Transport Research Laboratory

Road User Charges Review - Engineering Advice

by W H Newton and V Ramdas

CPR310

Contract No. 08/09-55

CLIENT PROJECT REPORT

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Prepared for:	Project Record:	Contract No. 08/09-55
		Road User Charges Review - Engineering Advice
	Client:	New Zealand Ministry of Transport
		Jonathan Petterson

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Executive summary

The New Zealand Ministry of Transport commissioned TRL Limited (Transport Research Laboratory) to provide independent advice on a number of issues connected with their Road User Charges Review. The key conclusions are:

Fourth Power Rule

- The fourth power equation does not accurately reflect the relationship between axle loads and pavement wear.
- Determining a more realistic exponent will depend on how road maintenance costs are related to heavy vehicle traffic on different strength roads.
- A high proportion of the Road User Charges (RUC) paid by the heaviest vehicles is based on the calculation of Equivalent Standard Axles (ESA). There is considerable uncertainty about the calculation of ESAs. It may be appropriate to reflect this uncertainty by reducing the relative importance of the ESA component of RUC.

Calculation of Equivalent Standard Axles

- Assumptions about reference loads, weight distribution across axle groups and payload distribution mean that the current ESA values are unlikely to be representative of real vehicles.

Relationship between fuel consumption and road network costs

- In general, measures to reduce road network costs will tend to increase fuel consumption (and other operating costs). Network costs related to ESA-kms would be expected to be reduced by spreading a vehicle's weight over more axles. In comparison, increasing the number of axles would increase the capital cost, rolling resistance, fuel consumption, tyre and maintenance costs, and the unladen weight of the vehicle.
- Additional data on vehicle use and operating costs would be required to produce a more detailed correlation. It is recommended that any analysis should also consider the impacts per unit of goods moved (tonne-km) to take into account payload capacity impacts.

Would charges penalising more damaging trucks make a difference in road wear?

- The TERNZ-Covec report presents evidence that operators' choices of vehicles are influenced by Road User Charges: "seven axles is sufficient for truck and trailer combinations to achieve 44 tonnes yet the most common truck and trailer combination has eight axles".
- The TERNZ-Covec report also shows that adopting Austroads reference weights and a second-power rule would make it slightly cheaper to operate with 7-axles than with 8-axles. It suggests that small shifts in fleet composition may occur over time. However, this analysis is reported in terms of \$/km rather than \$/tonne-km. The additional carrying capacity available using 7-axle vehicles may further promote their use, leading to a larger shift in fleet composition.
- More information on the actual performance of the different classes of road network and the types and timings of maintenance on the network is needed to evaluate the impact of potential resulting changes in ESAs on road wear and costs.

Gross weight as a proxy for road space requirements

- There is some uncertainty about the appropriate Passenger Car Equivalent (PCE) values. However, there is little justification for using weight as a proxy for space.

1 Introduction

The New Zealand Ministry of Transport commissioned TRL Limited (Transport Research Laboratory) to provide independent advice on a number of issues connected with their Road User Charges Review. The advice covers the following topics:

- Whether the assumptions about the impacts of vehicle weight and axle configuration in the Cost Allocation Model appropriately reflect road engineering practice and road network conditions in New Zealand. This will be informed by:
    - o Theoretical context on the nature of the relationship between road construction and maintenance costs and vehicle weight and axle loadings; and in particular
    - o An assessment of the relative merits of the different points of view on the relationship between axle weight and road wear and the relationship between axle configuration and road wear.
- The extent of correlation between fuel consumption of heavy vehicles and their road network costs;
- Whether there is an exponential relationship between real world road damage and variations in axle loadings in the weight ranges at which heavy trucks operate; and
- Whether a scale of charges penalising more damaging trucks will actually make a difference in road wear.

Following the submission of the initial report, the Ministry of Transport asked for further amplification in the following three areas:

- Conclusions regarding use of the fourth power rule.
    - o Any specific suggestions as to the manner in which it may be appropriate to reduce the relative importance of the ESA component of RUC taking on board the uncertainty around the calculation of ESAs (Equivalent Standard Axles).
    - o Whether there were any particular elements of the NZ road costs that should be re-allocated to other parameters of the model?
- Calculation of ESAs.
    - o Taking note of TRL view that the current assumptions in the model about weight distribution across axles are likely to be unrealistic, further and more specific comments on options for making the ESA more realistic.
    - o TRL view on how much improvement could be achieved in this regard and how significant were the potential benefits from such improvements.
- Gross vehicle weight
    - o Comments on the validity of using a formula based on gross vehicle weight as a proxy for road space requirements; (This approach had been criticised in comparison to the Australian approach, based on vehicle length).

TRL's advice does not repeat the research and analysis undertaken for previous reviews, but provides an overview of their key findings and conclusions and, where there are divergent views, an independent evaluation of the relative merits of those views.

TRL has reviewed a number of documents. These include:

- TERNZ-Covec Report: Heavy Vehicle Road User Charges Investigation – Final Report. A report produced by TERNZ-Covec for the Ministry of Transport (February 2008).
- McKenzie Podmore Report: Efficiency and Equity Issues in the Funding of Roading Expenditures. A report prepared by McKenzie Podmore Limited for the Local Government Forum and Road Transport Forum (May 2008).
- RR281: Effect on Pavement Wear of Increased Mass Limits for Heavy Vehicles – Concluding Report. Land Transport New Zealand Research Report 281.
- TERNZ Report: The Impact of RUCs on Heavy Vehicle Configuration Choice and its Effects. A report produced by TERNZ for the New Zealand Transport Agency (undated).

TRL's advice is presented in the following Sections:

- Section 2 covers the issue of the "fourth power rule". The applicability of the "fourth power" or other exponential relationship is a key issue discussed in the TERNZ-Covec and McKenzie Podmore Reports;
- Section 3 covers other assumptions about the impacts of vehicle weight and axle configuration;
- Section 4 covers the relationship between fuel consumption and road network costs;
- Section 5 covers whether a scale of charges penalising more damaging trucks would actually make a difference in road wear;
- Section 6 covers the use of gross weight as a proxy for road space requirements; and
- Section 7 covers other issues that may need to be considered.

2 Fourth Power Rule

2.1 Relationship between traffic loading and road wear

Road deterioration is influenced by a wide range of factors. These include:

- Design: the original design strength of the pavement;
- Foundations: the underlying ground conditions;
- Construction: the materials used and how well the road was constructed;
- Traffic: number and loading of vehicles travelling over the road, vehicle parameters such as speed, suspension type, and tyre and axle configurations;
- Maintenance: these activities could weaken or strengthen the road; for example, there can be significant impacts on road performance following the digging and reinstatement of trenches;
- Environment: varying moisture and temperature levels, freeze-thaw cycles, time of exposure to the environment, reactions of road materials to variations in the ambient environment; these factors can damage the road or make it more susceptible to other factors;
- Time: materials age. For example, roads which do not carry any traffic deteriorate over time.

There is also a range of types of deterioration including non-structural rutting (i.e. rutting of the surface layer), other surface deterioration, such as change in texture depth, cracking, structural wear, etc.

