Fatigue design criteria for road bridges in New Zealand

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An important note for the reader

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- Dr Stephen Hicks – General Manager, Structural Systems, Heavy Engineering Research Association
- Dr Andrew Dickson – Technical Director, Beca Ltd.

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Abbreviations and acronyms

An expanded glossary is provided in appendix I of this report.

AADT	Annual average daily traffic volume
ADTT	Average daily truck traffic (counts per day)
CAFL	Constant amplitude fatigue limit (also known as constant stress range fatigue limit)
Class 1	Heavy vehicle mass limits specified in the Land Transport Rule, Vehicle Dimensions and Mass 2002 (VDAM rule)
GVM	Gross vehicle mass – same as gross mass or gross combination mass (GCM) in this report, meaning the mass of the vehicle or combination and its load, equipment and accessories
HCV	Heavy commercial vehicle – defined in the NZ Transport Agency's *Economic evaluation manual* 2010 (EEM) as 'trucks or articulated vehicles with three or more axles' (not to be confused with 'heavy vehicle')
HMV	Heavy motor vehicles, with a gross mass over 3500kg (HCVs are heavier)
HPMV	High productivity motor vehicle defined by a 2010 amendment to the VDAM rule
LCV	Light commercial vehicle, with a gross mass up to 3500kg, excluded from heavy vehicle counts
MCV	Medium commercial vehicle (2-axle trucks with a gross mass over 3500kg)
MoT	Ministry of Transport
PAT	Pietzsch AutomatisierungsTechnik – the original supplier of bending plate WIM equipment
SN	S-N curves describe the relationship between the number of cycles (N) and fatigue strength for a constant stress range (S)
T&T	Truck-and-trailer unit
WIM	Weigh-in-motion – systems to weigh and record data for moving vehicles

Contents

Executive summary

Introduction

Fatigue is damage to structural components caused by repeated fluctuations of stresses less than design strengths, leading to gradual cracking. During their design life, bridge superstructures on busy roads may be subjected to more than 100 million cycles of loading from heavy vehicles and design for fatigue resistance is an important consideration.

In the absence of standardised fatigue loadings for New Zealand bridges, editions of the NZ Transport Agency's Bridge Manual prior to 2013 referenced British standards for fatigue loadings, but the suitability of those loads had not been tested for ongoing use in this country. With the introduction of higher productivity motor vehicles (HPMV) to New Zealand in 2010, the average vehicle weights were expected to increase over the next several years, raising further doubts about the suitability of the British standards. The 2013 edition of the Bridge Manual references interim guidelines based on Australian Standard *AS 5100.2-2004 Bridge design, part 2: design loads,* and adopts *AS 5100.6-2004 Bridge design, part 6: steel and composite construction* for steelwork design, including fatigue resistance.

The aim of this study was to provide the basis for an amendment to the Bridge Manual that would be suitable for the design of steel and composite bridges based on New Zealand heavy vehicle characteristics, with allowances for forecast long-term growth. This research was carried out between January 2012 and September 2013.

Current fatigue loading

The baseline bridge fatigue loading used in this study was derived from heavy vehicle data recorded at weigh-in-motion stations on New Zealand state highways, filtered to represent the more heavily loaded direction and to exclude periods with apparent discrepancies in data quality and calibration.

The first stages of the approach were to represent current heavy vehicle fatigue loading by varying numbers of repetitions of standardised vehicles causing at least the same cumulative fatigue damage as the recorded fleets of real vehicles. The following standard fatigue vehicle models were used:

- a scaled-down single M1600 fatigue vehicle from AS 5100.2
- a single 8-axle truck-and-trailer representing the dominant vehicle on New Zealand highways, but scaled up to 530kN total weight to represent fully loaded HPMVs
- a set of seven standard trucks (2 to 8 axles), each with two or three sets of axle weights, derived to fit common vehicle types at empty, part-laden, and fully laden weights. These vehicles, plus their proportions of total heavy vehicle counts, are known as a vehicle spectrum model.

The vehicle spectrum model provides the more accurate approach for detailed assessments under current heavy vehicle loading, but requires additional calculation effort compared with single-vehicle methods. The single-vehicle models are generally applicable to steel or composite steel–concrete bridge structures only, but the current vehicle spectrum models would also be relevant to fatigue assessment of reinforced and pre-stressed concrete bridge structures.

Future growth assessment

The heavy vehicle weight data used in this study was selected from periods between 2005 and 2011, prior to the appearance of the new HPMV vehicle types, which are permitted to carry masses exceeding the existing 44-tonne gross mass limit. Estimates of future adoption rates for the new higher mass limits applicable to approved routes, and data on new vehicle configurations, were obtained from published reports. The average increases in fatigue damage per vehicle were estimated using this data and applied to the proposed single fatigue vehicle models to represent the anticipated future fleet on HPMV-capable routes.

The growth allowances incorporated in the AS 5100.2 cycle count formulae (4% per annum geometric growth for 75 years – a total of 440 times the first-year loading estimate) were found to be the *minimum* that should be considered in a New Zealand fatigue loading model, given the forecast future freight volume and anticipated increases in vehicle mass limits.

As noted in the AS 5100.2 commentary, a 75-year fatigue design life is considered compatible with a 100-year design life, based on the existence of an inspection and maintenance regime to control possible long-term damage and the low probability of failure at the theoretical fatigue design life. It is anticipated that the next revision of AS 5100.6 will include guidance on selection of fatigue strength reduction factors, considering the consequences of failure and the ability to inspect and maintain the structure.

Selection of fatigue design loadings for New Zealand

Single-vehicle fatigue load models are preferred for ease of use compared with vehicle spectrum models. It should be noted that analysis models for fatigue design are normally separate from live load models for strength design, so there is no significant benefit from choosing a vehicle included in design live load models.

There is a trade-off required between close alignment with the Australian standards and a standard vehicle model that aligns with the most common large vehicles in New Zealand (truck-and-trailers) and appropriately represents loading on short, medium and long span lengths and transverse girders.

An 8-axle (twin-steer) truck-and-trailer vehicle weighing 530kN (54 tonne) was found to be the preferred standard fatigue vehicle model from a technical standpoint, as it is more representative of New Zealand vehicles, provides a more consistent fit to fatigue effects over a wide range of span lengths, and may require less analysis effort than the M1600 vehicle options.

Equivalent cycle counts per heavy vehicle and reduction factors for route types with lower average loading (route factors) were fitted to the New Zealand data.

Options for the use of modified M1600 vehicle fatigue loads are included in the report's recommendations.

Improvements to fatigue load application rules

The proposed application methods for the single-vehicle fatigue load models recommended in this report have been based on clause 6.9 of AS 5100.2. It was evident that the AS 5100.2 methods of application are generally safe-sided except where components are significantly affected by loadings in two adjacent lanes or opposing directions, or additional impact effects near road joints.

The report recommends modifications to AS 5100.2 procedures for the preferred 8-axle truck-and-trailer vehicle, or a scaled-down M1600 vehicle, to allow for accumulation of effects from adjacent lanes.

The dynamic load allowances and uniform stress-reduction factor included in the unmodified AS 5100.2 fatigue loadings are significantly different to other international codes, and this study found insufficient evidence to support their inclusion in fatigue loadings tailored to New Zealand bridges and derived from recorded vehicle weights including dynamic scatter. The recommended modifications to AS 5100.2

application rules have excluded both those factors and the net effect has been a small increase in loadings. An additional 30% dynamic amplification allowance has been retained within 6m of expansion joints.

Recommendations

It is recommended that the Transport Agency amend the Bridge Manual 3rd edition to provide guidance on fatigue loadings for New Zealand road bridges of steel or steel composite construction, based on clause 6.9 of AS 5100.2 with modifications to include the truck-and-trailer fatigue vehicle noted above. Route factors suitable for New–Zealand roads and other recommended modifications to the AS 5100.2 application rules have been included in this report.

The format of the fatigue loading recommendations to be included in a future amendment to the Bridge Manual requires further consideration by the Transport Agency regarding confirmation and acceptance of the design fatigue vehicle option and proposed implementation methods.

Case studies on typical bridge designs (for both existing loading standards and proposed future live loading) are recommended to inform decisions on adoption of the proposed loadings and design fatigue vehicle selection, and to provide worked examples to assist with dissemination to bridge designers.

Abstract

Road bridges are subjected to millions of cycles of heavy vehicle loading over their design lives, and the introduction of higher vehicle mass limits on New Zealand roads will significantly increase the rates of fatigue damage in bridge superstructures. The NZ Transport Agency's Bridge Manual has relied on British and Australian standards for fatigue design criteria, and the aim of this project was to provide the basis for amended fatigue loadings based on New Zealand heavy vehicle characteristics, with allowances for forecast long-term growth in volumes and vehicle masses.

The base fatigue loading was derived from analyses of effects on bridge spans of heavy vehicles recorded at weigh-in-motion sites between 2007 and 2011. The base fatigue loading was then adjusted for increases in legal vehicle masses permitted under a 2010 Land Transport Rule amendment (introducing HPMV – high productivity motor vehicles).

The recommended fatigue design vehicle is a 54-tonne 8-axle truck-and-trailer, which represents the dominant freight vehicle on New Zealand roads scaled up to full HPMV higher mass limits. Cycle counts for this vehicle were derived to fit New Zealand routes and growth forecasts. Factors enabling the continued use of the Australian fatigue design vehicle are included.

Other recommended fatigue design criteria draw on the Australian and Eurocode bridge design standards.

1 Introduction

1.1 Fatigue definition

Fatigue is the ‘damage, by gradual cracking of a structural part, caused by repeated applications of a stress which is insufficient to induce failure by a single application’ (British Standards Institution 1980).

Fatigue cracking in metal components starts at an existing flaw and grows at a slow rate under cycles of loading that are predominantly within in the normal levels of service loading. Explanations of the causes and processes are readily available in engineering literature and elsewhere (eg Wikipedia 2013a).

Bridge superstructures on busy roads may be subjected to more than 100 million cycles of loading from heavy vehicles over their design life, and design for fatigue resistance is an important consideration. This report is aimed at bridge engineers and assumes that the reader is familiar with the general principles of fatigue assessment and the relevant design standards.

The information on current and future heavy vehicle fatigue loading models presented in the report may also be of interest to road pavement engineers.

1.2 Research project purpose

The NZ Transport Agency engaged Beca Ltd (Beca) to carry out this research project with the following specified purpose:

> *To determine a fatigue loading spectrum that is wholly appropriate for use in New Zealand and to develop a process, or amend an existing process, for applying this into the design of road bridges.*

The need for this study arose from the absence of a fatigue load specification in the Transport Agency’s *Bridge manual* (2nd ed.) (Transit New Zealand 2003), which stated in clause 3.2.6:

> *The loading used in the fatigue assessment shall at least represent the expected service loading over the design life of the structure, including dynamic effects. This should be simulated by a set of nominal loading events described by the distribution of the loads, their magnitudes, and the number of applications of each nominal loading event.*
>
> *A standard fatigue load spectrum for New Zealand traffic conditions is not available. The loading in BS 5400: Part 10: 1980 clause 7.2.2 may be used but is likely to predict fatigue lives shorter than those which would be achieved in practice.*
>
> *In a case where fatigue details significantly influence the design, an appropriate loading spectrum shall be developed, taking account of current and likely future traffic.*

With the introduction of higher productivity motor vehicles (HPMV) in 2010, average vehicle weights are expected to increase over the next several years and bridge design standards must respond to this change. Vehicle mass limits and bridge design live loads have not changed significantly since the 1970s, and the suitability of the standard fatigue load spectrum in BS 5400: part 10 for ongoing use has not been tested.

The intent of this study was therefore to provide the basis for an amendment to the above clause, based on New Zealand heavy vehicle characteristics, with allowances for forecast long-term growth in vehicle masses and numbers.

1.3 Bridge fatigue design criteria

Fatigue design criteria for bridges typically consist of three separate elements:

- a vehicle loading spectrum comprising either a single vehicle, a selection of common vehicle types, or site-specific vehicle records, together with the repetition counts over the design fatigue life
- analysis procedure(s) to determine the corresponding design stress ranges and cycle counts for the selected vehicle loading spectrum
- material-specific fatigue life calculation methods for assessment of components.

The focus of this research was the vehicle loading spectrum, and suitable analysis procedures were adapted from existing design standards. Fatigue life calculation methods for structural steel components were considered to be adequately addressed by existing material design standards.

A key assumption for the research was that the loading spectrum is intended to be used for steel and composite steel–concrete bridges and the development of a single-vehicle model relies on that. Fatigue life assessment methods for reinforced and pre-stressed concrete bridges were available in some of the international codes reviewed for this study, but examination of their suitability for use in New Zealand was not part of the research scope.

1.4 Research objectives

In order to successfully fulfil the purpose stated above, the objectives for this study were:

- estimation of vehicle fatigue loading spectra to represent current heavy vehicle traffic on New Zealand roads
- estimation of vehicle fatigue loading growth parameters to represent historic and future heavy vehicle loading growth (in both numbers and maximum permitted weights)
- selection of appropriate analysis procedures and design requirements for estimating the corresponding design fatigue stress cycles
- selection of one or more appropriate fatigue life assessment methods from the available materials design standards applicable to fatigue design of bridges
- presentation of recommendations in a form that is suitable for inclusion in the Transport Agency's Bridge Manual.

1.5 Report outline

The report chapters generally follow the main steps of the research project.

Chapter 2 covers a review of international codes of practice (with details in appendix B) and shows the standard fatigue vehicle models from those codes. A summary of recommendations for New Zealand loadings from other studies is included.

Chapter 3 outlines the research steps and background to the methodology. Further details of methodology are included in the relevant sections of the report.

Chapter 4 summarises the heavy vehicle datasets used to derive the current fatigue load models, with the details of the data review and validation provided in appendix H. The study relies on vehicle weight data collected at high-speed weigh-in-motion (WIM) stations on the state highway network (locations shown in appendix A). A list of the WIM heavy vehicle types and classifications is provided in appendix A.

Chapter 5 presents the WIM site current fatigue loadings in terms of equivalent repetitions (causing the same fatigue damage) of standard fatigue design vehicles and the assessment loading for one lane specified by the Transport Agency (2013c). Appendix C presents additional outputs from the current fatigue load processing, including breakdowns by vehicle class, and an example of how the results for WIM sites could be applied to assessments of current fatigue loading at other locations.

Chapter 6 presents the standardised vehicle spectra representing current fatigue loading at the WIM sites and rationalised spectra in a form suitable for adjustments to fit different heavy vehicle mixes observed on other routes. Guidance on the usage of the vehicle spectra for assessment of structures under current loading is provided in appendix E.

Chapter 7 presents the available long-term heavy traffic growth statistics and summarises assessments of future growth allowances, including the effect of increases in legal vehicle mass. Details of the estimates for higher mass vehicles (HPMV) are provided in appendix F, and appendix G combines those estimates with longer term growth rate allowances to provide the assessments summarised in chapter 7.

Chapter 8 reviews the candidates for fatigue design vehicles and proposes three options, including the M1600 vehicle from the Australian bridge design code (Standards Australia 2004a) and a representative higher mass truck-and-trailer vehicle, with calibrations to fit the expected New Zealand heavy vehicle fleet following take-up of the new HPMV limits.

Chapter 9 summarises the estimated fatigue loading adjustments required to suit heavy traffic on other routes, based on the ‘route factor’ approach used in the Australian bridge design code. A selection of 2011 heavy vehicle count data from other Transport Agency state highway traffic-counter sites (see appendix D for details) was used to estimate adjustments applicable to other sites, relative to the WIM site estimates.

Chapter 10 proposes guidelines for implementation of the fatigue load models, including three options for the standard fatigue vehicle, and an alternative tandem-axle set model.

Chapters 11 and 12 contain the conclusions and recommendations.

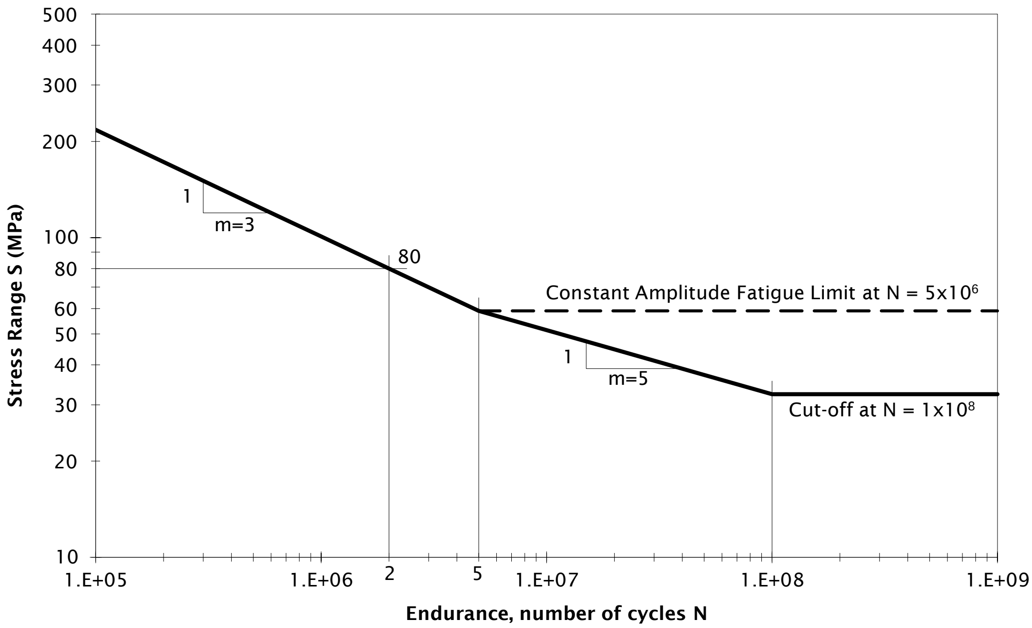
This research was carried out between January 2012 and September 2013 using selections of heavy vehicle data supplied by the Transport Agency from periods between 2005 and 2011.

2 Review of codes of practice and related literature

2.1 Fatigue strength for structural steel components

To illustrate the terminology used in this report, a typical S-N curve defining the relationship between the number of cycles at a stress range and the design fatigue strength is shown in figure 2.1. This particular example (for New Zealand, Australian and European standards) is relevant to welded attachments at the flanges of steel plate girders.

Figure 2.1 Design S-N curve showing fatigue strength for detail category 80



The key features to note are as follows:

- The S-N curve is multilinear on log-log scales, and each segment can be expressed as $N=k_mS^{-m}$.
- If all stress cycles are below the constant amplitude fatigue limit (CAFL) corresponding to the stress range limit at 5 million cycles, the fatigue life is considered to be unlimited (as indicated by the horizontal dashed line), because lower amplitude stress cycles do not contribute to crack growth.
- For normal (direct) stresses, a 3rd-power (m=3) relationship is applicable to stress ranges above the CAFL in structural steel components.
- For variable amplitude loading where some cycles may be above the CAFL, the cycles below the CAFL will contribute to the fatigue damage at a lesser rate, because some of the lower amplitude cycles following a cycle above the CAFL can cause crack growth.
- A 5th-power (m=5) relationship is applicable to stress ranges below the CAFL for variable amplitude loading.
- A cut-off limit is applied at 100 million cycles, where lower stress ranges are assumed not to contribute to fatigue damage.

- The detail category number (80 in this example) denotes the fatigue strength at 2 million cycles.

Further explanations are provided in steel design codes and their commentaries (eg NZS 3404, Standards New Zealand 1997).

Terminologies for the fatigue detail categories and details of the S-N curves vary amongst the international design standards, and S-N curves for other material types (such as reinforcing steel and shear connectors to concrete decks) may use different exponents (m).

The design S-N curves as illustrated in figure 2.1 are associated with an acceptably low probability of failure. Commonly, the mean S-N curves are empirical fits to fatigue test data, and the design curve is based on two standard deviations (on the log scale) below the mean curve (British Standards Institution 1980). The assumed probability of failure varies slightly between design codes but is typically 5% or less.

2.2 Fatigue design criteria for bridges

The fatigue loadings and design criteria for bridges in a selection of international codes have been summarised and compared (see appendix B). The following standards were reviewed:

- Australia – AS 5100 parts 2, 5, and 6 (Standards Australia 2004a–c)
- Europe – Eurocode 1, 2, 3 and 4 (British Standards Institution 2003, 2005a–c, 2006, 2007)
- UK – Eurocode National Annexes (British Standards Institution 2008a–c)
- UK – BS 5400: part 10 (British Standards Institution 1980)
- Canada – CAN/CSA-S6 (Canadian Standards Association 2006)
- US –AASHTO LRFD Bridge Design Specifications (American Association of State Highway and Transportation Officials 2010).

Detailed comparisons of the fatigue loading and material requirements are included in appendix B.2. A summary of key differentiators is provided in appendix B.1, with comments on which ones could be considered to represent best practice. A brief summary is included in section 2.3.6.

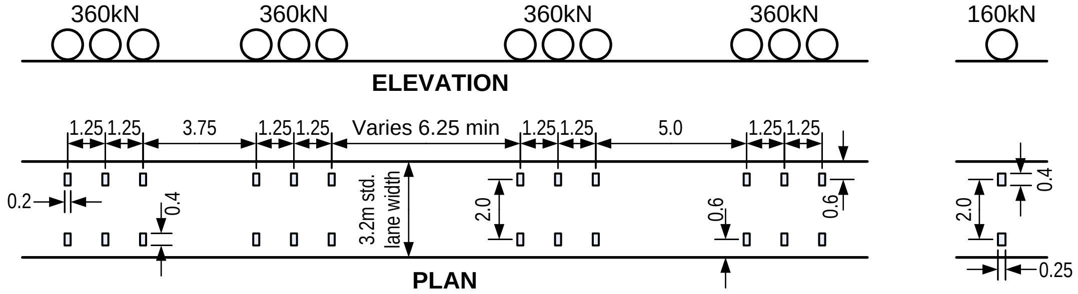
2.3 Fatigue load models for bridges

The current fatigue vehicle models from the surveyed international codes are summarised below. These models comprise either a single vehicle or a selection of common vehicle types, with scale factors and repetition counts over the design fatigue life.

2.3.1 AS 5100.2-2004

The fatigue vehicles in the Australian bridge design code are specified as 70% of the M1600 vehicle and A160 axle single-lane-design live loadings, excluding the accompanying UDL (uniformly distributed load).

Figure 2.2 AS 5100.2 live load vehicles (0.7 factor to be applied to these loads, dimensions in metres)



M1600 Fatigue Vehicle **A160 Axle**

A dynamic load allowance (α) is applied to the fatigue vehicle and axle loads (additional load is 40% of the axle load, 35% of a triple-axle set load or 30% for the vehicle loads).

The number of constant amplitude fatigue cycles calculated with the above loads placed within any design traffic lane to maximise the stress range for the component under consideration is:

A160 axle: (current number of heavy vehicles per lane per day) x 4 x 10^4 x (route factor)

M1600 vehicle: (current number of heavy vehicles per lane per day) x 2 x 10^4 ($L^{-0.5}$) x (route factor).

The route factor is 1.0 for principal interstate freeways and highways, reducing for other route types (see appendix B.2).

The code commentary (Standards Australia 2007) states that the maximum mass of heavy vehicles is assumed to increase from current values to that equivalent to SM1600 loading over a period of about 50 years, but that the cycle counts consider the average mass of vehicles rather than maximum allowable mass, as the percentage of vehicles loaded to maximum allowable mass is expected to decrease. The cycle count multipliers include a growth allowance and assume a 75-year period for fatigue design.

The background paper by Grundy and Boully (2004a) states that the M1600 vehicle cycle count formula is based on average damage per heavy vehicle being equivalent to $0.125L^{-0.5}$ cycles of M1600 (see section 5.5.1).

For short spans, the A160 axle load governs and the cycle count formula is based on damage per heavy vehicle being equivalent to 0.25 cycles of an A160 axle.

The 70% scale factor applied to the A160 and M1600 stress ranges was introduced because, as stated in the AS 5100.2 commentary (Standards Australia 2007):

- *The actual stresses in a component are generally less than the theoretically calculated values because of alternative load paths (such as bridge barriers) and the magnitude of actual components in comparison with line elements used to represent them in analysis.*
- *The actual lateral position of heavy vehicles varies and does not generally coincide with the critical lateral position.*

To summarise, the AS 5100.2 fatigue loading comprises:

- a fatigue vehicle and axle based on design live loads that are considerably heavier than current typical vehicles
- repetition counts that are lower than expected lifetime heavy vehicle counts and include a span length modifier for the vehicle load

- a dynamic load allowance equal to that for the design live load and a fixed stress-reduction factor to account for differences between the stresses, calculated with conservative assumptions and actual stresses.

2.3.2 Eurocode 1 (EN 1991-2: 2003)

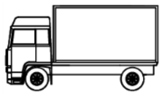
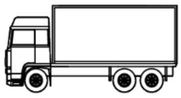
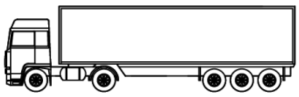
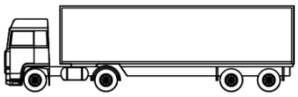
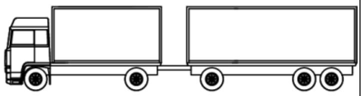
The Eurocodes define the five fatigue load models listed in table 2.1. Optional parameters and additional guidance are provided in National Annexes. Sedlacek et al (2008) provide the background details for the derivation of fatigue load models (FLM) 2, 3 and 4, using data from European WIM sites. Key points are as follows:

- The axle set weights for the 'frequent' truck model (FLM2) represent the upper 99th percentile values in terms of cumulative fatigue damage. Higher loads cause less than 1% of total damage.
- The equivalent axle set and total weights for FLM4 were based on the worst damage equivalent loadings (a concept discussed in chapter 5 of this report) from the WIM sites.
- A 3rd-power fatigue damage relationship was assumed for the loading development, while material codes specify modification factors based on higher powers for steel components and reinforcing steel.
- No additional dynamic allowances were included in the axle weights for FLM2 and FLM4 other than the inherent dynamic scatter and road roughness at the WIM sites (assuming 'good' pavements).
- The development of the FLM3 damage equivalence modification factors for steel bridges is described – these include adjustments for span length, component position and dynamic response.
- It is noted that FLM3 is normally not precise enough for details influenced by local loads, such as orthotropic steel or concrete bridge decks.

Table 2.1 Eurocode fatigue load models

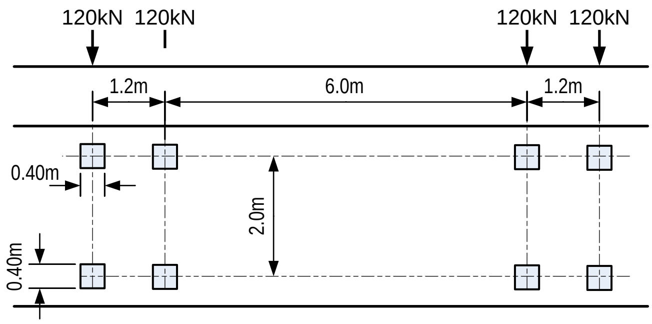
Model	Description	Stress range calculation	Purpose
FLM1	Lane loading – 70% of serviceability design tandem-axle loads + 30% UDL (see appendix B.2)	Difference of max. and min. stresses for all load arrangements	Unlimited life verification (stress range less than CAFL)
FLM2	Set of 5 'frequent' trucks (see table 2.2)	Difference of max. and min. stresses for individual vehicles centred in notional lanes	Unlimited life verification where multiple presence is not significant
FLM3	Standard fatigue vehicle (see fig. 2.3, 4 x 120kN axles)	Difference of max. and min. stresses for individual vehicles centred in notional lanes with modifications provided in the material codes	Fatigue life assessment using simplified procedures
FLM4	Set of 5 'standard' trucks (see table 2.2), in proportions varying with route type	Stress range spectra and cycle counts calculated for passages of single vehicles centred in notional lanes	Fatigue life assessments – National Annexes provide additional data
FLM5	Recorded heavy traffic data	As for FLM4 – requires allowances for road roughness and growth	Fatigue life assessments

Table 2.2 Eurocode fatigue vehicles based on five common truck types (FLM2 and FLM4)

Eurocode fatigue vehicle silhouettes	Axle spacings (m)	FLM2 frequent axle loads (kN)	FLM4			
			Equivalent axle loads (kN)	Vehicle percentages		
				Long distance	Medium distance	Local traffic
	4.5	90+190=280	70+130=200	20%	40%	80%
	4.2+1.3=5.5	80+140+140=360	70+120+120 =310	5%	10%	5%
	3.2+5.2+1.3 +1.3=11.0	90+180+120+120 +120=630	70+150+90 +90+90=490	50%	30%	5%
	3.4+6.0+1.8 =11.2	90+190+140+140 =560	70+140+90 +90=390	15%	15%	5%
	4.8+3.6+4.4 +1.3=14.1	90+180+120 +110+110=610	70+130+90 +80+80=450	10%	5%	5%

The annual heavy vehicle counts applied to slow lanes in the Eurocode models (summarised in appendix B.2) are based on road categories and are assumed to apply for the life of the structure. Thus heavy vehicle flows in slow lanes of multilane highways and motorways are taken as 2 million vehicles per year (5480 per day, which represents saturation flows) for the design life, but no allowance for future vehicle weight growth is included.

Figure 2.3 Eurocode standard fatigue vehicle (FLM3, 4 x 120kN axles)



The inclusion of fatigue load models for unlimited life checks (models 1 and 2) enables simple checks without detailed evaluations, but it is understood that these are conservative and that models 3 or 4 would normally be required for fatigue verifications.

Other features of the Eurocode models include:

- additional dynamic amplification factor of 1.30 at expansion joints, decreasing to 1.0 at sections 6.0m away
- allowance for a frequency distribution of transverse position for assessment of local effects with notional lanes located anywhere on the carriageway – vehicles are centred in notional lanes for general action effects.

2.3.3 UK National Annex to BS EN 1991-2: 2003

The UK National Annex provides further guidance and modifications to the fatigue load models to suit UK heavy traffic. The background to these changes is provided in a UK Highways Agency report (Flint & Neill Partnership 2004) and the additions include:

- a detailed set of equivalent trucks replacing the Eurocode FLM4 vehicles – these include high, medium and low axle weights for five common vehicle types, plus eight special types covering heavy transporters with very low counts
- guidance on the inclusion of multiple presence effects for vehicles in adjacent lanes or running in convoy.

Chapter 6 of this report and appendix B.2 include more details.

2.3.4 AASHTO LRFD bridge design specifications

The fatigue vehicle specified in the AASHTO LRFD specifications (American Association of State Highway and Transportation Officials 2010) is the standard 3-axle HL-93 design truck with a fixed 9.0m spacing between the second and third axles. For bridge deck local analysis, a refined 5-axle metric version (Federal Highway Administration 2012) is available (see figure 2.4).

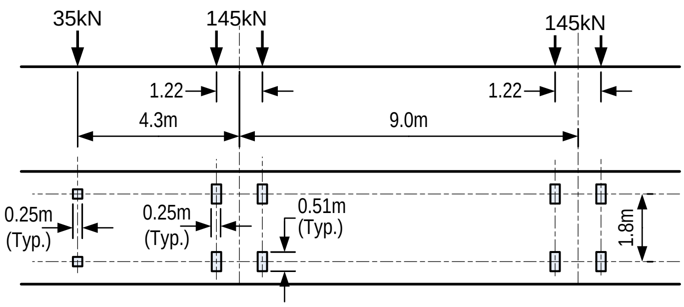
This vehicle represents legal-weight 5-axle semi-trailer rigs and is modified by the following factors for fatigue design:

- 1.15 dynamic load allowance factor (for the fatigue limit state), and
- 0.75 load factor for assessment of fatigue lives, or
- 1.50 load factor for infinite life checks.

