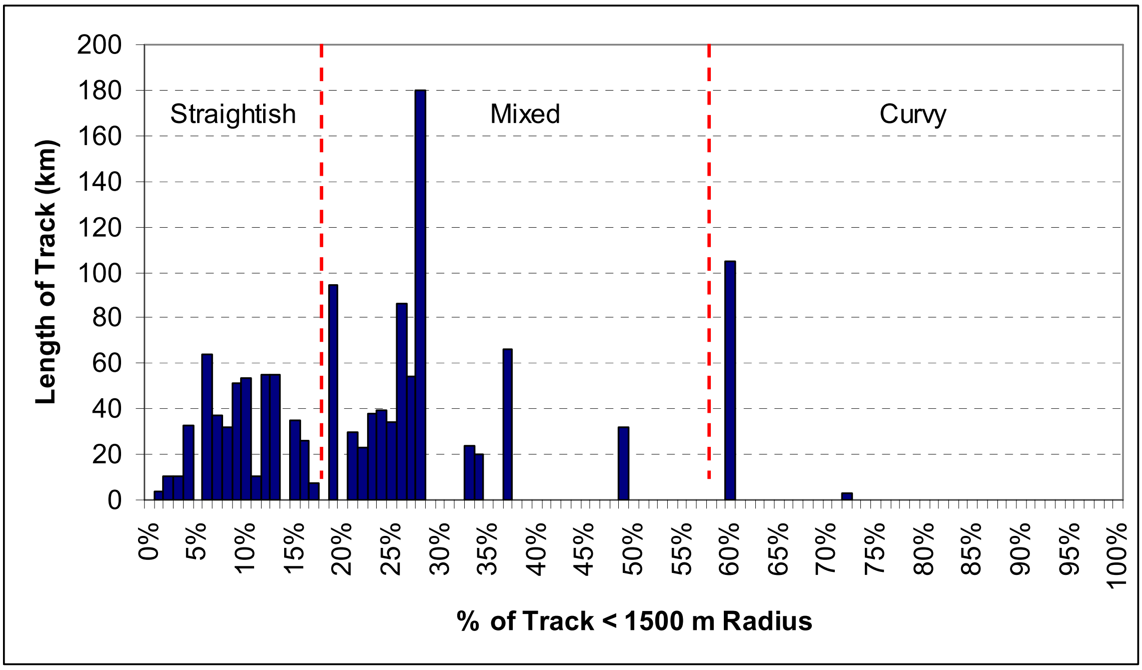

Figure 25. Distribution of Curvature in Primary Classes

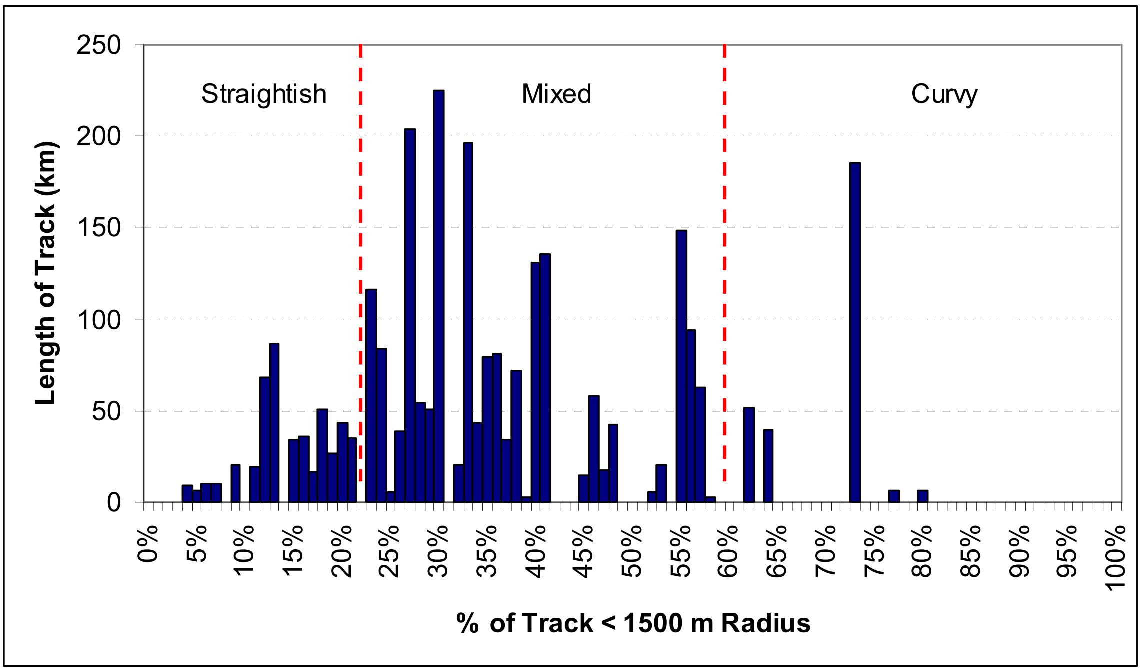

Figure 26. Distribution of Curvature in Secondary Classes

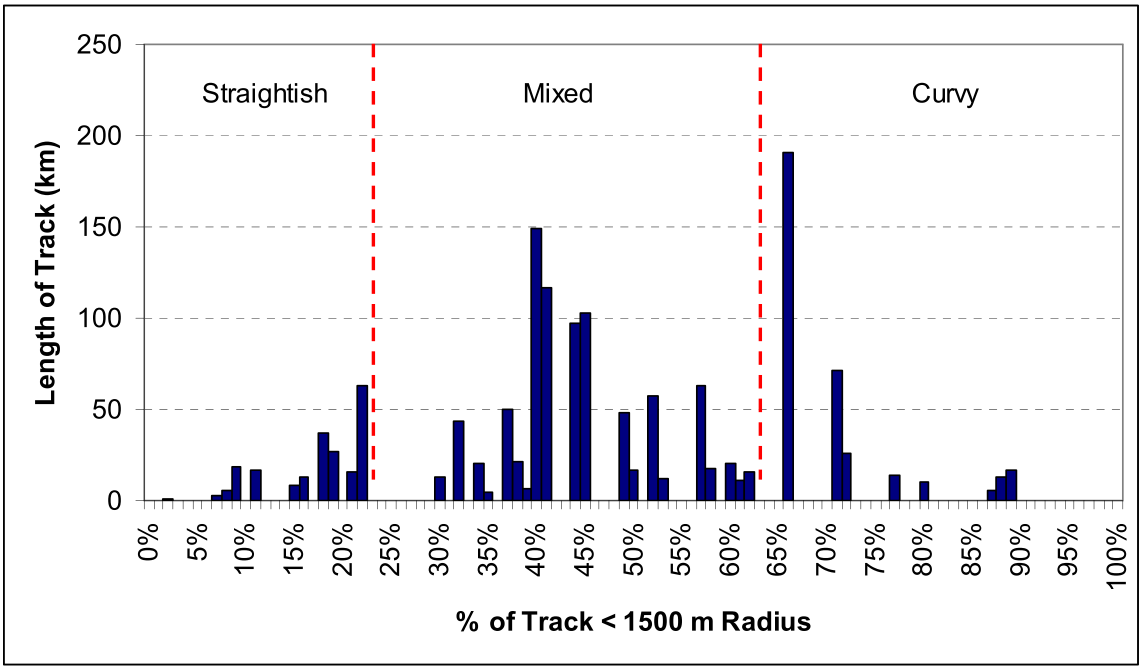

Figure 27. Distribution of Curvature in Rural Classes

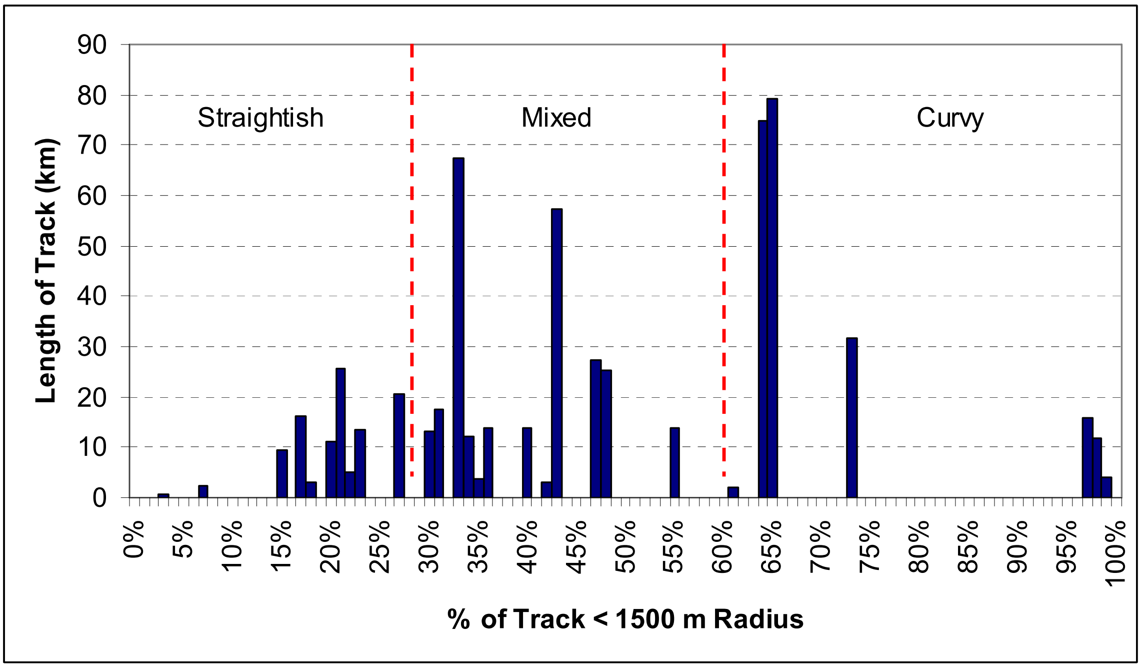

Figure 28. Distribution of Curvature in Freight Classes

Figures 24 through 28 shows that considerable judgement is required in choosing where to locate curvature class boundaries. The intention is to separate the 300 SRSs into 15 groups to keep variable usage manageable. Inevitably, some SRSs will be close to the boundary between two groups and so the charges that apply may differ if a different boundary was chosen.

A different curvature distribution has been used in calculating the variable usage charges for each combination of route class and curvature class. In each case, a curvature distribution representative of the SRSs in that group has been derived.

The variable track and structures costs for each combination of route class and curvature class have been calculated from the sum of costs for the SRSs in each group.

Traffic information is not currently available at the SRS level in sufficient detail for variable usage charging. The total tonnages of passenger and freight are available for each SRS. These are summed for each combination of route class and curvature class. The mix of passenger and freight traffic is assumed to be the same as the network total. The number of each type of vehicle is adjusted to give the appropriate passenger and freight tonnages for each combination of route class and curvature class.

The results of calculating variable usage charges for the particular curvature distribution and cost in each group are published separately.

5 CONCLUSIONS

A high-level review of the existing methodology for calculating variable usage charges provided no justification for immediate changes. However, it revealed several improvements that could be made.

- The source of the exponents in the equivalent damage formulae is undocumented.
- Reasonable alternative exponents give charges that can differ from the current ones by up to 100%.
- Axle spacing and lateral forces are not considered.
- Masonry and concrete bridges are not considered.
- The damage models are not calibrated to current service data.

A full revision of the existing methodology is recommended. This should result in state-of-the-art damage models calibrated to the latest service data. The new methodology should be fully documented and traceable. The revision should be completed in time for Control Period 5.

A new methodology has been developed to recover costs of damage caused by tangential wheel-rail forces. Stakeholder comments and suggestions have been considered in the development. Sensitivity studies on the key assumptions show that the new methodology is robust. In contrast to the existing methodology, reasonable alternative assumptions give charges that vary by less than 10%. For all except a few special cases, the variation is less than 5%.

A methodology has been developed for calculating variable usage charges at the national or route level. It uses traffic volume, cost, and curvature data from Network Rail's ICM. The 300 SRSs in the ICM have been grouped into 15 combinations of route class and curvature class. Although variations in traffic volume have been considered, the mix of passenger and freight vehicle types in each group is not currently known. It has been assumed to be the same as the network average.

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Appendix A

RESPONSES TO STAKEHOLDERS' WRITTEN COMMENTS

Stakeholder comments are shown in italics. Responses are shown in regular text.

Virgin West Coast Trains, 27 June 2007

Comment 1.1

We acknowledge that the current method for charging Train Operators for the damage that their vehicles cause to the Network is reasonable and that it gives some incentive to Operators to minimise such damage through the usage and ongoing establishment of track friendly vehicle types. Similarly the charging regime puts an onus on Network Rail to maintain and renew track in the most cost-effective manner through greater optimisation of possession opportunities.

Noted

Comment 1.2

The report proposes that the current variable charge (which reflects only vertical forces) will also need to incorporate a lateral (tangential) element as well. Although the Variable Access 'Usage' Charge remains effectively the same it is proposed that the methodology which addresses track and structure damage from vertical forces also needs to incorporate the damage from lateral and longitudinal effect.

Variable usage charges would be more cost reflective if they incorporated damage from tangential forces.

Comment 1.3

VWC accepts that this revised methodology could be implemented if certain fundamental issues are resolved which did not result in Train Operators potentially bearing the cost of Network Rail's inefficiencies in maintaining the Network. The existing track access-charging regime is applied nationally to fleets across the entire network (also see part 3.1 below), which means that where major projects may have taken place, (ie. the WCML - particularly with the ongoing high levels of renewal supported through the gradual implementation of enhanced maintenance regimes), we still continue to bear the costs of a route where 'wear & tear' costs are much lower than the national rate for any given fleet.