In this review, particular attention has been paid to the relationship between traffic loading and road wear. The TERNZ-Covec report describes the historical development of the “fourth power rule”. This “rule” relates structural road wear to the fourth power of the axle weight. The assumed structural wearing effect is expressed in terms of Equivalent Standard Axles (ESA) (some countries use slightly different terminology). Typically, 1 ESA is equivalent to an axle of 80 kN / 18,000 lb / 8.16 tonnes.

Thus a 10 per cent increase (i.e. 1.1 times the original number) in axle weight would lead to a 46 per cent increase in ESAs for a 4^{th} power relationship:

$$1.1 \times 1.1 \times 1.1 \times 1.1 = 1.46$$

Similarly, if a 2^{nd} power relationship applied, a 10 per cent increase in axle weight would lead to a 21 per cent increase in ESAs:

$$1.1 \times 1.1 = 1.21$$

and, if a 6^{th} power relationship applied, it would lead to a 77 per cent increase in ESAs:

$$1.1 \times 1.1 \times 1.1 \times 1.1 \times 1.1 \times 1.1 = 1.77$$

Figure 1 demonstrates relationships between Axle Weight and the number of Equivalent Standard Axles.

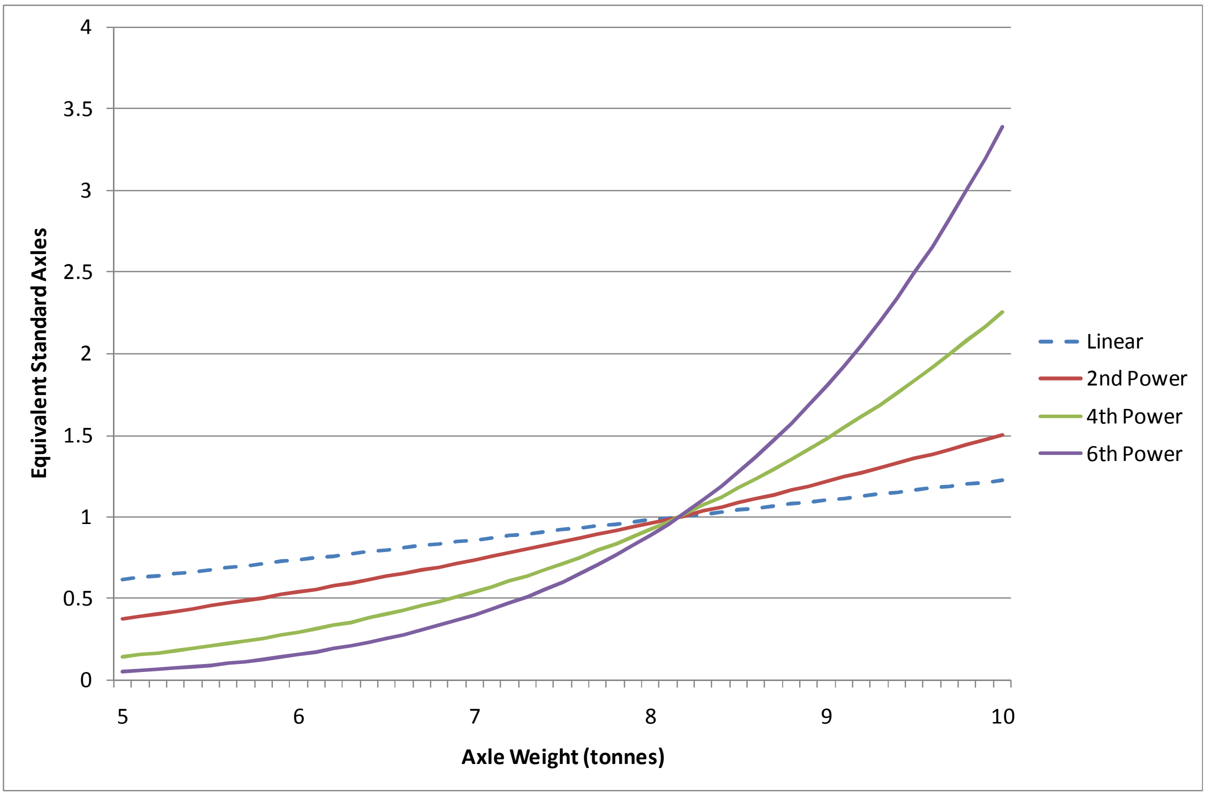

Figure 1. Power relationship between axle weights and ESAs

The debate on the damage law exponent is ongoing. The stated conclusion from the research study at the Canterbury Accelerated Pavement Testing Indoor Facility (CAPTIF) reported in RR281 was that for high strength pavements the damage law exponent should be reduced from the current value of 4 and for low strength, low volume roads higher values than 4 should be used. However, the range suggested was 1.1 to 3.4. This is consistent with other studies that have also suggested values for the exponent other than 4, and the wide range of exponents used in the design methodologies for roads in different countries. For example:

- A re-analysis of the original AASHTO Road test data was carried out by Addis and Whitmarsh in 1981. The analysis took account of the fact that an in-service road deteriorates under the action of a wide spectrum of wheel loads applied in a random sequence. The results suggested that the Road test data could be interpreted to give exponent values from 3 to 6, with higher values for weaker pavements. However, the consensus view reported was that “the 4^{th} Power relationship generates results about damaging power which, when applied to design, produce solutions that are in broad accord with observed behaviour; precise validation is difficult because the observed behaviour of roads under normal traffic cannot provide detailed information on the link between pavement damage and axle weight”.
- Atkinson, Merrill and Thom (2006) carried out a study in 2006 to identify wear factors for designing road pavements on UK’s strategic road network. The study identified the wide range of exponents used worldwide for different types of construction and condition parameters. The range of power laws used is shown in Table 1. As a result of the inconclusive results, the UK Highways Agency continues to use the 4^{th} power relationship in their pavement design procedures.

Table 1. Power law exponents for different modes of deterioration

Mode of Deterioration	Range of Exponents
Flexible Pavements	
Non Structural rutting	1.0 - 1.5
Cracking	1.3 - 3.1
Serviceability	4.4
Rutting	4.0 - 9.6
Asphalt fatigue	4 - 5
Rigid Pavements	
Rigid pavement cracking	5.5 - 18.0
Faulting at joints	0.7
Subgrade	
Deformation	4.0 - 7.4

- Phase 1 of a report to be published by the Forum of European Highways Research Laboratories (FEHRL) discussed the range of different exponents, the reference axle loads used throughout Europe and the implications of these differences (FEHRL, 2004). Whereas for fully-flexible pavements in Europe, the exponent is usually taken to be either 4 or 5, a much wider range of exponents are used for semi-rigid pavements.
    - In Germany, the Netherlands, the UK and Switzerland, no differentiation is made for different pavement types and a uniform exponent is used
    - In France, an exponent of 5 is used for traffic assessment on fully-flexible pavements while an exponent of 12 is used for other pavement types
    - In Belgium, an exponent of 4 is used for traffic assessment on fully-flexible pavements while an exponent of 33 is used for semi-rigid structures; the Belgian design method also uses different reference loads for traffic assessment on fully-flexible pavements (80 kN) than for semi-rigid pavements (130 kN)
    - In Spain, an exponent of 4 is used for flexible pavements while an exponent of 8 is used for semi-rigid pavements

2.2 How the “fourth power rule” is used

The “fourth power rule” (or other exponent) is primarily used when designing new roads. Different countries use different methods and assumptions, but the basic processes are similar (see Section 5 of Atkinson, Merrill and Thom, 2006). These processes are largely based on an empirical understanding of the relationship between:

- Expected traffic – including assumptions about vehicle weights, exponents, etc; and
- Road design – including the underlying ground, construction materials and thicknesses

The resulting designs tend to be conservative, having to allow for deficiencies in construction, traffic growth, changes in vehicle weights, etc. In practice, the assumption about the appropriate exponent tends to have a relatively small impact on the overall cost of the new road.