The typical design cycles per truck used with this loading is 2.0 for girder spans less than 12m or transverse members spaced at less than 6m, or 1.0 for longer spans (or 1.5 for interior support moments).

The load factors are currently under review (Mertz 2013), in the light of recent research on current vehicle fatigue effects (Wassef 2013). The criterion noted by Wassef for estimation of the load factor for infinite life checks is a CAFL exceedence frequency of 1 in 10,000 stress cycles, giving a factor of 2 (or more) over the stress ranges used for finite fatigue life estimates.

Figure 2.4 AASHTO fatigue vehicle – 325kN tandem-axle version for bridge deck analysis



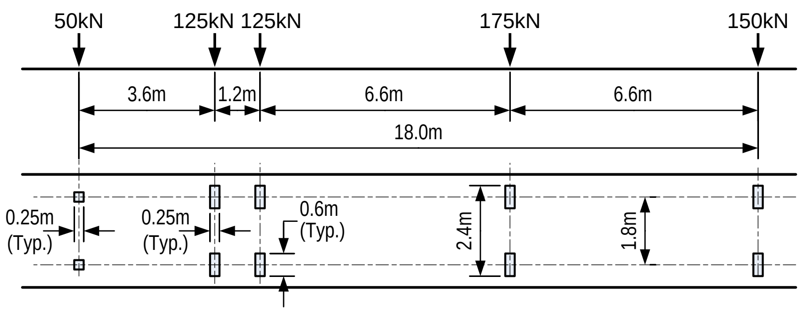
Estimates of average daily single lane truck counts over a 75-year fatigue design life are used with the per-vehicle loadings described above.

It should be noted that the AASHTO (and Canadian) codes use S-N curves for steel structures that are different to the European, Australian and New Zealand codes, in that the 3rd-power relationships are used for all stress levels and the CAFLs for different detail categories correspond to different cycle counts.

There is a separate AASHTO document (relating to evaluation of existing bridges) that was not reviewed, but details of the steel bridge fatigue evaluation procedures are provided by Bowman et al (2012). This includes methods for estimating remaining fatigue lives and recommendations for multiple vehicle presence allowances (estimated using WIM records from several US sites).

2.3.5 Canadian highway bridge design code

Figure 2.5 Canadian fatigue design vehicle (625kN x 0.52 = 325kN)



The fatigue vehicle in the Canadian code (Canadian Standards Association 2006) is the 5-axle CL-625 design vehicle (see figure 2.5), with a factor of 0.52 for the vehicle effects or 0.62 for the tandem-axle set alone. There is no additional dynamic allowance applied to these loads. The commentary notes that the 0.52 and 0.62 factors were calibrated against the AASHTO fatigue vehicle factored loads, including the 1.15 dynamic factor and allowing for the relative differences in design vehicle effects and legal truck weights. Other parts of the fatigue design criteria (see appendix B.2) are similar to the AASHTO specifications, including a factor of 2 applied to stress ranges in the infinite life check.

2.3.6 Differentiators between international fatigue design criteria

A comparison of key features of the surveyed design codes is provided in appendix B. The key conclusions and comments are summarised in table 2.3.

Table 2.3 Conclusions from comparing international fatigue design loadings

Key criteria	Conclusions and comments
Design life	Australian and North American codes adopt a 75-year fatigue design period considering that fatigue life estimates normally represent the onset of cracking. Unless the Transport Agency requires higher levels of protection afforded by a 'safe life' approach and longer periods nominated in the Eurocodes, there does not appear to be a reason to differ from AS 5100. A longer design life could be specified in project-specific requirements, and the strength reduction factor can be used to address reliability levels.
Fatigue load models	Best practices (eg Eurocodes, UK Annex) are to provide a design vehicle load spectrum in addition to a standard vehicle method suitable for steel bridges. The Australian and two North American codes all adopt the vehicle specified for the design live loads and base the cycle counts on estimated average daily truck traffic (ADTT) counts over the 75-year life. The Australian code is unique in its use of a very high vehicle loading with a lower variable cycle count.

Key criteria	Conclusions and comments
Dynamic load allowances	AS 5100.2 is unusual as the other codes apply a reduced allowance compared with design live loads, or allow for dynamic effects in the base fatigue load models. AS 5100.2 may not adequately address requirements near expansion joints. The Eurocode approach (additional factor near joints) has merit.
Stress range calculations	The Eurocodes with the UK Annex and either the standard fatigue vehicle model (FLM3) for steel and steel-concrete composite structures or the vehicle spectrum model (FLM4) are considered to represent best practice generally. A standard vehicle method using the maximum stress range for one standard vehicle passage is the preferred approach for simplified design procedures. Multiple presence should be considered where the effect may be significant. AS 5100.2 is the only code that includes a fixed reduction factor to allow for differences between calculated and real stress ranges. The UK National Annex provides best practice for application of vehicle spectra load models.
Lifetime vehicle count basis	The inherent growth allowance in AS 5100.2 is massive compared with international codes (and this is considered to be appropriate given our developing infrastructure and vehicle standards), and may increase the average lifetime vehicle counts to levels comparable to the international codes. The British, European and North American interstate highway loadings are based on running at lane capacity over the design life, but no vehicle mass growth allowances are included.
Route type differentiation	There is wide variation in approaches for this parameter: The UK and North American per-vehicle loadings are fixed and only the daily counts are varied; the Eurocodes allow for 3 traffic mix types; while the Australian code allows for 4 different route types.

The above key criteria are addressed in the body, conclusions and recommendations of this report.

2.4 New Zealand studies

2.4.1 New Zealand Heavy Engineering Research Association (HERA) – recommended draft fatigue design criteria for bridges

The 3rd edition of the Transport Agency's *Bridge manual* (2013c) references interim guidance for steel bridges prepared by Clifton (2007) based on AS 5100.2 (see section 2.3.1 above). The recommended route factors for New Zealand roads are 0.9 for principal state highways, 0.65 for major urban roads, 0.45 for other rural routes and 0.3 for other urban roads (around 90% of the Australian factors). The source for these route factors is the work summarised in section 3.3 of this report, using 2005 WIM data (excluding the newer data collection sites).

2.4.2 A new vehicle loading standard for road bridges in New Zealand

Taplin et al (2013) undertook a parallel research project for the Transport Agency to consider the appropriate live loading standard to suit future higher mass vehicles on New Zealand roads. The report recommends that 80% of the Australian SM1600 vehicle design loading be adopted for the design of new road bridges.

This has been taken as a strong indication that adoption or modification of the AS 5100.2 vehicle fatigue load model should be provided for the New Zealand bridge fatigue design loadings.

3 Research methodology

3.1 Outline

The methodology for this research project included the following steps:

1. reviews of fatigue loading and design provisions in international codes of practice (see chapter 2)
2. engagement with the Steering Group and peer reviewers to confirm the proposed methodology and industry requirements
3. collection, analysis, and validation of heavy vehicle data from available WIM site records (see chapter 4)
4. development of damage equivalent fatigue loading at WIM sites, based on single design vehicles (see chapter 5)
5. development of equivalent standardised vehicle spectra representing current fatigue loading at WIM sites (see chapter 6)
6. estimation of prior growth rates to be used for assessment of existing bridges, and future long-term growth assumptions to account for projected increases in vehicle numbers and average loading (see chapter 7)
7. selection of one or more suitable design fatigue vehicles and calibration to fit the long-term growth in heavy vehicle mass and volume (see chapter 8)
8. generalisation of the WIM site fatigue load models to fit other route types (see chapter 9)
9. preparation of fatigue design guidelines for road bridges comprising load models, fatigue analysis procedures and adoption of an appropriate design standard for steel and composite steel–concrete bridge design (see chapter 10).

Relevant methodology details are included in each section of the report, and additional background notes are provided below.

3.2 Heavy traffic data collection

The Transport Agency owns eight WIM stations on the state highway network, including two stations at the Auckland Harbour Bridge (AHB) managed by the Auckland Motorway Alliance (AMA) and the Auckland Harbour Bridge Alliance (AHBA). There are also traffic-counting sites spread around the state highway network. Outputs from the Transport Agency-managed systems are available from the Transport Agency's Traffic Monitoring System (TMS) database, while the AHB data is maintained by the AMA in a dedicated database system.

The Transport Agency publishes annual reports with lists of annual average daily traffic counts (AADT). *State highway traffic data booklet 2008–2012* (2013a) estimates heavy vehicle percentages at all traffic-counter sites over several years, and the *Annual weigh-in-motion (WiM) report 2012* summarises data from the WIM sites (NZ Transport Agency 2013e).

This current study relies on WIM data for estimation of the fatigue loadings, and a substantial sample of vehicle data was obtained from the database systems noted above. Appendix H contains our report entitled 'Heavy vehicle data collection, analysis and validation summary', which summarises our initial data analysis and validation. Chapter 4 of this report lists the adopted datasets and references the main summary of heavy vehicle weight characteristics that is contained in appendix H.

3.3 Previous research on adaptation of the AS 5100.2 fatigue load models to New Zealand heavy traffic

An earlier study (Beamish et al 2006), which carried out an assessment of fatigue loading on the AHB, adopted similar methodologies to those of Grundy and Boully (2004a; 2004b) for estimates of equivalent fatigue vehicle loading derived from WIM data. The tools for data analysis and calculation of effects on bridge spans developed for the AHB studies were the basis of the data processing in this research project.

A selection of data from other New Zealand WIM sites (for March 2005) was also analysed for comparison with the AHB data. Those results indicated that adoption of the AS 5100.2 was thought to be feasible, but required further investigation to determine the parameters for other routes. Subsequent review of the results for the rural WIM sites carried out by Clifton (2007) led to interim recommendations for the application of AS 5100.2 fatigue loading to New Zealand bridges.

The fatigue loading estimates for the AHB site indicated that the M1600 fatigue vehicle from AS 5100.2 was unsuitable for assessment purposes, and a site-specific model based on HN[1] loading effects was developed for assessment of the truss bridge deck girders under the current loading.

The AHB study also found that the UK vehicle spectrum model from BS 5400: part 10 (1980) would provide a slightly conservative fit to the 2006 heavy traffic data for span lengths of interest. The comparisons between the AHB data and the rural WIM site data also indicated the UK spectrum would give lower fatigue loading per heavy vehicle than the New Zealand data, and would not be suitable for use without modification.

The earlier work for the AHB site and other WIM sites formed the basis of the methodology used in this study for estimates of equivalent single-vehicle loading, as described in chapter 5 of this report.

The AS 5100.2 fatigue loading method was thought to be attractive for a number of reasons:

- Loading is relatively simple to apply because it utilises a single cycle of the standard moving vehicle live loading included in the bridge live load standard.
- Concerns about the high loading for the M1600 vehicle are offset by a 0.7 reduction factor and a relatively low number of repetitions, decreasing with span length.
- The base fatigue vehicle covers 'platoons' of future HPMV vehicles.
- Calibration to New Zealand WIM data might be achieved by adjusting the route factors. A similar calibration process could be applied to any other suitable design vehicles.
- The Transport Agency had already adopted the HERA recommendations (Clifton 2007) based on AS 5100.2 for major projects.
- The future heavy vehicle fleet trends with the introduction of higher mass vehicles to New Zealand were perceived to be heading in a similar direction to Australia.

There were also some perceived disadvantages:

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[1] The unfactored design loading representing normal highway bridge loading, as defined in the Transit NZ *Bridge manual*, 2nd ed. (2003), comprising a 10.5kN/m UDL and two 120kN axles at 5m spacing.

- For small bridges or localised effects, the M1600 bogie loads may give high stresses compared with normal vehicle loading.
- The high loading might be problematic for the assessment of existing structures because the service loading could exceed the upper limit on the stress range.
- As the M1600 truck is not a current design vehicle in New Zealand, there was no particular reason to use it other than to facilitate direct use of AS 5100.
- The calibrations to WIM data (in both the Australian and New Zealand studies) are intended to be applicable to steel bridges and the applicability to reinforced or pre-stressed concrete structures is unclear.
- The route factors proposed in the HERA recommendations were not checked for suitability for future HPMV loadings or for use on routes other than the main highways represented by the Transport Agency's WIM sites.
- The future growth allowances implicit in the AS 5100.2 loadings have not been reviewed for applicability to New Zealand roads.
- The damage equivalence relationship used in the AS 5100.2 loading derivation is heavily weighted toward the higher stress range part of the S-N curves (less than 5 million cycles, or less than 180 repetitions per day) where a 3rd-power relationship applies for steel. For more frequent loading, a 5th-power relationship applies, and calibrations are expected to be conservative for longer spans.

The potential advantages and disadvantages of the AS 5100.2 fatigue loadings were investigated in this study.

3.4 Vehicle spectrum methods

The intention of the research project was to limit the scope to steel or composite steel–concrete bridges, as assumed in the methodology proposed for the development of a single fatigue vehicle. However, the review of the international standards identified that comprehensive fatigue assessments of reinforced concrete and pre-stressed concrete bridges could be carried out using the Eurocode verification procedures, but S-N curves for reinforcing and pre-stressing steel use higher powers (exponent m=5 to 10). Therefore single fatigue vehicle models calibrated for equivalent damage in structural steel components should not be applied to concrete structures.

Unless the vehicle spectrum is considered to fit the European models represented by FLM4 in EN 1991-2: 2003, there is currently no appropriate way of using the Eurocode 2 simplified methods based on a single design fatigue vehicle for fatigue assessment of concrete structures in New Zealand. On the other hand, the UK National Annex to EN 1991-2 offers a comprehensive spectrum, including overload permit vehicles, which may be used for the assessment of concrete structures.

The project Steering Group agreed that the research project scope should include a standard vehicle spectrum option to fit the *current* heavy vehicle loading, which would be material neutral and provide for detailed assessments of complex structures. The methodology for estimating the vehicle spectra for current loading at the WIM sites is explained in chapter 6.

3.5 Generalisation to other route classes

The average fatigue damage per heavy vehicle is very sensitive to vehicle mix, and thus a hierarchy of route types should be provided for in order to avoid unnecessarily conservative loadings on local roads.

Recently, the Transport Agency (2013d) introduced a classification system for state highways that reflects traffic volumes and preferred heavy freight routes. However, there is significant uncertainty around the current and future vehicle mix on those routes, and very limited data available.

In other codes it is apparent that simplicity is preferable and no more than three different heavy traffic mixes are normally considered (as for Eurocode 1 Fatigue Load Model 4), with up to four road categories determining the design heavy traffic volumes. AS 5100.2 uses estimated day one heavy counts with a code-specified multiplier allowing for heavy vehicle volume and mass growth, and a route factor to adjust for different vehicle type mixes. The necessity for project-specific determinations of heavy vehicle counts (as for AS 5100.2) versus specified daily heavy vehicle lane counts by road type (the Eurocode approach) was not explicitly considered in this project. However, the availability of heavy vehicle count information for state highways was reviewed and is discussed in chapter 9 and noted in the recommendations.

Variations in heavy traffic mix were explored by first checking which state highways had periods of axle-classified counts in 2011. Samples were reviewed to check applicability and differences from the WIM sites. Initially, it was expected that the classified heavy vehicle counts could be applied to average fatigue damage measures for each vehicle class (see appendix C) to estimate the average fatigue damage per heavy vehicle. However, the availability of representative vehicle spectra allowed for a more efficient methodology where the WIM vehicle fleets were replaced by the standardised spectra vehicles. Where vehicle class mixes at other sites differed from the WIM sites, the proportions of vehicles in each class were adjusted.

The results of evaluations at a wide range of rural sites are summarised in chapter 9. Unfortunately, there was no classified count data available for urban sites apart from the AHB.

3.6 Long-term growth allowances

3.6.1 Historic vehicle loading growth

By agreement with the project Steering Group, it was considered unnecessary to provide generic guidance for the assessment of historic fatigue loading, as the few existing fatigue-prone bridges have required detailed assessments and retrofitting or replacement. Therefore, a simple review of national historic growth statistics is provided in chapter 7.

For special studies of fatigue-prone structures, it would be necessary for the bridge consultant to establish the particular route history and local factors affecting load growth in order to carry out a detailed assessment of existing bridges. A simplified uniform growth rate method modifying the current vehicle loading spectra should be suitable for screening. For old steel structures with weight restrictions in place, the spectra derived in this study will not be appropriate

3.6.2 Estimates of future growth in vehicle fatigue loading

The design fatigue loading spectra must allow for future growth in both numbers of heavy vehicles and average loading. The 2010 amendment to the *Vehicle dimensions and mass (VDAM) rule* (NZ Transport Agency 2010a) introduced increased gross and axle set mass limits for approved HPMVs.

Methods for estimating suitable allowances for future growth are discussed in chapter 7, and details of the methodology for estimating the effect of higher mass HPMVs on average fatigue damage per heavy vehicle are provided in appendices F and G. The equivalent single-vehicle fatigue load models were adjusted for HPMV effects, but not the vehicle spectrum models.

4 New Zealand heavy vehicle characteristics

4.1 Heavy vehicle definition

A heavy motor vehicle (HMV) is a vehicle with gross mass over 3.5 tonnes, but the actual mass of such vehicles may be less than 3.5 tonnes when not fully loaded. Transport Agency reports define measured weights of over 3.5 tonnes as 'heavies' at their WIM sites.

The heavy vehicle counts used for fatigue assessments exclude Transport Agency classes 1–3 (vehicles with a wheelbase less than 3.2m, cars towing trailers, and other light vehicles; see appendix A). This criterion, which is consistent with the definition in AS 5100.2 clause 6.9, also excludes short-wheelbase 2-axle trucks with a gross mass over 3.5 tonnes. Buses are included in the heavy vehicle counts.

The above definition must not be confused with heavy commercial vehicles (HCV), defined in the *Economic evaluation manual (EEM)* (NZ Transport Agency 2010b) as vehicles with three or more axles, and are either rigid trucks (with or without a trailer) or articulated vehicles. This narrow definition excludes all buses, and heavy trucks with two axles. Therefore, if HCV counts or percentages are specified in project design requirements, they should be interpreted as the counts for vehicles with three or more axles when applying the information in this report. However, the latter definition is not consistently applied in transportation studies and clarification should be sought.

4.2 Data sources and reviews

A separate report issued in May 2012 presents a review of heavy traffic data acquired from WIM stations managed by the Transport Agency, and lists the datasets used to derive the fatigue loading spectra presented in this report. Our report 'Heavy vehicle data collection, analysis and validation summary', with updates, is attached as appendix H. Maps showing the WIM site locations and other Transport Agency telemetry (continuous counter) sites are provided in appendix A.

Annual reports presenting the summarised data from WIM sites are provided on the Transport Agency website (NZ Transport Agency 2013e) and AADT for the telemetry sites and other counter sites are provided in the Transport Agency's annual traffic data booklets (NZ Transport Agency 2013a), which include estimates of heavy vehicle content.

Table 4.1 Details of Transport Agency-owned WIM stations in New Zealand

Site ref.	ID code	Location name	Highway position	Inception date	Lanes	Comments
01N00463	48	Drury	01N-0461/2.24	Jan 2001	4	Motorway
00500259	101	Eskdale	005-0249/10.26	Jul 2010	2	Freight, logging route
00200176	49	Te Puke	002-0171/4.4	Jan 2000	2	Freight route
01N00628	51	Tokoroa	01N-0625/3.5	Jan 2000	2	Freight route
01S00285	52	Waipara	01S-0284/0.6	Jan 2000	2	Freight route
03500321	108	Hamanatua Bridge	035-0321/0.091	Nov 2011	2	High proportion of logging trucks
01N18423		AHB southbound	01N-0414/9.0	Dec 2000	5	Urban motorway
01N28423		AHB northbound	01N-0414/8.6	Jun 2006	5	Urban motorway

Table 4.1 lists the current Transport Agency WIM sites. At the time of writing, no data was available from the new Hamanatua site, but inspection of recent data indicated a high proportion of fully loaded 8-axle logging trucks in one direction.

4.3 Datasets for fatigue loading

The WIM datasets selected for use in the fatigue loading assessments are listed in tables 4.2 and 4.3. The heavy vehicle records were filtered to exclude invalid data records and light vehicle classes. Non-standard vehicle types not included in the Transport Agency vehicle classification scheme (see appendix B) were also excluded in the data obtained from the Transport Agency database. Thus, the number of heavy vehicle records per day in table 4.2 is less than the average counts obtained from the unfiltered summary count data (see table 4.3) and therefore the daily fatigue damage estimates should be increased in proportion to the total heavy vehicle counts. Previously analysed data for the AHB (listed in table 4.3) includes all heavy vehicles for each direction (distributed over three to five lanes) and does not require correction for missing vehicles.

Table 4.2 Datasets selected for analysis of fatigue loading

Site	Lane	Time period	Heavy vehicles	Days	Heavies/day/lane
Drury	1 northbound	Jan–Sep 2005	486,031	266	1827
Drury	1 northbound	May 2010– Mar 2011	542,233	301	1801
Drury	1 southbound	Jan–Dec 2011	650,029	351	1852
Eskdale	Eastbound	Oct 2010–Feb 2011	38,167	141	271
Eskdale	Westbound	Oct 2010–Feb 2011	39,598	141	281
Te Puke	Westbound	Jan–Jun 2005	106,016	139	763
Te Puke	Westbound	Nov–Dec 2007	45,266	61	742
Te Puke	Westbound	Jan–May 2010	126,102	151	835
Tokoroa	Northbound	Nov–Dec 2005	39,135	61	642
Tokoroa	Northbound	Jan–Jul 2010	121,842	212	575
Tokoroa	Northbound	Jan–Jun 2011	116,871	180	649
Tokoroa	Southbound	Aug–Dec 2011	98,989	153	647
Waipara	Northbound	Jan–Feb 2007	16,270	38	428
Waipara	Southbound	Nov 2010–May 2011, Sep–Dec 2011	172,857	332	521
Total			**2,599,406**		

At the Drury site (dual carriageway), the inner lanes were excluded from the analysis due to relatively low counts (5–6% of total heavy vehicles) and uncertain calibration reliability. The mass distributions for the inner lanes were similar to the outside lanes so the fatigue loadings per vehicle for the outside lanes were considered valid for the directional totals in table 4.3.

Table 4.3 includes counts for the State Highway 1 (SH1) Paekakariki axle classifier site north of Wellington. This site provides good-quality counts by vehicle class and was used as an example for estimation of fatigue loading on routes not covered by WIM sites.

At the urban highway sites (AHB and Paekakariki), it was evident that doubling the observed counts for 3+-axle vehicles to obtain the total heavy counts (as recommended in the UK National Annex to Eurocode 1) is a satisfactory approximation. At the other sites, the average 2-axle heavy vehicle counts added 25–45% to the 3+-axle totals.

Table 4.3 Average daily vehicle counts for selected datasets

Dataset	All vehicles	Heavy vehicles with ≥2 axles		Heavy vehicles with ≥3 axles	
		Count	%	Count	%
Drury Jan–Sep 2005, northbound	20,137	2055	10%	1443	7.2%
Drury May 2010–Mar 2011, northbound	20,483	2148	10%	1553	7.6%
Drury Jan–Dec 2011 southbound	20,957	2094	10%	1459	7.0%
Eskdale Oct 2010–Feb 2011, eastbound	1997	289	14%	234	12%
Eskdale Oct 2010–Feb 2011, westbound	1979	291	15%	241	12%
Te Puke Jan–Jun 2005, westbound	9203	841	9.1%	597	6.5%
Te Puke Nov–Dec 2007, westbound	10,787	967	9.0%	667	6.2%
Te Puke Jan–May 2010, westbound	9849	936	9.5%	697	7.1%
Tokoroa Nov–Dec 2005, northbound	4415	712	16%	514	12%
Tokoroa Jan–Jul 2010, northbound	4398	680	15%	571	13%
Tokoroa Jan–Jun 2011, northbound	4304	668	16%	562	13%
Tokoroa Aug–Dec 2011, southbound	4441	796	18%	622	14%
Waipara Jan–Feb 2007, northbound	4385	515	12%	384	8.8%
Waipara Nov 2010–May 2011, southbound	3981	571	14%	421	11%
Waipara Sep–Dec 2011, southbound	3736	670	18%	404	11%
AHB Mar 2007, southbound	82,597	3104	3.8%	1589	1.9%
AHB Mar 2007, northbound	84,337	3203	3.8%	1571	1.9%
AHB Mar 2011, southbound	76,055	3059	4.0%	1567	2.1%
AHB Mar 2011, northbound	81,267	3094	3.8%	1573	1.9%
Paekakariki 2011, northbound	11,626	921	7.9%	521	4.5%
Paekakariki 2011, southbound	11,581	874	7.5%	522	4.5%

4.4 Weight calibrations

In the absence of detailed calibration information for the Transport Agency sites, dataset selections were guided by average steer-axle weights for 6-axle semi-trailer rigs, being in the expected range for loaded vehicles, in order to eliminate periods where there may have been significant calibration discrepancies. It is a well-established principle that this parameter is relatively insensitive to variations in average payload, and it is commonly used for monitoring calibration accuracy of WIM stations in Australia and the US.

As there can be genuine explanations for small variations in this parameter between sites (eg fuel load, fleet mix, or large differences in average payload – which may have seasonal variations), there may be calibration variances present in the datasets selected using this parameter. As the average steer-axle weights for the chosen datasets were generally at the middle to high end of the expected range, it is unlikely that calibrations were low for those periods, and high settings of around +2% would not be unexpected. A calibration discrepancy of +2% would increase calculated fatigue damage by 6–10% (with 3rd- to 5th-power rules), and this potential minor conservatism was noted when fitting fatigue load models to analysis results derived from the processed WIM datasets.

5 Current fatigue loading on main highways – design vehicle approach

5.1 Introduction

An equivalent design fatigue vehicle approach represents bridge fatigue loading as a single vehicle with a varying number of repetitions chosen to cause at least the same cumulative fatigue damage as the fleet of real vehicles expected to cross the bridge.

The baseline bridge fatigue loading used in this study was derived from the New Zealand WIM datasets listed in chapter 4. The basic processing methodology used to assess the equivalent single-vehicle fatigue loadings was similar to that of Grundy and Boully (2004a; 2004b) and Roberts and Heywood (2004). The principles of this method are as follows:

- Codified fatigue life verification procedures for structural steel bridge components use *one* stress cycle value equal to the difference between the maximum and minimum stress values at points of interest for passages of the nominated design vehicle across the structure.
- Bending moments, shear forces and support reaction forces for bridge spans are used as substitutes for stress in the calibration of the design fatigue vehicle, and the ranges of these actions (trough to peak) during passages of the vehicles are used in place of stress cycle ranges.
- *One* cycle (the maximum range) of bending moment, shear force or reaction force for the design vehicle on a particular span length is therefore used as a reference value for comparison with the corresponding effects for the vehicle fleet.
- For structural steel components, the appropriate fatigue damage measures are cumulative summations of the 3rd and 5th powers of the 'stress' cycle ranges (bending moment ranges, etc).

The design fatigue vehicle calibration can be expressed as:

$$\sum \begin{pmatrix}\text{fatigue damage}\\ \text{for each heavy}\\ \text{vehicle in fleet}\end{pmatrix} = \begin{pmatrix}\text{average fatigue}\\ \text{damage per}\\ \text{heavy vehicle}\end{pmatrix} \times \begin{pmatrix}\text{heavy vehicle}\\ \text{traffic volume}\end{pmatrix} = \begin{pmatrix}\text{single cycle}\\ \text{fatigue damage}\\ \text{for design vehicle}\end{pmatrix} \times \begin{pmatrix}\text{equivalent}\\ \text{number}\\ \text{of cycles}\end{pmatrix}$$

5.2 Initial selections for design vehicles

5.2.1 Reference loading – 0.85HN

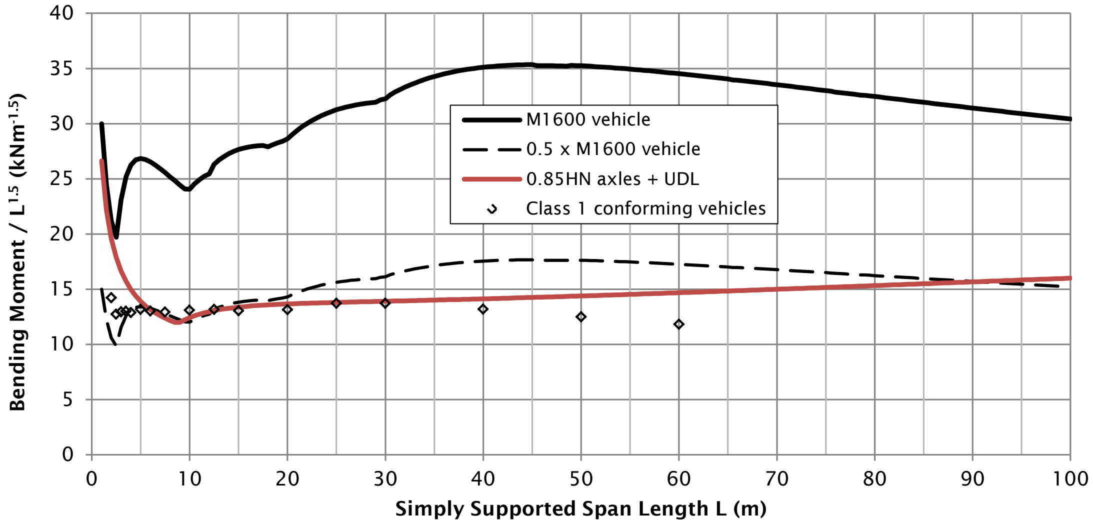
The single-lane assessment loading specified in the *Bridge manual* (NZ Transport Agency 2013c) for the evaluation of existing bridges subject to Class 1 vehicle loadings is 85% of the unfactored HN loading (axle loads plus uniform load). The single-lane 0.85HN effects on simply supported spans (maximum bending moment, shear forces and interior support reaction force) without impact were used as convenient reference loadings to non-dimensionalise the per-vehicle load effects. This was intended to be a scaling device, to provide repetition counts relative to a loading similar to current maximum legal weight vehicle effects.

5.2.2 AS 5100.2 fatigue vehicle – M1600

Following the Grundy and Boully (2004a) approach, the initial evaluations of fatigue loading at the New Zealand WIM sites also used M1600 as a reference loading. It is useful to compare the magnitudes of these loadings, and consider the likely scaling factors that might be necessary to reduce M1600 effects down to current service levels.

There is no standard method for comparing the effects of design vehicle loadings over a wide range of span lengths. Taplin et al's 2013 report 'A new vehicle loading standard for road bridges in New Zealand' used span moments divided by $Length^{1.5}$ as a convenient scaling device when comparing loadings from several standards. We adopted this for comparing the vehicle moments shown in figure 5.1.