This argument for route-based charging is noted.

Comment 1.4

We would therefore suggest that in order for us to adopt such a change, that proposals are put forward for the charge be based upon simple route specific criteria (this will enable greater alignment with the complex application of such a Rail Surface Damage charge [RSD] on curved track) as well as specific to the speed and type of individual rolling stock.

Noted.

Comment 2.1

It is clearly obvious from the report that the complexity of such a charge would lead to issues surrounding its transparency in terms of methodology and cost application. The lack of transparency could lead to uncertainty in the application of such a charge, particularly regarding its ability to incentivise the Industry to optimise vehicle design and implementation.

The proposed methodology is a compromise between a detailed analysis and an over-simplified approach to the issue of calculating rail surface damage from individual vehicles. Transparency is provided by describing the method of calculation together with its inputs.

Comment 2.2

It must also be highlighted that by moving to a route based regime it will add complexity if utilised against Network Rail's Infrastructure Cost Model which segregates the network into 300 individual route segments. We therefore believe that generic examples of route (primary, secondary etc) based on the four curvature types (mixed, straight etc.) are a reasonable place in which to start considering a RSD charge. This will maintain transparency through a simplistic but relative charging methodology akin to the Train Operators' operational area.

This recommendation has been adopted.

Comment 3.1

One specific example pertinent to VWC and representative of those issues surrounding the technical complexity of introducing a RSD charging mechanism is in conjunction with tilting train operation. This is explained in detail in section 5.1.4 below.

The proposed new methodology can handle specific cases such as tilting trains.

Comment 5.1.1

VWC considers that certain technical assertions made by TTCI in this part of the report are incorrect.

This comment is assumed to be an introduction to the specific comments that follow.

Comment 5.1.2 – Effect of Track Maintenance and Standards

...RSD is not only caused as a factor of railhead 'wear & tear'; it is also reliant upon the level of track maintenance and the standards to which such work is undertaken.

This issue is more general than the introduction of a rail surface damage (RSD) term. The methodology aims to recover the long-run variable cost of maintaining and renewing track. Included is the cost of grinding and rail renewal that will always be part of railways operations.

Comment 5.1.3 – Effect of Curve Radius on Rail Surface Damage

It is an established fact that Network Rail's maintenance standards require the attainment of a reasonable level of geometric quality. This quality if sustained would result in no identifiable RSD damage (either vertically or horizontally) to the network on track that is straight or with a curve radius above 2500mm. This results in only approx 20% of the network having some resultant vehicle damage 'wear & teat, reducing further to those sections of track with a radius of less than 1000mm, which again in terms of installation and lubrication is Network Rail's responsibility.

The T-gamma tables, on which the methodology is based, account for the reduction in forces at large curve radii. The damage at each band of curve radius is factored by the length of track in the band. Thus, the effect of curve radius on RSD is handled correctly.

Comment 5.1.4 – Handling Pendolino Trains

Furthermore in conjunction with the VWC Class 390 Pendolino fleet, there is no reference within the report that when such rolling stock operates in tilt mode at linespeed, it mitigates against the effect of RCF, whilst compensating for any lack of bogie steering capability. This concept has been demonstrated during track force testing conducted with Pendolinos, and has been previously accepted by Network Rail during various WCML technical forums.

A default T-gamma table will be used for these vehicles based on their assumed primary yaw stiffness. VWC are invited to submit an alternative table and provide details of the modelling and testing used to derive it. It should be noted that track force testing does not measure directly the forces that cause RSD.

Comment 5.1.5 – Grinding Effort

It is also apparent that, the Grinding programme with which Network Rail performs its function in managing damage to track could not consistently be applied to the entire network, as there is insufficient yellow plant to affect this maintenance nationally. However this could be managed more effectively by only grinding track which is straight and has a radii of less than 2500mrn, in turn increasing the ability to cover more of the applicable network.