This approximation is however, more difficult to justify when used to calculate road user charges, particularly where the same exponent is used for all road types, traffic conditions etc. Indeed, there appear to be few cases where the "fourth power rule" is explicitly included in road user charging / taxation systems. The UK Vehicle Excise Duty (VED) used to be based on detailed cost allocation but has been simplified, partly as a response to increase in foreign heavy vehicle traffic. It still includes an element that reflects ESAs (see Table 2).

Table 2. UK Vehicle Excise Duty Rates (from 13 March 2008)

Vehicle Type	Vehicle Excise Duty (£ per year)
5-axle up to 40 tonnes	£1,850
6-axle up to 44 tonnes	£1,200

Using the "fourth power rule" for charging per km or per year is much more problematical than using it in road design because the marginal infrastructure cost associated with use of a particular vehicle depends on so many different factors. These factors include: design of the vehicle; how it is maintained; how heavily loaded it is; how the weight is distributed between the axles; how strong the road is; how rough the surface is; as well as other factors connected with road deterioration.

2.3 Appropriate factors to use in New Zealand

Both the TERNZ-Covec and McKenzie Podmore Reports draw attention to the results from the research study at the Canterbury Accelerated Pavement Testing Indoor Facility (CAPTIF) reported in RR281. These reports suggest that the exponent of the power relationship might be reduced from 4 to 2 (TERNZ-Covec) or 2.25 / 1.5 (McKenzie Podmore).

Determining the power laws using an accelerated testing facility requires:

- Use of a suitable range of representative road structures.

  Section 3.1 of RR281 reports that "Compared with the possible pavement types present in the New Zealand state highway network, this accelerated pavement loading set is considered to be fairly limited".

- Ascertaining appropriate definitions of end of life.

  The definition of end of life involves consideration both of the condition parameter or parameters on which to judge this and the level of threshold condition taken as end of life. The CAPTIF test included measurements of rutting and VSD (Vertical Surface Deformation). The point is made in Section 3.2 of RR281 that despite stating that the rutting and VSD parameters are comparable, ".. all the pavements should be of similar strength. However quite different performances in terms of rutting and VSD were obtained".

- Testing using a range of typical wheel loads.

  Only 3 different wheel loads were considered in the trials. It is not immediately obvious from RR281 how the effects of these different wheel loads on performance have been considered. A more careful examination of other previously referenced reports is needed to resolve this issue.

- Means of converting the test results to the real road environment.

  Due to insufficient tracking (a frequent limitation of accelerated pavement testing), the actual results have been statistically extrapolated to estimate the passes to end-of-life, introducing significant uncertainties. Another major issue is the difficulties in extrapolating results from accelerated tests in a covered facility to real roads exposed to varying temperature and moisture. Section 7 of RR281 specifically considers Road User Charges:

  "One of the findings of this report suggests that the value of damage law exponent *n* depends on the pavement strength. Pavement strength has been classified by way of structural number (SNP) as used in dTIMS deterioration modelling. Low strength pavements (low SNPs) will result in high damage law exponents of 4 or greater, while medium and high strength pavements (medium and high SNPs) suggest an exponent of less than 4 and sometimes as low as 1 is more appropriate."

There is therefore uncertainty about how the CAPTIF results should be interpreted and its robustness for use in introducing significant changes to the damage law exponent for charging purposes. A future position based charging system may be able to charge lower rates for strong roads than for weaker roads. It may also be possible to estimate heavy vehicle travel on different strength roads and make an adjustment to the assumed exponent.

It was noted that the Highways and Network Operations Group (HNO) of the NZ Transport Agency "considers that the current 4th Power relationship for wear is an appropriate average for most New Zealand roads. This view is based on HNO's research at CAPTIF …" (NZ Transport Agency, 2008).

Further evidence on the traffic loading and the deterioration of actual New Zealand roads is needed to clarify some of the relationship issues.

2.4 Elements of Road Costs

Table 3 gives the breakdown of costs, within different work categories, allocated on the basis of ESA-km and is based on information from the CAM07-08 Spreadsheet.

Of the costs allocated to ESA-km:

- 12% of the total costs are allocated to new roads. Allocating 12% (State Highways) to 15% (Local Roads) of the cost of new roads to ESA-kms appears to be reasonable.
- 74% of the total costs are allocated to the various types of pavement maintenance. This appears to be a relatively high allocation, particularly given the uncertainty associated with the use of the 4th power. The proportions that should be allocated to ESA-km will depend on the mechanisms of deterioration (whether structural or surface).

  For example, examining the performance of pavements on the strategic network in England has shown that:

  - Strong well-built pavements, even if heavily trafficked, did not weaken gradually through the effects of cumulative traffic loading but maintained their strength with time. The deterioration (e.g. cracking or deformation) is far more likely to be found in the surfacing rather than deeper in the structure. This is generally the case provided the surface deterioration is treated before it begins to affect the structural integrity of the pavement and the pavements remain structurally serviceable for indeterminate periods without need for structural maintenance.

Table 3: Allocation of pavements costs to ESA-km

Work Category	Allocation of Expenditure to ESA-km ($ million)			
	State Highways	Local Roads	Total	% of total spend ($469M)
New Roads	$41.6	$15.1	$56.7	12%
Pavement Maintenance				
Area Wide Pavement Treatment	$29.9	$67.2	$97.1	21%
Pavement Maintenance	$26.8	$53.8	$80.6	17%
Maintenance Chip Seals	$17.2	$32.4	$49.6	11%
Rehabilitation	$0	$39.0	$39.0	8%
Road Reconstruction	$6.8	$24.7	$31.5	7%
Thin Asphaltic Surfacing	$13.1	$11.1	$24.2	5%
Seal Extension	$0	$16.6	$16.6	4%
Road Reconstruction - pavement	-	-	$4.8	1%
Seal Widening (Maintenance)	$0	$1.8	$1.9	0%
Total	$93.9	$246.5	$345.2	74%
Other Works				
Major Drainage Control	$1.3	$6.0	$7.3	2%
Bridge Renewals & New Bridges	$0.6	$0.5	$1.1	0%
Railway Level Crossings	$0.0	$0.5	$0.5	0%
Total	$1.9	$6.9	$8.9	2%
Other Costs				
Professional Services	$14.9	$14.6	$29.5	6%
Police (CV Investigation, RUC Enforce.)	-	-	$16.3	3%
Highway Administration	-	-	$11.2	2%
Strategy Studies	$0	$0.8	$0.8	0%
Transportation Studies	$0	$0.6	$0.6	0%
Total	$14.9	$16.0	$58.3	12%
Overall Total	$152.3	$284.6	$469.1	100%

Note: Costs not allocated to State Highways or Local Roads are only included in the Total Column.