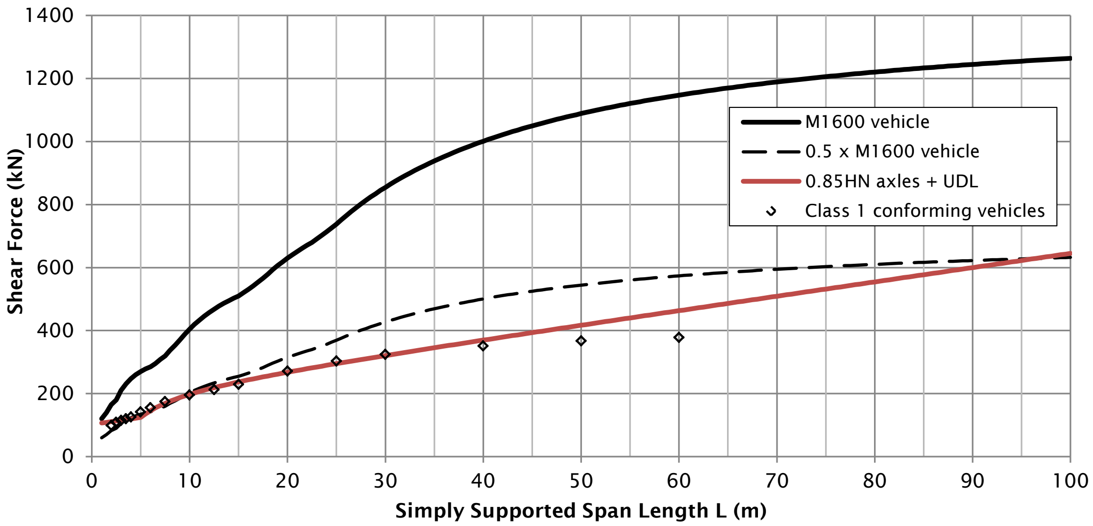
Figure 5.1 Comparison of M1600 and 0.85HN bending moments, both scaled by $1/span^{1.5}$



The existing assessment loading moments (0.85HN) are less than 50% of the M1600 vehicle at 20m to 90m span lengths, and similar to 0.5xM1600 at 5m to 15m spans. Figure 5.1 also compares 0.5xM1600 and 0.85HN bending moments with the single-cycle maxima for a selection of conforming Class 1 vehicles. The 0.85HN moment is higher than the legal vehicle's at spans less than 5m, due to the heavy single-axle load (102kN) being larger than the Class 1 limit of 80kN for standard dual-tyre axles.

The M1600 plots show dips in the curves at spans less than 5m, where tandem axles have less effect than single axles, and triple axles have even less. The AS 5100.2 loading uses an A160 (160kN) axle to adequately cover short spans, and 50% of that (80kN) matches the Class 1 single-axle weight limit of 8200kg.

Figure 5.2 M1600 shear forces compared with 0.85HN



Similarly, the shear force plot in figure 5.2 shows that the Class 1 and 0.85HN effect is similar to 0.5xM1600 at 5m to 15m spans.

Relevant points to note from the above comparisons are as follows:

- The 0.85HN loading is a convenient choice for a reference loading aligned with Class 1-conforming vehicle loads for spans of 5m or more.
- The M1600 vehicle can be used as a reference loading for comparison with the Australian studies but 0.5xM1600 (or 0.5xA160 on very short spans) would be a more appropriate starting point for a vehicle aligned with the current loading.

Other suitable vehicles could be considered, but to meet the objectives of the current study, the results have been initially presented in terms of both the M1600 vehicle (to facilitate comparisons with the AS 5100.2 model) and the Bridge Manual single-lane assessment loading (0.85HN).

5.3 Processing methodology

The cumulative fatigue damage measures used for evaluation of vehicle effects were summations of the 3rd and 5th powers of mid-span bending moment ranges (trough to peak) for passage of the vehicles over a simply supported span. The end shear forces and reactions for a 2-span bridge were also evaluated. These measures are appropriate for fatigue loading on structural steel components, noting that for the design of new structures, all stress cycles are expected to lie in the range where the 5th power is applicable (with the possible exception of overweight permit vehicles). The 5th-power rule is applicable to all shear stress ranges, but higher power rules would apply to shear studs (8th power) and reinforcing or pre-stressing steel (5th to 10th powers in the Eurocodes).

The selected raw vehicle datasets (see table 4.1) were processed to evaluate fatigue damage sums for several girder span lengths in the range 2m to 60m. In the bulk processing step, the reference loading for the equivalent cycle counts was the unfactored 0.85HN loading (UDL plus axle loads, no impact). The process is applied to a simply supported span as follows:

- For each vehicle and span length, calculate maximum span bending moment, shear force and support reaction on a structure with two simply supported spans. The cycles (trough to peak ranges ΔS_i) and cycle counts for the response history are calculated using a rainflow counting algorithm (Downing and Socie 1982). For manual evaluation, the (equivalent) reservoir method (BS 5400: part 10, appendix B) may be used. The Wikipedia (2013b) article provides background and explanation of the rainflow counting method, and Buhl (2008) provides the computer code (Schluter 1989) that was adapted for this study.
- The mid-span moment, shear force and reaction ranges are converted to equivalent repetition counts for the peak values for the vehicle, and for the reference load value (a single cycle of the moment, shear force or reaction range due to 0.85HN loading, ΔS_{ref}), eg $\text{counts}_{\text{ref}} = \frac{\sum(\Delta S_i{}^m.\text{counts}_i)}{\Delta S_{\text{ref}}{}^m}$.
- These damage equivalent counts are computed for both 3rd- and 5th-power rules (m=3, m=5).
- The number of equivalent repetitions of the reference loading is summed for all vehicles and the average number of equivalent repetitions per heavy vehicle is calculated.
- These summations of repetition counts are initially calculated using the 0.85HN effects as the reference loading. As noted in section 5.2.1, this is intended to be a scaling device, to provide counts relative to a loading similar to current maximum legal-weight vehicle effects.

- Subsequently, the total or average repetition counts for each span length can be converted to the equivalent repetition counts for proposed fatigue design vehicles, starting with the M1600 vehicle to enable comparisons with the AS 5100.2 fatigue loadings; eg:

$$\text{M1600 counts} = \text{0.85HN counts} \times \left(\frac{\Delta S_{0.85\text{HN}}}{\Delta S_{\text{M1600}}}\right)^m$$

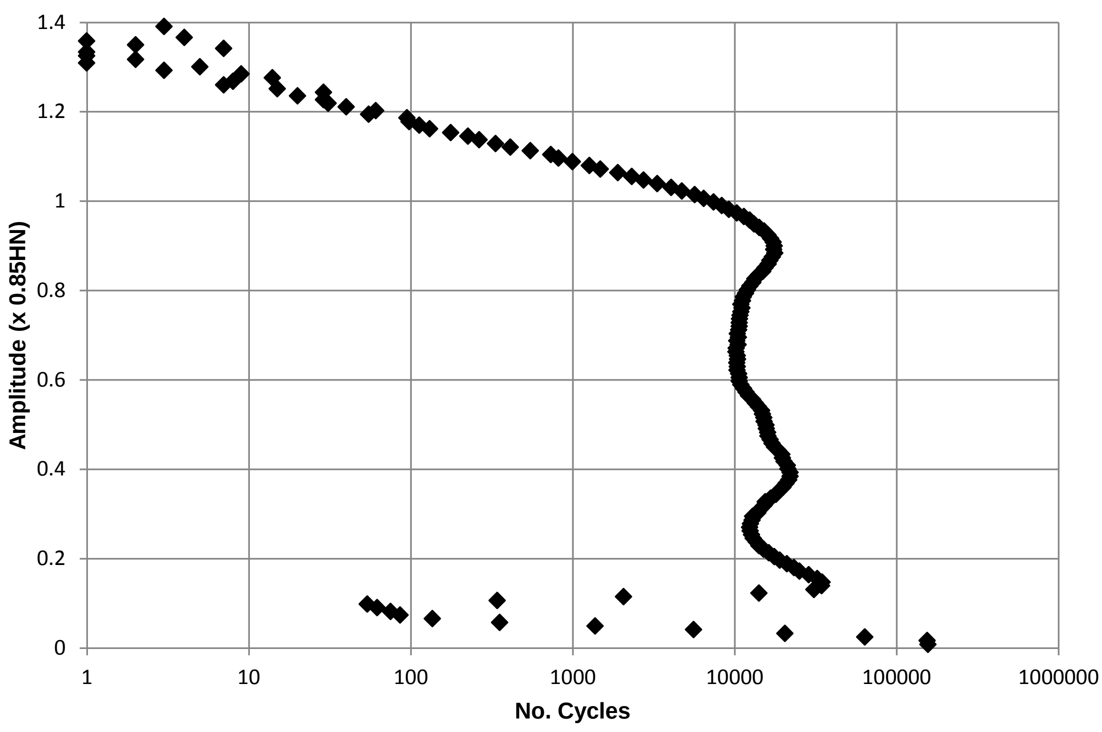
The outputs from this processing were stored in a SQL server database (one record per vehicle for each span length) to facilitate tabulation in a variety of formats, including collation of damage summations and averages per heavy vehicle by vehicle class, site, lane and time periods.

5.4 Fatigue load processing results

5.4.1 Bridge response

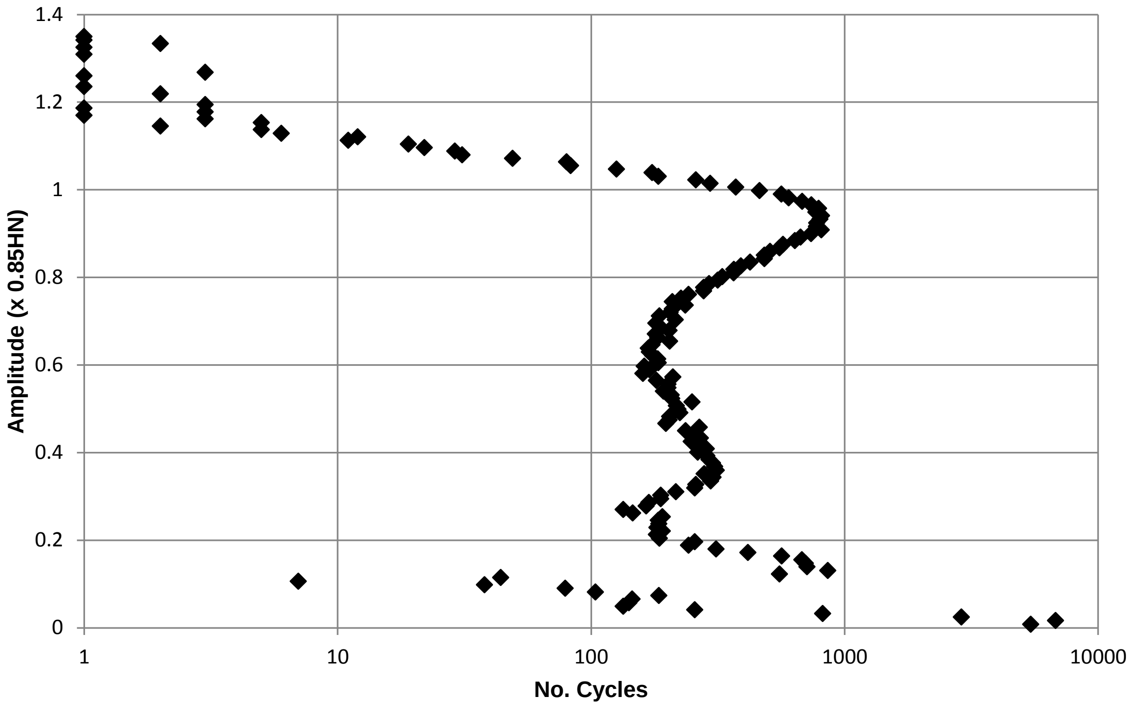
The vehicle processing output is illustrated in figure 5.3, which shows the histogram of bending moment results for the selected SH1 Drury WIM site record sets passing over a 20m simply supported span, relative to the unfactored single-lane 0.85HN loading effect. As the cleaned data excludes unclassified vehicle types, the small number of very high results (up to 140% of 0.85HN moment) excludes exceptional overweight vehicles (such as large mobile cranes and transporters) but includes common low-loader configurations (eg PAT type 62 – semi-trailers with three widely spaced axles). At this site, vehicle effects are well distributed across the 0.2–1.0 amplitude range while only 1.9% of the cycles exceed 0.85HN. In contrast, the Eskdale site (high proportion of logging trucks) has a much higher proportion of results close to the 1.0 x 0.85HN effects in one direction (see figure 5.4).

Figure 5.3 Fatigue loading – bending moment cycles for 20m span, SH1 Drury WIM site, outside lanes (all selected periods, 1.69 million heavy vehicles, 10kNm increments)



The histogram outputs of bending moment ranges with cycle counts illustrated in figures 5.3 and 5.4 can be useful in fatigue assessments of simply supported girders, but they were not required in this study as the fatigue loadings have been presented in terms of equivalent repetitions of a selected vehicle loading, or as an equivalent set of standardised vehicles (see chapter 6), which could be used to calculate stress range histograms.

Figure 5.4 Fatigue loading – bending moment cycles for 20m span, SH5 Eskdale eastbound (Oct 2010–Feb 2011, 38,200 heavy vehicles, 10kNm increments)



5.4.2 Fatigue loading – comparison with Australian results

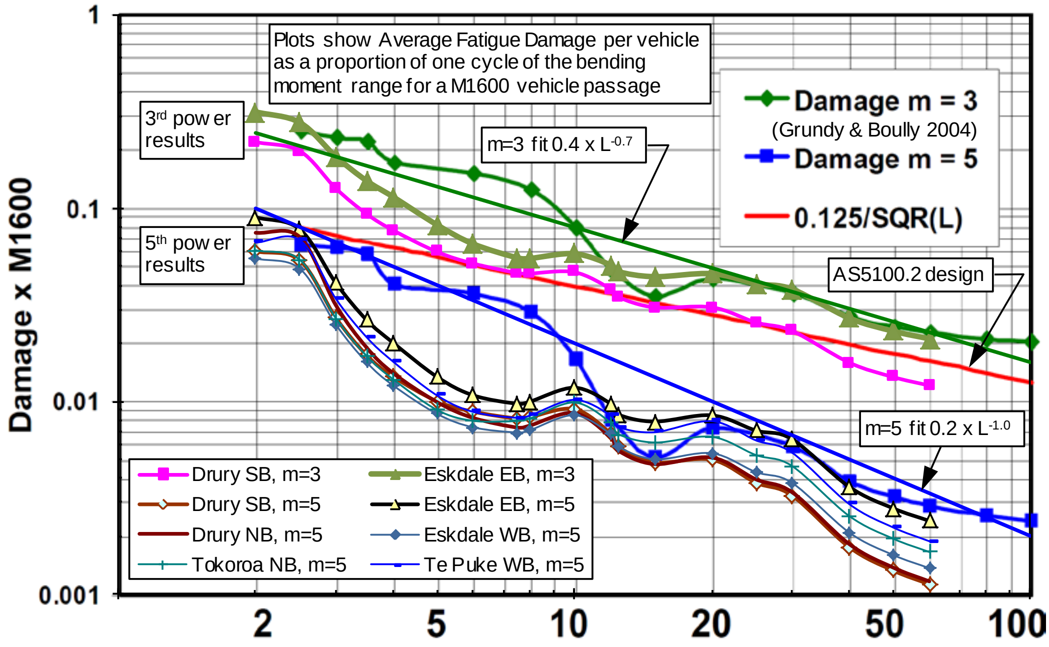
In figure 5.5, the results for selected WIM datasets are compared to the results presented by Grundy and Boully (2004a) for the reference site used in the derivation of the AS 5100.2 fatigue loading for principal interstate highways (the dark green and blue lines). In this chart, the vertical axis is the average fatigue damage per heavy vehicle expressed as a fraction of the damage for a single cycle of 100% M1600 vehicle loading (excluding the UDL), and the horizontal axis is the simply supported span length. The red line marked 'AS 5100.2 design' indicates the average damage per heavy vehicle adopted for the AS 5100.2 design fatigue loading ($0.125L^{-0.5}$) on principal interstate highways. The 'best-fit' lines proposed by Grundy (2002a) for 3rd-power ($0.4L^{-0.7}$) and 5th-power ($0.2L^{-1.0}$) rules are also shown.

From this comparison, several observations can be made on the relativity between recent Australian and New Zealand heavy vehicle loadings on main highways:

- The Eskdale eastbound results (large proportion of fully loaded logging trucks) are very similar to the Hume Highway results for spans over 20m (related to total vehicle mass) or at very short spans (single-axle loading).
- The results for the other New Zealand sites are lower, 70–85% of the Eskdale results (at 10–30m spans).

- There are substantial differences in damage per vehicle at short spans (3–10m), explained by significantly heavier double- and triple-axle sets on a higher mass route (eg 42.5-tonne semi-trailers, 62.5-tonne B-doubles), and a higher proportion of such vehicles in Australia, whereas the dominant (legal) types at the New Zealand WIM sites are 44-tonne truck-and-trailers with tandem axles.
- The dip in damage per vehicle between 10m and 20m is less pronounced in the New Zealand data, reflecting differences in axle set effects for the dominant vehicle types compared with the axle set effects for the M1600 vehicle.

Figure 5.5 Comparison of New Zealand WIM site results with Hume Highway results (Australia) (bending moments in simply supported spans)



The New Zealand datasets represented in figure 5.5 did not contain significant numbers of HPMV vehicles (with higher axle set and gross masses), whereas the Australian sample included higher mass limit vehicles. Thus, it is conceivable that once significant take-up of the new limits occurs, the average damage per heavy vehicle may trend toward to the results for the Australian sample (recorded in 2001).

The results shown in figure 5.5 also show that the average damage per vehicle is much less than for the M1600 vehicle, typically less than 1% for a 5th-power damage rule. Therefore, the equivalent cycle counts applied in the AS 5100.2 fatigue loadings are orders of magnitude less than the true fatigue cycle counts for typical vehicles.

5.5 Fatigue loading – M1600 options

5.5.1 Unmodified M1600 vehicle

One of the options considered for a standard fatigue vehicle in this study was the M1600 vehicle as per AS 5100.2 (with or without a scale factor). This required adjustments to the cycle count parameters to fit the New Zealand heavy vehicle mixes, volumes and expected future growth.

As described by Grundy and Boully (2004a), the basis of the AS 5100.2 fatigue load cycle counts is as follows:

- Damage per truck (including the effects of all cycles) is represented by a proportion of the damage due to only *one* cycle of the maximum stress range for one passage of the M1600 design vehicle. The additional cycles caused by multiple axle sets are accounted for in the cycle count formula, removing the requirement to calculate cumulative damage from different stress ranges for the design vehicle.
- Where the majority of stress cycles have amplitudes exceeding the CAFL, the average damage per vehicle will be close to the results for the 3rd-power rule, or closer to the 5th-power results where the majority of cycles are below the CAFL.
- Thus for short spans, the AS 5100.2 design curve for damage per truck fits the results for a 5th-power rule (see figure 5.5), as the number of significant cycle counts for axle and axle set loading is expected to exceed $5x10^6$ over the bridge design life.
- For medium to long spans, there are fewer significant stress cycles; however, it is still expected that most stress cycles for medium-span-length bridges designed for current loading should be below the CAFL. In unpublished committee notes, Grundy (2002a) provides estimates of growth rates in fatigue loading per vehicle over a three-year period (up to 15% per annum for 5th-power rule, 50m span). A compromise curve ($0.125L^{-0.5}$) between the 3rd- and 5th-power curve fits (see figure 5.5) was chosen to represent average equivalent cycles of M1600 loading per truck on the principal interstate highways.
- The cycle count formulae specified in AS 5100.2 allows for a 75-year fatigue design life with average 4% per annum compound growth in fatigue damage from the number of trucks per lane at opening of the bridge (ie $1.6x10^5$ x daily truck count per lane). The authors note that this allows for mass growth and higher initial rates of growth on some routes, capped at expected saturation volumes.
- A route factor (0.3–1.0) is applied to the cycle counts to reduce average damage per vehicle to fit the more lightly loaded heavy traffic mixes.
- A scale factor of 0.7 is applied to the stress range for the M1600 vehicle, for reasons unrelated to the loading curve fit choices outlined above.

In figure 5.6, the results for additional WIM datasets are included in the comparison with M1600 fatigue loading for both 3rd- and 5th-power rules, and in figure 5.7 the results for shear force cycles are compared to the moment and support reaction effects.

Figure 5.6 New Zealand WIM site results (bending moments) vs M1600 loading formula

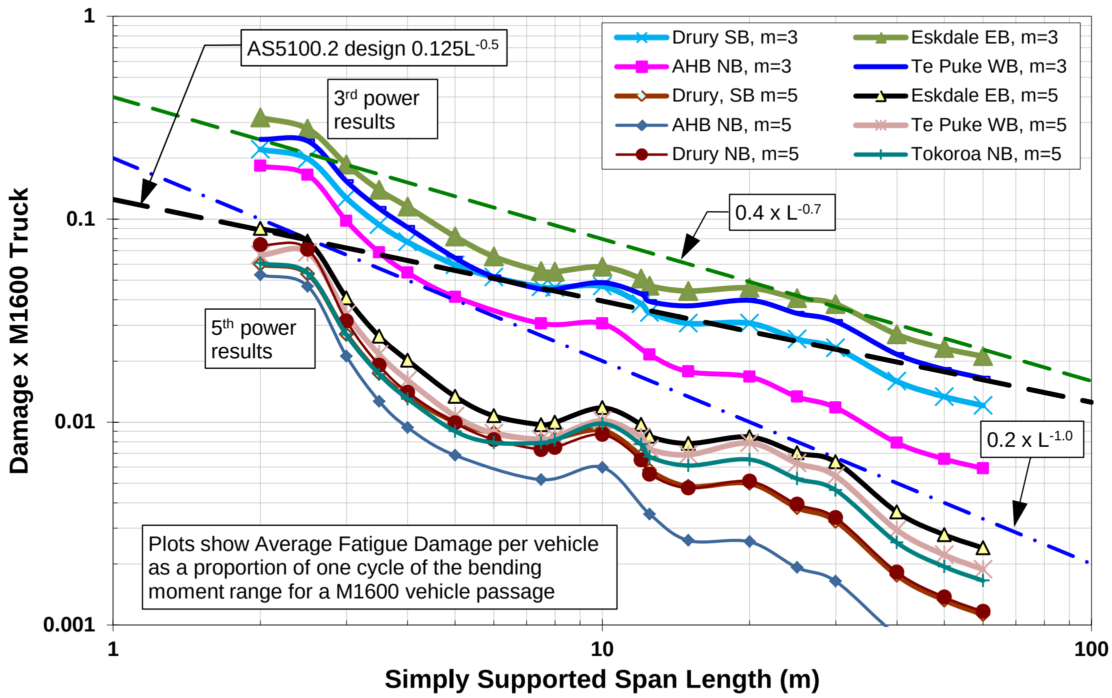
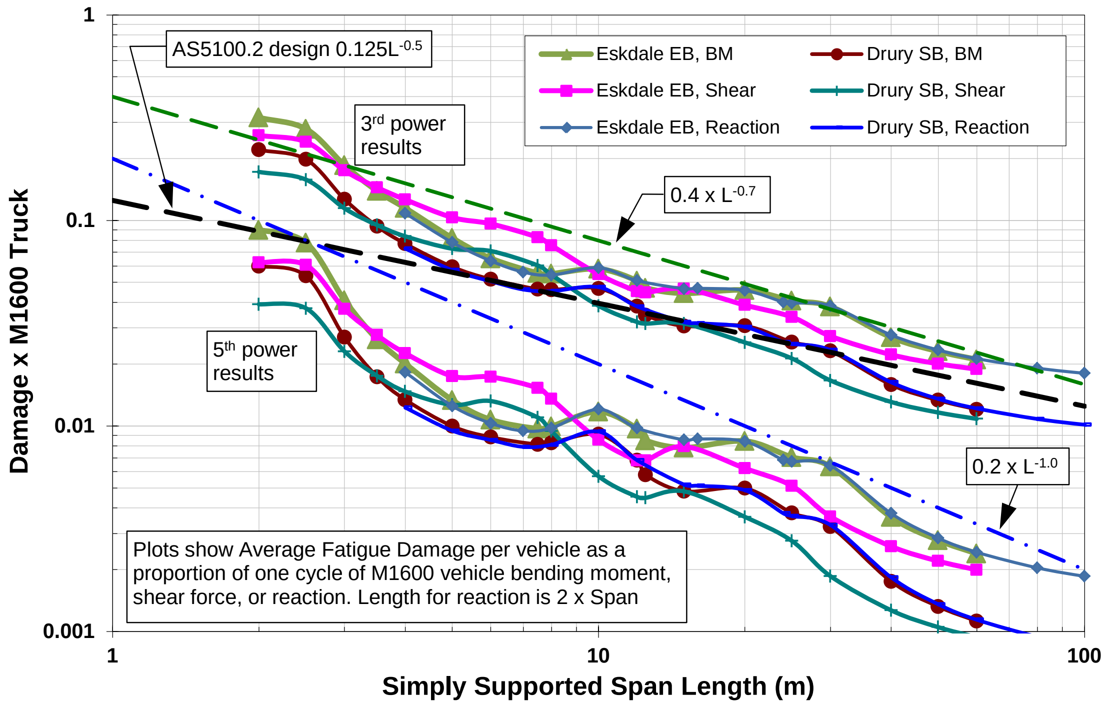


Figure 5.7 Comparison of results for bending moment, shear force, support reaction



In addition to the comments for figure 5.5, we can make the following observations:

- Results are generally well below the fit lines for the Australian sample shown in figure 5.5, except for the Eskdale site at 20–30m span lengths or at very short span lengths.

- Apart from the AHB, the SH1N Drury WIM site (motorway) has the lowest effects (reflecting the higher proportion of smaller trucks).
- The other sites (SH1N Tokoroa, SH2 Te Puke and SH1S Waipara – not shown in figure 5.6) have very similar effects.
- For the support reaction at two simply supported spans, L is taken as the sum of the adjacent spans and the resulting curves are almost identical to the curves for moments.
- The curves for shear force (see figure 5.7) are somewhat different from the moment curves, giving higher damage per vehicle for spans between 4m and 10m (thereby filling in the dip observed in the moment curve).

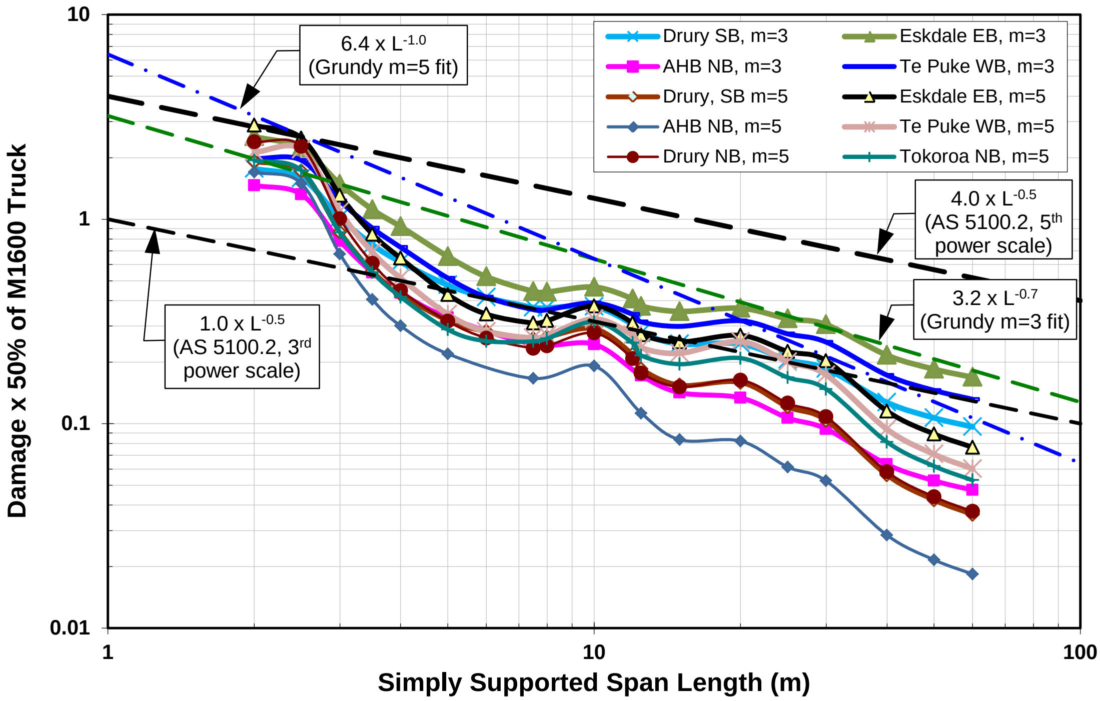
5.5.2 Reduced M1600 options

As noted in section 5.2.2, 50% of the M1600 vehicle is expected to be a more appropriate choice for representing current loading. Figure 5.8 shows the effect on the results shown in figure 5.6 of reducing the M1600 reference loading to 0.5xM1600. The dashed lines show the same AS 5100.2 cycle count formula and fitted lines proposed by Grundy (2002b) as shown in figures 5.6 and 5.7 but scaled according to the 3rd or 5th powers of the M1600 scaling factor (0.5^{-5}=32 for the 5th-power fit and AS 5100.2 design equation, or 0.5^{-3}=8). The outcome is a set of curves where the 3rd- and 5th-power results overlap, and the damage equivalent cycles of the 0.5xM1600 reference loading are in the order of 0.1–2 cycles per heavy vehicle on average. Note that the scaled versions of the AS 5100.2 design cycle equation ($0.125L^{-0.5}$) with either a 3rd-power assumption ($1.0L^{-0.5}$) or a 5th-power assumption ($4.0L^{-0.5}$) are very poor fits. Therefore a replacement cycle count formulae is necessary if a scaled-down M1600 vehicle is adopted as the design fatigue loading.

In figure 5.8, the similarity between the 3rd- and 5th-power results is a useful observation, because it demonstrates that calibration of a design fatigue vehicle appropriately matched to the most damaging real vehicles is likely to be much less sensitive to the component type and applicable S-N curve exponent.

An equivalent damage ratio of 1.0 in figure 5.8 indicates that average damage equivalent moment per vehicle (with a 3rd- or 5th-power rule and all moment ranges accounted for) is equal to the maximum moment range for one passage of the reduced fatigue vehicle. For 0.5xM1600, this equality applies at around 3–4m span lengths. For spans in the 10–20m range, ratios in the 0.1–0.4 range indicate that average damage per vehicle is roughly equivalent to 10–40% of trucks operating at maximum loading, with the remainder being lightly loaded.

Figure 5.8 New Zealand WIM site results (bending moments) vs 50% of M1600 vehicle



5.5.3 Fitting the M1600 vehicle to current fatigue loadings at the WIM sites

To estimate the multiples of M1600 that represent current vehicle loading, the scale factor can be further reduced until the equivalent cycle counts approximate the expected number of cycles per vehicle at short to medium spans. The plot in figure 5.9 for 40% of the M1600 vehicle load indicates that this would be the appropriate level to represent the *average* effect of current vehicles, and an alternative multilinear fit (on log scales) to the Eskdale results is shown.

Coincidently, the alternative assessment loading proposed by Taplin et al (2013) is 40% of SM1600, but that loading includes a uniform load with the M1600 or S1600 vehicle loads.