Network Rail's grinding program is focused on sections of track that require grinding. Likewise, the RSD usage charging methodology recovers cost from required levels of grinding.

Comment 5.1.6 – Squats

Furthermore it has become evident that RSD is not necessarily primarily caused by tangential forces. Up to 40% of all track damage is caused through defects known as 'Squats' which are not linked to rail surface damage and thus should not be associated with RSD costs.

Although Squats may be initiated by some other cause, they are propagated by the same forces that produce rolling contact fatigue and wear.

Comments 5.2.1 and 5.2.2 – Route-based Charging

The data that is identified in this section purports to representing just one type of rail vehicle over a number of differing curvatures and cants. The various connotations of 'RSD effect' caused by just one vehicle operating over a number of track type variables, gives weight to applying a vehicle/route specific charge, as a national average figure per fleet/vehicle type would be unrepresentative of the actual effect mused by such vehicles.

Therefore route based charging is necessary; but to what depth and complexity does a charging regime have to be to capture most or all of the RSD?

It is agreed that introducing a RSD term strengthens the already existing argument for route-based charging. The RSD methodology needs to be at least as deep and complex as the current vertical damage methodology.

Comment 5.3.1 – Cost Transparency

It is apparent from the base data used in this section that most of the data (where understood) is derived from internal Network Rail sources, which does not allow for transparency and the consequential ability to agree or refute the figures being used. To this end how can VWC be sure the figures correctly represent accurate traffic growth and uplifted rates?

The traffic and annual uplifts are agreed each year with the ORR.

Comment – 5.4.1 – Freight and Passenger

What VWC fail to understand is why there is such a major increase in VAC costs (inc RSD) as against a minimal increase for Freight. In table 4 the change in traffic volume for Freight is about 40% lower than for Passenger, but in table 7 the RSD charge is only 10% of that for Passenger.

The shift from passenger to freight is caused by:

a) there being less increase in freight traffic compared to passenger, and

b) freight traffic produces less RSD cost than passenger traffic

Comment 5.4.2 – Freight on Tighter Curves

Taking into consideration that RSD should only apply to approx 20% of the network (see 5.1.3 above), and that freight vehicles tend to run round tighter curves, combined in our particular case regarding tilting rolling stock, how can such a high RSD charge be appropriate?

The numbers presented in Table 7 of the report are for network averages. In this case all vehicles are assumed to go around all curves in the network. Appendix D of the report shows how the charges might vary by route.

Comment 6.1

As we have emphasised above, we are not in disagreement to the principle of RSD charging but it must be administered in a correct and impartial way. To undertake this it must be foundered on a straightforward route-based regime rather than a national regime, which could not take into consideration the differing vehicle types, volumes of traffic and maintenance regimes appropriate to each Train Operator and the route(s) to over which they operate.

There are definite advantages in introducing RSD charging, even on a national basis. There are further advantages in introducing it on a route basis.

Comment 6.2

Furthermore the document takes no account of those principles as to how and where RSD is to be maintained (grinded), and/or renewed. There is an onus on Network Rail to uphold its infrastructure responsibilities the same way VWC is incentivised to minimise track damage through the use of track friendly and tilting rolling stock - this is not clearly evident from the report.

The report states that variable usage charges are based on infrastructure and vehicles maintained to satisfy the industry standards and working instructions.

Comment 6.2

VWC is not therefore in a position to support this proposal without improved transparency and regard to those issues highlighted above.

Responses to the issues highlighted by VWC are given above. Further work is underway to improve transparency.

ATOC and GNER, 29 June 2007

Section 2 – Precedent

…even the relatively simplistic VTA model used today is worthy of review in that:

- *vehicle type charges are national rather than route specific as recommended by V/TSIC*
- *an estimate of average or typical operating speeds is used for each vehicle type leading to under and over recovery.*

Agreed.

Section 5 – Requirements

Network Rail propose to establish a new track access charging regime that extends the existing regime to include track damage costs and vehicle parameters that relate to rail surface damage.

Passenger train operators might support this change, provided that a new regime:

- *Is based on a broadly accepted technical rationale*
- *Delivers true incentives to introduce vehicles that cause lower levels of track damage*
- *Cost changes are embraced within existing franchise agreements*

The proposed methodology attempts to satisfy the first two requirements. It is assumed that existing arrangments.

…it has not been possible to determine what change in the proposed RSD VTA charge term would occur as a result of reducing the primary yaw stiffness of the MKIV fleet.

The use of T-gamma tables is an attempt to simplify the data requirements while still reflecting the differences in performance between vehicles. Reducing the primary yaw stiffness of the Mk IV vehicle would result in a different T-gamma table and hence a different usage charge.

Section 6.1 – Technical Report Section 2

The document asserts that rail surface damage depends on the curving performance of a vehicle, (paragraph 2 of section 2.2). This is misleading because it fails to mention that rail surface damage is also highly dependent on the performance of Network Rail in managing the infrastructure and the standards and parameters to which this work is delivered.

If track is maintained by Network Rail to a reasonable geometric quality there will be no identifiable rail surface damage (rcf or side wear) on track that is straight, or curved with a radius in excess of 2,500m. Typically, only around 20% of the network will consist of curves with a radius of less than 2,500m.

Furthermore, the degree of rail side wear on curves that are tighter than 1,000m is highly dependent on both the installation, and the performance of track lubricators, a Network rail responsibility.

The established philosophy is to base usage charges on a network maintained according to standards. If the standard calls for lubricators on curves less than a certain radius of curvature, then charges should be based on the lubricators being in place and operational. The use of T-gamma tables and the distribution of track in bands of curvature deal with the issue of less RSD on straight and less curvy track.

Section 2 refers to a complex technical analysis in Appendix A that purports to link calculations of Tgamma (the curving performance of a vehicle) to track damage costs. At the heart of this analysis is the belief that grinding is carried out in proportion to the amount of crack damage. Whilst this forms part of Network Rail's aspiration for their rail grinding programme, it is believed that Network Rail's real performance in grinding rails is quite different to their aspirations. Therefore, a fundamental part of the technical analysis is not rooted in fact:

- *Network Rail does not have enough grinding trains to cover all of the network, some track will never be ground.*
- *Network Rail grinds both straight track – where there should be no need to grind for rail surface damage – and curved track – where only curve radii below 2,500m will suffer rail surface damage and require grinding*

The charges are based on the long-run grinding requirements and not what is currently achieved.

There appear to be a number of detail inconsistencies within Appendix A.

Further specific comments on Appendix A are welcome.

The document has a key technical assumption, that rail surface damage is caused primarily by tangential forces (paragraph 2 of section 2.2). This is untrue. Rail surface damage also includes the growth of defects known as squats; that are not linked to tangential forces. Around 40% of all rail replacements are due to squats. Any costs associated with replacement of rails because of squats should be independent of rail surface damage.

See comments on squats above.

Section 6.2 – Technical Report Sections 3 and 4

Section 3 identifies a table of data that describes the curving performance of one vehicle type, on a range of curve radii, and a range of cant deficiency values. This demonstrates that, with an assumed, perfect track geometry, curving performance can vary by a factor of 400 between tight curves and gentle curves. Further variation by a factor of 6 is given by the extent of cant deficiency on any given curve. Clearly, the extent of rail surface damage that can be caused by any individual vehicle on a curve is highly dependent on the curve that it operates over, the cant of the track in the curve, and the operating speed of the vehicle on that curve.

"*This table [Table 1] forms a persuasive argument that rail surface damage costs cannot be allocated on a network wide basis, assuming that all vehicles operate over all curves with assumed levels of cant and of operating speeds.*

The RSD damage term could be included with network average charges, if desired, by making the same type of assumptions that are currently made in the vertical damage methodology.

If track access charges are to be linked to the costs of rail surface damage, and are to incentivise the use of the most appropriate train configurations, the access charges must bear on vehicle types that do the most damage.

Agreed. The proposed use of $T\gamma$ tables determines the rail surface damage caused by different vehicle types.

Any vehicle type, almost regardless of its parameters, that operates on a predominantly straight route will not cause significant levels of rail surface damage. MkIV coaches on ECML are a good example of this point. A charging regime that is applied across the network, would apply high charges to MkIV coaches, because of rail surface damage that they would cause if they operated on the WCML!

Nineteen percent of the ECML between Kings Cross and Doncaster has a curve radius less than 2500m. MkIV coaches are commonly understood to cause rail surface damage on these curves.