- Laboratory studies of surface deterioration on experimental pavements using the TRL Pavement Test Facility (equivalent of CAPTIF), showed an almost linear response of area to load (i.e. for surface wear the power exponent is 1).

- 2% of the total costs are allocated to other highway work, including drainage control and bridge renewals.
- 12% of the total costs are allocated to 'other' costs – including enforcement and administration.

Three work categories make up about 54% of the total allocation of expenditure to ESA-km, Area wide pavement maintenance (21%), pavement maintenance (17%) and maintenance chip seals & thin asphaltic surfacing (16%).

2.4.1 *Area wide pavement treatment*

This work category has the highest allocation of expenditure to ESA-km. The treatments included are described as thin overlays, rip and relay and chemical stabilisation (i.e. both structural and surface treatments).

Thin overlays are generally considered to be a superficial treatment and not a strengthening treatment. The structural contribution of rip and relay treatment depends on the depth of material being replaced. Chemical stabilisation is generally used to treat the lower layers (i.e. foundation).

It is difficult to comment in detail without an indication of the design and proportions of spend on the different treatments. However, given the combination of structural and surface treatments, the 65/25 allocation to ESA-km and GVW-km appears to be heavily biased to structural damage.

2.4.2 *Pavement maintenance*

Pavement maintenance is defined as maintenance of the structure and serviceability of the road and includes a variety of work types. As with the area wide pavement treatment, there is insufficient information to make detailed comments on the allocation. The treatments include both structural and surface treatments and therefore could in principle have a higher proportion allocated to GVW-km.

Some related points:

- Appendix F (Review of cost allocation model, 2001) states that 'higher volume roads having a higher proportion of wear related costs, which is allocated to the ESA vehicle cost characteristic'. The higher volume roads may also be the stronger roads and, as noted in Section 2.3, a lower exponent may be more appropriate. , i.e. allocation to ESA-km would be lower;
- Effect of utilities – Digging and reinstating of trenches is recognised to impact negatively on the structural and surface properties of the pavement. Analysis of the impacts of the damage caused by utility trenches on the local roads network in the UK has shown that they are responsible for just under 8% of the ~£800M maintenance expenditure. Also, trenching reduces the structural life of the pavement by about 18%.

2.4.3 *Maintenance chip seals and Thin asphaltic surfacing*

Maintenance chip seals (pavement resurfacing of an established sealed road) and Thin asphaltic surfacing (surfacing treatment technically necessary as an alternative to conventional chip sealing) are surface treatments. However, 16% of the costs are allocated to ESA-km.

The allocation of a higher proportion to GVW-km is appropriate. However, the logic of allocation to ESA-km is not immediately clear.

Laboratory studies using the TRL pavement facility have shown a power exponent of 1 for surface wear (i.e. all costs would be allocated on the basis of number of heavy vehicles or more appropriately, to GVW-km).

2.4.4 Rehabilitation

This is described as treatment required for the benefit of road users and this covers all the different categories of users. The basic principle of rehabilitation could result from a range of condition and result, as shown in the examples of this type of work, in a range of treatments. The current allocation is heavily biased towards ESA-km. At one extreme, where major maintenance is required the allocation could be appropriate, but depending on the type and nature of work carried out, this could change. The source of wear and the amount / type of damage driving the rehabilitation are critical to the allocation process. One option may be to allocate in a similar manner to reconstruction.

2.4.5 Reconstruction

The allocation appears appropriate.

2.4.6 Other work categories

The total expenditure against the following work categories represents only a small proportion of the total costs (14%). Having a complicated methodology for allocating these costs may not deliver additional value. General comments:

- Drainage: there is an initial cost associated with the provision of drainage and part of this is due to the provision of the higher strength required for heavy vehicles. Once provided, drainage forms part of the 'base facility'. Deterioration of the drainage system can affect the strength of the pavement and the weaker pavement is then more susceptible to structural wear from heavy vehicles. However, heavy vehicles do not directly inflict damage on drainage. Allocation to ESA-km seems inappropriate.
- Bridge renewals and new bridges: the allocation appears appropriate.
- Railway level crossings: in the UK, maintenance of the crossing area is the responsibility of the railway infrastructure owners, with Highway Authorities responsible for the approaches to the crossing. The maintenance of the crossing area is driven mainly by the requirement to provide a safe surface (such as anti skid) for the different categories of users (car drivers, pedestrians, etc).
- Policing: the logic of allocation to ESA-km is not clear.
- Professional Services: Treating these costs as part of the maintenance expenditure simplifies the allocation process and may be justified for that reason. However, as with policing, the allocation to ESA-km appears inappropriate.

2.5 Risk and Uncertainty

An alternative approach would be to consider the uncertainty associated with the ESA figures. This could involve:

- Defining a range of possible scenarios (for example, different power laws or allocations of costs)
- Looking at the sensitivity of the cost model to the different scenarios / assumptions
- Associating a probability to each major scenario (with the sum of probabilities equal to 1.0)
- Calculating values based on the scenarios weighted by the probabilities

This approach could aid developing a consensus, or could lead to more debate, depending on whether there is general agreement about the scenarios and probabilities.

2.6 Conclusion

Consideration of the available evidence has led to the following conclusions:

- As stated on page 25 of the TERNZ-Covec report: ".. the fourth power equation does not accurately reflect the relationship between axle loads and pavement wear".
- Determining a more realistic exponent will depend on how road maintenance costs are related to heavy vehicle traffic on different strength roads.
- A high proportion of the Road User Charges (RUC) paid by the heaviest vehicles is based on the calculation of Equivalent Standard Axles (ESA). There is considerable uncertainty about the calculation of ESAs. While the uncertainty has limited effect on road design, it is more difficult to justify its use for road user charging. However, the evidence so far produced from the CAPTIF study (and other studies worldwide) is insufficiently robust to justify changes in the damage law exponent or select a different single exponent for road user charging purposes. It may be appropriate to reflect this uncertainty by reducing the relative importance of the ESA component of RUC.

3 Impacts of vehicle weight and axle configuration in the Cost Allocation Model

3.1 Calculation of ESAs

In addition to the exponent, there are a number of other assumptions that are built into the calculation of ESA values. These are discussed in the TERNZ-Covec report and include:

- Reference loads (see Section 5.1 of the TERNZ-Covec Report): these incorporate assumptions about the relative impact of closely-spaced axles and different tyre sizes. There is logic in using similar assumptions in road design and in calculating ESAs for Road User Charging. However, the factors do not include wide single tyres (used commonly on semi-trailer axles). There is considerable debate about the relative impacts of wide single and twin tyres.
- Weight distribution across axle groups (see Section 5.2 of the TERNZ-Covec Report): the assumption that the vehicle weight is distributed across axles in proportion to the reference loads is unrealistic. Data from the weigh-in-motion (WIM) sites could be used to make this more realistic of typical vehicles (see Section 3.2 of this Report).
- Assumed payload distribution (see Section 3.4 of the TERNZ-Covec Report): it is assumed that half of vehicle travel is at full load and half is empty. This is unrealistic. If it were the case, the WIM data presented in Figures 4, 5, 10 and 11 of the TERNZ-Covec Report would show two equal peaks – one at RUC licence weight (full load) and one at a much lower weight (empty). In practice, vehicles carrying bulk commodities between a single source and a single destination tend to travel either full or empty, most other vehicles tend to have the patterns shown in these figures (see Section 3.3 of this Report).