The suggested fit curve for 0.4xM1600 (considering only the 5th-power results) gives:

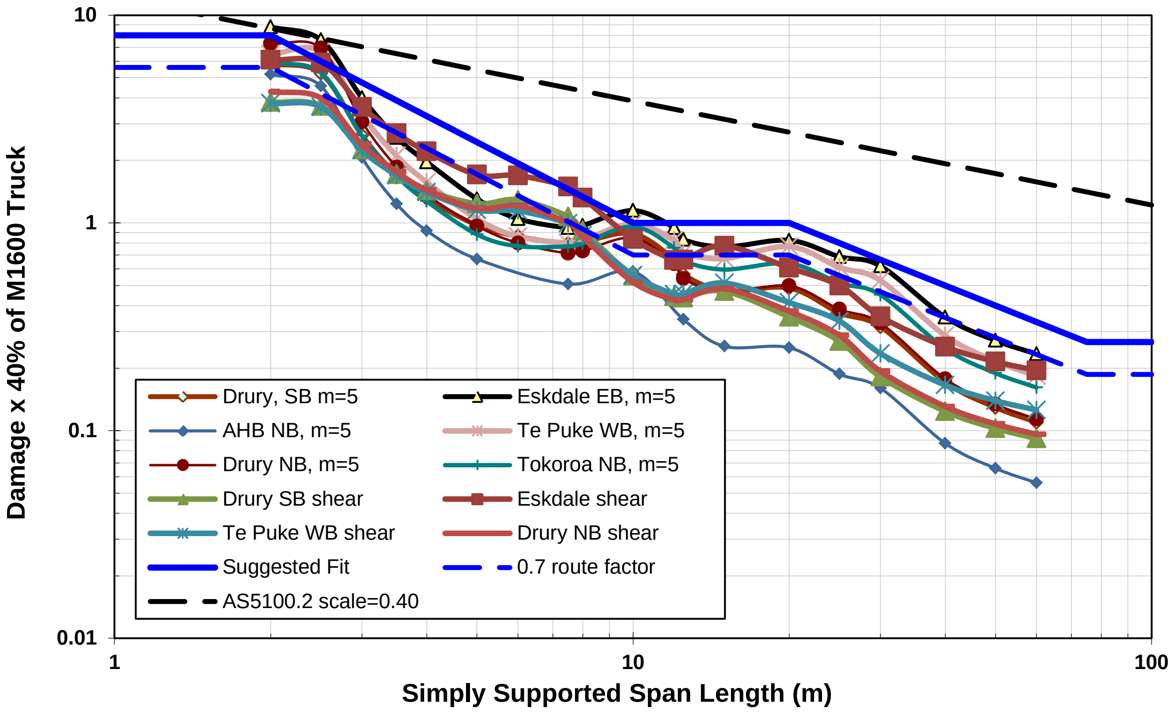
- 1 equivalent cycle for 10–20m spans
- 8 cycles at very short spans (eg 1 cycle per axle for truck-and-trailers)
- cycle counts that are inversely proportional to span length at 20–80m.

A constant value is proposed at longer spans because at very long spans, the results depend mainly on gross vehicle mass (GVM) for fully laden long vehicles.

The upper dashed line in figure 5.9 (labelled AS 5100.2 scale=0.4) shows the effect of applying a 5th-power scaling factor to the AS 5100.2 cycle count formula ($0.125L^{-0.5}/0.4^5$).

The dashed line labelled ‘0.7 route factor’ indicates that applying a route adjustment factor of 0.7 to the suggested upper fit could represent the more typical freight routes (Tokoroa, Drury).

Figure 5.9 New Zealand WIM site results (moments, or shear force where stated) vs 40% of M1600 vehicle



The curve fit shown in figure 5.9 targets the average heavy vehicle effect. However, at one or more equivalent repetitions of the design truck per heavy vehicle, the lifetime cycle counts are likely to exceed $1x10^8$ (the cut-off limit on the S-N curves), and an incorrect fatigue life may be calculated by the methods given in AS 5100.6-2004.

The general approach of applying one cycle per vehicle at medium span lengths, with additional cycles at shorter spans, is similar to the approach in AASHTO LRFD. The issue of equivalent cycle counts exceeding the practical limit for fatigue assessment is addressed in the AASHTO code by requiring an 'infinite life check' when average daily heavy vehicle lane counts exceed a threshold number, varying with fatigue detail category.

The AASHTO infinite life check compares twice the stress range used for the finite-life check with the CAFL. We note that this multiplier (2.0 x 0.75 x HS20 design truck) is not a reliable guide to what would be necessary for an unlimited life check, as it is expected that AASHTO will soon increase the fatigue load factors (Mertz 2013) to better fit recent US heavy traffic data (Wassef 2013).

Thus, although 0.4xM1600 loading is considered to be too low for practical purposes, the fit shown in figure 5.9 is a useful illustration of the curve fit form to be proposed later in this report.

5.6 Fatigue loading – 0.85HN options

5.6.1 Dataset short listing

Given the similarity between the results for most of the rural state highway WIM datasets in the charts above, a more limited selection of datasets was appropriate for subsequent steps in this study. The representative sets used for the subsequent steps were considered to be (in order of decreasing severity):

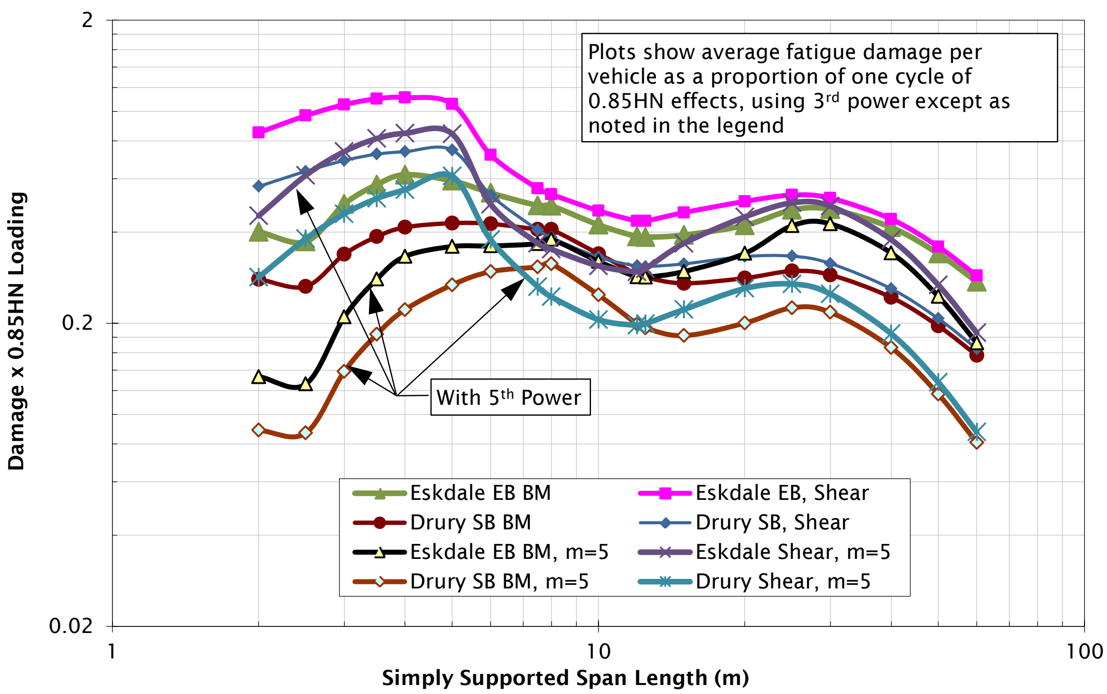
- Eskdale eastbound (representing high logging vehicle content prior to enforcement being introduced)

- Te Puke westbound (also representing typical data from Tokoroa, Waipara)
- Drury northbound 2005 (significant bulk aggregate haulage)
- Drury southbound 2011 (higher rigid-truck content)
- AHB northbound (high-volume urban motorway)

5.6.2 Fatigue loading relative to 0.85HN loading

From the results for 0.85HN loading (for a single lane) used as the reference loading (see figure 5.10), it is apparent that a simple relationship between damage per vehicle and span length (of similar form to the M1600 relationship) does not exist, and there are significant differences in the form of the cycle count versus span relationships for shear force and bending moment at short spans. However, the numerical results in terms of equivalent numbers of repetitions of 0.85HN are of interest for assessment of *current* fatigue load effects, assuming that the 0.85HN loading is used for live load evaluation and the maximum stress ranges for one loaded lane are readily available.

Figure 5.10 WIM site results vs 0.85HN single-lane loading (damage equivalent cycles per heavy vehicle)



In figure 5.10, it is apparent that the results for the 5th-power rule are less than, but are of similar order to, the results with the 3rd-power rule. Thus it may be advisable to adopt the 3rd-power rule at all span lengths if using equivalent repetitions of 0.85HN effects for fatigue assessments of existing structures designed to older loading standards, such that normal stress levels under frequent loadings are expected to exceed the CAFL. Alternatively, a more accurate assessment using vehicle spectra (see chapter 6) can be carried out to estimate the stress range spectra. Using only the 3rd-power results for normal (direct) stress ranges is conservative.

For assessment of detail categories subject to shear stress, the 5th-power rule is applicable at all stress ranges.

5.6.3 Fatigue loading – breakdown by vehicle class

Figure 5.10 shows the fatigue loading at a few WIM sites on main highways or urban motorways, which may or may not adequately represent the damage per vehicle characteristics on other route types. Breaking down the damage summations by vehicle type shows their relative contributions, and enables more detailed comparisons between sites. These summations were readily available from the bulk processing of WIM data outlined in section 5.3. Appendix C includes a presentation of the results grouped by vehicle class in graphical form (see appendix table A.1 for a list of vehicle configurations in each class).

The results presented in appendix C illustrate the following points:

- With regard to the reduction of WIM vehicle data to damage equivalent repetitions of the 0.85HN assessment load, these results may be sufficient for rough estimates of current fatigue loading on girder bridges on the applicable routes if adjustments are made to obtain appropriate annualised counts.
- Class 12 (twin-steer truck-and-trailers) makes the larger contribution to fatigue loading at all rural sites, followed by semi-trailers (with 6–8 axles).
- Classes 11 (7-axle truck-and-trailers) and 13 (B-Trains) are ranked third or fourth, while rigid trucks have a minor contribution (except at the urban sites).
- At the AHB site, semi-trailers have a more significant contribution and rigid trucks + buses (classes 4, 5, 6) contribute about 35% of the damage on short spans. The high contribution from class 11 occurs in the northbound direction only, and is mainly associated with bulk haulage (eg aggregates) and other construction material deliveries.
- The significant differences in the form of the cycle count versus span relationships for shear force and bending moment at short spans (as seen in figure 5.10) arise from the mismatch between typical single axle loads and the HN axle loads (0.85x120kN).

The purpose of these breakdowns and comparisons between sites is to present the ‘typical’ damage per vehicle for each vehicle class. These results could be used in conjunction with vehicle class counts on other routes to estimate the average damage per vehicle, provided that the weight distributions for each vehicle class at WIM sites are similar on other route types. This is tested in section 5.6.4.

As previously noted, a 5th-power S-N curve is applicable to detail categories subject to shear stress, and the 5th-power results are provided in appendix C. The span end shear force results derived using a 3rd power would be applicable to the evaluation of normal stresses at components most affected by girder support forces, and not welds loaded in shear.

5.6.4 Fatigue loading – variation in damage per vehicle for common classes

Figures 5.11 and 5.12 show the variation in damage per vehicle for the most common class 12 and 9 vehicle types (mid-span moment with 3rd-power rule), for all the processed datasets. These showed variations between sites and periods but there appeared to be sufficient similarity between sites to propose that fatigue loading data for each class may be applied to other sites, and that a rationalised selection of datasets can be used in further analysis.

The most notable exceptions were the significant directional bias for the type 891 vehicles at Eskdale and Te Puke, and type 751 vehicles (class 11, 7-axle truck-and-trailers) at the Drury and AHB sites.

Figure 5.11 Average damage per vehicle, 8-axle truck-and-trailer (PAT type 891, class 12)

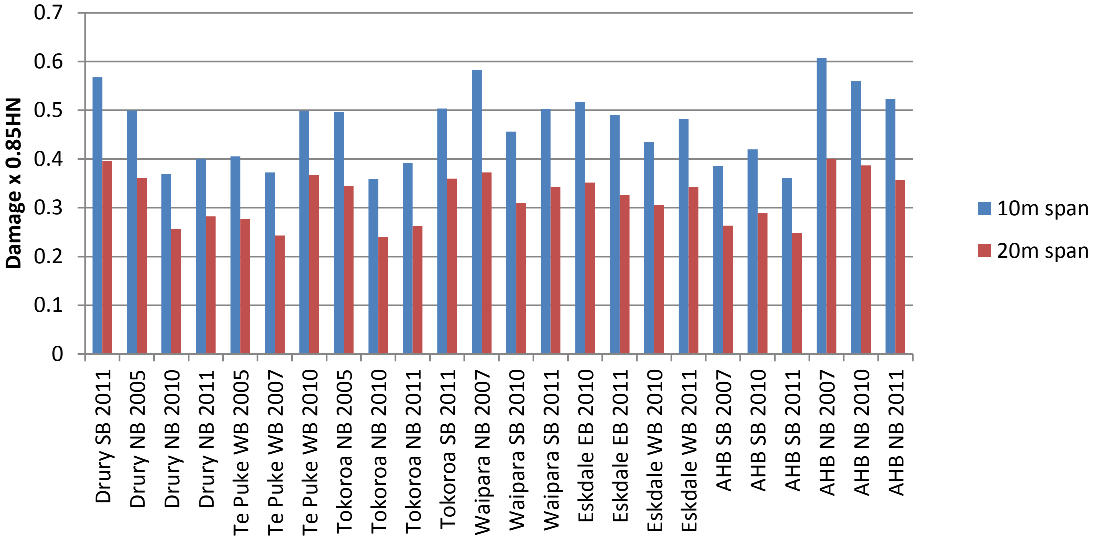
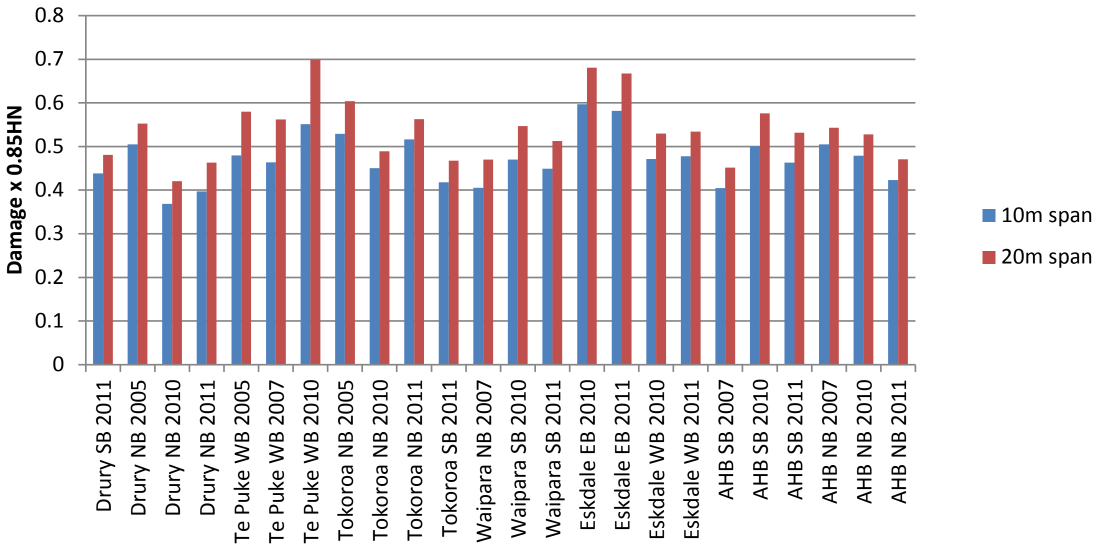


Figure 5.12 Average damage per vehicle, 6-axle semi-trailer (PAT type 69, class 9)



5.6.5 Application of WIM site results to other routes

The purpose of the fatigue loading presentations in terms of equivalent cycles of the 0.85HN effects, with breakdowns by vehicle class, is to assist with estimates of current and historic fatigue loadings on existing structures. An example of how the data would be applied to another site where WIM data is not available, but heavy vehicle counts by class have been recorded through periodic surveys or continuous monitoring, is included in appendix C.

This process would be more complex than applying a single vehicle fatigue model, but may be less complex than a full vehicle spectrum approach (see chapter 6).

5.7 Alternative fatigue vehicle options

The possibility of adopting a 'real' truck type or fatigue vehicles from other countries as the reference vehicle for current fatigue loading instead of M1600 or HN variants was also explored. For this exercise, a selection of current legal mass vehicles and HPMV *pro forma* vehicles was considered and the equivalent numbers of repetitions were calculated, as for the equivalent M1600 effects.

5.7.1 Candidate vehicles

The following vehicles were evaluated (see appendix C, table C.1, for configuration details).

- *Pro forma* combination vehicles representing either current vehicles or future HPMVs:
  - 44-tonne R22T22 truck-and-trailer (Class 1 conforming)
  - 54-tonne (530kN) version of the R22T22 vehicle (with same axle spacings)
  - 57-tonne 10-axle truck-and-trailer (R23T23 conforming to HPMV limits)
  - 45-tonne A124 semi-trailer vehicle at maximum HPMV axle set mass limits.
- A selection of 4- or 5-axle fatigue vehicles from other codes:
  - AASHTO HL-93 (o-oo—oo 325kN metric tandem-axle variant used for deck analysis)
  - Canadian CL-625 (o-oo—o—o, 625kN x 0.52=325kN)
  - Austroads T44 (o-oo—oo) scaled down to 39 tonnes (legal weight of A123 semi-trailer)
  - Eurocode FLM3 vehicle (oo—oo), 480kN but scaled down to average (5th-power weighted) mass through factors defined in the steel code (EN 1993-2) to align with our vehicle gross masses.

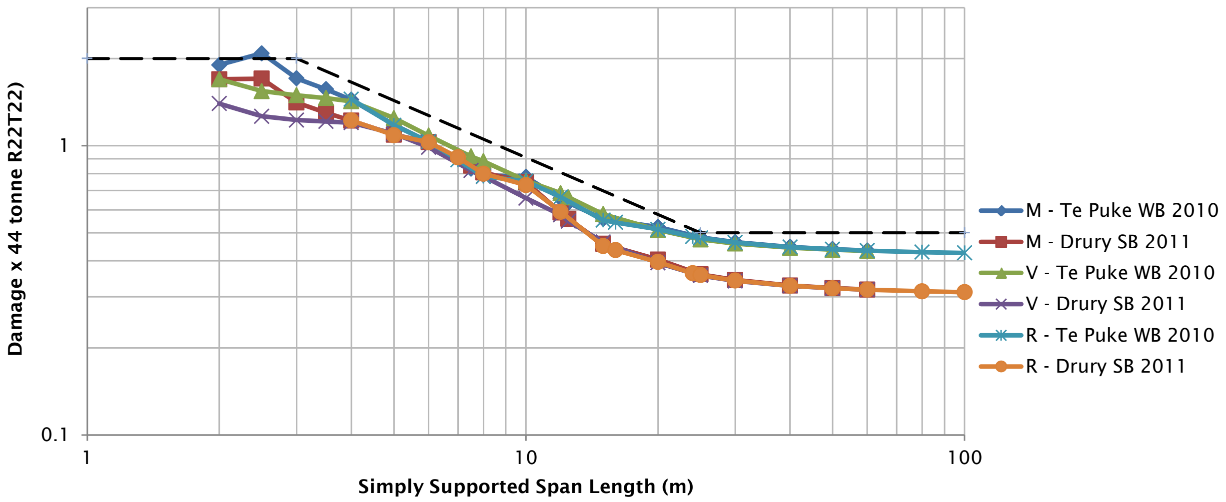
The previously processed WIM data are converted to equivalent cycles of the above vehicles by the same method used for deriving the M1600 equivalent loadings as outlined in section 5.3.

5.7.2 Current long vehicles and proposed HPMV vehicles

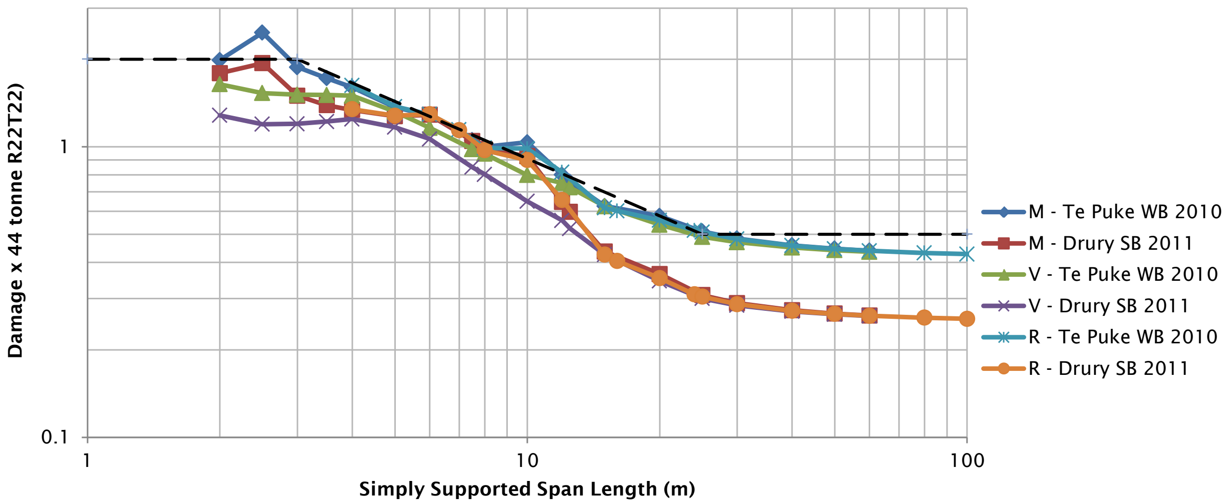
Figure 5.13 shows the fatigue loading for the Drury and Te Puke sites in terms of a single cycle of the maximum effect for a 44-tonne R22T22 (8-axle truck-and-trailer) conforming to Class 1 legal limits.

Figure 5.13 Average damage per heavy vehicle relative to a single cycle of moment (M), shear force (V) or reaction (R) for a 44-tonne truck-and-trailer

(a) With 3rd-power damage rule



(b) With 5th-power damage rule

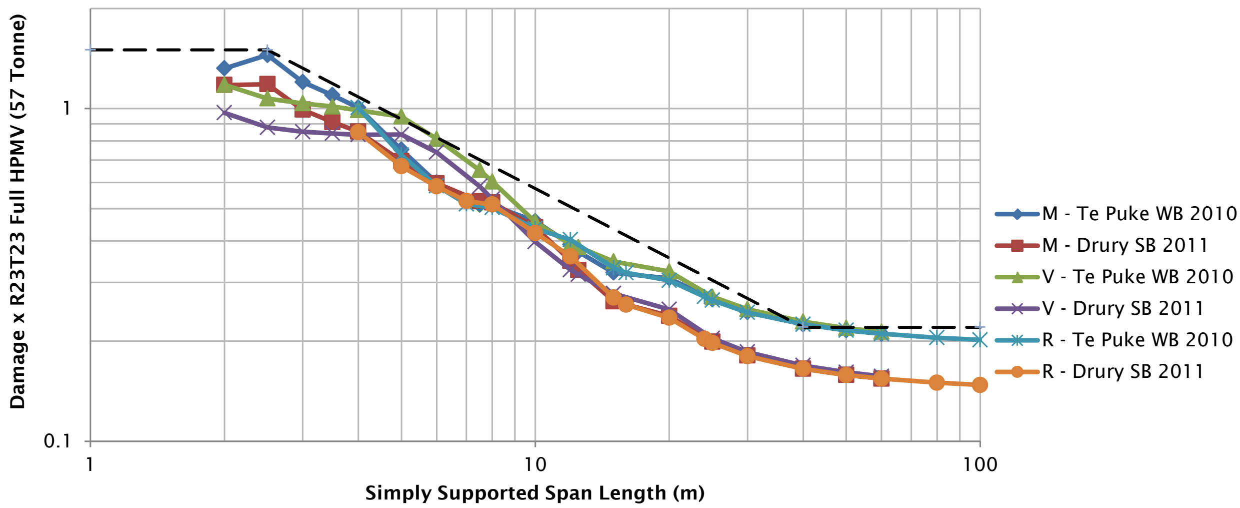


A possible multilinear fit for the 5th-power results is shown in both the above figures, showing that the 5th-power equivalent counts are a little higher than the 3rd-power results at 3–20m spans.

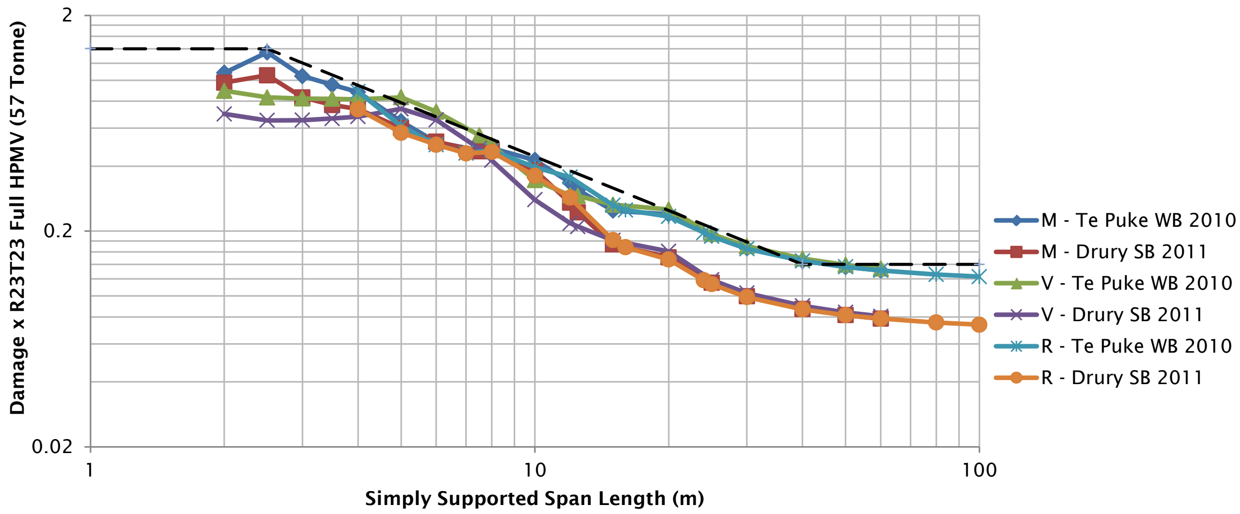
Figure 5.14 shows the fatigue loading for the Drury and Te Puke sites in terms of a single cycle of the maximum effect for a R23T23 57-tonne HPMV (10-axle truck-and-trailer).

Figure 5.14 Average damage per heavy vehicle as a proportion of a single cycle of moment, shear force or reaction for a 57-tonne 10-axle truck-and-trailer (at full HPMV mass limits)

(a) With 3rd-power damage rule



(b) With 5th-power damage rule



With the larger reference vehicle there is a significant difference between the 3rd- and 5th-power equivalent counts at spans over 10m.

Figure 5.15 shows the fatigue loading for the Drury and Te Puke sites in terms of a single cycle of a proposed 530kN R22T22 truck-and-trailer representing current vehicles upgraded to the HPMV mass limits vehicles with no increase in length.

Figure 5.15 Average damage per heavy vehicle as a proportion of a single cycle of moment, shear force or reaction for a 54-tonne (530kN) truck-and-trailer, using 5th-power damage rule

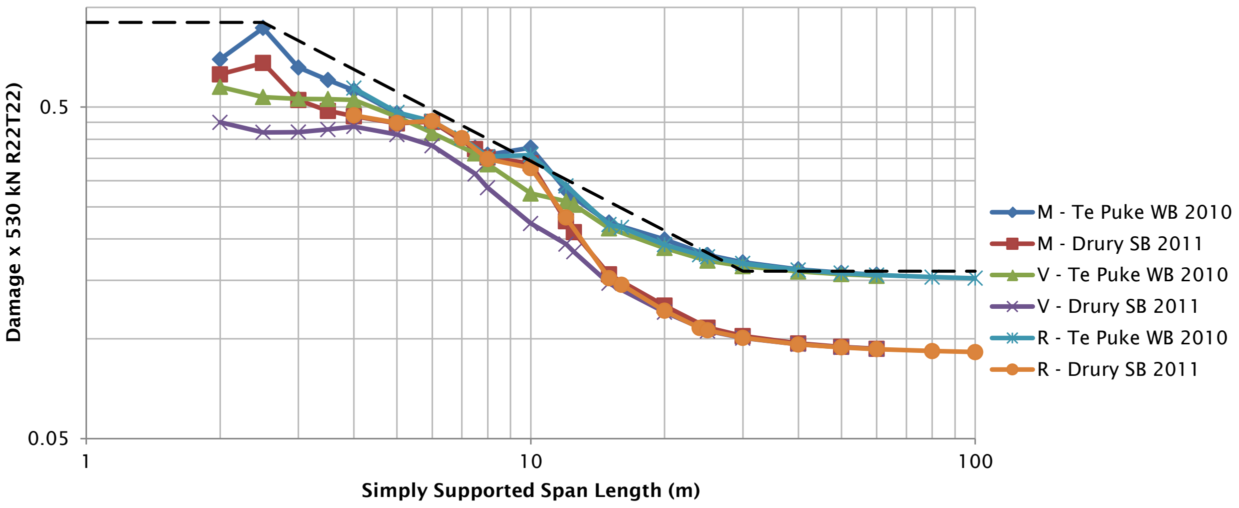
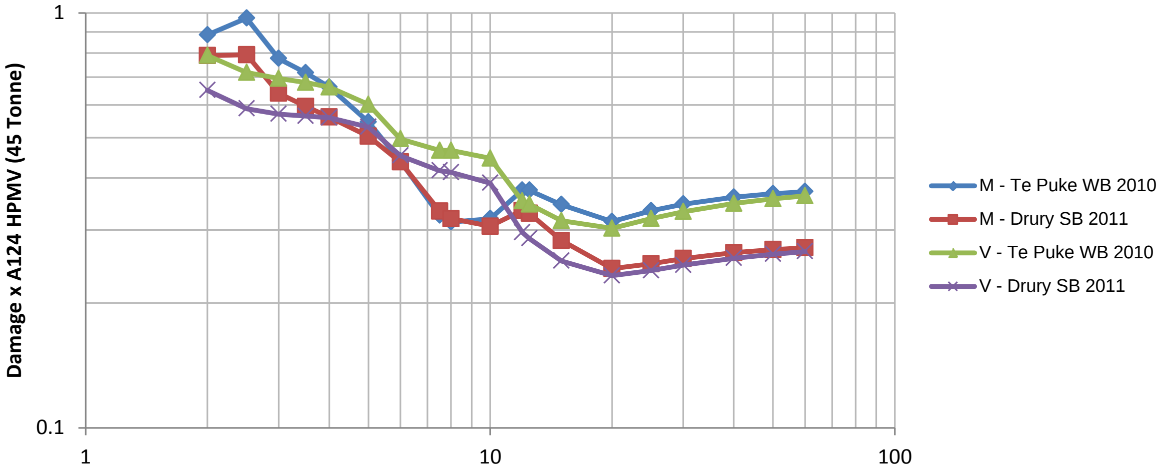


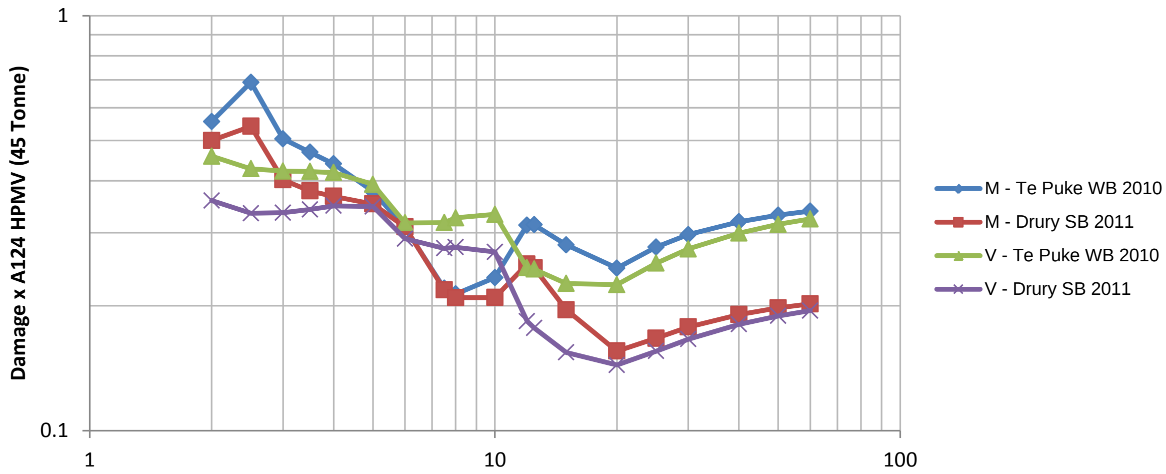
Figure 5.16 shows the corresponding results for a tractor + quad-axle semi-trailer rig at the maximum HPMV axle mass limits.