Section 6.3 – Technical Report Sections 5 and 6

In section 5, Network Rail data is used to nominate the variable track usage charge that would be applicable in 2005/6 (Table 6), based on those set for 1999/2000 (Table 2), and with updates to reflect traffic growth and changes in Network Rail costs. The increases seem to be based entirely on references that are ***internal Network Rail documents*** *that are not publicly available.*

This section of the document is crucial, as it establishes the size of the variable track access "pie" – see Figure 1, but does so in a way that cannot be understood, without access to the identified Network Rail documents i.e. transparency is required

It is intended to make these documents available for the consultation process.

In section 6, paragraph 2, the document implies that the means of calculating rcf damage from freight trains might not yet be proven. It is unclear why the document believes that there is a need for further investigation of rail surface damage from freight vehicles. ATOC believes that appropriate techniques exist to estimate the track damage done by passenger vehicles, and that these techniques are applicable to freight vehicles, without the need for further research.

The further work on freight vehicles involves checking the appropriateness of the key assumptions that were made to produce the initial estimate of charges.

In section 6, Table 7 takes the total value for variable track access charges identified in Table 6, and reapportions it, taking rail surface damage into account. There is minimal increase of overall costs for the freight sector, but a 50% increase for the passenger sector, relative to 1999/2000 costs.

The costs being compared by ATOC are affected by changes in traffic and costs from 1999/2000 to 2005/06 and the introduction of the new rail surface damage term.

V/T TAG Minutes 22 – 5 June 2007

Minute 2.1

…asked if the constant 'J' [that converts damage to cost] within the surface damage component was dependant on route.

Both network average and route specific values of this constant are being calculated.

…asked why category one, freight locomotives had been split into those with and without steering linkages as they would differentiated by their Tγ value.

Specific models of the Class 60 and 66 locomotives have been used because of their different curving performance.

…said he saw the advantage of the categories and the Tγ tables could be used as a default.

Noted.

…questioned why the Tγ tables for new trains had to be published

…expressed concern that if a new train was built then a competitor could reverse engineer and so establish the train configured.

Tγ tables are used to avoid publishing details of vehicles' suspension designs. Since there is more than one way of producing the same *Tγ* it is not true that the design of a vehicle's suspension can be deduced from its *Tγ* values.

…asked whether Tγ was evaluated with traction forces.

Traction and braking forces are not included. To do so would require assumptions about occurrences of their application during curving.

…asked why the zero cant deficiency column had been used for passenger trains which tend to operate at higher cant deficiency.

…suggested that using column zero was doing a disservice to passenger vehicles and perhaps a Tγ column for cant deficiency should be used for passenger vehicles, and a Tγ column for cant excess used for freight vehicles. This might reduce the current prospective finance shift between the two sectors. A sensitivity test should be undertaken.

It is now assumed that passenger vehicles operate with cant deficiency and freight vehicles operate at balance speed or with cant excess. A sensitivity study into the effect of this assumption is presented in this report.

…asked how tilting trains would be assessed.

An alternative set of *Tγ* numbers will be agreed for special cases such as tilting trains.

…stated that a clear understanding is required of how the charging regime is built up in order to give confidence in it and drive the appropriate behaviour.

This report and other publications are intended to provide that understanding.

…questioned whether the issue of wheel profile had been considered.

Mid-life worn wheel profiles are used in the calculations. A sensitivity study on the effect of wheel profile is presented in this report.

…asked if this [a review of the vertical force component of the track access charge] was being done.

An initial review of the existing methodology is presented in this report. A detailed review is recommended before Control Period 5.

...said that manufacturers were being encouraged (particularly by the revised TAC) to provide bogies with good curving performance but when stability problems caused by high equivalent conicity between the wheel and rail are encountered (eg because of tight gauge track or worn rail profile) manufacturers/Operators are being left with a problem. This was not a tenable position and someone must accept responsibility for controlling maximum conicity levels.

The variable usage charges are based on the assumption that the infrastructure is maintained according to Railway Group Standards.

V/T TAG Minutes 23 – 17 July 2007

Minute 4

…TG questioned why mode 2 defects would not be included.

A vehicle's propensity to cause rail surface damage is expected to be demonstrated by its steady state curving performance.

...said that the propensity to cause RCF Mode 0, 1 and 2 could be caused by different parts of the wheel."

Agreed. The steady state approach has been chosen to give an appropriate level of complexity.

...said that he understood that squats were initiated subsurface and that it was vertical loads that caused them.

Although there are different views on what initiates a squat, it is generally agreed that tangential forces are responsible for propagating cracks from the initial defect.

…questioned how S&C costs will be dealt with.

The proportion of S&C costs due to damage from tangential forces has been estimated and included in the variable usage charge.

...said that track quality could be as specified in the standards but cracks could still be caused by modes 1 and 2"

Agreed. For Control Period 4 vehicles will be charged based on their propensity to produce Mode 0 RCF. Further improvements to the charging regime could be made for CP5 if deemed necessary.

... said that route based charging would incentivise good behaviour/design.

Agreed. Network average charging with the new term for rail surface damage will incentivise improved curving performance. Route-based charging would provide a stronger incentive on routes with a high proportion of curves.

...suggested this [a single worn wheel profile] could be challenged where wheels wear characteristic is different to that shown.

A sensitivity study on the effect of wheel profile is presented in this report. Alternative wheel profiles will be considered if there is evidence they are representative.

...asked that as there are not many wheel profiles, why were the common profiles not utilised to make the assumptions?

Although there are many new profiles the differences between worn profiles are assumed to be insignificant. A sensitivity study on the effect of wheel profile is presented in this report.

Railway Industry Association InfraTIG Minutes – 20 June 2007

...observed that axle spacing as well as axle load was a significant factor to include in any revised [equivalent damage] equation.

Agreed. A full review of the vertical damage charging methodology is recommended.

Doubt was expressed that the relatively small tranche of the TAC to which changes would be applied may not be large enough to incentivise the substantial investment entailed in the development of new, lighter trains.

The cost of a train with good curving performance is not necessarily higher than one with poor curving performance.

It was observed that mixing freight traffic and passenger services with various stopping patterns would invalidate the cant profile calculation on individual curves.

A sensitivity study on the effect of speed in curves is presented in this report.

Railway Industry Association email – 30 May 2007

1 I had understood that RCF is worst for a range of 'middle sized' curves, but table 1 [in TTCI UK NR Report No. 07-003] seems to suggest that the factor is increasingly more severe as curves become tighter (except when operating at cant excess)

Table 1 shows $T\gamma$, which is not the same as RCF. $T\gamma$ is transformed by the proposed damage function into wear and/or RCF.

2 *How is coefficient of friction dealt with?*

A value of 0.4 is assumed for all contact points except the gauge face of the high rail where it is assumed to be 0.2. A sensitivity study on this assumption is presented in this report.

3 *It could be argued that RCF is replaced by sidewear in sharp curves, but this should be offset by track lubrication is it should not be the means by which the top corner of table 1 [in TTCI UK NR Report No. 07-003] is filled in.*

Correct. In sharp curves $T\gamma$ is high enough to cause wear even though the curve is assumed to be lubricated.

4 *The proposed approach seems to create a perverse incentive to Network Rail to allow track to deteriorate, since worse track attracts higher access charges, as well as causing more fatigue damage to the vehicle*

There is no perverse incentive since the cost of maintaining track in deteriorated condition is more than the benefit from any increase in variable usage access charges. The specification and control of track quality is handled outside the access charging regime.

5 *I am puzzled as to why the variable use percentages are so low, because this implies that a 'one train a year' railway would cost around 70% of the cost of the existing railway. There are some obvious costs, such as repair of structures, and drainage, which are train operation independent, and possibly the effects of frost/dry weather on vertical geometry, but I struggle to think of other things.*

Variable usage access charges are based on marginal cost. i.e. the additional cost of operating a vehicle on a network already operating at current traffic levels.

6 *Curving performance is a function of more than yaw stiffness, and a rough formula (but beware formulae when thinking about curving) is:*

yaw stiffness x wheelbase

wheel radius x wheel radius

Agreed. The use of $T\gamma$ tables avoids the need to use curving performance formulae.

7 *I don't understand the tables with straight missed curvy etc bars, but some of the comments do bear out my fist comment, about inclusion of really sharp curves.*

The tables show the distributions of curvature for “Straightish”, “Mixed” and “Curvy” track. Any route on the network will fall into one of these groups.

8 How are the traction characteristics of locomotives taken into account?

These are not considered because it is impractical to know when traction (and braking) is applied at particular curve radii.

9 Tilt trains working at high cant deficiency reduce propensity to generate rail RCF. How will the charge regime allow for this factor.

A $T\gamma$ table will be used that reflects the particular curving performance of tilting trains.

10 In principle I have no problem with the inclusion of a variable charge for plan-view behavior

Noted.