3.2 Weight distribution between axles

In practice, the weight distribution between axles will depend on the vehicle's unladen weight, dimensions, load carried and position of the load.

The following example is based on weigh-in-motion (WIM) data for 5-axle articulated vehicles (2-axle tractive-unit and 3-axle semi-trailer) travelling on a UK motorway.

Using the regression lines in Figure 2, the approximate unladen (assuming a lightweight semi-trailer) and fully-laden axle weight distributions would be as shown in Table 4:

Table 4: Example weight distribution on a UK 5-axle articulated vehicle

	Unladen (13 tonnes)	Fully-laden (40 tonnes)
Axle 1 (steering)	5.12 t	6.86 t
Axle 2 (drive axle)	3.62 t	11.29 t
Semi-trailer bogie	4.26 t	21.85 t
Total	13.00 t	40.00 t

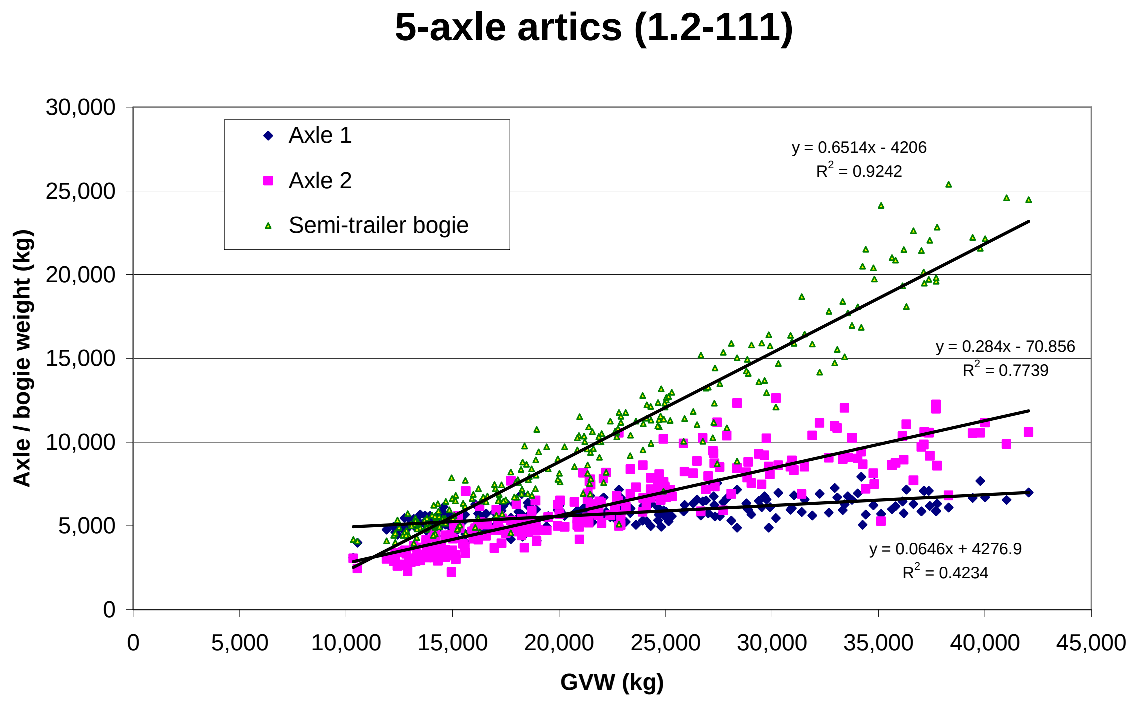

Figure 2. WIM data for 5-axle articulated vehicles on a UK motorway

The weight distribution changes as the vehicle is loaded. When unladen, about 40 per cent of the weight is on the first axle (due to the position of the engine, cab, etc). At full load, only 17 per cent of the weight is on this axle. (UK vehicles are generally “forward-control” / cab-over, the change in front axle weight would be lower for “normal-control” vehicles.)

3.3 Proportions of empty and fully-laden travel

The NZ Cost Allocation Model assumes that half of the distance travelled is at full load and half at no load. In practice, the proportions of load will depend on the type of load being carried. Whilst it would not be practicable to charge vehicles on the basis of the type of load, it is likely that the types of load vary between types of vehicle. For example, in the UK 4-axle rigid vehicles are generally used to transport bulk commodities (aggregates, coal, etc). These commodities tend to be transported in bulk from a single origin to a single destination. As a result, 4-axle rigid vehicles tend to be empty or fully loaded (Gross Vehicle Weights from WIM data are shown in Figure 3) – their UK weight limit is 32 tonnes.

In comparison, articulated vehicles tend to carry a wide variety of loads with relatively few operating near the maximum weight. For example, less than 20 per cent of 5-axle articulated vehicle in the WIM data were operating at over 30 tonnes (limit = 40 tonnes).

Figures 8 to 11 of the TERNZ-Covec Report show NZ WIM weights for four different types of trailer. The patterns for types 37 and 43 have two peaks (more typical of bulk loads), whilst those for types 29 and 33 do not.

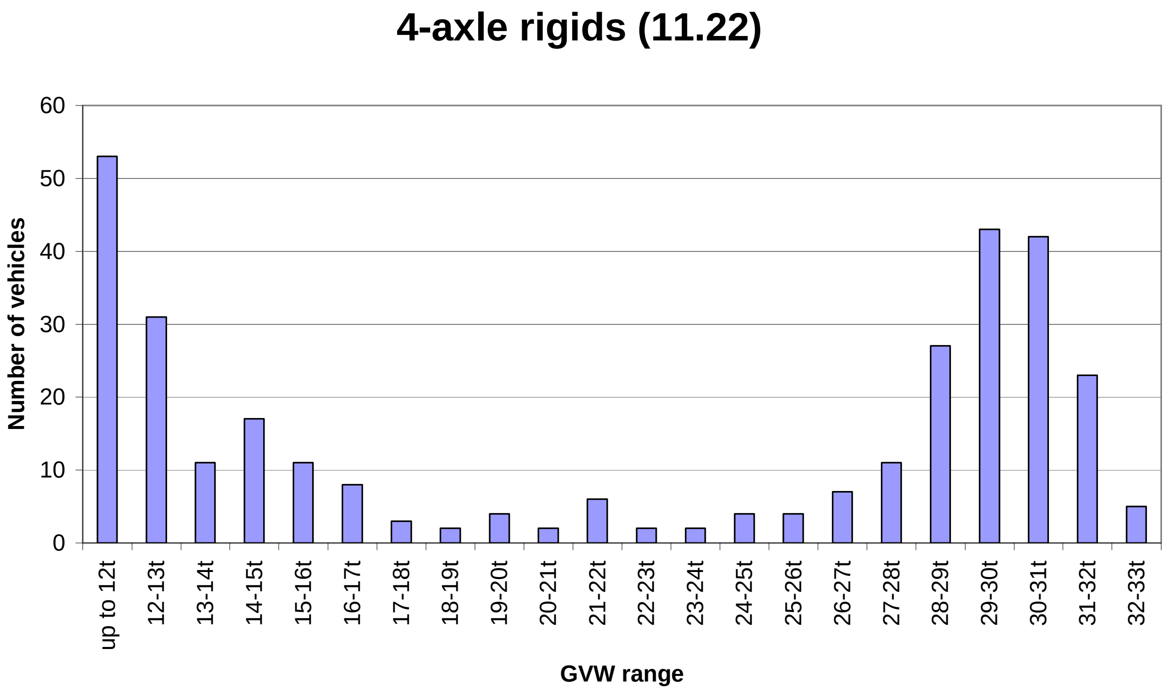

Figure 3. Gross Vehicle Weight range of 4-axle rigids on the UK network

3.4 Conclusion

The examples above have used data from a UK WIM site. Similar analysis could be conducted using NZ WIM data (partially done in Sections 3.3 and 3.4 of the TERNZ-Covec Report). This would identify how realistic the current assumptions are and the potential impacts of a change in the assumptions. The outcome could change the allocation of charges between different types of vehicle.