Figure 5.16 Average damage per heavy vehicle as a proportion of a single cycle of moment or shear force for a 45-tonne articulated truck (A124 full HPMV limits)

(a) With 3rd-power damage rule



(b) With 5th-power damage rule



5.7.2.1 Interpretation

The current fatigue loadings at the WIM sites may be represented in terms of equivalent cycle counts repetition based on current or future trucks.

The three truck-and-trailer options all provide simple curve fit options. For example, the Te Puke dataset could be represented by the Class 1 (44-tonne) truck envelope actions using:

- 0.5 cycles of the R22T22 truck effect per heavy vehicle at spans over 25m
- 2 cycles at short spans (4m or less)
- log linear fit between these values.

Similar relationships can be derived for the other datasets and truck-and-trailer types.

Thus, it is feasible to determine simplified cycle count formulae relating current fatigue loading to repetitions of a current 44-tonne truck-and-trailer combination or one of the new HPMV vehicle types. The particular R23T23 vehicle used for figure 5.14(b) provided the closest straight-line fit to the 5th-power results (on log-log scales) indicating that its combination of axle sets and weights and spacings provides a more consistent representation to current vehicles than alternatives, perhaps because providing double- and triple-axle sets at the maximum permitted masses enables parts of the vehicle to represent rigid trucks on shorter spans, while the long truck-and-trailer combination also fits the effects of long vehicles on the longer spans.

The shorter (A124) or lighter (44-tonne R22T22) vehicles produce curves that level out or increase at span lengths over 20m, whereas the curves for R23T23 (or M1600) vehicles level out at longer span lengths (over 40m for R23T23).

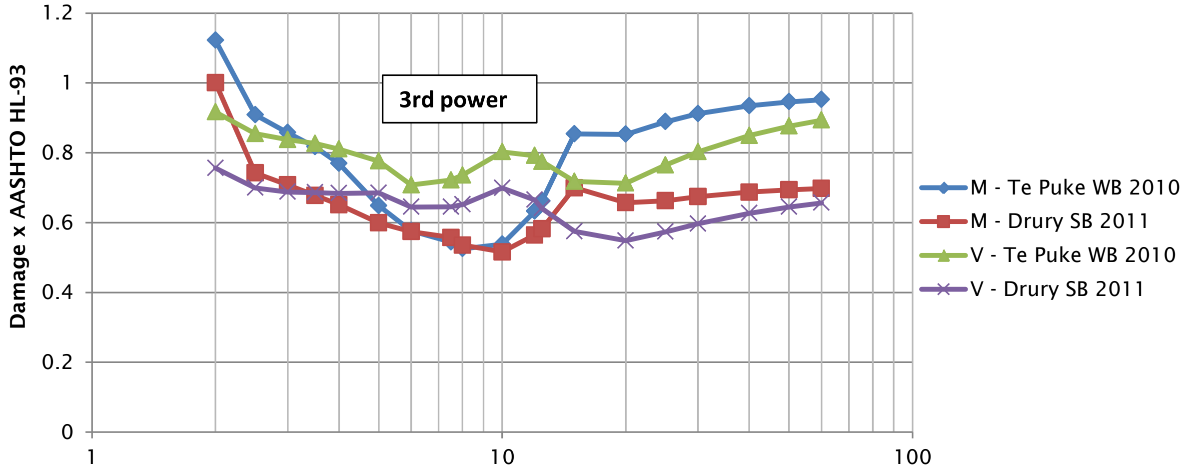
Realistic vehicles such as these, used with appropriate adjustment factors for span length, may prove to be useful for assessments under current traffic loading and could potentially be used as the basis of design fatigue loadings.

5.7.3 Standard fatigue vehicles based on articulated trucks

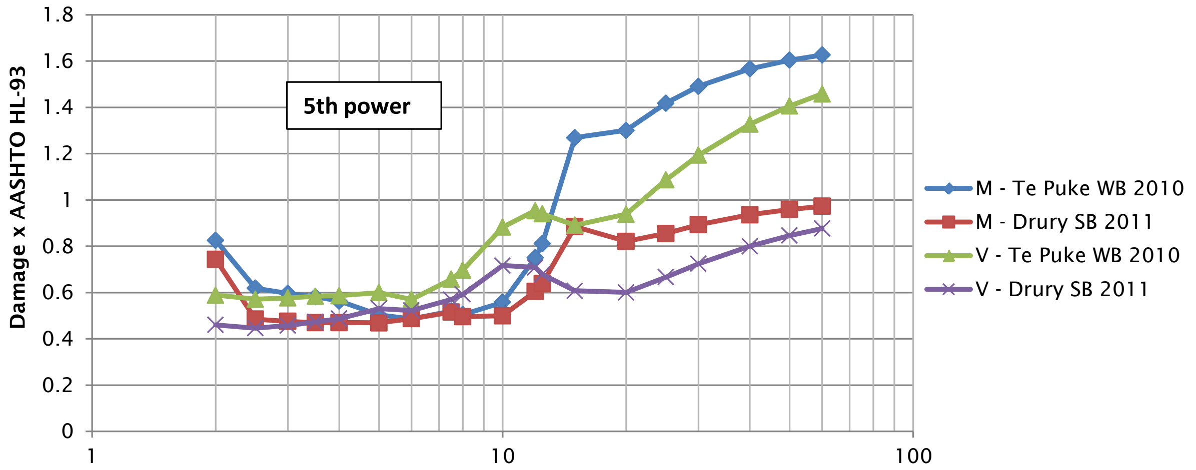
The results for the tandem-axle version of the 325kN AASHTO vehicle (without a scaling factor) are shown in figure 5.17. The 0.75 load factor used for evaluation of finite fatigue lives (AASHTO 2010) was not applied because the loading was found to be too low to represent the New Zealand WIM datasets.

Figure 5.17 Damage per heavy vehicle relative to AASHTO fatigue vehicle (metric tandem-axle variant representing a 325kN semi-trailer)

a) 3rd power

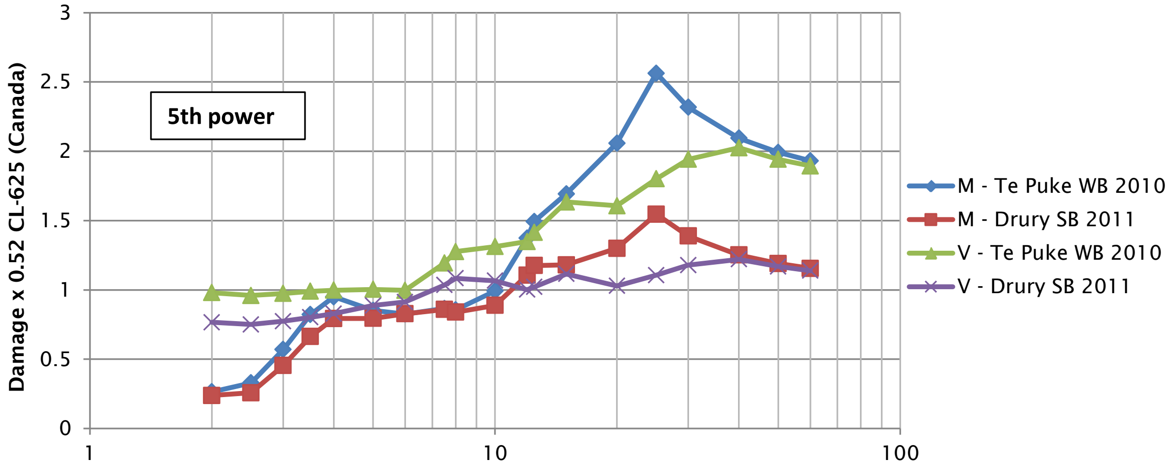


b) 5th power



The results for the Canadian standard vehicle (representing a B-Train) are shown in figure 5.18.

Figure 5.18 Damage per heavy vehicle relative to Canadian fatigue vehicle (CL-625x0.52)

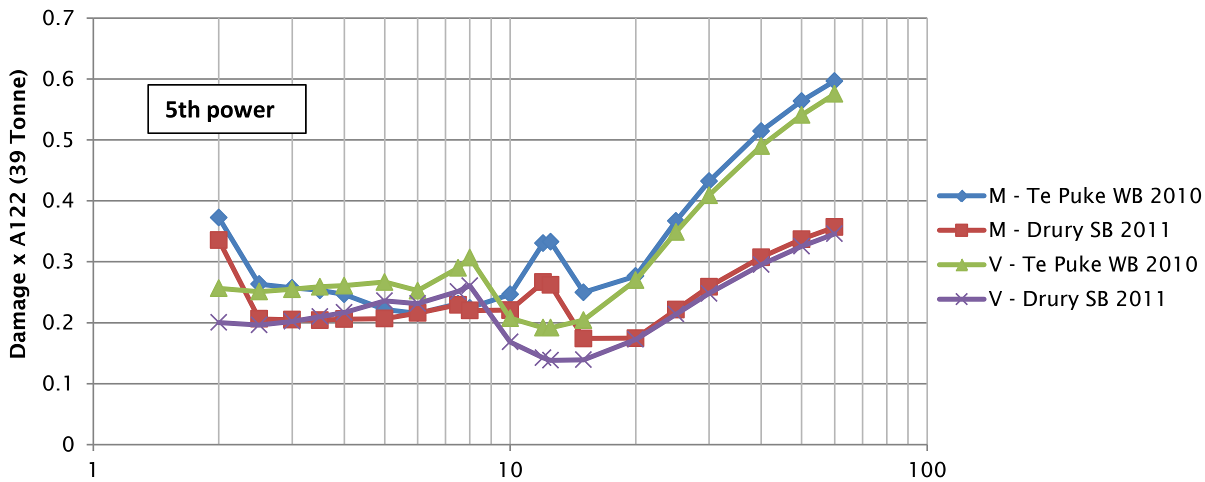


A damage ratio greater than 1.0 indicates that the average fatigue effect per heavy vehicle is greater than one cycle of the reference vehicle effect. Both the US (75% HL-93) and Canadian standard fatigue vehicles (52% CL-625) are applied with cycle count multipliers of 2.0 for span lengths less than 12m. Therefore, using one of these models (with 5th-power damage rule) would underestimate the New Zealand fatigue loading at spans of 12m or more, and overestimate loading on short spans. The load factor of 75% specified in the AASHTO code results in fatigue loading much lower than that for the New Zealand vehicles, and lower than the Canadian code, but the factor is expected to increase to 80% in the next edition (Mertz 2013). An impact factor of 1.15 is also applied to the AASHTO fatigue loading.

It should be noted that the US and Canadian codes use a 3rd-power fatigue design S-N curve at all stress ranges (including ranges below the CAFL), and for the 3rd-power evaluation using the AASHTO vehicle (see figure 5.17) it is apparent that there is a better balance between the short- and long-span results for the New Zealand WIM data:

The results for the Austroads T44 vehicle, reduced to 39 tonnes to approximate the legal weight of the most common semi-trailer (A123), are similar to the AASHTO HL-93 vehicle, but would need to be scaled down further to represent average trucks.

Figure 5.19 Damage per heavy vehicle relative to 39-tonne version of Austroads T44 vehicle, midrange length

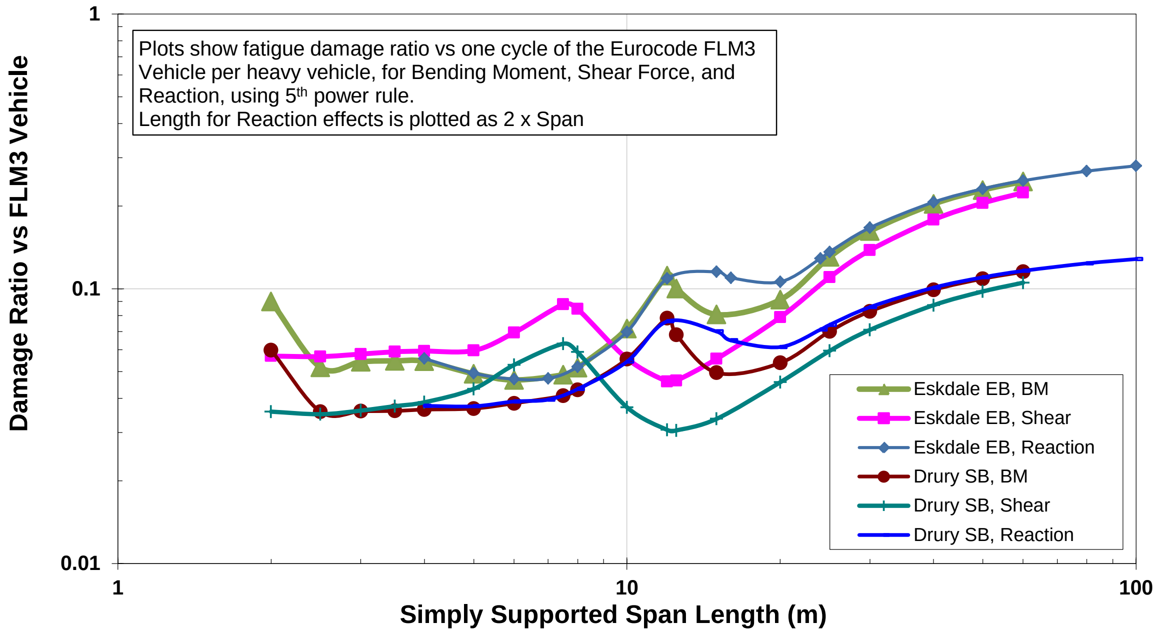


In summary, it appears that none of the three standard vehicles above are generally suited to the New Zealand vehicle mixes at the full range of span lengths. The AASHTO vehicle (with increased scale factor), or the similar Austroads vehicle (with reduced scale factor) would only be suitable at shorter span lengths (less than 15m).

5.7.4 Eurocode fatigue load model 3 (FLM3) vehicle

The Eurocode FLM3 vehicle consists of two tandem axles (120kN x 2) with 6m spacing, so its geometry is quite similar to the HL-93 and T44 vehicles, ignoring the relatively light steer axles, so it is not surprising that the plots look somewhat similar; ie with higher relative effects at short spans compared with New Zealand WIM data on longer spans.

Figure 5.20 Damage per heavy vehicle relative to FLM3 vehicle



The Eurocodes present fatigue design criteria in terms of damage equivalent stress ranges at $2x10^6$ cycles (for steel structures) and apply factors to adjust for average vehicle mass, traffic volumes and span length (including multiple cycles per vehicle and dynamics). Thus, it is appropriate to compare average damage equivalent moments (using the 5th-power rule and incorporating the effects of all cycles) for the New Zealand sites versus a single cycle of FLM3. We can also apply the average vehicle mass correction factor specified in Eurocode 3 (EN 1993-2:2006), which is the ratio of the 5th-power-weighted average vehicle weight to the FLM3 vehicle weight (480kN).

The 5th-power damage equivalent average moment range M_{eq} for a set of N vehicles is $M_{eq} = \left(\frac{\Sigma(\Delta M)^5}{N}\right)^{0.2}$ where the summation includes all cycles for all heavy vehicles and is calculated for mid-span bending moment in simply supported spans.

Figures 5.21 and 5.22 show that the Eurocode standard vehicle model would be quite conservative (for current vehicle weights) at short and medium spans, even though it can be adjusted to New Zealand vehicle weights. At longer spans, applying the vehicle mass adjustment factor would provide a good fit.

There are other adjustment factors in Eurocode 3 that would further increase the difference at shorter spans, but despite this conservatism at short spans the inherent mechanism for adjusting to changes in average vehicle mass would allow this model to be used safely in New Zealand, provided the appropriate average annual vehicle counts are used.

Figure 5.21 Ratio of damage equivalent moment for WIM vehicle data to the FLM3 vehicle moment

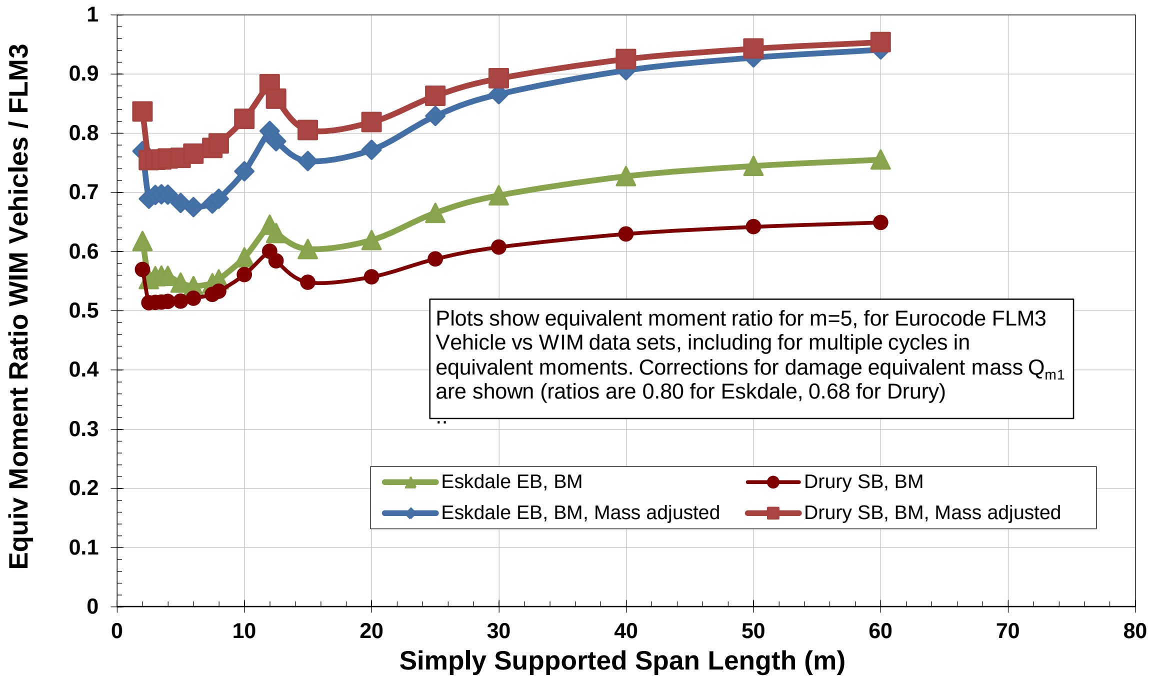


Figure 5.22 – Inverted form of figure 5.20, ratio of FLM3 vehicle moment to WIM damage equivalent moment

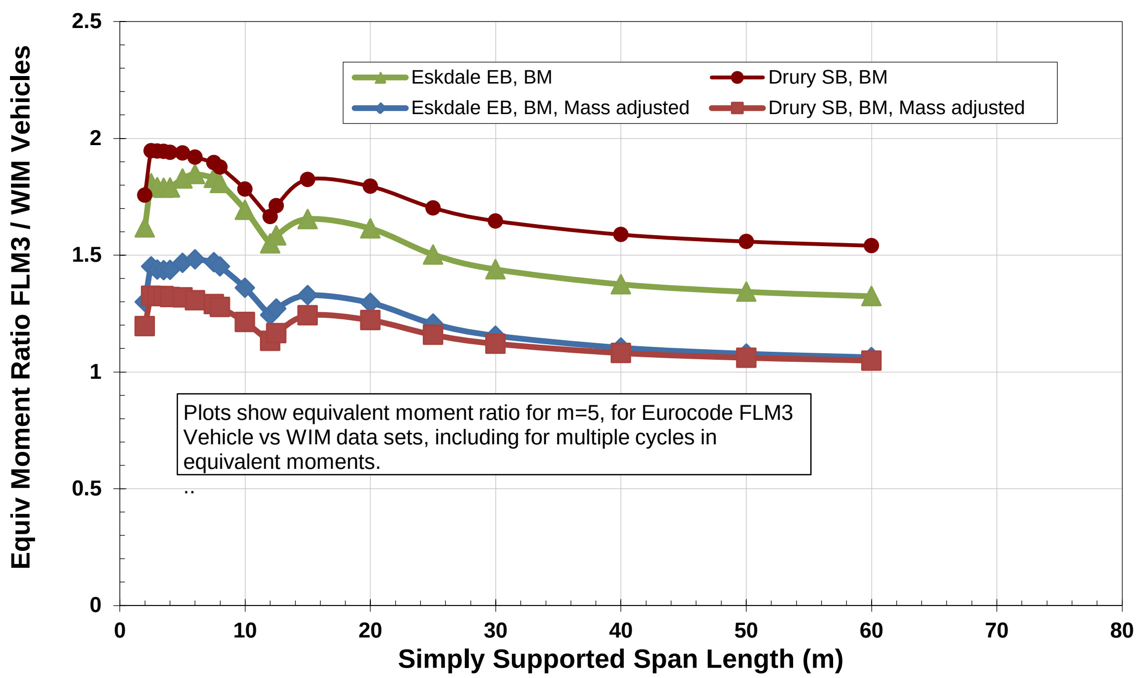


Figure 5.22 further illustrates the point that the although the FLM3 vehicle can be adjusted to fit the New Zealand vehicle weights for long spans, this results in a poor fit at short spans.

5.8 Damage equivalent vehicle weights

The mass adjustment factor applied in figures 5.21 and 5.22 was based on 5th-power-weighted average vehicle weights. Eurocode 3 (EN 1993-2:2006) defines $Q_{m1} = \left(\frac{\sum n_i Q_i^5}{\sum n_i}\right)^{\frac{1}{5}}$ for gross weights in the slow lane, to allow for adjusting the standard vehicle FLM3 to national parameters. Table 5.1 shows the maximum values for the processed WIM data at each site, with the ratio to the 480kN FLM3 vehicle.

Table 5.1 Average vehicle weights at New Zealand WIM sites (5th-power-weighted) vs 480kN FLM3 vehicle

WIM Site	Direction	Year	Weight	Direction	Year	Weight	Ratio to FLM3
SH1 AHB	Southbound	2010	264kN	Northbound	2010	277kN	0.58
SH1 Drury	Southbound	2011	327kN	Northbound	2011	330kN	0.69
SH1 Tokoroa	Southbound	2011	349kN	Northbound	2011	354kN	0.74
SH1S Waipara	Southbound	2010/11	351kN	Northbound	2007	336kN	0.73
SH2 Te Puke	Eastbound	–	–	Westbound	2010	362kN	0.75
SH5 Eskdale	Eastbound	2010/11	385kN	Westbound	2010/11	341kN	0.80
UK vehicle spectrum (National Annex to EN 1991-2:2003)						260kN	0.54

For the only urban site (the AHB), the equivalent weights were similar to the value for the vehicle spectrum in the UK National Annex (Q_{m1} = 260kN, excluding the infrequent overload vehicles).

An implication of this comparison is that the UK vehicle spectra (and its predecessor in BS 5400.10) may adequately represent our urban motorway heavy vehicle weights, but not the rural state highways.

5.9 Summary

This section has demonstrated how the bridge fatigue loading at the New Zealand WIM sites may be reduced to equivalent repetitions of a design fatigue vehicle. Comments on the suitability of the vehicles considered are as follows:

- Current fatigue loadings can be expressed as equivalent cycles of the 0.85HN assessment live load effects on simply supported spans. However, the necessity to include the uniform load part to obtain realistic moments and shear forces with increasing span length, and the relatively heavy axle loads, make it unsuitable for general use as a fatigue vehicle. Despite these practical limitations, the 0.85HN load effects serve as convenient reference actions in the numerical processing for this study.
- The M1600 vehicle appears to be suitable but requires a reduction factor and modifications to the cycle count formulae to fit current heavy vehicle data, along with New Zealand-specific route factors and heavy vehicle counts.
- Normal weight or higher mass truck-and-trailer combinations are also suitable options and should enable closer fits to the current New Zealand heavy truck data compared with the M1600 vehicle.
- None of the articulated truck variants would provide an adequate fit at medium to long spans, but would be suitable for shorter spans.
- The Eurocode FLM3 vehicle is a safe-sided option but would be conservative at short spans. Adoption of this vehicle would require adoption of several parts of the Eurocodes for determining damage equivalence factors.

6 Vehicle spectrum models

6.1 Introduction

Representation of fatigue loading caused by an entire population of heavy vehicles using a single vehicle type may be convenient for the design of typical steel bridges, but it lacks the generality that may be required for detailed assessments, complex structures and materials other than structural steel. A vehicle spectrum model substitutes a set of representative vehicles and repetition counts for the entire heavy vehicle population.

As Flint and Neill (2004) noted in the background document for the Eurocode 1 UK National Annex:

- *[The vehicle spectrum] Model 4 is intended to provide the most accurate basis for projecting fatigue lives, in the absence of traffic data obtained at the actual bridge site. …. the degree of saving in materials [compared to the conservative models 1 & 2] will be offset to some extent by the additional calculation effort, so Model 4 is likely to be most appropriate on large projects where weight saving is particularly important (e.g. suspension and cable stayed bridges) or where the design effort will be offset by economy of scale ….*(p11)
- *Model 4 should also be used wherever influence line lengths are short and have reversals in sign within loaded lengths that are similar to typical vehicle dimensions, for which the stress cycle pattern is sensitive to individual vehicle wheelbases* (p12).

They also noted that FLM4 may be more appropriate than the standard vehicle model (FLM3) where influence lines are complex and/or where two or more lanes influence the design detail. The above comments are pertinent to the current New Zealand loading, and additional opportunities arise from availability of a suitable vehicle spectrum, including:

- more accurate identification of the current mix of heavy vehicles on the main highway (compared with the table provided in the EEM 2010b)
- evaluations of the effects of higher mass vehicles by modifications to the vehicle spectrum effects or substitution of new vehicles
- simplification of further testing of the design fatigue vehicle models through replacement of the WIM datasets with equivalent-vehicle spectra
- applicability to reinforced and pre-stressed concrete structures (in conjunction with suitable material standards such as EN 1992-2:2005).

6.2 Methodology

6.2.1 International codes of practice with vehicle spectra

The Eurocode FLM4 is a simple spectrum comprising five standard trucks (2–6 axles, 200kN–490kN weight), with three sets of percentages to represent local, medium-distance and long-distance traffic. The derivation of the spectra (Sedlacek et al 2008) used the most onerous WIM data from a site in France, with a 3rd-power damage rule to determine one equivalent weight for each truck type. The axle set weights for the standard trucks were selected fit the maximum damage equivalent axle set weights from the WIM datasets, and therefore incorporate normal road roughness effects applicable to good-quality pavements.

Sedlacek et al noted that the (standard) FLM4 model is relevant to deck components with influence length up to 20m, while FLM3 is relevant for main components of bridges with influence lengths of 20m or more (however, Eurocode 3 provides for 10–80m span lengths).

Comprehensive vehicle load spectra intended to represent UK heavy vehicle traffic are specified in BS 5400, part 10: 1980 and the UK National Annex to Eurocode 1. These include up to six standard truck types with two or three weight groups for each type (30kN–360kN) plus a set of eight heavy transporter vehicles (630kN–3680kN, but these are only 0.05% of total counts). According to notes in BS 5400: part 10, the 1980 version was based on 'weighbridge records of moving traffic taken between 1971 and 1974'. It is apparent from the notes and comparisons with more recent weight data reported by Gurney (1992) that the weights did not include additional allowances for impact beyond that included in the measurements.

The Eurocode 1 UK National Annex version amends the standard UK vehicle spectrum to cover changes in truck types, and replaces the equivalent vehicle spectrum in the Eurocode FLM4. The background document (Flint and Neill 2004) provided the guidance for use of this model (included in the Annex), including treatment of multiple presence.

The average vehicle mass adjustment used with the Model 3 standard vehicle model is specified in the UK National Annex to Eurocode 3 as Q_{m1}=260kN (see section 5.8 for a comparison with New Zealand data). This relatively light weight matches the standard vehicle spectrum excluding the special vehicles over 600kN. Given that dynamic amplification for steel bridges is allowed for in a separate adjustment factor in Eurocode 3, it is understood that the UK standard vehicle spectrum excludes additional dynamic allowances beyond road roughness effects already present in the base data.

None of the other codes surveyed included a vehicle spectrum model and, considering that the standard FLM4 model in Eurocode 1 is derived using a 3rd-power damage equivalence model, the UK Annex approach was considered more relevant to the New Zealand study.

6.2.2 Vehicle spectrum development approach

The chosen approach for the initial vehicle spectra development was as follows:

- Provide a reasonably comprehensive spectrum in the style of BS 5400: part 10 and the UK Annex to Eurocode 1, covering the common New Zealand vehicle types.
- Link the heavy vehicle type counts to the NZTA 2011 class scheme (see appendix A).
- Allow for significantly different route types through variations in the vehicle type counts, with fixed axle weights representing each weight band.
- Allow for directional bias by adopting datasets for the more heavily loaded directions.
- Tune the spectra to fit the fatigue damage characteristics (see chapter 5) at all span lengths.
- Exclude heavy overload vehicles with non-standard axle configurations.
- Exclude additional dynamic impact effects (treated separately).

6.2.3 Methodology outline

The process for determining vehicle spectra representing the current WIM site data was as follows:

- Identify the most common vehicle types and appropriate groupings of vehicle classes to be represented by standardised vehicles. Seven vehicle types were selected.