11 The use of "Tgamma" energy or some derivative of it seems sensible as it can encompass a range of different plan-view damage mechanisms (eg wear or rcf)

Agreed.

12 Care is needed that the parameter used incentivises the use of vehicles that are actually beneficial from a "system" view and does not lead to perverse behaviour. I am particularly concerned that use of a "network average" could lead to vehicles running on routes for which they are totally unsuitable. Some form of charge tailored to route or route-type seems necessary to avoid this.

The proposed rail surface damage variable usage charge will incentivise the use of vehicles with good curving performance. Providing high speed stability can be achieved where necessary, this is believed to be a benefit for the system.

13 Some of the input data used seems somewhat arbitrary eg wheel-rail friction levels, cant deficiency (balancing speed), wheel profiles (new for some vehicles, worn for others) and I would wish to see a sensitivity study to clarify whether the relative charges between different vehicles are significantly affected by these choices.

These sensitivity studies are included in this report.

14 Section 2, figure 1 [in TTCI UK NR Report No. 07-003], appears to suggest that the total variable charge will remain the same but in future will be made up of two parts - Vertical + Tangential. BT would like to see an increase in the variable part (together with a reduction in fixed part) to provide more incentive and funding for technical innovation.

This report discusses the apportionment of variable usage costs, which is independent of the amount of the variable usage cost.

15 The report discusses IPR (trade secrets). BT is fully prepared to provide T gamma tables such as Table 1 in Section 3 [in TTCI UK NR Report No. 07-003]. We have already provided this information to NR for the Class 221. Of course, we would not expect this information to be widely circulated or 'published' . However, we don't not consider that measuring suspension stiffnesses and then publishing them respects IPR!

Some stakeholders have said suspension stiffness does represent IPR.

16 The cost associated with the existing vertical track charge is fully in the hands of the train manufacture. It only depends on the vehicle design (speed, axleload & unsprung mass). Each Supplier is free to optimise as he see fit. Therefore it is a fair system although the incentives to fund innovation may be too small.

Noted.

17 […] optimisation. As you are well aware, the compromise between stability and curving performance has always been most important parameter that is a required input - conicity. How can a vehicle Supplier optimise the train (as required by the new RSD term) if NR is not taking any responsibility for rail conicity? Our problems on Hull Trains are well known. Our Contract specified 0.4 operating conicity. As a responsible Supplier, we optimised the bogie correctly but the train is unstable on certain 'tight to gauge' sections of track. The train operator considers that we did not take into account the known poor quality of NR track and NR say that track is within standards! The problem is that the standards do not control conicity!!! Should now pay for the increased cost of bogie maintenance on this 'well optimise' solution?

The $T\gamma$ values are calculated using typical mid-life wheel and rail profiles. They could be recalculated using specific profiles if agreed between the operator and Network Rail. Track gauge specifications and control are outside the scope of variable track usage charges.

18 […] requested by NR. We complied with this requirement by offering a 30% reduction in a typical bogie yaw stiffness, reflecting that this is a 120 kph application. Fortunately, in view of our Hull Train experience, we asked NR for information on the worn rail condition and gauge. Together with worn P8 wheel information, we concluded that the actual conicity is between 0.6 to 0.75. With this conicity, we are unable to offer any reduction in yaw stiffness. If the new charges had already been in place, who would have paid the additional TAC - it should not be the Operator, it should not be BT because we are prepared to optimise - therefore I assume that NR would pay until the track has been fixed?

The rail surface damage component of variable usage charge would be based on a typical mid-life wheel and rail profiles, not on the specific conicities on the route in question unless agreed between Network Rail and the train operator.

19 This incentive for reduced yaw stiffness will certainly result in problems for the Train Operator and Supplier if nobody has a Contractual responsibility to control the operating conicity. Each Tender/Contract will need to define the Contractual track parameters for the actual route, then the Supplier can optimise the bogie and the Operator will know who pays if there are problems in service.

Agreed. A new standard on conicity would seem appropriate regardless of any changes to the variable usage charging regime.

20 ... I agree with your comments on tilting trains and the benefits of operating at higher cant deficiency. However, the Train Operator has little control over the actual allowable speed on the curves since this depends on the track quality. The Class 221 spends very little time operating at enhanced permissible speed so Virgin would be unable to realise the full reduction in the TAC that the train can provide.

The rail surface damage component of the variable access usage charge would be based on typical, actual operating speeds and cant deficiencies.

21 Some suspension types have a high primary yaw stiffness but this is balanced by a reliable low maintenance solution. Within Europe, high yaw stiffness bogie, such as TGV, are fitted with on-train wheel flange lubrication, does NR consider that on-train lubrication should be encouraged by a track charge incentive?

This question requires further study. In principle, if benefits could be identified from on-train wheel flange lubrication these would be shared between Network Rail and the train operator.

Siemens email – 2 January 2008

1 ... it is stated that "parties would have to submit the accompanying modelling file", if they want to change the T-gamma tables by submitting own calculations. Additionally, it is stated that a similar process will apply for new trains. Our question is how is it secured that these data will be handled confidential? Which type of file is needed (just a file, which is describing the model [e. g. a Word-Dokument], or a file, which can be used by a simulation progam)?

The intention is that parties can provide their own T-gamma tables, provided they can demonstrate the calculations have been performed correctly. The supporting evidence would be kept secure and confidential by Network Rail.

2 The Class 185 DMU cars are each equipped with one motor bogie and one trailer bogie. How has this be considered for the assumption of the curving class and the determination of the unsprung mass?

The Class 185 has been considered as having both bogies powered.

3 The T-gamma values for the curving classes Coach_50_40, Coach_50_50, Coach_50_60 and perhaps other classes, which are used in APPENDIX C, are missing.

The net damage for these and other has been interpolated between adjacent vehicles with slightly different parameters.

4 In chapter 2, different methods for the calculation of the vertical track damage are compared and a sensitivy analyses of several exponents have been performed. Finally, it is recommended in the report that the method regarding vertical track damage should be revised until CP5.

From the supplier's point of view, it would be preferred if the methods for vertical and tangential track damage remain unrevised (or only with little adjustments) for at least 10 years (i. e. CP4 and CP5). That would the suppliers allow to have stabil design criteria for new vehicles. Additionally, the time of CP4 could be used to monitor the usability of the new tangential track damage method. If it is necessary, slight changes of the tangential track damage method could be introduced for CP5.

Noted

If the vertical track damage method will be revised, the new method should also consider that the vertical forces on the track are not only dependent on the unsprung mass but also on the inertia of the unsprung mass around the x-axis, because the vertical track irregularities of the left and the right rail are usually not parallel (see Six, Klaus: "Abhängigkeit dynamischer Q-Kräfte von der Massenverteilung im Fahrwerk", Elektrische Bahnen Vol. 104 (2006) No. 11, pp. 530 - 534). Thus, it is suggested to consider an additional factor.

It is also suggested that the new method allows stakeholders to submit own calculations of the vertical track forces for a new vehicle - this should be similar to the method for the tangential track damage. It could also be useful to calculate these damage values on a route based approach, too. The route sections should be the same as for the tangential track damage method (chapter 4).

Otherwise, the vertical forces on the track are usually measured during the admission tests of a new vehicle type in some countries. These measured results could also be used for determing the vertical damage. Such a method has already been introduced for calculating the track access charges of the Austrian Federal Railways for locomotives.

Additionally, it should be mentioned that both methods (vertical track damage and tangential track damage) do not consider the track damage, which is caused by the lateral track forces (Y-forces). These forces might cause damage on the track regarding its lateral alignment, when the vehicle is hunting or during curve *negotiation. The Austrian method is considering this issue. Thus, if the method will be revised it is suggested to introduce a new method regarding the lateral track damage.*

These comments will be considered in any future review of vertical damage usage charges.

5 *Serveral tables in chapter 2 (e. g. Table 6 or Table 7) show the effect on the distribution of the variable usage charges as a result of the sensitivy analyses. The total sum of these variable chages is 379,545 £k/year. Does this value also include the variable usage charge for the tangential damage? How much are the variable usage charges for the vertical damage and the tangential damage?*

These tables concern sensitivity studies on the existing usage charge that only considers damage from vertical forces.

6 *Table 12 (Page 22): The 4th column of this table shows the primary yaw stiffness. Is this the "primary yaw stiffness" or the "effective primary yaw stiffness", which is also considering the effect of axle spacing within the bogie? How is this primary yaw stiffness defined, which is shown in this table? It would be necessary to have there a calculation method in order to determine this value for new vehicles, because this could be a criterion for new designs. Additionally, we are a little bit confused about the unit "MNm/mrad" - is that correct?*

These values are the primary yaw stiffness of an axle on a bogie with a 2.6 m wheelbase. The units stated are incorrect. They should be MNm/rad (Mega Newton meters per radian).