Consideration could be given to applying the RUC system to combinations rather than separately to powered vehicles and trailers. This should simplify the system, reducing administration costs and removing the need to monitor trailer travel. The charge could be based on the “worst” combination applied for. It would also make it easier to analyse vehicle impacts as the WIM systems weigh complete combinations.

The factors considered in this Section mean that the current ESA values are unlikely to be representative of real vehicles.

4 Relationship between fuel consumption and road network costs

4.1 Impact of number of axles

In general, measures to reduce road network costs will tend to increase fuel consumption (and other operating costs). Network costs related to ESA-kms (provided that the assumed power is greater than 1), would be expected to be reduced by spreading a vehicle's weight over more axles. In comparison, increasing the number of axles would increase the capital cost, rolling resistance, fuel consumption, tyre and maintenance costs, and the unladen weight of the vehicle. This is partly reflected in Table 23 of the TERNZ-Covec report, reproduced below as Table 5.

Table 5. Costs of 7 and 8 axle combinations

Costs ($/km)	7-axle	8-axle
Fuel & Oil	$0.53	$0.54
Repairs & maintenance	$0.31	$0.31
RUCs	$0.46	$0.37
Tyres & Tubes	$0.09	$0.09
Fixed vehicle Costs	$0.87	$0.88
Business Costs	$0.03	$0.03
Total	$2.29	$2.24

Table 5, comparing the costs of 7 and 8-axle combinations at 44 tonnes, shows that:

- Fuel and oil, and fixed vehicle costs are greater for the 8-axle vehicle than for the 7-axle vehicle. We believe that tyre costs would also be increased as the assumed 8-axle vehicle would have 2 additional tyres
- RUCs are lower for the 8-axle vehicle than for the 7-axle vehicle

Similarly, pages 4-5 of the TERNZ report identifies two factors where an increase in the number of axles would lead to an increase in fuel consumption:

- "The use of 8-axle configurations in place of the 7-axle alternatives for weight constrained loads results in an increase in vehicle-kms of about 3.6% because of the decrease in payload capacity."
- "There is also an increase in the tare weight of the vehicle which results in increased fuel consumption during empty running. This adds a further 0.8% to the fuel consumption and hence the emissions impacts."

4.2 Conclusion

Additional data on vehicle use and operating costs would be required to produce a more detailed correlation. It is recommended that any analysis should also consider the impacts per unit of goods moved (tonne-km) to take into account payload capacity impacts.

5 Would a scale of charges penalising more damaging trucks actually make a difference in road wear?

This raises a number of issues:

- Do Road User Charges influence heavy vehicle selection and use?
- Would revised Road User Charges lead to a change in Equivalent Standard Axles?
- Would a resulting change in Equivalent Standard Axles lead to a change in road wear?

5.1 Do Road User Charges influence heavy vehicle selection and use?

An operator's choice of heavy vehicle will be influenced by a number of factors (similar issues are covered on pages 12 to 13 of the TERNZ report). These include:

- Regulations – including speed limits, and Vehicle Dimension and Mass Rules: for example, the preference for truck and full trailer combinations rather than B-trains (see Table 8 of TERNZ-Covec report) may reflect the relatively short maximum length for B-trains (20m – the same as for truck-trailer combinations).
- Consignment size: the typical weight and volume of goods to be moved. For example, 2-axle vehicles will be chosen for relatively-small deliveries whilst maximum weight vehicles will be chosen for large-scale movement of bulk materials.
- Operating costs (including Road User Charges): the operating cost per kilometre generally increases as the size of vehicle increases. However, provided that suitable loads are available, the operating cost per tonne-km decreases as the size of vehicle increases (for example, the employment costs may be slightly higher but the amount of goods moved is significantly greater).
- Operational factors: these include the layout of collection / delivery areas, the roads used (width, curves, gradients, etc) and flexibility (for example, tractor semi-trailer combinations can quickly uncouple one semi-trailer and then couple another whilst a truck-trailer combination has to wait for the truck to be unloaded).

The TERNZ-Covec report presents evidence that operators' choices of vehicles are influenced by Road User Charges. On page 44, they comment that:

> "Thus, for example, seven axles are more than sufficient for a B-train to achieve 44 tonnes, yet the most common B-train configuration has eight axles and nine-axle B-trains are more prevalent than seven axle B-trains. Similarly seven axles is sufficient for truck and trailer combinations to achieve 44 tonnes yet the most common truck and trailer combination has eight axles. Each additional axle adds approximately one tonne in weigh to the vehicle and thus reduces its payload capacity by this amount. Clearly the reduction in RUCs associated with the greater number of axles warrants this loss of productivity."

Similarly, the analysis of operating costs in Section 7.3 of the TERNZ-Covec report shows that the current level of RUCs is sufficient to promote the use of an additional axle.

TRL analysis of New Zealand Weigh-in-motion data for 2007 (from the State Highway Traffic data Booklet 2003-2007) demonstrates the relative dominance of 8 axle vehicles; particularly on longer-distance trips (at Tokoroa and Waipara) (see Figure 4).