- Examine the typical weight histograms for each of the common vehicle types to identify the bands needed to approximate the distribution (empty, fully laden, medium if required).
- Confirm the WIM datasets to be used for the vehicle spectrum fitting. Initially, the largest recent dataset (SH1 Drury 2011 southbound) was used to develop the standard vehicles.
- Fit the standard vehicle weights and counts to the mass histograms for the chosen vehicle class groupings, so that total of standard vehicle weights = total weight of vehicle in the group. After finalising the vehicle weights for each band, matching the sums of the 3rd power of the vehicle weights provided a better starting point for the total fatigue damage measure, by avoiding undue bias toward counts in the upper band.
- Assign axle spacings and weights to the standard vehicles, using averages from the WIM datasets as a guide.
- Calculate the responses and fatigue damage measures for the standard vehicles on all spans (as equivalent cycles of 0.85HN loading using 3rd-power rule).
- Tune the standard vehicle counts to fit damage summations to the selected WIM datasets. This process (automated using Excel Solver) required significant trialling to identify the preferred optimisation strategy and constraints. The chosen solutions were based on:
  - starting counts fitted to weight spectra, to match sums of GVM^3 for each class group
  - fatigue damage (equiv. 0.85HN cycles for moment, shear force and reactions) no less than the WIM dataset for 3–60m span lengths
  - minimise the total absolute difference from the starting counts – this makes adjustments in counts for each vehicle weight band, and minor changes in the vehicle mix.

This produced vehicle spectra that provided an approximate fit to the WIM total weights and a good fit to the damage equivalent fatigue cycle counts, with minimal conservatism (generally less than 10% additional cycles).

6.2.4 WIM dataset selection

Table 6.1 lists the datasets selected for vehicle spectra fitting.

Table 6.1 WIM datasets considered in the vehicle spectra fitting

Site	Direction	Periods	Comment
SH1 Drury	Southbound	2011	Higher loading in this direction
	Northbound	2005, 2010, 2011	Class 11 fully loaded in this direction
SH2 Te Puke	Westbound	2007, 2010, 2011	Higher loading toward the port
SH5 Eskdale	Eastbound	2010, 2011	Fully loaded logging trucks (class 12)
	Westbound		Empty logging trucks (class 6)
SH1 AHB	Southbound	March 2010 and March 2011	Classes 12, 13 heavier in this direction
	Northbound		Class 11 fully loaded in this direction

6.3 Weight histograms and standardised vehicle configurations

Table 6.2 shows the form of the weight histograms for the common vehicle types on which the standardised vehicle sets are based. This identifies the types with bi-modal distributions where two weight bands are sufficient (eg type 751).

Table 6.3 sets out the chosen standardised vehicles and the vehicle classes that they are intended to represent.

It can be seen that some of the sets must cover a wide range of configurations (and weight limits), particularly set 4, where a 6-axle vehicle is used to cover all semi-trailer vehicles, including the newer 7- and 8-axle rigs (types 791 and 826). Therefore, the rear-axle set weight for the set 4 top band is increased to adequately cover the quad-axle set weights, and the optimisation process distributes total counts to fit the total damage sums.

Table 6.2 Weight histograms for common truck types

NZTA Class	4	5	6	9	11	9	9	13	12
PAT Type No.	21	31	45	69	751	791	826	851	891
Axle config.	0--0	0--00	00--00	0-00--000	0-00--00--00	0-00--0000	00-00--0000	0-00--000--00	00--00-00--00
Drury SB 2011									
Drury NB									
Eskdale EB									
Eskdale WB									
Te Puke WB 2010									
AHB NB 2010									

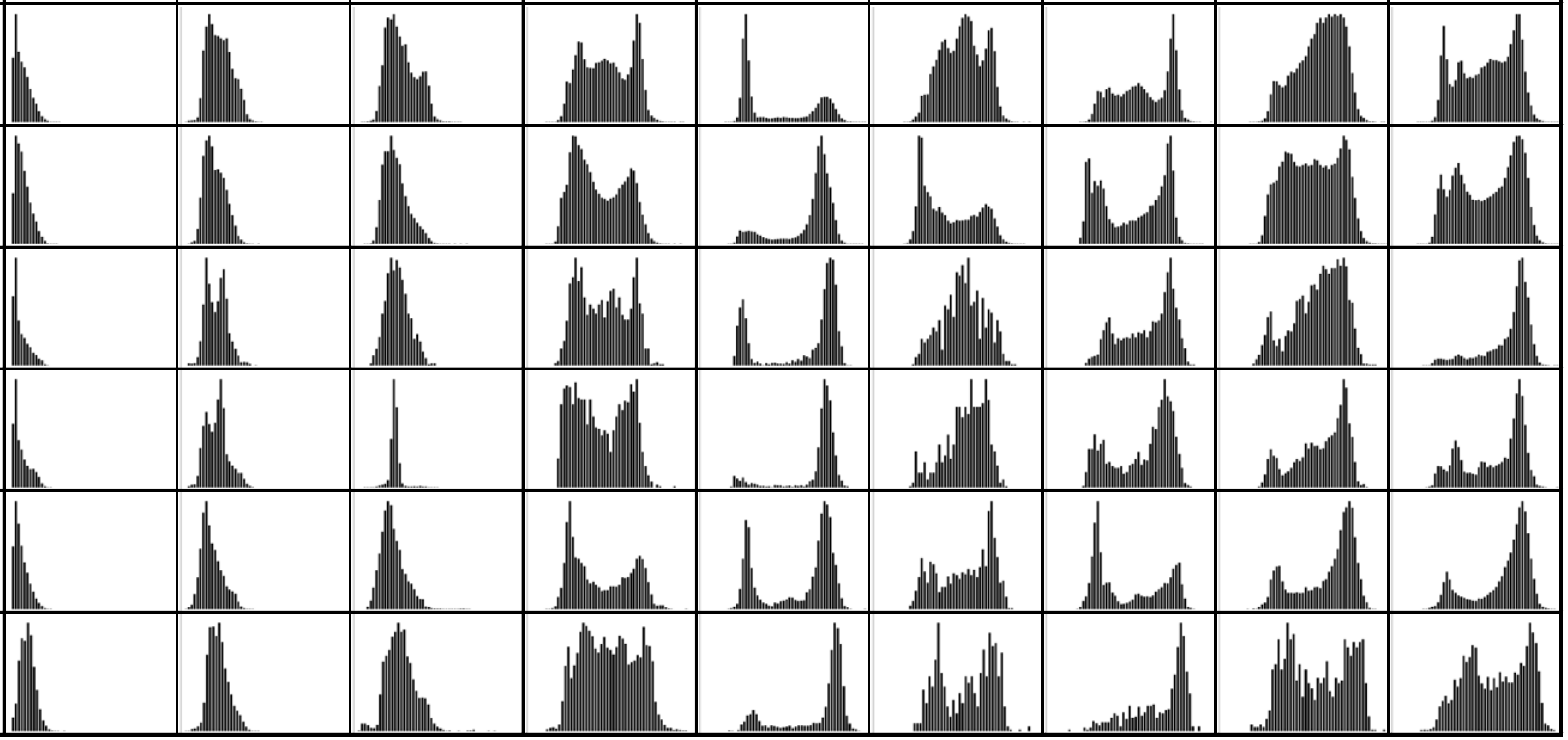


Table 6.3 Equivalent trucks for detailed fatigue load models

Set	NZTA 2011 class	Truck types	Main PAT types	Total axles	Standard vehicle configuration, axle spacings (m)	Wheel base (m)	Loading group	Code	Total weight (kN)	Axle loads (kN)							
1	4	2-axle	21	2	Rigid truck		H	1H	150	50	100						
					o--o		M	1M	90	30	60						
					4.3	4.3	L	1L	50	20	30						
2	5	3-axle	31	3	Rigid truck		H	2H	210	60	75	75					
					o--oo		M	2M	170	50	60	60					
					5.0 1.3	6.3	L	2L	110	40	35	35					
3	6, 7	4-axle rigid or artic	45	4	Rigid truck oo--oo		H	3H	260	55	55	75	75				
					1.7 3.6 1.3	6.6	L	3L	160	40	40	40	40				
4	8, 9	5–8 axle artic	69, 791, 826	6	Articulated		H	4H	420	60	75	75	70	70	70		
					o-oo---ooo		M	4M	310	49	60	60	47	47	47		
					3.7 1.3 6.1 1.3 1.3	13.7	L	4L	200	48	40	40	24	24	24		
5	10, 11	Single-steer T&T[a]	751	7	Truck-and-trailer o--oo---oo--oo		H	5H	450	60	75	75	60	60	60	60	
					4.0 1.3 5.5 1.25 3.2 1.25	16.5	L	5L	180	40	30	30	20	20	20	20	
6	12	Twin-steer T&T	891	8	Truck-and-trailer		H	6H	450	45	45	70	70	55	55	55	55
					oo--oo--oo--oo		M	6M	350	40	40	55	55	40	40	40	40
					1.8 3.3 1.3 4.2 1.25 4.3 1.25	17.4	L	6L	210	35	35	30	30	20	20	20	20
7	13	B-Train single-steer	851	8	B-Train		H	7H	450	52	65	65	56	56	56	50	50
					o-oo--ooo--oo		M	7M	360	50	53	53	44	44	44	36	36
					3.7 1.3 4.3 1.3 1.3 4.3 1.3	17.5	L	7L	220	46	34	34	22	22	22	20	20

a) T&T = truck-and-trailer.

b) Proposed wheel contact areas: 220x220 for steer axles (2.0m track), 500x200 for dual-tyre axles (1.8m track).

c) The single large tyres that are seen on 4-axle semi-trailers (types 791,826) are not used on the older triple-axle trailers (type 69), but would be specified as 300x200 (2.0m track) where required.

6.3.1 Comments on the class groupings in table 6.3:

1, 2 Classes 4 and 5 may have a light trailer in addition (new in the 2011 class scheme).

3 Class 6 includes 5-axle rigid trucks with a triple-axle set, class 7 is mostly o-o—oo.

4 Set 4 represents effects of all 5–8-axle semi-trailer rigs and 4-axle rigid trucks with a tandem-axle simple trailer (PAT type 68).

5 Class 10 trucks (R12T12) have similar roles to class 11 but are becoming less common. Six-axle transporters (o-oo---o-o-o) are also included in class 10 counts. The Class 1 mass limit is 44 tonnes for all the included types.

6 Class 12 includes twin-steer B-Trains with up to 11 axles (2011 class scheme), but no 11-axle vehicles were recorded and the proportion of 10-axle vehicles was small.

7 Class 13 includes A-trains (very rare at the WIM sites).

6.4 Vehicle spectra fitting at selected WIM sites

The best-fit vehicle spectra in terms of counts per 100,000 heavy vehicles fitted to the five selected WIM datasets are shown in table 6.6, with the proportions of the set within each weight band, and the overall share for each vehicle set.

Inspection of the weight band splits for each vehicle type suggested that rationalisation of these would assist in estimation of vehicle spectra for other routes where only the vehicle class counts are available. Because the degree of directional loading bias at other sites is uncertain, we assumed the more conservative numbers would apply. Thus for the Drury standardised spectra, we assumed a 75/25 spit for class 11 in both directions. Table 6.7 shows the proposed rationalised fits, with vehicle mix % values as recorded, rather than the fitted numbers shown in table 6.6.

The effect of the rationalisation was to increase conservatism in the spectra fits. For the SH1 Drury fit, the average increase in equivalent cycle counts was 12% over the fitted version (3rd power), as illustrated in figure 6.1 (or 5% for the Eskdale fit and 11% for the Te Puke fit).

Figure 6.1 Fitted spectra for Drury compared to processed WIM data (moment cycles using 3rd-power rule)

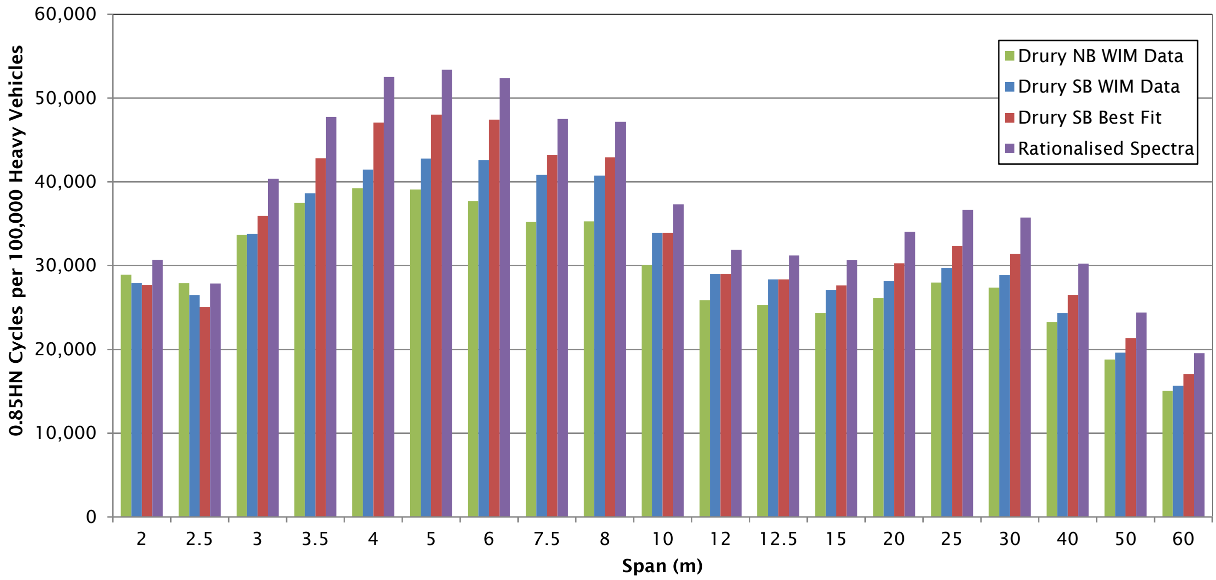
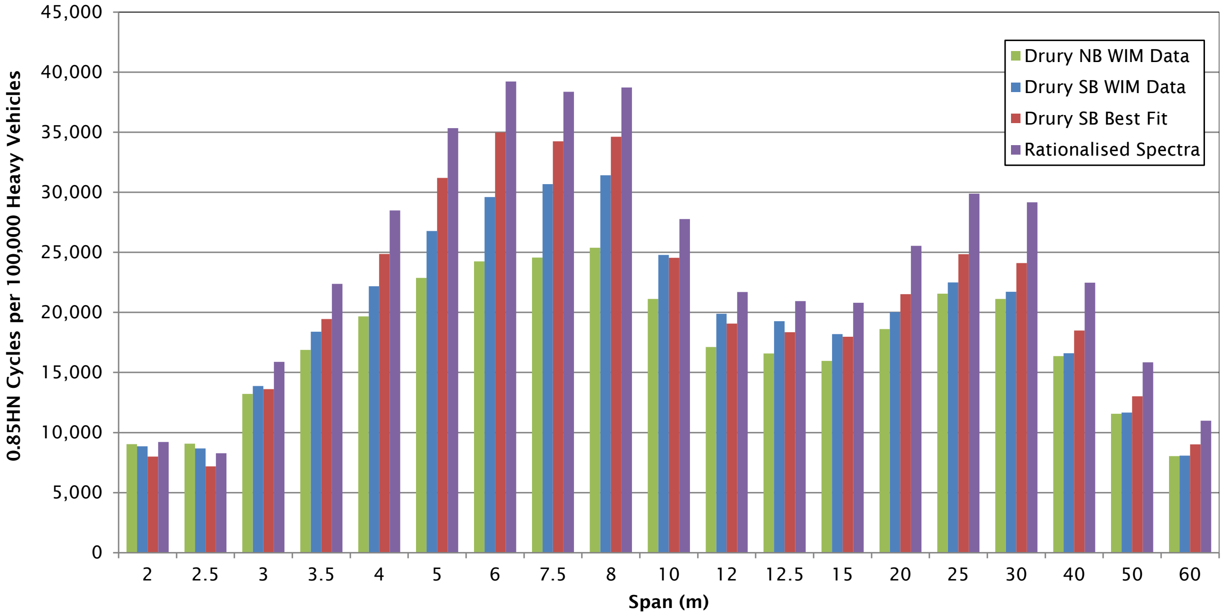


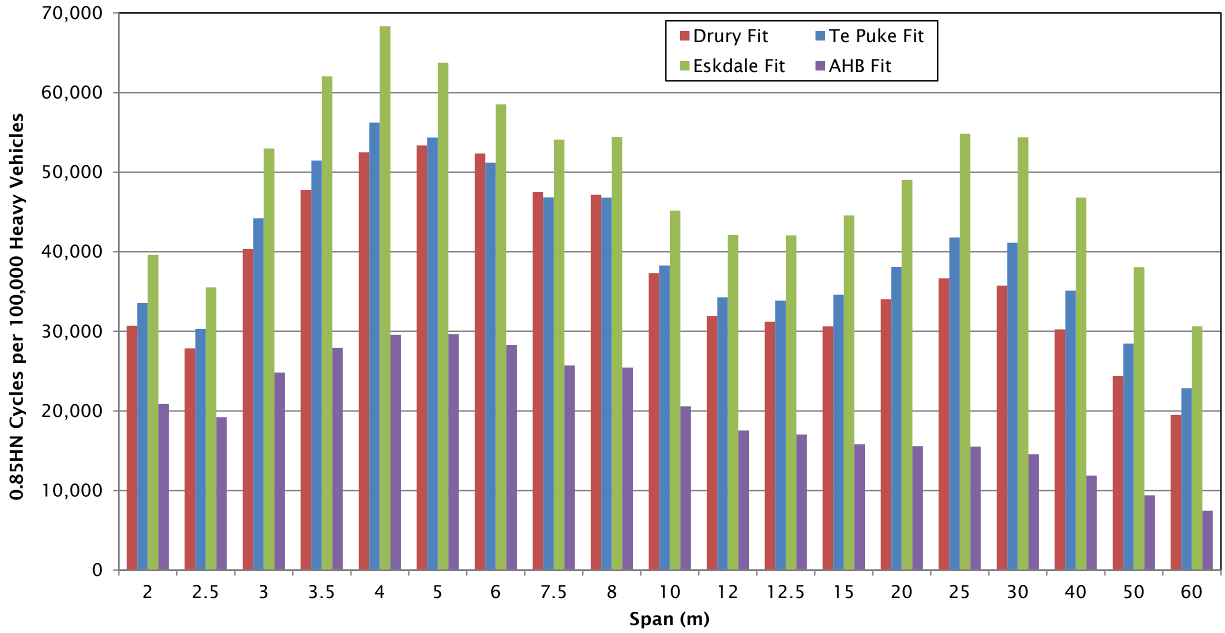
Figure 6.2 Fitted spectra for Drury compared to processed WIM data (moment cycles using 5th-power rule)



The 5th-power differences between the rationalised and fitted spectra (figure 6.2) are greater than those for the 3rd-power rule (16% for the Drury data shown above, 7% for the Eskdale fit, and 13% for the Te Puke fit).

Figure 6.3 compares the rationalised spectra for the three main highway sites (where the raw WIM datasets have been replaced by the rationalised vehicle spectra from table 6.7 below) and shows that the resulting spectra for Te Puke had greater fatigue effects than Drury at most span lengths, and the Eskdale effects per vehicle were around 50% greater than the Drury fit at long spans, or up to 30% greater at short spans.

Figure 6.3 Comparison of rationalised spectra effects (moment cycles using 3rd-power rule)



6.5 Comparison of equivalent axle counts per vehicle

The spectra derivation based on tuning to bridge loading effects did not attempt to match axle set weight spectra, although the effects were captured and adequately matched through fitting to the moment effects for short spans. However, we could compare the resulting equivalent axle counts (computed used a 4th-power rule with standard axle group reference weights) and compare these to the Transport Agency datasets (maxima for the individual periods and lanes included in the evaluations, calculated by summing the per-vehicle equivalent standard axle (ESA) values supplied in the Transport Agency raw data tables).

Table 6.4 Equivalent standard axles (ESA) per heavy vehicle comparison

	Drury	Eskdale	Te Puke	AHB
Av. ESA/vehicle (spectra)	1.63	2.03	1.74	1.04
Transport Agency data (max.)	1.5	1.92	1.54	–

Thus, pavement loading effects for the fitted spectra were not substantially different from the values derived from the raw WIM data.

6.6 Comparison of damage equivalent vehicle weights

In section 5.8, the 5th-power weighted average weights for the raw WIM data were compared. Eurocode 3 (EN 1993-2:2006) defines $Q_{m1} = \left(\frac{\sum n_i Q_i^5}{\sum n_i}\right)^{\frac{1}{5}}$ for gross weights in the slow lane to adjust the standard vehicle fatigue model (FLM3) to national parameters.

Table 6.8 uses this measure to compare average weights for raw WIM datasets with the fitted and rationalised spectra, by vehicle classes. The equivalent weight values for the proposed spectra are 60–87% of the 450kN top weight band vehicle.

By comparing the average equivalent weights for the raw WIM datasets to the fitted standard vehicle spectra, we could confirm that the fitted spectra are good representations of the actual data, and are safe-sided in all cases.

The ratios between the average weights for the rationalised spectra and the raw datasets ranged from 1.01 (Eskdale) up to 1.07 at the Drury site (ie the spectrum vehicles were 7% heavier on average, due to reversing the directional bias for the single-steer truck-and-trailers).

Table 5.1 compares the raw WIM dataset average weights to the 480kN Eurocode 3 FLM3 standard vehicle. Table 6.5 repeats this calculation for the rationalised spectra.

Table 6.5 Average vehicle weights for the proposed vehicle spectra vs the 480kN FLM3 vehicle

Vehicle spectra	Average weight Q_{m1}	FLM3 scale factor
SH1 Drury	348kN	0.73
SH5 Eskdale	391kN	0.81
SH2 Te Puke	366kN	0.76
SH1 AHB	280kN	0.58

Note that the above factors did not include future increases for higher mass vehicles, or the adjustments for annual truck counts (which also affect the related damage equivalence factor in Eurocode 3).

Table 6.6 Standard truck counts for best fits to WIM site data

Standard vehicle details					Site																				
					Drury NB			Drury SB			Eskdale EB			Eskdale WB			Te Puke WB			AHB NB			AHB SB		
Set	Axles	Configuration	Load group	Total weight (kN)	Fit per 100,000 vehicles	Group split	Set mix	Fit per 100,000 vehicles	Group split	Set mix	Fit per 100,000 vehicles	Group split	Set mix	Fit per 100,000 vehicles	Group split	Set mix	Fit per 100,000 vehicles	Group split	Set mix	Fit per 100,000 vehicles	Group split	Set mix	Fit per 100,000 vehicles	Group split	Set mix
1	2	o--o	H	150	900	0.03	26%	1200	0.05	26%	1000	0.05	21%	1000	0.06	18%	700	0.03	27%	5200	0.10	50%	5350	0.11	50%
			M	90	7700	0.30		9500	0.36		4500	0.21		4600	0.26		8100	0.30		10,000	0.20		10,500	0.21	
			L	50	17,500	0.67		15,600	0.59		15,600	0.74		12,200	0.69		18,300	0.68		34,600	0.69		34,500	0.69	
2	3	o--oo	H	210	500	0.05	11%	2000	0.19	10%	500	0.08	6%	200	0.03	7%	500	0.06	9%	5000	0.20	25%	3650	0.15	25%
			M	170	3700	0.33		4200	0.41		2500	0.42		3400	0.50		1800	0.20		3400	0.13		3300	0.13	
			L	110	6900	0.62		4100	0.40		3000	0.50		3200	0.47		6500	0.74		16,900	0.67		18,100	0.72	
3	4	oo--oo	H	260	500	0.07	7%	1600	0.25	6%	500	0.12	4%	500	0.02	28%	500	0.08	6%	900	0.16	6%	800	0.15	5%
			L	160	6500	0.93		4700	0.75		3700	0.88		27,000	0.98		5700	0.92		4700	0.84		4600	0.85	
4	6	o-oo--ooo	H	420	3300	0.18	19%	5800	0.28	20%	3400	0.30	11%	4000	0.34	12%	3200	0.25	13%	2300	0.26	9%	1200	0.13	9%
			M	310	6200	0.33		9100	0.45		5500	0.48		3300	0.28		3200	0.25		3050	0.34		2400	0.27	
			L	200	9200	0.49		5500	0.27		2500	0.22		4300	0.37		6500	0.50		3600	0.40		5300	0.60	
5	7	o-oo--oo--oo	H	450	8600	0.74	12%	3500	0.43	8%	5300	0.72	7%	5800	0.88	7%	6500	0.60	11%	2900	0.73	4%	1300	0.34	4%
			L	180	3100	0.26		4700	0.57		2100	0.28		800	0.12		4300	0.40		1100	0.28		2500	0.66	
6	8	oo--oo-oo--oo	H	450	7200	0.42	17%	6500	0.33	20%	33,300	0.78	43%	11,900	0.57	21%	18,800	0.68	28%	1350	0.25	5%	2050	0.37	6%
			M	350	3800	0.22		7900	0.40		6600	0.16		3100	0.15		4300	0.16		3700	0.68		3100	0.56	
			L	210	6300	0.36		5500	0.28		2600	0.06		5700	0.28		4600	0.17		400	0.07		400	0.07	
7	8	o-oo--ooo--oo	H	450	2100	0.26	8%	2800	0.33	9%	2100	0.28	7%	4300	0.48	9%	3600	0.55	7%	250	0.28	1%	450	0.47	1%
			M	360	3700	0.46		4600	0.53		4200	0.57		3200	0.36		1700	0.26		400	0.44		400	0.42	
			L	220	2300	0.28		1200	0.14		1100	0.15		1500	0.17		1200	0.18		250	0.28		100	0.11	

Note:

NB = northbound; SB = southbound; EB = eastbound; WB = westbound.

Table 6.7 Rationalised truck weight spectra with standardised weight group proportions

Standard vehicle details						Drury fit			Eskdale EB fit			Te Puke WB fit			AHB NB fit		
Set	NZTA classes	Axles	Configuration	Load group	Vehicle weight (kN)	Vehicle mix	Group split	Fit per 100,0000 vehicles	Vehicle mix	Group split	Fit per 100,0000 vehicles	Vehicle mix	Group split	Fit per 100,0000 vehicles	Vehicle mix	Group split	Fit per 100,0000 vehicles
1	4	2	Rigid truck o--o	H	150	27.2%	0.05	1360	21.1%	0.05	1055	28.9%	0.05	1445	50.0%	0.10	5000
				M	90		0.35	9520		0.35	7385		0.35	10,115		0.20	10,000
				L	50		0.60	16,320		0.60	12,660		0.60	17,340		0.70	35,000
2	5	3	Rigid truck o--oo	H	210	10.3%	0.20	2060	6.0%	0.20	1200	8.9%	0.20	1780	25.0%	0.20	5000
				M	170		0.40	4120		0.40	2400		0.40	3560		0.15	3750
				L	110		0.40	4120		0.40	2400		0.40	3560		0.65	16,250
3	6+7	4	Rigid truck oo--oo	H	260	6.1%	0.25	1525	4.3%	0.25	1075	6.2%	0.25	1550	5.5%	0.25	1375
				L	160		0.75	4575		0.75	3225		0.75	4650		0.75	4125
4	8+9	6	Artics o-oo--ooo	H	420	20.0%	0.30	6000	11.4%	0.30	3420	13.1%	0.30	3930	9.0%	0.26	2340
				M	310		0.48	9600		0.48	5472		0.48	6288		0.34	3060
				L	200		0.22	4400		0.22	2508		0.22	2882		0.40	3600
5	10+11	7	Truck+trailer o-oo--oo--oo	H	450	8.1%	0.75	6075	7.4%	0.75	5550	9.5%	0.75	7125	4.0%	0.75	3000
				L	180		0.25	2025		0.25	1850		0.25	2375		0.25	1000
6	12	8	Truck+trailer oo--oo-oo--oo	H	450	19.9%	0.40	7960	42.5%	0.80	34,000	27.2%	0.70	19,040	5.5%	0.50	2750
				M	350		0.35	6965		0.15	6375		0.15	4080		0.30	1650
				L	210		0.25	4975		0.05	2125		0.15	4080		0.20	1100
7	13	8	B-train o-oo--ooo--oo	H	450	8.4%	0.55	4620	7.3%	0.55	4015	6.2%	0.55	3410	1.0%	0.55	550
				M	360		0.30	2520		0.30	2190		0.30	1860		0.30	300
				L	220		0.15	1260		0.15	1095		0.15	930		0.15	150

Table 6.8 Comparison of equivalent (5th-power weighted average) vehicle weights, WIM data vs spectra

				SH1 Drury						SH5 Eskdale EB				SH2 Te Puke WB				SH1 AHB					
Standard vehicle details				WIM vs fit				Rationalised		WIM vs fit		Rationalised		WIM vs fit		Rationalised		WIM vs fit				Rationalised	
Set	NZTA classes	Configuration	Top band weight (kN)	NB 2011	NB fit	SB 2011	SB fit	Spectra mix	Spectra weight	2010-2011	EB fit	Spectra mix	Spectra weight	2010	Fit	Spectra mix	Spectra weight	NB 2010-2011	NB fit	SB 2010-2011	SB fit	Spectra mix	Spectra weight
1	4	2-axle rigid truck	150	78	86	83	90	27.2%	90	80	87	21.1%	90	75	83	28.9%	90	87	98	88	99	50.0%	98
2	5	3-axle rigid truck	210	147	150	168	170	10.3%	171	152	159	6.0%	171	138	145	8.9%	171	152	162	146	155	25.0%	163
3	6+7	4-5 axle rigid truck	260	178	179	202	207	6.1%	207	177	188	4.3%	207	172	181	6.2%	207	192	195	195	193	5.5%	207
4	8+9	5-8 axle artics	420	320	321	343	348	20.0%	351	350	351	11.4%	351	348	333	13.1%	351	335	339	307	307	9.0%	339
5	10+11	Single-steer truck+trailer	450	415	423	361	381	8.1%	425	418	421	7.4%	425	400	407	9.5%	425	417	422	360	365	4.0%	425
6	12	Twin-steer truck+trailer	450	385	390	378	383	19.9%	393	432	433	42.5%	435	424	422	27.2%	424	387	382	404	396	5.5%	405
7	13	(single-steer) B-train	450	375	378	384	392	8.4%	413	384	388	7.3%	413	413	412	6.2%	413	377	380	410	408	1.0%	413
Average				330	338	327	334		348	385	388		391	362	362		366	271	272	261	260		280
Rationalised/fit				1.06	1.03	1.07	1.04			1.02	1.01			1.01	1.01			1.03	1.03	1.07	1.08		

Notes:

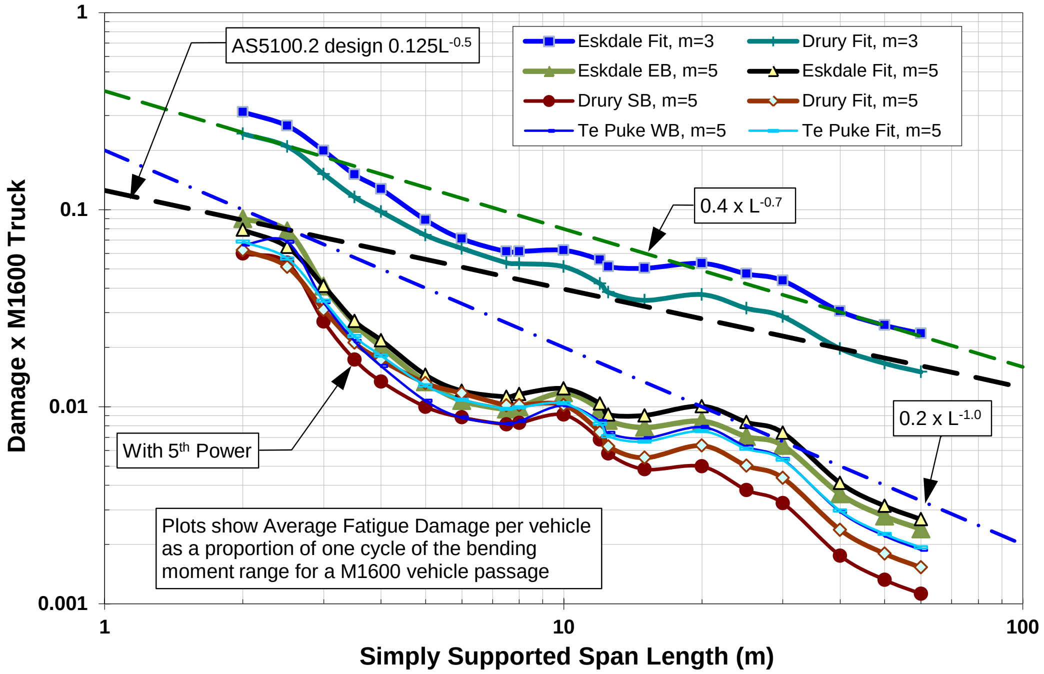
a) The above table compares 5th-power weighted average weights $\left(\frac{\sum n_i W_i^5}{\sum n_i}\right)^{\frac{1}{5}}$ where there are n_i vehicles in each weight band W_i.

b) This confirms that the average weights for best-fit spectra are equivalent to, or slightly heavier than, the target WIM datasets, while the ‘rationalised’ spectra are aligned with the more heavily loaded directions to give safe-sided outcomes for current heavy traffic at the WIM sites.