7 *Pages 23 - 25: Several assumptions are described, which have been used for the Tgamma calculations. It might be reasonable if a party wants to submit their own calculations for a particular vehicle to use these assumptions, too, if they apply for a specific vehicle. This would allow to have comparable results between the different parties. However, the information on these pages give not the necessary full information for these calculations.*

For example: It is stated on page 24 that the friction coefficient might be reduced at the gauge face of the high rail. However, no information can be found where the border between these two friction coefficients is defined. Is there a transition area between these two values? Our simulations have shown that the Tgamma values at the wheel can change significantly only by changing the transition area between the friction coefficients on the tread and on the flange! Additional questions regarding track irregularities or the calculation of the Tgamma values (maximum value or average for a given distance?) may arise.

Thus, is it highly recommended that Network Rail should issue a document, which gives detailed guidelines how the Tgamma values have to be created by any party. With these guidelines any party should be able to perform these calculations without any remaining question to Network Rail. (of course, the assumptions of these *guidelines may be changed if they do not apply in a specific case - e. g. higher cant deficiency for tilt trains)*

All the information required will be made available.

We would also suggest that Nework Rail will publish a parameter sheet and the Tgamma results of a benchmark vehicle. Any party could then check their calculations first with this benchmark vehicle if these results are comparable with theose, which are published by Network Rail.

Noted

8 Tables 13 and 14: We would like to please Network Rail to transmit us the profile-files. How are the profiles for the left and the right wheel different? Which difference does this have on the curve negotiation (right-hand or left-hand curves)?

The left and right wheel profiles used for the freight vehicle modeling are the same. The left and right wheel profiles used for the passenger vehicle modeling are very similar, and there is no significant difference between the T-gammas generated on the left and right hand curves.

9 Remark to Chapter 3.2.3: Especially, Figure 19 shows a disadvantage of the top-down approach. It is generally known that due to the reduction of the friction coefficient (by lubrication), the rcf and wear damage (regarding to the Tgamma model) is reduced. Hence, also the costs for the track maintenace for the repair of the rcf and wear damage will be less. This would result in lower track access charges if a bottom-up approach would be used. However, Figure 19 shows that the track access charges could be reduced for most of the passenger vehicles by up to 2 %, when there is no lubrication considered and the vehicles are causing more damage on the track. This is due to the fact that (by using the top-down approach) the total sum of the track maintenance costs is a fixed value, which is just distributed to the different vehicles. Therefore, the benefit of lubrication does not have a positive effect regarding lower track access charges and there seems to be no incentive to Network Rail to invest in track lubricators for the damage reduction. A bottom-up approach would have this incentive.

The ORR sets efficiency targets to network Network Rail. These incentivize Network Rail to reduce track maintenance and renewal costs by, for example, using lubricators.

Additionally, we could not find any incentive to Network Rail to maintain an appropiate track quality within these methods. This would also be important to have because it is generally known that a poor track quality may lead to further damages (e. g. rcf can be caused by major track irregularities). The costs for repairing the additional damages seems to be included into the top-down approach.

The ORR sets track quality targets to Network Rail. Track quality levels are also specified in Network Rails standards.

10 Table 17 (Page 33): Are there also tables for the different route and curvature classes available, which are similar to Table 11? This would allow to optimize the design of a new bogie to a reasonable curve distribution.

Route and curvature classes are no longer being considered for CP4.

11 Page 36, last paragraph: The route based charges have the advantage that the vehicle design can be adjusted on the requiremnts of the track for a specific route it is supposed to be introduced. However, when the curve distributions are separated into 15 different classes, it does not seem to be reasonable that the traffic mix is still assumed on the network base. We would recommend to determine the values of the traffic mix for each route and curving class or at least for each route class.

Noted

12 Page 48: It is stated that the influence of the traction and brake forces are not included into this calculation method. However, we know from our experience, that the traction and brake forces have a major influence either on the amount of the Tgamma values and also on the position of the damage on the wheel and the rail. Thus, this should be considered in some way.

This effect was considered. It was decided that the complication of including traction and braking was not justified.

13 Figure B1: The curves of the crack damage and the wear damage are actually properties of the whole tribological system and, therefore, dependent on the wheel and rail material (and other parameters). For example, the values for the wear damage, which can be found in the literature, have a wide range. How will be dealt with this issue, when new materials are introduced (e. g. head hardened rails)?

A recalibration of the usage charges may be required if and when a significant proportion of the rail on the network is head hardened.

14 Table B1: How have these values been assumed? (especially the last two rows)

The first four values have been taken from current practice and standards. The last two values are from Ref. B1.

15 APPENDIX B: This appendix is showing how the track maintenance costs are related to the track damage; this seems to us like a bottom-up aproach, because to each amount of rcf or wear damage an amount of costs is matched (see equation B16).

*However, as far as we understand the top-down aproach the total track maintenance cost is related to the total damage (total costs = k * total damage with total damage = sum of the damages of the entire fleet). Hence, the factor k is calculated depending on the different amounts of the total damage of the entire fleet. After k has been determined, the costs for a vehicle can be calculated by the following equation: costs = k * damage * vehicle miles.*

Thus, we could not find the link between these approaches. We would like to ask for further information regarding this issue.

A hybrid approach has been followed. The total variable cost that should be recovered through the usage charge is known. It is apportioned between the vehicles using the network according to engineering analysis of the damage they each cause.

Freightliner Ltd. letter – 13 February 2008

Wagons and Laden Weight - We are concerned with regard to the Average Loaded Weights given to the intermodal wagons within the model. It would appear that the weights given are broadly the maximum gross weight allowed on those wagons. We understand that this maybe appropriate for other commodities, e.g. coal, but request recognition that intermodal wagons are rarely loaded to their full weight capacity.

Weight assumptions will be checked.

Speed of Class 86 and Class 90 locomotives - We would suggest that on the freight side of the coin that locomotive speeds are limited to the speed assumption for the freight wagons they haul. Furthermore we would suggest that there is no difference between the loaded or empty running speed of intermodal trains.

Speed assumptions will be checked.

Absence of "track friendly" TF25 bogie - It is with regret that we noticed the absence of the TF25 bogie that is considered to be track friendly and as such "rewarded" for use. We are currently seeking approval for release of data regarding the TF25 we use and will share the data as and when we can. Additionally, the exclusion of LTF13 creates concern however we are unable currently to provide actual data for these.

A category for TF25 bogies will be added when this information has been received and processed.

General Completeness - We suggest that all bogie types are included as this is an opportunity to get the spread of charges proportionately cost reflective of the pre-efficiency target and so encourage positive track friendly investment over the next control period.

This would require detailed knowledge and modelling of all freight bogies, which is not considered practicable in time for CP4.

Appendix to ATOC letter – 30 January 2008

4.3 ATOC would value clarifications in the following areas:

- *Rail life is assumed to be a function of sidewear only; are there not a number of other factors that control rail life, including the effects of vertical track forces?*

The methodology is only used to apportion variable costs due to lateral forces. The existing methodology is used to handle costs (including reduction in rail life) due to vertical forces.

- *Rail grinding (the cost of rail grinding) is assumed to be done exclusively because of rail rcf; are there not other benefits such as the control of corrugations and the enhancement of short wavelength irregularities around welds that reduce vertical track forces. Should this not reduce the cost element of rail grinding applicable to rsd?*

95% of the rail grinding cost is assumed to be due to rail RCF.

- *Rail rcf cracks are assumed to exist uniformly throughout curves; although there are situations where this is true there are there not many situations where this isn't the case?*

It is assumed that the entire curve is ground if RCF is uniform or in patches.

- *Rail grinding (the cost of rail grinding) is assumed to be carried out everywhere on the network. The rationale for this proposal , together with Tγ values contained in Appendix D of Doc 2 make it clear that track with a curve radius greater than 1500m (the range of track for which trackside lubrication should not be considered) is most unlikely to need any grinding at all; this amounts to around 80% of the network. Should this not reduce the cost element of rail grinding applicable to rsd?*

No. 95% of rail grinding is assumed to be driven by RCF. The methodology calculates the amount of rcf damage (and wear) depending on curves radius.

- *It is assumed that the costs and the processes for controlling rsd in S&C can be averaged in with plain line. Given that the cost of rsd in S&C is around 40% of the total cost for rsd, is this a valid assumption?*

The simplifying assumption that has been made is that a vehicle with the propensity to cause RSD in curves will have a similar propensity to cause it in S&C.

- *Rail grinding is assumed to remove rail surface to match the depth of rcf cracks, when cracks are at a critical size. This does not seem to be a practical way of managing rail grinding. The document makes no assessment of the possible benefits of earlier grinding when cracks are smaller and growing more slowly.*

The use of the word critical in the report was an error. The assumption is that grinding takes place when the cracks can be removed in a typical grinding cycle (0.5 mm depth of grind).