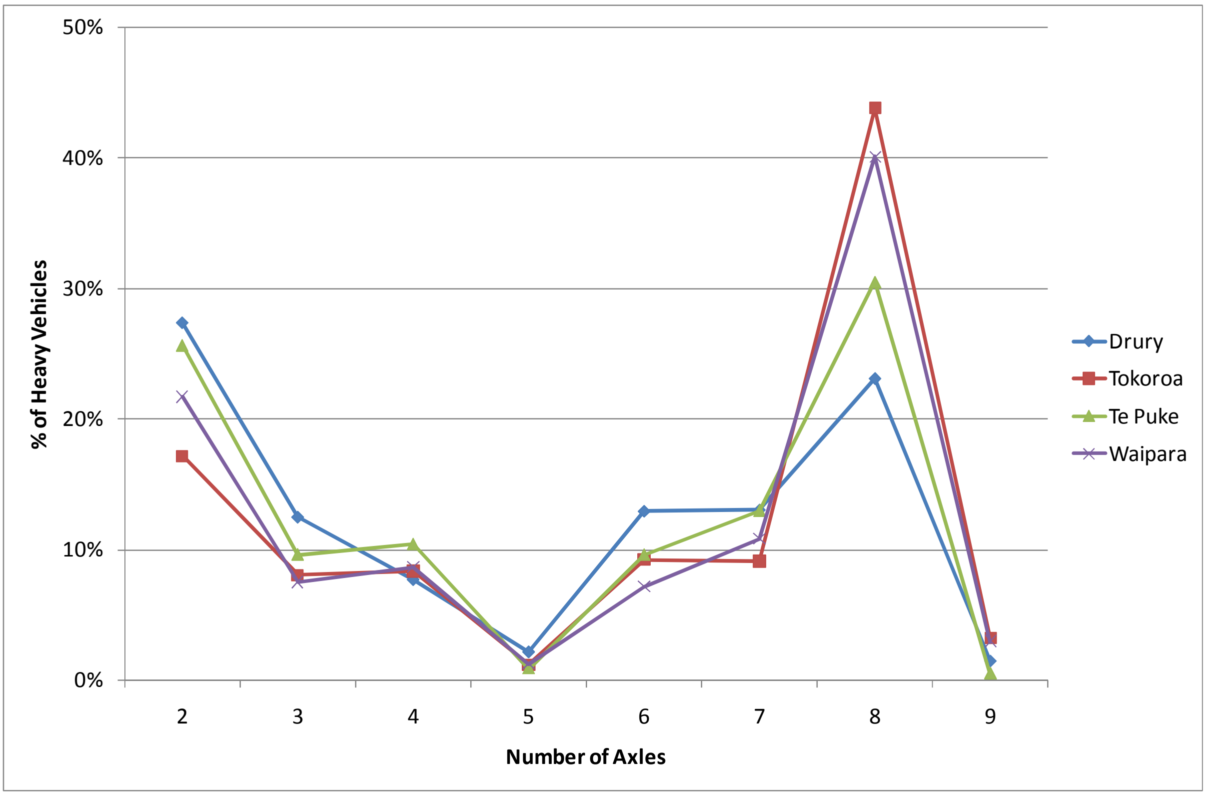

Figure 4. New Zealand WIM data (2007)

5.2 Would revised Road User Charges lead to a change in Equivalent Standard Axles?

Section 7.3 of the TERNZ-Covec report shows that adopting Austroads reference weights and a second-power rule would make it slightly cheaper to operate with 7-axles than with 8-axles. It also suggests that small shifts in fleet composition may occur over time.

However, this analysis is reported in terms of $/km rather than $/tonne-km. The additional carrying capacity available using 7-axle vehicles may further promote their use, leading to a larger shift in fleet composition. Such changes could lead to an overall increase in ESAs. The resulting ESAs will depend on how the 7-axle vehicles are used – they could simply replace 8-axle vehicles (carry equivalent loads), or the operators may take advantage of the increased carrying capacity by carrying heavier loads on fewer trips (potentially fewer vehicle-km but more ESA-km).

5.3 Would a resulting change in Equivalent Standard Axles lead to a change in road wear?

An overall increase in ESAs might, in principle, be expected to convert into an increase in road wear and therefore potentially in increased highway maintenance costs. However, the actual impact on road wear and maintenance costs is influenced by a number of factors including:

- Uncertainty in the power law exponent (see Section 2) and the relationship to the relative strengths of the road pavements; this could result in different impacts on different parts of the network;

- How maintenance is carried out on the network, for example, reaction time to change in condition, when maintenance is carried out, impacts of budgets, annuality etc.

More information on the actual performance of the different classes of road network and the types and timings of maintenance on the network is needed to evaluate the impact of changes in ESAs on road wear and costs.

5.4 Conclusion

It is recommended that the following work be commissioned to identify the potential change in Equivalent Standard Axles:

- Structured interviews with representative heavy vehicle operators to identify how they would respond to changes in Road User Charges. Key issues to investigate include: what are the drivers for selecting the vehicle fleet; incentives to change their vehicle fleets; how quickly they would do so; current use of their fleet; and how they would use the increased carrying capacity.
- Estimation of revised vehicle-km, ESA-km and ESA/tonne-km for the before and after scenarios, including sensitivity analysis.

6 Gross Weight as a Proxy for Road Space Requirements

The Road User Charges (RUC) calculation includes an element to take into account the effective space requirements of a vehicle, measured in terms of Passenger Car Equivalents (PCE). However, it is calculated in terms of vehicle weight:

For powered vehicles: PCE = 0.875 + GVW / 8,

For unpowered vehicles: PCE = GVW / 8,

(where: GVW is the maximum gross weight nominated in a licence application).

Thus a 44 tonne 8-axle truck-trailer (weight distributed evenly between the truck and trailer as on page 75 of the TERNZ-Covec Report) would have a PCE score of 6.375 and a notional 1 tonne vehicle would have a score of 1.000.

This method raises the following questions:

- Are space requirements related to maximum gross weight?
- Which costs are allocated to PCE-km?
- Are there alternative methods of accounting for space requirements?

6.1 Are space requirements related to maximum gross weight?

The "Land Transport Rule – Vehicle Dimensions and Mass, 2002" Table 6 specified the relationship between the maximum gross mass and the distance between the centre of the first axle and the centre of the last axle (see Figure 5).

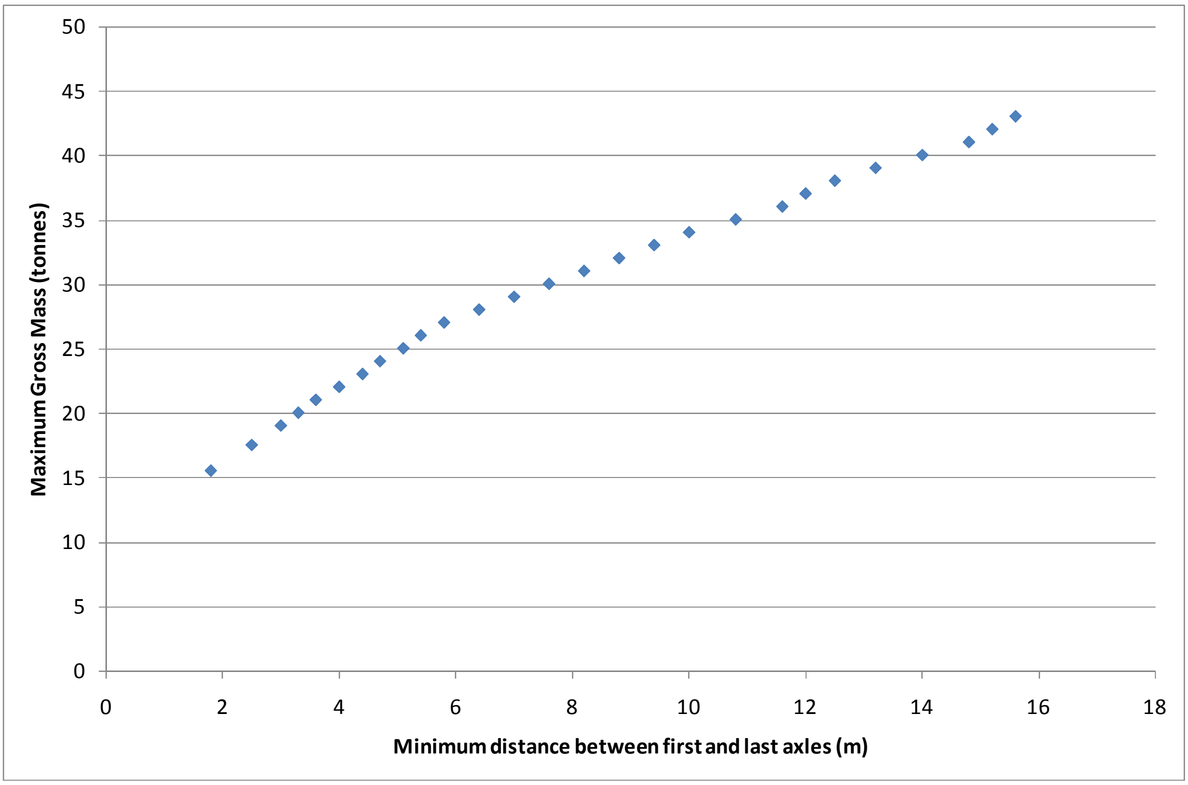

Figure 5. Maximum gross mass and distance between axles

This is roughly linear. However, it doesn't establish a relationship between space and licensed weight. For example, a 30 tonne vehicle is required to have an axle spacing of at least 7.6 metres, but it could be significantly longer. Data from WIM systems may clarify whether there is a relationship between licensed weight and vehicle length.