6.7 Comparison of fatigue damage estimates

The bridge fatigue loading for a selection of the fitted spectra relative to the M1600 fatigue vehicle is shown in figure 6.4 (compared to the results for WIM datasets shown in figure 5.5). This shows that changes introduced by rationalising the spectra were relatively minor, except at the Drury site where switching the fully loaded single-steer truck-and-trailer vehicles to the southbound direction increased average damage per vehicle.

Figure 6.4 Comparison of rationalised spectra effects (M1600 moment cycles)



6.8 Commentary on vehicle spectra usage

The rationalised vehicle spectra presented in table 6.7 are representations of the *current* fatigue loading per 100,000 heavy vehicles at the four selected WIM sites, which may be used in fatigue life assessments.

- Guidance on the usage of the spectra for assessment of structures under current loading is provided in appendix E. This is based on the guidance in the UK National Annex to Eurocode 1.
- The presentation of the vehicle set counts as proportions of the total heavy traffic allows for adjustments to suit other routes, if the mix of vehicle types is known.
- The relative proportions of vehicles within each weight band of a vehicle set vary between sites and it is necessary to select the site with comparable freight mix (expected proportion of fully loaded vehicles versus volume-constrained loads).
- Further rationalisation of the choices would be appropriate if reference spectra are to be provided in a future Bridge Manual commentary.
- Proportions of vehicles in the upper weight bands for sets 4 to 7 represent the contributions from fully laden vehicles, which may be candidates for upgrades to higher mass vehicles (to be considered in chapter 7).

7 Growth allowances

7.1 Introduction

This study has considered three parts of long-term growth in fatigue damage rates:

- historic growth rates for heavy traffic volumes and vehicle weights (required for the assessment of existing bridges)
- future projections of growth in heavy vehicle numbers and the freight task
- additional growth in fatigue damage due to long-term increases in mass limits (HPMVs and beyond).

7.2 General growth rates

The available information sources for long-term growth indicators were:

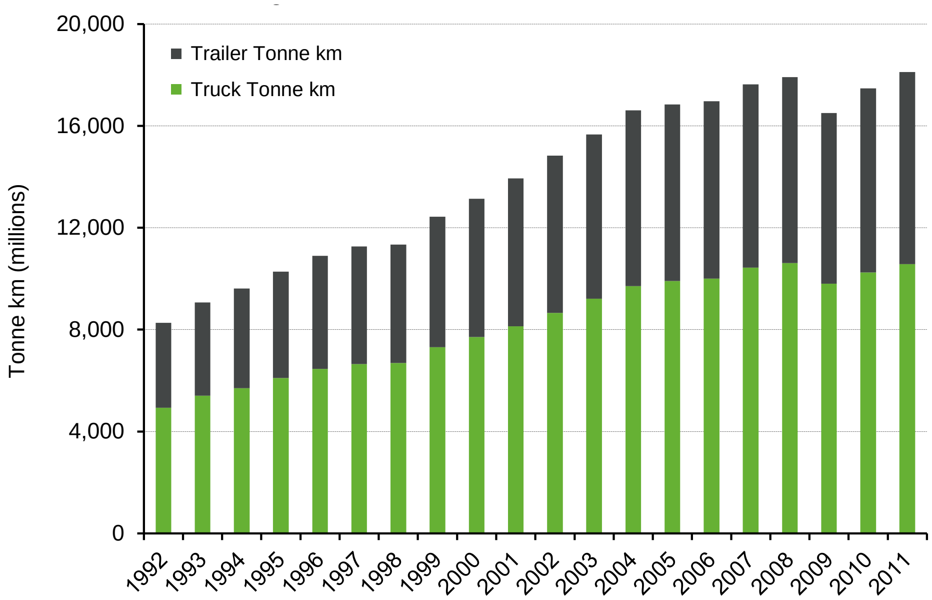
- Ministry of Transport (MoT) annual fleet statistics: tonne-km freight task growth
- State highway traffic growth index (NZ Transport Agency 2013a)
- Gross domestic product (GDP) real growth index (constant prices)
- Funding and investment guidelines for HPMV implementation (NZ Transport Agency 2010a)
- EEM (NZ Transport Agency 2010b)
- Reference project studies – Auckland Harbour Bridge and Additional Waitemata Harbour Crossing.

Key results from these studies are presented below.

7.2.1 Ministry of Transport (MoT) annual fleet statistics

Figure 7.1 shows estimates of the national freight task as tonne-km, which is the aggregate of payload tonnes x km travelled (MoT 2012).

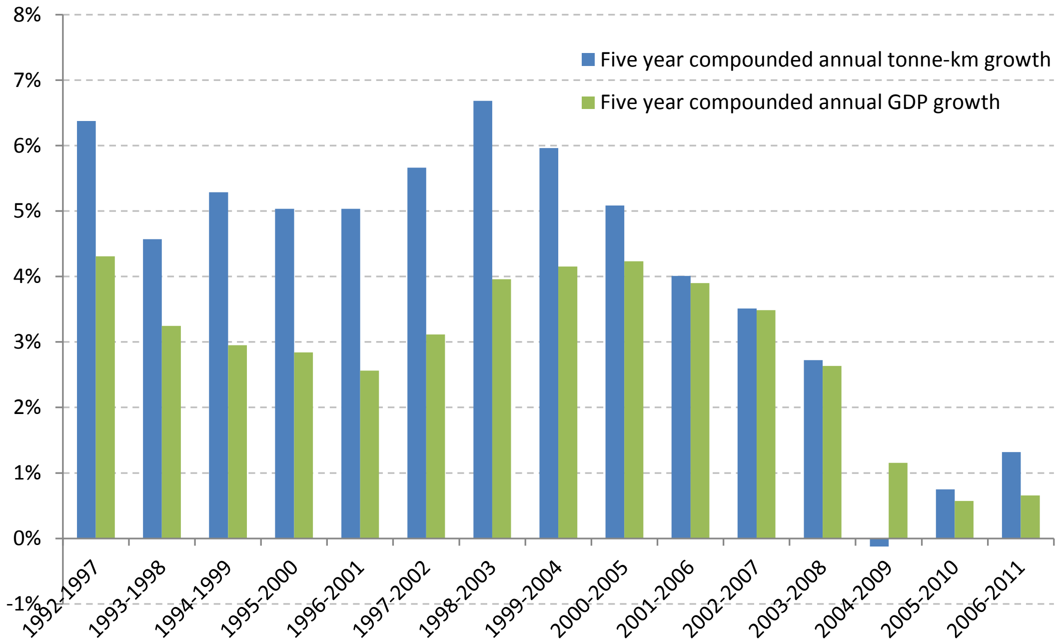
Figure 7.1 Freight task growth data from 2011 annual fleet statistics (MoT 2012)



These statistics were derived from road user charge (RUC) data. 2011 was the last year before changes to the RUC charging system and the above series has not been updated for the 2012 fleet statistics report. The lingering impact of the global financial crisis and increased fuel prices is seen in the 2009–2010 data.

The fleet statistics report compared freight task growth rates to GDP growth, showing that freight growth was well ahead of GDP growth until 2005 and now tracks at similar rate, supporting an assumption that future HCV growth should continue at a similar rate to GDP growth.

Figure 7.2 Freight task growth rates compared to GDP growth rates (MoT 2012)



7.2.2 State highway traffic growth index versus GDP growth

From the state highway index data (NZ Transport Agency 2013a) shown in figure 7.3, we deduced the following:

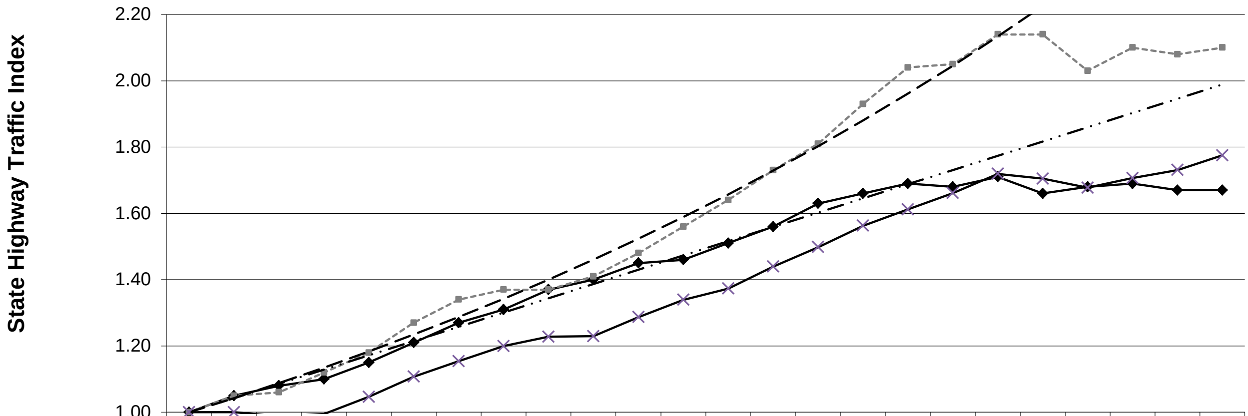
- Heavy traffic growth to 2007 was consistent with a 4.3% pa compound (geometric) rate.
- Total volumes followed a linear (arithmetic) growth line, until 2005.
- Major changes in GDP growth (MoT 2013) lagged behind traffic growth by approximately two years.

The chart in figure 7.3 uses 1989 as the index base year and does not clearly show the more recent relationships. In figure 7.4, the indices have been adjusted to use 2000 as the base year. It is seen that:

- tonne-km and the heavy traffic count indices have been very similar since 1996
- heavy traffic and GDP growth from 1994 to 2012 has been very similar.

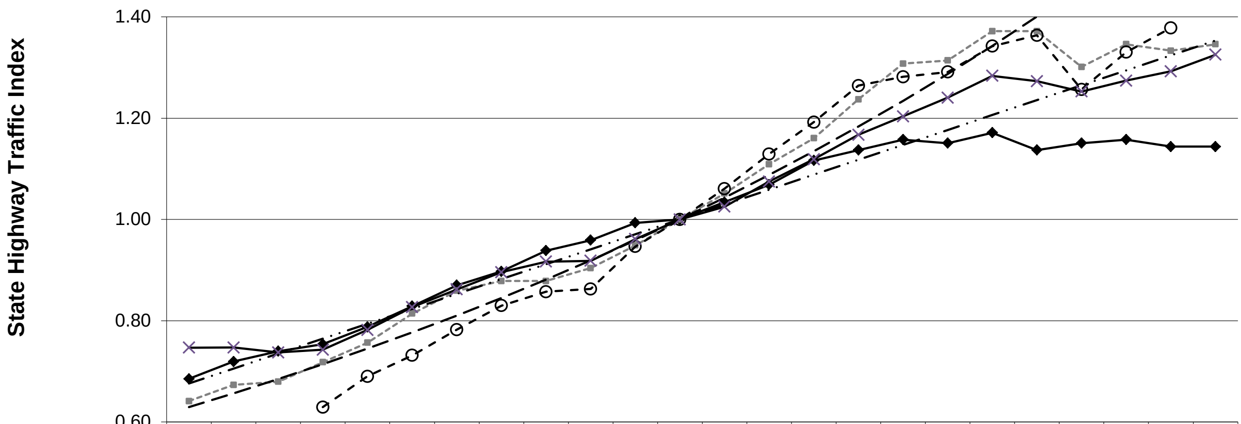
The state highway heavy traffic index measures the average growth in heavy traffic volumes across the country, and does not incorporate measures for the distance travelled or vehicle weights (as the tonne-km statistic does). However, it is apparent that both measures are linked to GDP growth.

Figure 7.3 State highway traffic index vs GDP index (base year 1989)



	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
All	1.00	1.05	1.08	1.10	1.15	1.21	1.27	1.31	1.37	1.40	1.45	1.46	1.51	1.56	1.63	1.66	1.69	1.68	1.71	1.66	1.68	1.69	1.67	1.67
Heavy	1.00	1.05	1.06	1.12	1.18	1.27	1.34	1.37	1.37	1.41	1.48	1.56	1.64	1.73	1.81	1.93	2.04	2.05	2.14	2.14	2.03	2.10	2.08	2.10
4.3% cmpd	1.00	1.04	1.09	1.13	1.18	1.23	1.29	1.34	1.40	1.46	1.52	1.59	1.66	1.73	1.80	1.88	1.96	2.05	2.13	2.23	2.32	2.42	2.52	2.63
4.3% lin	1.00	1.04	1.09	1.13	1.17	1.22	1.26	1.30	1.34	1.39	1.43	1.47	1.52	1.56	1.60	1.65	1.69	1.73	1.77	1.82	1.86	1.90	1.95	1.99
GDP Index	1.00	1.00	0.99	0.99	1.05	1.11	1.15	1.20	1.23	1.23	1.29	1.34	1.37	1.44	1.50	1.56	1.61	1.66	1.72	1.70	1.68	1.71	1.73	1.78

Figure 7.4 State highway traffic index vs GDP index (base year 2000)



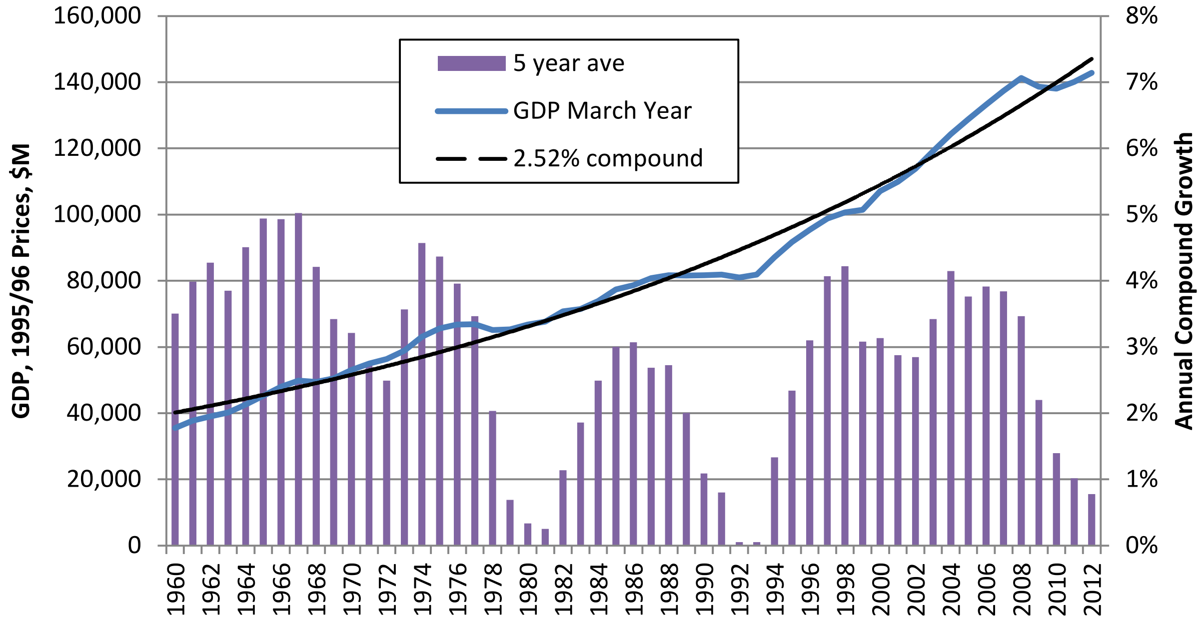
	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
All	0.68	0.72	0.74	0.75	0.79	0.83	0.87	0.90	0.94	0.96	0.99	1.00	1.03	1.07	1.12	1.14	1.16	1.15	1.17	1.14	1.15	1.16	1.14	1.14
Heavy	0.64	0.67	0.68	0.72	0.76	0.81	0.86	0.88	0.88	0.90	0.95	1.00	1.05	1.11	1.16	1.24	1.31	1.31	1.37	1.37	1.30	1.35	1.33	1.35
Tonne-km				0.63	0.69	0.73	0.78	0.83	0.86	0.86	0.95	1.00	1.06	1.13	1.19	1.26	1.28	1.29	1.34	1.36	1.26	1.33	1.38	
4.3% cmpd	0.63	0.66	0.68	0.71	0.74	0.78	0.81	0.85	0.88	0.92	0.96	1.00	1.04	1.09	1.13	1.18	1.23	1.29	1.34	1.40	1.46	1.52	1.59	1.66
2.9% lin	0.68	0.71	0.73	0.76	0.79	0.82	0.85	0.88	0.91	0.94	0.97	1.00	1.03	1.06	1.09	1.12	1.15	1.18	1.21	1.24	1.27	1.29	1.32	1.35
GDP Index	0.75	0.75	0.74	0.74	0.78	0.83	0.86	0.90	0.92	0.92	0.96	1.00	1.03	1.07	1.12	1.17	1.20	1.24	1.28	1.27	1.25	1.27	1.29	1.33

7.2.3 GDP growth over past 50 years

Figure 7.5 shows that the average compound growth rate for real GDP since 1960 (Statistics New Zealand 2013) was 2.5% per annum. The moving averages over five-year periods seldom exceeded 4%.

It is apparent that the compound (geometric) growth rate is more applicable to national GDP growth than an arithmetic (linear) growth rate. Figures 7.3 and 7.4 indicate that geometric growths were also applicable to historic heavy vehicle counts. However, the traffic count and freight task growth measures were influenced by the expansion of the highway network, and it is unclear which type of growth rate assumption was generally appropriate at single bridge locations.

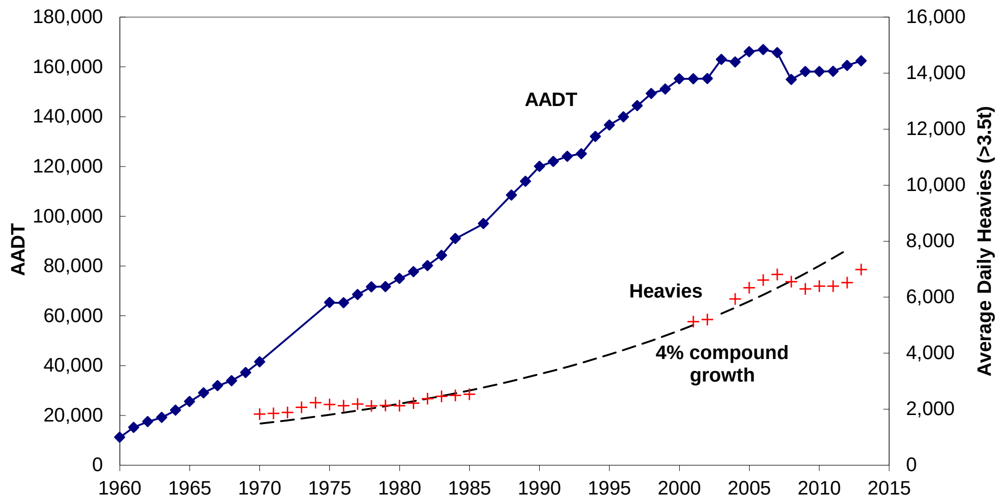
Figure 7.5 Long-term GDP growth



7.2.4 Auckland Harbour Bridge (AHB)

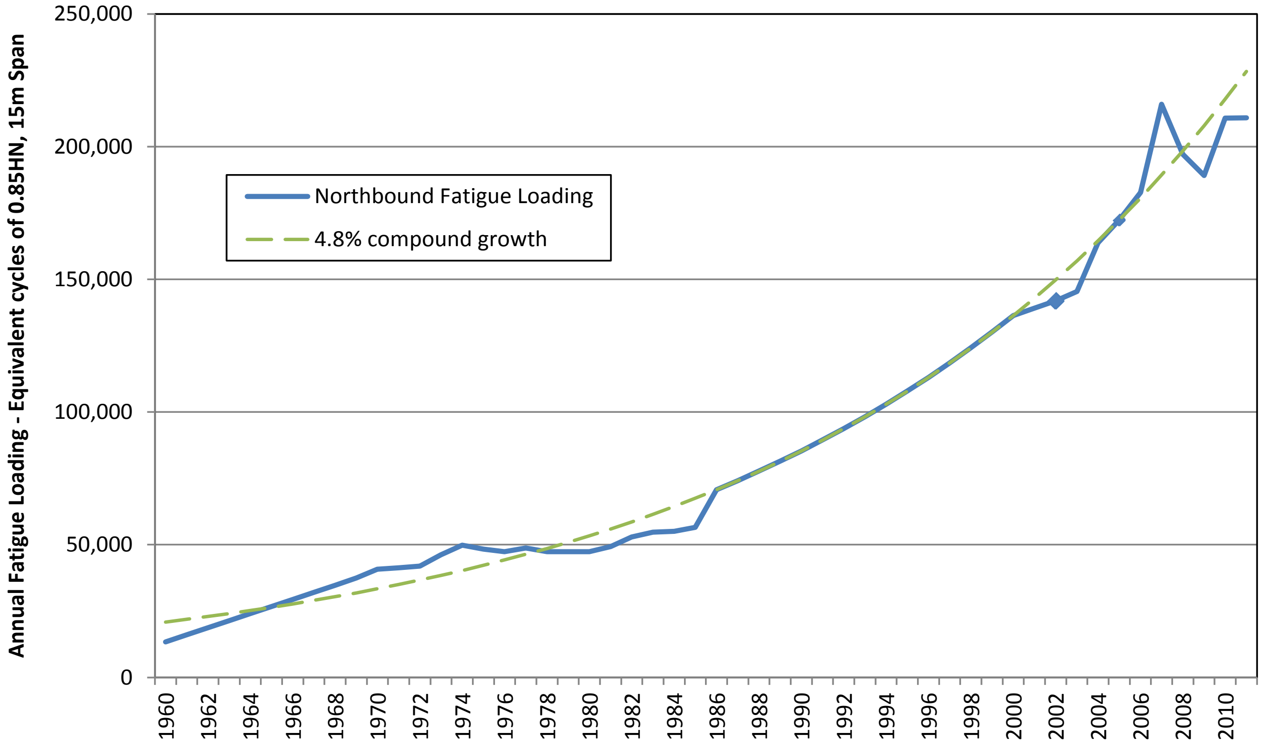
The AHB is the second most heavily trafficked part of the state highway network, behind the Grafton Road-Gillies Ave section of the Auckland Southern Motorway, with a similar proportion of heavy vehicles to that section. Growth in heavy vehicle numbers from 1978 to 2008 fitted a 4% compound growth rate, while total volumes followed a linear growth trend until 2006. There was no growth in annual counts over the past few years, but the most recent data from November 2012 onwards indicated an upward trend in total volumes and heavy vehicle counts.

Figure 7.6 AHB annual average daily traffic (AADT) counts



For long-term fatigue life assessments of the longitudinal deck beams (Beca 2012), the growth in northbound fatigue loading was derived using available WIM data since 1996, and data supplied by Works Consultancy from an estimate of fatigue load spectra (Darnell et al 1986). Their data from 1970 to 1985 was based on analysis of toll records that included vehicle types, which enabled the approximate mass distributions to be estimated. Therefore, long-term changes in common vehicle types from 1970 were covered in this data (for example, 5→6 axle semi-trailers, 6→7 axle truck and trailers). Heavy vehicle data prior to 1970 was not studied and constant percentage content was assumed. Given the considerable growth in demand, the early years (with a 4-lane structure from 1959 to 1969) were much less important for the growth in fatigue loading compared with current loading on the 8-lane structure.

Figure 7.7 AHB, growth in northbound fatigue loading (total for 2–5 lanes)



As shown in figure 7.7, the data indicates a compound growth rate in loading for the northbound direction of 4.8% over 50 years. The sharp increase in 2005–2007 coincided with significant additional construction activity north of the bridge (the northern busway), and roughly double the number of 7-axle truck-and-trailers compared with 2011. An increase in these vehicles was also observed at the Drury WIM site (which is one of the aggregate supply routes), showing that additional short-term growth surges at a regional level should be anticipated in the future. Similarly, a period of minimal growth is seen to be a poor indication of long-term trends, and caution should be exercised when interpreting data from the past few years.

7.2.5 Additional Waitemata Harbour Crossing

Estimates of the future traffic demands for the AHB corridor were prepared for the *Additional Waitemata Harbour Crossing* study (Young and Clark 2010). Their report indicates the following:

- Future heavy traffic demand is expected to follow (or perhaps lead) GDP growth.

- Forecast annual GDP growth rate from the forecast per-capita real GDP growth (1.8% pa) combined with population growth rate was approximately 3% pa.
- For urban areas, HCV growth rates may be lower than this figure.

7.2.6 Transport Agency guidelines

The EEM (NZ Transport Agency 2010b) provides default traffic growth rates (for all vehicles), which vary by region and type of road. For urban arterial routes and rural strategic routes, the maximum values are 3% per annum arithmetic growth, up to 2.5% on other rural routes, or up to 2.0% on other urban routes.

The HPMV funding and investment guidelines (NZ Transport Agency 2010a) states:

> *The freight task is forecast to increase by 70 to 75% over the next 25 years with all modes carrying a share of the increase. For the purpose of determining the benefits of implementing the 2010 VDAM amendment, a nominal arithmetic growth in road freight of 2% per annum should be allowed for* (p.28).

Thus, a 3% per annum arithmetic growth rate in freight task (from 2010) over 25 years is expected, which is consistent with the forecast GDP growth rate used in the *Additional Waitemata Harbour Crossing* study (Young and Clark 2010), and a 3% growth rate for total traffic on the applicable routes. The lower nominal figure is for evaluating the funding of upgrades and is not suitable for estimating increases in fatigue or pavement damage.

7.2.7 Conclusion – general historic growth rates

Estimation of fatigue life consumption in existing structures requires an estimate of current fatigue loading and the historic growth rates. Assuming a lower historic growth rate increases the aggregate fatigue damage and shortens the estimated remaining life.

For routes with historic traffic growth patterns considered to be typical of the national trends, the available data indicated the following:

- Long-term annual growth in heavy vehicle counts was 4–4.3%, compound.
- Growth in fatigue loading was higher, due to the long-term trend toward longer, heavier vehicles with more axles. From the AHB (urban motorway) data, a long-term compound growth rate of 4.8–5% was indicated (total loading for all lanes). On line-haul or rural routes with high proportions of truck-and-trailers the effect of long-term changes in typical configurations (6→7→8 axles) may have increased the difference between average fatigue damage growth rates and vehicle count growth rates.

We recommend that the characteristics and history of the bridge route should be considered and the adopted historic fatigue loading growth rate should not be more than 5% compound unless supported by assessment of the applicable heavy traffic data.

7.2.8 Conclusion – future general growth rate

Transportation studies indicate that freight task growth should be similar to GDP growth, with the current forecast being approximately 3% per annum. The Transport Agency's recommendations for assessing the benefits of the 2010 VDAM amendment state that a nominal linear growth in freight task of 2% per annum should be allowed for in the benefit estimates (this is taken to be a pessimistic allowance).

Thus, 3% per annum (linear) should be assumed in the heavy traffic volume growth estimates (or the freight task growth where efficiency gains through bigger payloads are accounted for). This is somewhat in conflict with historical estimates showing 4% per annum geometric growth in heavy vehicle numbers but it can be observed that road capacity increases were necessary to accommodate such growth, and the gap between the (higher) freight task growth rate and the GDP growth rate has closed (figure 7.2).

For individual bridge lanes, the truck counts per lane are limited to saturation volumes (generally in the range 4000–5500 trucks per day in the slow lane, based on the values used in the European, North American and Australian codes). These practical limits would eventually restrict long-term growth rates in single lanes.

Accordingly, the 3% per annum arithmetic heavy traffic volume growth rate guideline was adopted for this study.

7.3 Future vehicle mass growth

The 2010 amendment to the VDAM rule introduced increased gross and axle set mass limits for approved vehicles. Uptake of the new limits has been restricted by available routes, due to concerns with bridge capacities (and additional pavement damage). The bridge capacity studies (eg Waldin 2012) indicated that the full HPMV effects are comparable to 0.90HN on spans up to 25m and 0.95HN on spans over 25m (which are the assessment loadings included in the amended Bridge Manual). Thus, the overall span moment effects were estimated to increase by around 10%.

The Transport Agency has recently introduced a 'lower bound' alternative HPMV with maximum axle group masses as for the Class 1 limits and restricted to 50 tonne gross mass (to be known as '50MAX'), which is expected to be approved for all Class 1 routes except where there are bridges with lower posted mass limits.

7.3.1 Evaluation of additional fatigue loading with HPMV limits

A review of the available information on expected take-up of the new HPMV mass limits and evaluations of the HPMV contributions to fatigue loading is provided in appendix F. It is considered that the optimistic take-up interest scenario proposed by Stimpson (2012) for the 50MAX business case is appropriate for estimating potential mass growth over the next 10 or more years, and that the key assumptions on volume-constrained payload ('cube-out') proportions and operator interest are also relevant to the full HPMV mass limit take-up on designated strategic routes.

The adopted methodology set out in appendix F for assessing the average damage increases per heavy vehicle can be summarised as follows:

- Vehicles in the 'H' (high) load bands of the rationalised vehicle spectra (table 6.7, vehicle sets 4–7) are assumed to be the eligible vehicles that would have a commercial interest in upgrading. This approach simplifies the estimates because the proportions of empty and cube-out vehicles are defined by the lower and medium load bands. For example, 40% of twin-steer truck-and-trailers passing the Drury site could operate at higher mass.
- Existing fatigue damage estimates for the HPMV upgrade candidates are assumed to be equivalent to the 'H' spectrum vehicles.
- The incremental damage increases are assessed by comparing effects for *pro forma* HPMV vehicles (at the higher mass limit) with the 44-tonne *pro forma* Class 1 vehicles they would replace. The ratios of damage (with 5th-power rule) caused by these vehicles varies with span and vehicle combinations.
- These damage ratios for vehicles at exact mass limits are assumed to apply to all vehicles, so that the effect of the spread present in the existing WIM data is preserved. This is necessary to maintain the

effect of dynamic scatter in recorded axle weights and normal variance in actual mass, and the current levels of overweight vehicles.