- *The proposal calculates Tγ, and hence wear and rcf damage, using surprising values for friction coefficients*

A sensitivity study on coefficient of friction is presented in the report. The sensitivity to the assumed values is considered small in comparison with existing, accepted sensitivities.

4.4.1 NR should advise ATOC on the extent to which current knowledge of rcf calculations of rail rcf on TPE routes might affect the proposed method for calculating TACs. If the effect is considered to be substantial, further actions may be necessary.

Route-based charging is no longer being proposed for CP4.

4.4.2 ATOC would like NR to demonstrate that the cant deficiency assumption used in the proposal will still permit the calculation of adequately cost-reflective TACs.

A sensitivity study on cant deficiency is presented in the report. The sensitivity to the assumed values is considered small in comparison with existing, accepted sensitivities. Exceptions to the general assumption on cant deficiency will be made for special cases such as tilting trains.

4.4.3 ATOC would like NR to demonstrate that a broader, and more probable, set of friction coefficient values do not produce significant changes in TAC relative to those based on friction coefficients assumed in the document.

This request will be considered.

4.4.4 ATOC would like NR to demonstrate that the rail and wheel profiles assumed will still permit the calculation of adequately cost-reflective TACs.

A sensitivity study on freight vehicle wheel profiles is presented in the report. The sensitivity to the assumed profiles is considered small in comparison with existing, accepted sensitivities. Assuming typical mid-life wheel and rail profiles is considered a reasonable approach to deriving cost-reflective variable usage charges, and is consistent with the philosophy of basing these charges on the as-maintained condition of track and vehicles.

4.5 ATOC would like NR to provide comparisons between the proposed route and traffic data and data from ACTRAF and established curve histograms, demonstrating that there are appropriate levels of agreement.

Route-based charging is no longer being proposed for CP4.

Appendix B The document seems to make the following assumptions in working logic, all of which are implicit rather than explicit:

- *Rail replacement is exclusively because of reductions in rail size that are a consequence of grinding and of rail wear*

That portion of the rail replacement costs due to tangential forces is due to this. A portion of rail replacement costs is also handled by the existing variable usage charging methodology.

- *Grinding, and the associated cost, are applied wherever rail rcf cracks achieve a 2mm length*

Varying this assumption would shift costs between grinding and renewal. A sensitivity study on ratio between these costs is presented in the report. The sensitivity to the assumed profiles is considered small in comparison with existing, accepted sensitivities.

- *Rail rcf cracks with a 2mm length exist in quantities, in one location, that it is cost-effective to grind*

It is assumed that once RCF appears in one location on a curve it won't be long before it is sufficiently widespread to justify grinding the whole curve.

- *Grinding delivers no other benefit than the elimination of rail rcf damage*

95% of the benefit from grinding is assumed to be the elimination of RCF

- *The purpose of grinding is to eliminate rail surface material that has an exhausted fatigue life, leaving fresh material at the running surface of the rail*

A principal purpose of grinding is to remove cracks when they are small and before they propagate to transverse rail breaks.

- *Rail wear is a consequence of vehicle induced forces on curves that are lubricated according to Network Rail standards*

It is an accepted principal that variable usage charges are based on the network maintained according to the required standards. Even lubricated rails wear.

Appendix B Given the earlier assumption that the exclusive purpose of grinding is to eliminate rcf damage, it seems illogical for the analysis to assume that grinding and rail wear will occur together in one location.

There is a region in the whole life rail model (T-gamma between 65 and 175 N) where wear is occurring, but cracks are growing at a faster rate. In this case it is necessary to supplement natural wear by grinding to remove RCF.

Equation B13 The appearance of this equation in the document is preceded by two qualifying statements. This suggests that equation B13 can only be used in situations where the qualifying statements are true.

This derivation has been changed to avoid the need for the qualifying statements.

Table B1 It is important that these values [renewal and grinding costs] are related to the assumptions made in the analysis. Network Rail should demonstrate that these costs are de-coupled from the other drivers for grinding and renewal work, such as condition of ballast, sleepers, pads, fastners etc and condition of welds. It is not clear that use of ICM is able to deliver the appropriate cost data to be compatible with this analysis.

The ICM is used to calculate variable usage costs for track and structures. A percentage of these costs is assumed to be due to tangential forces. It is proposed to recover this percentage with the new methodology. Other drivers for track and structure maintenance and renewal are handled by the existing methodology based on vertical forces.

Table B1 As with grinding depth, Network Rail should provide data to support the assertion that a mean of 10mm [side loss limit] reflects the condition of rail that is renewed because of side loss.

Varying these assumptions would shift costs between grinding and renewal. A sensitivity study on ratio between these costs is presented in the report. The sensitivity to the assumed profiles is considered small in comparison with existing, accepted sensitivities.

Table B1 ATOC assume that these [crack and wear damage rates] are simply indicative values.

These values were taken from the Whole Life Rail Model (Ref. B1).

West Coast Trains Ltd. letter – 1 February 2008

Clearly on the WCML with Tilting Rolling Stock operating over curves at up to 300mm CD, the average figure of 40mm is somewhat unrealistic, particularly as such high CD's help our tilting vehicle's curve performance. We would therefore suggest that in order to make the RSD term representative for WCTL in terms of the applicable 'T-Gamma' figures (Traction Force exerted x Creepage); that Network Rail re-calculates in incremental steps a FULL range of CD's for each vehicle – (i.e. Class 390 and 221). This when applied to the "CD's themselves as determined by the linespeed profile for each vehicle's route, will thus ensure the RSD is correctly weighted for each 'tilt' applicable vehicle.

Although route based charges are no longer proposed for CP4, a network average cant deficiency for tilting trains could be considered.

… although any re-calculation of T-Gamma values is not necessarily too onerous to undertake, our belief is that the VAMPIRE modelling tool used to calculate curve values etc., does not currently encapsulate Class 390 and Class 221 values. However there would be the possibility, subject to cost, that should Alstom be approached, they may be able to undertake such T-Gamma re-calculations for us, utilising their "ModKat" programme. This would thereby ensure that any RSD value for WCTL would be robust and fair.

This would be the preferred approach. Alstom calculations would be subject to technical audit.

It is also widely acknowledged by the Industry that the WCML is the busiest Freight route in the country, not necessarily in terms of the heaviest hauled services but in terms of the timetable quantity, length and volume of services operated. Combine this with the intensive use south of Rugby and in the NW with passenger services, and you immediately see that 'wear & tear' is high. Although appropriate maintenance and renewal provisions are/will be in place, there is nevertheless the issue that any VTA charge needs to be, not only cost reflective in terms of average RSD but also relevant to the tonnage and damage covered over any particular route. This gives more credence to our belief that individual route/vehicle value application is necessary.

Route-based charges are no longer proposed for CP4.

Appendix B

RAIL SURFACE DAMAGE FUNCTION

Rail surface damage is calculated using a function developed by AEA Technology Rail.[1] Figure B1 shows this function separated into its two components of crack damage and wear damage.

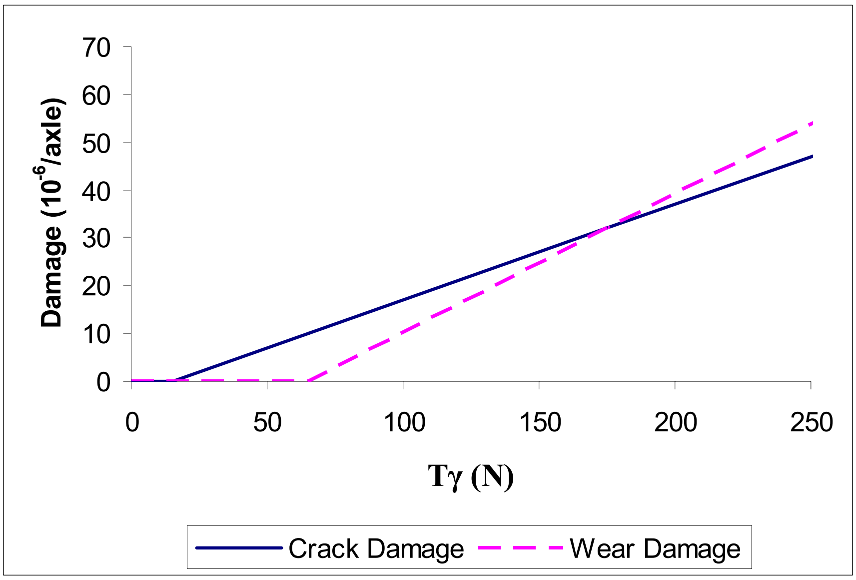

Figure B1. Separated Rail Surface Damage Functions

The parameter on the X-axis of Figure B1 is a combination of lateral and longitudinal forces (T_{lat} and T_{long}) and creepages (γ_{lat} and γ_{long}) as defined in Equation B1:

$$T\gamma = T_{Lat}\gamma_{Lat} + T_{Long}\gamma_{Long} \qquad \text{(B1)}$$

Total rail surface damage is assumed to be a combination of crack damage and wear damage. Figure B1 shows there are four regions to consider:

1. For $0 < T\gamma \leq 15$ N, there are no maintenance or renewal costs associated with rail surface damage.

2. For $15 < T\gamma \leq 65$ N, cracks are removed by grinding. The amount of grinding is proportional to the amount of crack damage. Eventually enough material is ground from the head of the rail to require the rail to be renewed.