6.2 Which costs are allocated to PCE-km?

Table 6 is based on information from the CAM07-08 Spreadsheet.

Nearly 80 per cent of the costs associated with PCE-kms are for new roads / property. Therefore, the method of allocating PCE-kms to vehicles should reflect how they affect the space requirement costs of new roads / property (strength elements being assigned to GVW-km or ESA-km).

On uncongested roads, it could be argued that the costs associated with lane width, curvature, over-bridge height clearance, junction flare, etc are increased by the requirements of large vehicles. In practice, these costs are likely to be a relatively small proportion of the total cost.

On congested roads, large vehicles would be expected to have a greater impact on congestion than would passenger cars as they tend to travel more slowly, have poorer acceleration and braking, and take up more space on the road. However, the proportion of heavy vehicles tends to be lower during peak traffic flow periods. At junctions, there is a greater impact due to the space requirements of large vehicles resulting in the need to increase the size of junctions, the number of lanes, etc.

Table 6. Allocation of costs to PCE-km

Work Category	Allocation of Expenditure to PCE-km ($ million)			
	State Highways	Local Roads	Total	%
New Roads	$234.8	$71.1	$305.9	52%
Property Purchase	$133.4	$1.4	134.8	23%
Traffic Management	$83.1	$0.4	$83.6	14%
State Highway Administration	-	-	$21.1	4%
Minor Safety Projects	$0	$16.6	$16.6	3%
Property Management	$13.3	$0	$13.3	2%
Advance Property Purchase	$0	$6.3	$6.3	1%
Road Reconstruction	$2.1	$0	$2.1	0%
Territorial Authority Admin. Support	-	-	$1.5	0%
Strategy Studies	$0.2	$0.8	$1.0	0%
Seal Widening (Maintenance)	$0	$0.9	$0.9	0%
Transportation Studies	$0	$0.6	$0.6	0%
Crash Reduction Studies	$0	$0.1	$0.1	0%
Professional Services	$0	$0	$0.0	0%
Total	$466.9	$98.2	$587.7	100%

Note: Costs not allocated to State Highways or Local Roads are only included in the Total Column.

6.3 Are there alternative methods of accounting for space requirements?

The impact of heavy goods vehicles on UK congestion was considered in Section 4.8 of the NERA report. This considered the impact of heavy vehicles on junction capacity and on traffic. Generally heavy goods vehicles (more than 2 axles) had Passenger Car Unit (PCU) values of 1.75 to 3.00. However, these values were based on work published in 1965 when goods vehicles were much smaller than today but also had poor acceleration and braking. A brief review of the US Highway Capacity Manual has indicated that truck PCU values of 2 (signalised intersections) and 1.0 to 2.5 (two-lane highways) are used in the USA.

There is some uncertainty about the appropriate PCE values. However, there is little justification for using weight as a proxy for space. Is there information about how this relationship was derived? It would be more appropriate to use a value related to length, perhaps having standard values for a truck and for a trailer.

6.4 Conclusion

There is uncertainty about the appropriate Passenger Car Equivalent (PCE) values. However, there is little justification for using gross vehicle weight as a proxy for space.

7 Wider issues

The TERNZ-Covec and McKenzie Podmore reports have highlighted potential changes to the Road User Charging system. These raise wider issues including:

- The overall cost to New Zealand – including the National Land Transport Programme, operator costs, administration and enforcement.
- Winners and losers: any significant change is likely to lead to some road users paying higher charges and others paying lower charges. This could have wider social impacts. For example, the McKenzie Podmore report refers to existing cross-subsidisation between State Highways and local roads (page 9).
- Vehicle choices: the existing RUC system (and weight and dimensions regulations) appears to encourage the use of 8-axle truck-trailer combinations. A revised system may encourage the use of other vehicles. Is there a rationale for which vehicles are encouraged?
- Transitional issues: if the RUC system is changed, there are likely to be issues connected with the transition from the old system to the new system.

7.1 Overall cost to New Zealand

The final conclusion of the TERNZ-Covec Report (on page 87) is: "The Road Transport Forum has mooted replacing RUCs with a fuel excise duty on diesel and weight-dependent registration fees to reduce compliance costs". It is recommended that any change in charging system be viewed in terms of the estimated overall cost to New Zealand. This includes considering:

- Road construction and maintenance cost – the current system appears to encourage the use of 8-axle combinations, other systems might reduce this incentive and may also increase road costs.
- Vehicle operating costs – including purchase, fuel, tyres, wages, etc. Changes in the charging system could lead to changes in vehicle use. Consideration should include costs imposed on the operator by the charging system, for example in fitting and maintaining distance recorders.
- Administration and enforcement costs.
- Safety. There are potential impacts due to the relative safety of different types of vehicles (for example, B-trains may be more stable than truck-trailer combinations) and by reducing exposure (fewer vehicle km would be expected to lead to fewer crashes).

7.2 Winners and Losers

Any change is likely to lead to some road users paying higher charges and others paying lower charges. For example:

- Changing from an exponent of 4 to a lower value would be expected to reduce the charges paid for the heaviest vehicles and increase the charges paid for lighter vehicles.
- Changing from a distance-based system to a time based registration fee would decrease the charges for vehicles that travel large distances (for example, long-distance truckers) and increase the charges for those travelling shorter overall distances (for example, those involved in multiple collections or deliveries).

Such changes may change the costs of communities – for example, increasing or decreasing the transport costs of more remote rural communities.

7.3 Vehicle choices

The combination of Road User Charges and the Vehicle Dimension and Mass Rule appears to be encouraging the use of 8-axle truck-trailer combinations. Does the Ministry of Transport have a view on the type(s) of vehicle that should be encouraged? This could take into account their impacts on the road infrastructure, safety, environment and operating costs. For example, in the UK the use of 6-axle articulated vehicles is encouraged through weight limits (allowed to operate at 44 tonnes compared with 40 tonnes for 5-axle vehicles) and the Vehicle Excise Duty rates. This is to balance efficient transport with reduced road infrastructure costs.

7.4 Transitional issues

If there is a change, there are likely to be transitional issues. For example, the requirement to offer rebates to operators who have pre-paid at a higher rate than applies in future. These issues would need to be considered, costed and timed actions planned.

Acknowledgements

The work described in this report was carried out in the Infrastructure Division of the Transport Research Laboratory.

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