3. For $65 < T\gamma \leq 175$ N, less grinding is required to remove cracks since some are removed by wear. Grinding and wear combine to remove

material from the head of the rail, and the rail eventually requires renewal.

4. For $T\gamma > 175$ N, grinding is no longer required since cracks are being removed completely by wear. Eventually the wear reaches the point where the rail requires renewal.

The function for calculating the equivalent miles travelled by a vehicle in terms of rail surface damage is derived by considering the annual cost due to rail surface damage on a mile of track. In general, the annual cost for a mile of track will be the sum of the annual grinding cost and the annualised renewal cost:

$$\frac{Cost}{Year} = \frac{GrindingCycles}{Year} \times GrindingCost + \frac{RenewalCost}{RailLife} \qquad \text{(B2)}$$

Since grinding is performed when the cracks in the railhead reach a critical size (i.e. RCF Damage = 1):

$$\frac{GrindingCycles}{Year} = \frac{RCFDamage}{Axle} \times \frac{Axles}{Year} \qquad \text{(B3)}$$

Rail is commonly renewed when the material lost on the side of the rail reaches a specified limit. Thus:

$$RailLife = \frac{SideLossLimit}{SideLoss/Year} = \frac{SideLossLimit}{SideLoss/Axle \times Axles/Year} \qquad \text{(B4)}$$

Now:

$$\frac{Cost}{Year} = \frac{Cost}{Axle} \times \frac{Axles}{Year} \qquad \text{(B5)}$$

Substituting Equation B3, B4 and B5 into Equation B2 gives:

$$\frac{Cost}{Axle} = \frac{RCFDamage}{Axle} \times GrindingCost + \frac{SideLoss}{Axle} \times \frac{RenewalCost}{SideLossLimit} \qquad \text{(B6)}$$

where:

$$\frac{RCFDamage}{Axle} = \frac{CrackDamage}{Axle} - \frac{WearDamage}{Axle} \qquad \text{for } 0 < T\gamma < 175 \text{ N} \qquad \text{(B7a)}$$

$$\frac{RCFDamage}{Axle} = 0 \qquad \text{for } T\gamma \geq 175 \text{ N} \qquad \text{(B7b)}$$

and:

$$\frac{CrackDamage}{Axle} = 0 \text{ for } T\gamma \leq 15 \text{ N} \tag{B8a}$$

$$\frac{CrackDamage}{Axle} = CrackDamageRate(T\gamma - 15) \text{ for } T\gamma > 15 \text{ N} \tag{B8b}$$

and:

$$\frac{WearDamage}{Axle} = 0 \text{ for } T\gamma \leq 65 \text{ N} \tag{B9a}$$

$$\frac{WearDamage}{Axle} = WearDamageRate(T\gamma - 65) \text{ for } T\gamma > 65 \text{ N} \tag{B9b}$$

At $T\gamma = 175$ N the crack and wear damage rates are equal. Thus:

$$WearDamageRate = \frac{160}{110} \times CrackDamageRate \tag{B10}$$

Now, the amount of material lost from the side of the rail for each axle is the sum of the depth ground and the depth worn for each axle:

$$\frac{SideLoss}{Axle} = \frac{DepthGround}{Axle} + \frac{DepthWorn}{Axle} \tag{B11}$$

where:

$$\begin{aligned} \frac{DepthGround}{Axle} &= \frac{DepthGround}{GrindingCycle} \times \frac{GrindingCycles}{Axle} \\ &= \frac{DepthGround}{GrindingCycle} \times \frac{RCFDamage}{Axle} \end{aligned} \tag{B12}$$

For $15 < T\gamma \leq 175$ N:

$$\frac{DepthWorn}{DepthGround} = \frac{WearDamage}{RCFDamage} \tag{B13}$$

Thus:

$$\begin{aligned} \frac{DepthWorn}{Axle} &= \frac{WearDamage}{RCFDamage} \times \frac{DepthGround}{Axle} \\ &= \frac{DepthGround}{GrindingCycle} \times \frac{WearDamage}{Axle} \end{aligned} \tag{B14}$$

Substituting Equations B11, B12 and B14 into Equation B6 gives15 < $T\gamma \leq$ 175 N:

$$\frac{Cost}{Axle} = \frac{RCFDamage}{Axle} \times GrindingCost + \frac{DepthGround}{GrindingCycle} \times \left(\frac{RCFDamage}{Axle} + \frac{WearDamage}{Axle} \right) \times \frac{RenewalCost}{SideLossLimit} \quad \text{(B15)}$$

and finally for 15 < $T\gamma \leq$ 175 N Equation B16:

$$Cost = RCFDamage \times GrindingCost + \frac{DepthGround}{GrindingCycle} \times \left(RCFDamage + WearDamage \right) \times \frac{RenewalCost}{SideLossLimit} \quad \text{(B16)}$$

For $T\gamma \geq$ 175 N:

$$\frac{DepthWorn}{Axle} = k \times \frac{WearDamage}{Axle} \quad \text{(B17)}$$

At $T\gamma$ = 175 N the depth worn per axle from Equations B14 and B17 should be the same. Thus:

$$k = \frac{DepthGround}{GrindingCycle} \quad \text{(B18)}$$

Substituting Equations B11, B17 and B18 into Equation B6 gives for $T\gamma \geq$ 175 N:

$$\frac{Cost}{Axle} = \frac{DepthGround}{GrindingCycle} \times \frac{WearDamage}{Axle} \times \frac{RenewalCost}{SideLossLimit} \quad \text{(B19)}$$

and finally for $T\gamma \geq$ 175 N Equation B20:

$$Cost = \frac{DepthGround}{GrindingCycle} \times WearDamage \times \frac{RenewalCost}{SideLossLimit} \quad \text{(B20)}$$

Thus, an equations have been derived that gives the cost of rail surface damage in terms of known variables and the wear index ($T\gamma$) generated by a vehicle. Table B1 lists assumed values for the variables in Equation B15.

Table B1. Constants and Assumed Values

Grinding Cost	£2,000 /km	Cost to grind a km of track (may involve more than one pass)
Renewal Cost	£250,000 /km	Cost to renew the rail for a km of track (one rail only)
Depth Ground	0.5 mm/grinding cycle	Depth of material removed from the gauge face of the rail per grinding operation (may involve more than one pass)
Side Wear Limit	10 mm	Maximum allowable gauge face wear at the gauge point of the rail
Crack Damage Rate	0.2×10^{-6} /axle	Amount of crack damage accumulated per axle pass
Wear Damage Rate	0.291×10^{-6} /axle	Amount of wear damage accumulated per axle pass

Note that:

1. The results are sensitive to the ratio of grinding cost to renewal cost, not their absolute values.
2. Side wear limit is derived from Reference 2. It is based on a nominal head width of 70mm and an average limit on head width of 60mm before corrective action is taken.
3. Crack and wear damage rates are taken from Reference 1.

Substituting the values from Table B1 into Equation B16 gives$15 < T\gamma \leq 175$ N:

$$Cost = 14{,}500 \times RCFDamage + 12{,}500 \times WearDamage \tag{B21}$$

Using Equation B7:

$$Cost = 14{,}500 \times CrackDamage - 2{,}000 \times WearDamage \qquad \text{for } 0 < T\gamma \leq 175 \text{ N}$$

(B22a)

Substituting the values from Table B1 into Equation B20 gives:

$$Cost = 12{,}500 \times WearDamage \qquad \text{for } T\gamma \geq 175 \text{ N}$$

(22b)

where *CrackDamage* and *WearDamage* are defined in Equations B8 and B9 respectively in terms of $T\gamma$.

References

1. Burstow, M.C. October 2003. “Whole Life Rail Model Application and Development for RSSB – Development of an RCF Damage Parameter.” AEA Technology Rail, Derby.

2. Network Rail. October 2005. “Inspection and Maintenance of Permanent Way.” *Network Rail Standard MR/SP/TRK/001*, Issue 02, London, UK.