- The damage ratios are reduced in proportion to the estimated payload ratios to allow for fewer trips being required to move the same freight tonnage.
- The aggregated results are presented in appendix figures F.8 and F.9 as modified versions of the equivalent M1600 fatigue vehicle evaluations in chapter 5 (similar to figures 5.8 and 5.9), and also for alternative truck-and-trailer vehicles (similar to figure 5.14).
- Aggregated damage increase factors for the vehicle fleets are presented in table F.5.

7.3.2 HPMV take-up scenarios

Several combinations of take-up scenarios were considered for the eventual mix after full take-up of the higher mass limits, as it was apparent that the relative impacts of the current and longer wheelbase vehicles will vary with span length. The scenarios set out in appendix F (table F.5, section F.6) cover:

- weight increases with same length vehicles (cases 1a, 1b)
- length and (greater) weight increases vehicles (cases 2a, 2b)
- with trip savings (cases 1a, 2a) or without trip savings (cases 1b, 2b)
- 50MAX with trip savings
- anticipated future increase in as-of-right axle weight limits for all other vehicles.

The scenarios without trip savings were intended to cover the possibility that designated HPMV routes may attract a larger share of the freight task, so that the same number of trips using larger vehicles would provide the capacity to move a larger freight volume. Those scenarios gave the largest increases in average damage per vehicle.

7.3.3 Conclusions – future vehicle mass growth rate

A wide range of scenarios are possible for the transition to higher mass vehicles. Given the high level of interest evident in approved and pending HPMV higher mass permit applications, and the introduction of the lower bound '50MAX' standard for routes not approved for HPMVs, the more optimistic scenarios set out in the business case studies were considered appropriate for the estimation of fatigue growth rates in the short to medium term. From the analysis outcomes presented in appendices F and G, we came to the following conclusions:

- The 50MAX optimistic scenarios corresponded to average mass per vehicle growth of 0.4–0.8% per annum, but adversely affected short spans (up to 10m) and longer spans (over 25m) only.
- The full HPMV higher mass limit scenarios corresponded to average mass per vehicle growth of 0.9–1.8% per annum over an assumed 10-year take-up period (relative to current truck counts, and allowing for efficiency gains).
- Fatigue loading increases for short spans were higher than for medium to long spans, due to disproportionately higher axle set mass increases. The increases per vehicle were partly offset by trip savings and diluted by no changes to volume-constrained loads and unladen return trips.
- Resulting estimates for fatigue damage growth estimates (with net freight task growth of 3% pa) were in the 10–14% range (per annum) for medium spans and 12–20% for short spans. These damage

growth rates assumed that a 5th-power fatigue damage rule was applicable (as it should be for new designs and shear stress ranges generally), and allowed for the optimistic take-up scenarios.

It is not known how far beyond the new HPMV limits that future vehicle gross masses will be allowed to increase to. At 1% per annum average increase over 100 years, *typical* masses might increase from 44 tonne to 88 tonne. However, it is presumed that an upper limit would be applied to future axle mass increases, which would control the growth on short-span effects. Taplin et al (2013) proposed a future 102-tonne upper bound vehicle with 27-tonne triple-axle and 32-tonne quad-axle sets (approximately 45% above the current HPMV limits) as the basis for a revised bridge design loading. Those would be the top-end values, while axle weights in average fully laden vehicles would be less.

7.4 Discussion – long-term fatigue damage growth rates

7.4.1 Basis of AS 5100.2 growth allowance

The cycle counts specified in AS 5100.2 clause 6.9 allow for:

- a 75-year fatigue design life
- an approximately 4% compound growth rate in equivalent cycle counts
- total cycle counts of approximately 440 times the year 1 count (average per year of 5.8 times the presumed year 1 fatigue damage).

The Standards Australia BD-090 committee notes (Grundy 2002b) indicate that this is derived by considering:

- year 2000 as base year
- a linear increase in truck counts (per slow lane) from 1500 to 4000 per day over 50 years (3.3% pa initially), capped at 4000 thereafter
- axle mass increasing by 33% (from a 6- to 8-tonne average) over 12 years then stabilising.

It can also be observed that similar total counts are generated by applying 2.5% uniform compound growth for 100 years.

7.4.2 New Zealand growth scenarios

For the New Zealand vehicle growth rate, a range of scenarios was explored (see appendix G.6) and the following observations were made:

- An ongoing compound growth rate for damage was necessary to adequately represent a combination of mass and volume growth.
- A scenario with 0.7% pa vehicle mass linear growth (capped at 30% increase beyond a 10-year initial HPMV take-up period) with 3% pa linear volume growth fitted the AS 5100.2 multiplier for fatigue damage cycles (440 x base year).
- Uncapped mass limit growth (at 0.7% pa) would result in much higher damage at 75+ years (700 x base year at 75 years).
- The scenarios generally supported the AS 5100.2 approach (~4% compound damage growth rate) but at lower assumed mass growth rates than Grundy's example, due to the use of the 5th-power damage rule.

- If the optimistic HPMV take-up scenarios were to be covered, a higher growth rate should be assumed (eg 4.3% over 75 years from appendix G.6, scenario (d) with 1% pa mass growth – 527 x base year).
- A 100-year fatigue design life would require 60–75% more design cycles (a roughly 10–12% reduction in stress range for the fatigue vehicle) compared with the 75-year life used in AS 5100.2.
- Even with pessimistic assumptions for growth rates, the 100-year multipliers exceeded the AS 5100.2 allowance.

Our conclusions were as follows:

- Growth allowance requirements are driven by the government decision to allow higher mass vehicles with heavier axles, and the anticipated future mass increases discussed in Taplin et al's live load study report (2013), plus general growth in the freight task.
- The rate and extent of future growth in fatigue damage rate is uncertain.
- The growth multipliers incorporated in the AS 5100.2 cycle count formulae (4% per annum compound growth for 75 years) represent the *minimum* that should be considered in a New Zealand fatigue loading model.
- The cycle counts should be increased by at least 60% if a longer fatigue design period (eg 100 years) is mandated. Alternatively, an increase in design fatigue vehicle weight by at least 10%, with no increase in cycle counts, would have a similar effect.
- If significant numbers of vehicles with gross mass and axle mass limits similar to the proposed future 102-tonne upper bound vehicle (Taplin et al 2013) are expected on New Zealand roads within the 75 to 100-year time frame, then the proposed fatigue damage growth allowances discussed above may be insufficient.

8 Design fatigue vehicle selection and calibration

8.1 Candidate vehicles

Evaluations of current fatigue loadings in terms of equivalent repetitions of potential design fatigue vehicles were presented in chapter 5, with proposed fit lines for equivalent cycles per heavy vehicle. These require increases to fit the effects of the rationalised vehicle spectra, representing current heavy vehicles, presented in chapter 6, plus the effects of HPMV higher mass vehicles (see appendix F).

The *potential* standard fatigue vehicle candidates that we investigated for use in a New Zealand-specific fatigue load model using a single-vehicle approach were as follows:

- *The M1600 vehicle as per AS 5100.2, with amendments to cycle count formulae and route factors to suit New Zealand traffic mixes and future growth expectations*: A scale factor of *0.6* was proposed to reduce effects on short spans down to serviceability levels. Taplin et al (2013) proposed a factor of 0.40 applied to SM1600 loadings and a 100kN axle load (instead of the A160 axle) for Class 1 evaluation loading, and 0.8 x SM1600 for the SLS design live load. A 0.6 scale factor applied to the M1600 vehicle would be midway between the current loading and the proposed future SLS design load, so seemed to be a reasonable choice for a vehicle representing average fully laden long vehicles over the design life.
- *A pro forma truck-and-trailer combination to either current legal or HPMV limits, with appropriate cycle count formulae for New Zealand traffic mixes and future growth expectations*: This could be one of the following standardised configurations:
  - 44-tonne R22T22 Class 1 truck-and-trailer (or the 450kN standard spectrum vehicle 6H)
  - 530kN version of the R22T22 standard spectrum vehicle (HPMV variant 6HM, see table F.7)
  - 57-tonne 10-axle truck-and-trailer (R23T23, defined in table F.6).
- *A 4- or 5-axle standardised vehicle similar to other codes*: As these are normally taken from the design live loading, and none is proposed for New Zealand, we investigated the following vehicles:
  - AASHTO HL-93 (metric tandem-axle variant used for deck analysis, 325kN x 0.75)
  - Canadian CL-625 (o-oo---o---o, 625kN x 0.52)
  - Austroads T44 (o-oo—oo) scaled down to 39 tonne (legal weight of A123 semi-trailer)
- Eurocode FLM3 fatigue vehicle (oo—oo), 480kN but scaled down to average (5th power weighted) mass through modification factors defined in the steel code to align with our vehicle gross masses.

The existing Bridge Manual HN live load was not considered suitable as the basis of a new standard fatigue model, given the generally inconsistent fit to the effects of realistic vehicles and the necessity to include the accompanying distributed load to represent Class 1 vehicle loading on medium spans.

The advantages and disadvantages of the candidate vehicles are described in table 8.1 below.

Table 8.1 Fatigue vehicle advantages and disadvantages

Fatigue vehicle	Advantages	Disadvantages
M1600 x 1.0	• Same as AS 5100.2 • Opportunity to apply with minimal changes to AS 5100.2 • Simple to apply if New Zealand adopts AS 5100.2 with minor modifications • Simple relationship between design cycles, daily truck counts and span length • Fatigue vehicle effects may be derived from live load analysis in simple cases only (separate fatigue analyses are usually necessary)	• Unrealistically high for future New Zealand loading (Taplin et al 2013 proposes 80% for future live load standard) • Design cycle counts at medium to long spans do not fit the 5th-power evaluations (overly conservative) • A single-axle load is necessary to cover short spans (<5m), but load and cycle counts appear to be excessive • Axle set effects are much higher than current (and future) triple- or quad-axle sets – short-span effects are not representative of typical trucks
M1600 x 0.6	• Compatible with SM1600-based LL standard • Simple to apply if New Zealand adopts AS 5100.2 with minor modifications • Opportunity to modify existing AS 5100.2 format of cycle count formulae to fit New Zealand spectra and likely growth parameters. Propose to specify with less onerous but more realistic methods of application • Stress ranges are closer to the envelope of expected higher mass vehicles • Similar axle weights to current vehicles	• Not the same as AS 5100.2 – requires new design cycle count formulae • Alternative axle load (or tandem set) is necessary to cover short spans • All M1600 variants (including the first option above) may overestimate hogging moment effects over supports for continuous span lengths in the range where the variable spacing places 2 triple-axle sets near the middle of adjacent spans • Separate fatigue vehicle analysis always required
HPMV vehicles: R22T22 54 tonne or R23T23 57 tonne	• Representative of future New Zealand higher mass vehicles (medium term) • Rigid trucks on short spans are well represented by part of the vehicle • Stress ranges similar to higher mass vehicles • Axle and axle set weights similar to current vehicles. Separate analysis with a single-axle load is not necessary • Well suited to short-span deck components (eg ladder decks) • Reasonably simple relationship between design cycles, daily truck counts and span length	• Not directly compatible with SM1600-based LL standard • Requires new rules for application (but this is also an opportunity to address concerns with the AS 5100.2 rules relating to multiple lanes and multiple presence) • Separate fatigue vehicle analysis always required • Potential short-term issue for off-the-shelf analysis software, due to new vehicle
R22T22 44 tonne	• Represents Class 1 vehicles • Stress ranges similar to average vehicles • Similar advantages to the HPMV versions noted above	• Similar disadvantages to the HPMV versions noted above • Design cycle counts exceed lifetime vehicle count (generally more than $1x10^{8}$)
HL-93 x 0.75, CL-625 x 0.52, Reduced T44	• Established code vehicles • Axle set weights similar to current vehicles • Suited to short-span deck components	• Poor fits to New Zealand vehicles on medium to long spans • Tuned to US S-N curves (3rd-power rule) and design approach • Not compatible with AS 5100
FLM3	• Enables application of Eurocode 3 simplified methods • Simple scaling to New Zealand vehicle masses • Higher axle weight limits may be adequately covered already	• Requires adoption of Eurocodes in part • Higher vehicle load intensities than New Zealand (conservative mass/length) • Uncertain relationship to New Zealand future average annual truck counts

Adaptation of the Eurocode fatigue load models would have been an option if there was industry support, although it was understood that there is a strong preference to adopt AS 5100. Adoption of the Eurocode models might require an alternative 'frequent' truck model FLM2 (used to verify unlimited life) because the axle set configurations do not align with current and proposed future New Zealand vehicles. A fatigue load model suitable for unlimited life verification is not included in AS 5100.2, and the development of an appropriate model would require reliable estimates of future vehicle weight limits and configurations. Direct use of the Eurocode provisions was not envisaged at the start of this research project, and therefore was not explored in detail.

8.2 Adopted short list

The appropriate choice of fatigue vehicle could not be considered in isolation from the future vehicle growth scenarios and design code selections. In view of the substantial growth outlined in chapter 2, arising from forecast economic growth and future trends toward longer higher mass vehicles, it was necessary to select a vehicle generating significantly higher stresses than current 'average' fully laden vehicles – otherwise the design cycle counts, including future growth allowances, would be likely to exceed the cut-off limit on the SN curves (at $1x10^8$ cycles) in most cases, possibly leading to incorrect fatigue life calculation. For that situation, the exemption from further assessment in AS 5100.6 13.7.1 might apply, and the effects of higher stresses from future heavier vehicles could not be evaluated appropriately.

This study indicated that the standard fatigue vehicle effects should target the expected 'average' vehicle over the design life, or higher, to obtain cycle counts falling in the $5x10^6$ to $1x10^8$ range (where the 5th-power rule is valid for normal stress cycles), and that were of a similar order to the expected total cycle counts for the top weight band vehicles.

The proposed vehicle shortlist is outlined in table 8.2.

Table 8.2 Fatigue vehicle shortlist

Option	Vehicle	Scale[a]	Max. axle set	Comment
A	M1600	0.7x(1+α)	3 x 113.4kN (340kN)	Used with AS 5100.2 cycle count formulae (status quo), where dynamic load allowance α=0.3 for the vehicle or 0.35 if a single-axle set governs (span <10m)
B	M1600	0.6	3 x 72kN (216kN)	Evaluate without additional impact (other than normal dynamic scatter and road roughness effects captured in the WIM datasets)
C	R22T22 530kN	1.0	2 x 75kN (150kN)	Current vehicle dimensions increased to 54 tonne Evaluate without additional impact as for B

a) See chapter 10 discussion of the dynamic load allowance and 0.7 reduction factor in AS 5100.2.

A long combination vehicle was considered to be preferable over a 4- or 5-axle vehicle for the following reasons:

- Only the maximum stress ranges are computed for the standard vehicle and additional cycles are not evaluated. On shorter spans, the maxima could be generated by a subset of the fatigue vehicle axle sets (eg two to six axles).
- The effects of both rigid trucks on shorter spans and long vehicles on medium to long spans were adequately covered by the long-vehicle options, whereas the effects of 4- or 5-axle vehicles did not adequately cover New Zealand vehicles on longer spans.

- Treatment of multiple cycles per vehicle is handled through separate adjustment factors in most of the surveyed codes. BS 5400.10 and the vehicle spectra methods (eg Eurocode FLM4) are the exceptions.

8.3 Equivalent cycle counts for shortlisted fatigue vehicles allowing for higher mass limits

For this evaluation we adopted a similar style of cycle count formulae to AS 5100.2, where the equivalent cycle count per heavy vehicle varies with length, and a route factor is applied to fit equivalent cycle counts per heavy vehicle to the site/route-dependent vehicle mix. The equations were fitted to the estimated fatigue loadings (in terms of damage equivalent repetitions of the proposed vehicle) with maximum expected HPMV take-ups (no trip savings), as those demands should be assumed to eventually become the new base demands for bridges to be constructed on main highways over the next 10–20 years.

8.3.1 Option A – M1600 vehicle

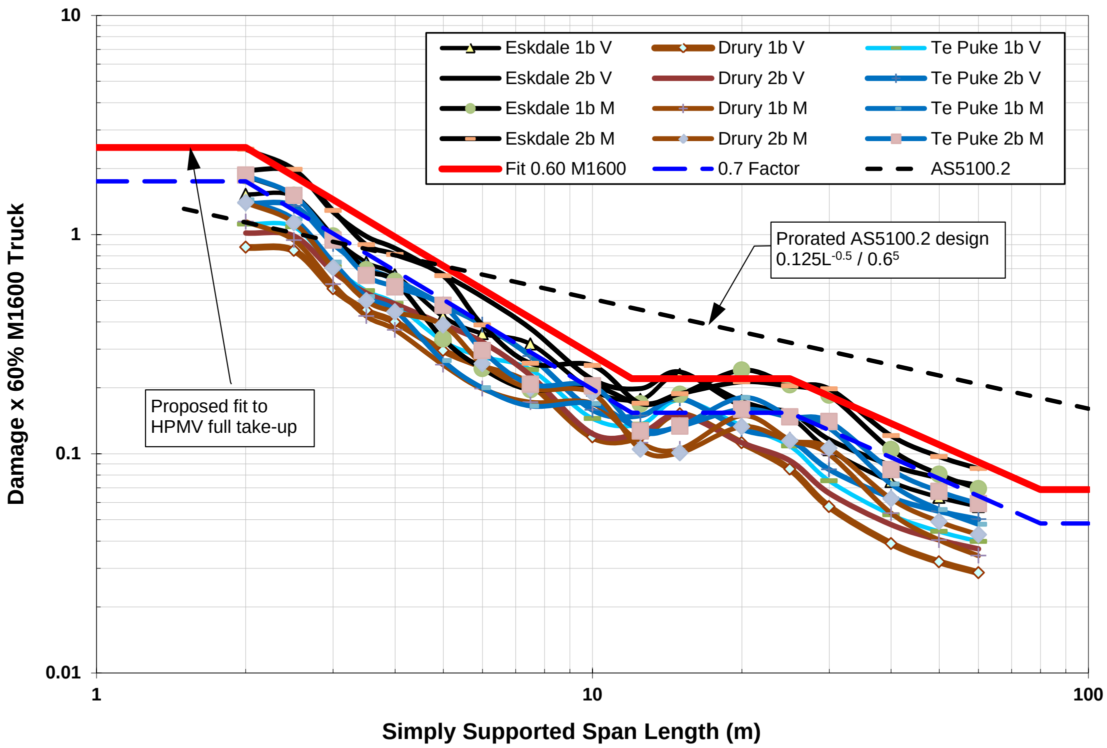
This option would adopt the AS 5100.2 cycle count formula. The evaluation results comparing equivalent damage estimates with full HPMV take-up to equivalent damage for current vehicle spectra (see chapter 6) are shown in appendix F. Figure 8.1, which is the chart for option B, includes a scaled version of the AS 5100.2 cycle count formula to show how this would fit the enveloped results. The AS 5100.2 cycle count formulae with cycle counts proportional to $L^{-0.5}$ were a conservative fit to New Zealand data for spans over 5m, with a route factor of 1.0 representing the Eskdale estimates (with high logging vehicle content).

At very short spans (less than 5m), the AS 5100.2 cycle count formula was inadequate and a single-axle model (similar to A160 in AS 5100.2) or an axle set model would be necessary.

8.3.2 Option B – reduced M1600 vehicle

Figure 8.1 shows the form of the relationship between simply supported span length and damage equivalent cycles of 60% of M1600 actions for the envelope of fatigue loadings with full HPMV take-up (see appendix F for descriptions of scenarios 1b and 2b, which assume use of additional freight capacity and no trip savings).

Figure 8.1 Equivalent damage (cycles) per truck relative to 0.6xM1600 effects



The base equivalent cycle counts for option B (fit to 0.6xM1600) would be based on:

- 2.5 cycles per truck for span L ≤2m

reducing to:

- 0.25 cycles per truck for span 12m ≤L ≤25m
- cycle count proportional to L^{-1} for L>25m with lower bound at L=80m.

Interpretation:

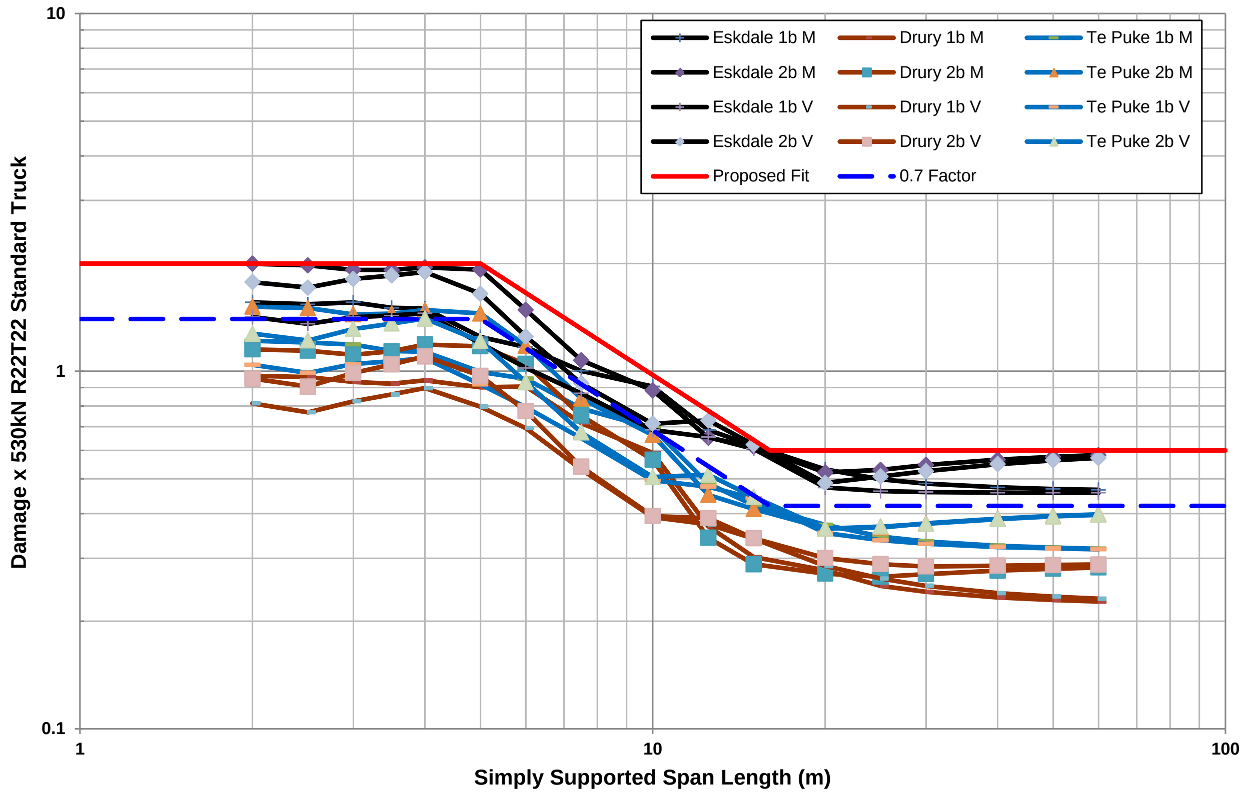
- At 4m span, the full HPMV loading spectrum (for the SH5 Eskdale vehicle mix) was equivalent to one cycle of 0.6xM1600 per truck on average (ie one cycle of the 216kN triple-axle set loading).
- At very short spans, the equivalent count per truck increased to 2.5 cycles of 72kN axle load.
- At intermediate span lengths (12–25m), an average of four trucks produced the same fatigue loading as one cycle of the 0.6xM1600 loading.

The envelope loading was for high take-up of the full HPMV mass limits, with very high proportions of fully laden truck-and-trailers in one direction. For the other routes, estimates of the applicable reduction factors are provided in section 9.1. The '0.7 factor' shown in figure 8.1 indicates the factor specified in AS 5100.2 for urban freeways.

8.3.3 Option C – 530kN 8-axle truck-and-trailer as fatigue vehicle

Figure 8.2 shows the form of the equivalent cycle count relationship between simply supported span length and damage equivalent cycles of the 530kN prototype truck-and-trailer vehicle for the same fatigue loadings as in figure 8.1.

Figure 8.2 Equivalent damage (cycles) per truck relative to a 530kN truck-and-trailer (single cycle)



Thus the base equivalent cycle counts for option C (530kN truck-and-trailer) were based on:

- two cycles per truck for span L ≤5m

reducing to:

- 0.6 cycles per truck for span L ≥16m.

Interpretation:

- At 8m span, the full HPMV loading spectrum (for the SH5 Eskdale vehicle mix) was equivalent to one cycle of the 530kN truck.
- At short spans, the equivalent count per truck increased to two cycles (of the 2x75kN axle set).
- At medium to long span lengths, an average of 1.7 trucks produced similar fatigue loading to one cycle of the 530kN truck loading.
- The near constant form of the curves at spans less than 5m suggested that a tandem-axle set with a constant count multiplier would adequately represent the short-span effects for the HPMV scenarios. This suggested that for the M1600 options A and B, a tandem-axle set model could be preferable to a scaled-down A160 single-axle model.

8.4 Discussion

A separate study of the future bridge live loading requirements for New Zealand (Taplin et al 2013) recommended adoption of a scaled-down SM1600 model, so the simplest option from an implementation viewpoint would be to follow the AS 5100.2 approach as closely as practicable. The resulting outcome may be similar to the HERA recommendations (Clifton 2007).

However, the pros and cons noted in table 8.1 should be considered. The AS 5100.2 commentary suggests that one of the reasons for adopting M1600 as the fatigue design vehicle, rather than one of the standard trucks investigated by Roberts and Heywood (2004), was to avoid the requirement to introduce further design vehicle loads. This research has shown the following:

- All three vehicle options outlined above have merit, and all would require separate fatigue analysis cases in the design process (because the M1600 fatigue vehicle excludes the UDL component, and only one lane is loaded concurrently), thus the design effort should be generally similar.
- There is a trade-off required between alignment with AS 5100.2 and a standard vehicle that aligns with the most common large vehicles in New Zealand (truck-and-trailers) and appropriately represents loading on short, medium and long span lengths, as well as transverse girders.
- The AS 5100.2 vehicle, or a scaled-down version, has significant disadvantages as noted in table 8.1, while the alternative standard vehicle (option C) appears to offer a better fit to the New Zealand loading and may require less calculation effort than the AS 5100.2 vehicle.

The base fatigue loading calibrations for these options (design vehicle plus equivalent cycle count per heavy vehicle) were pitched at the future point where estimated HPMV take-up, to the maximum limits specified in the 2010 VDAM rule amendment, has occurred on the main freight routes.

In summary, the options considered for a single design fatigue vehicle were:

A unmodified M1600 as per AS 5100.2

B 0.6xM1600 with equivalent cycle counts specific to New Zealand

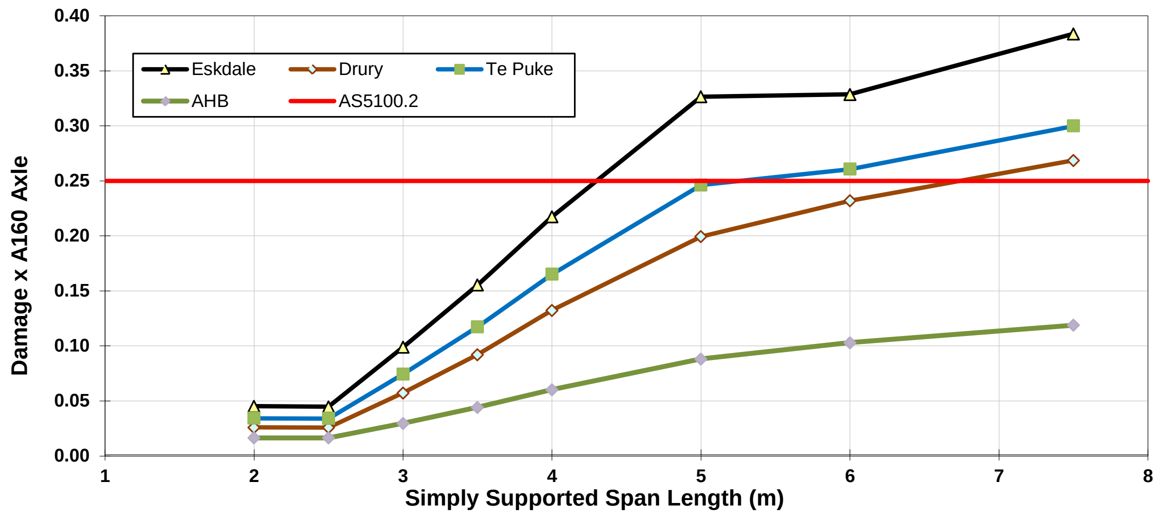
C 530kN R22T22 with equivalent cycle counts specific to New Zealand.

The application methods for all three vehicle options are discussed in chapter 10.

8.5 Design axle loading

A design axle loading selection is also required if a M1600 variant is chosen. The flat-line fit at 2–5m span in figure 8.2 indicates that a standard tandem-axle set provided a consistent fit that should be suitable for short spans and deck plates. The fatigue design cycle counts for the A160 axle in AS 5100.2 appear to be aligned with cycle count estimates for bending moments in 4m spans (Grundy 2001), whereas estimates for 2m spans required fewer cycles. This was confirmed by a comparison with the effects of New Zealand vehicle spectra (envelope of the HPMV modified results) as shown in figure 8.3.

Figure 8.3 Equivalent damage (cycles) per truck relative to 160kN single-axle load



The equivalent cycle count formula for the A160 axle load in AS 5100.2 is based on 0.25 cycles per heavy vehicle, and this was also valid for the maximum effects with full HPMV take-up (at just over 4m spans). For spans less than 4m, the results in figure 8.3 show that the A160 loading could be very conservative for components governed by a single axle. At spans in the order of 4m, the A160 axle cycle count formula was applicable.

Figure 8.2 shows that the maximum average axle set fatigue loading (with full HPMV take-up) was equivalent to two cycles of a 150kN tandem-axle set per vehicle. This was very similar to the tandem-axle load in the Canadian code (2x125kNx0.62=155kN, with a cycle count multiplier 2.0 for spans less than 12m).

In order to fit the A160 cycle count formula (0.25 cycles per vehicle), we required a tandem axle with the weight $150\text{kN} \times \left(\frac{2.0}{0.25}\right)^{0.2} = 227\text{kN}$.

Therefore a 230kN tandem-axle set (2 x 115kN) with standard-size dual tyres would be a suitable substitute for the A160 axle set for assessment of short span components (less than 4m), using the same cycle count equation as AS 5100.2.

At 0.25 cycles per vehicle, the lifetime counts would not exceed $1\text{x}10^8$, whereas the equivalent counts for a 150kN set would exceed this practical limit in most cases, and therefore the legal-weight tandem-axle set might not be suitable for designing to a specified life (using the existing steel codes). However, it would enforce a requirement for the corresponding stress ranges to be lower than the fatigue cut-off limit.

The potential issue with lifetime cycle counts for axle loadings exceeding $1\text{x}10^8$ is avoided in the Eurocodes (British Standards Institution 2005b) by using an alternative fatigue life verification format, which calculates the equivalent fatigue stress range at $2\text{x}10^6$ cycles. With this format, use of a 150kN tandem axle would be practicable.

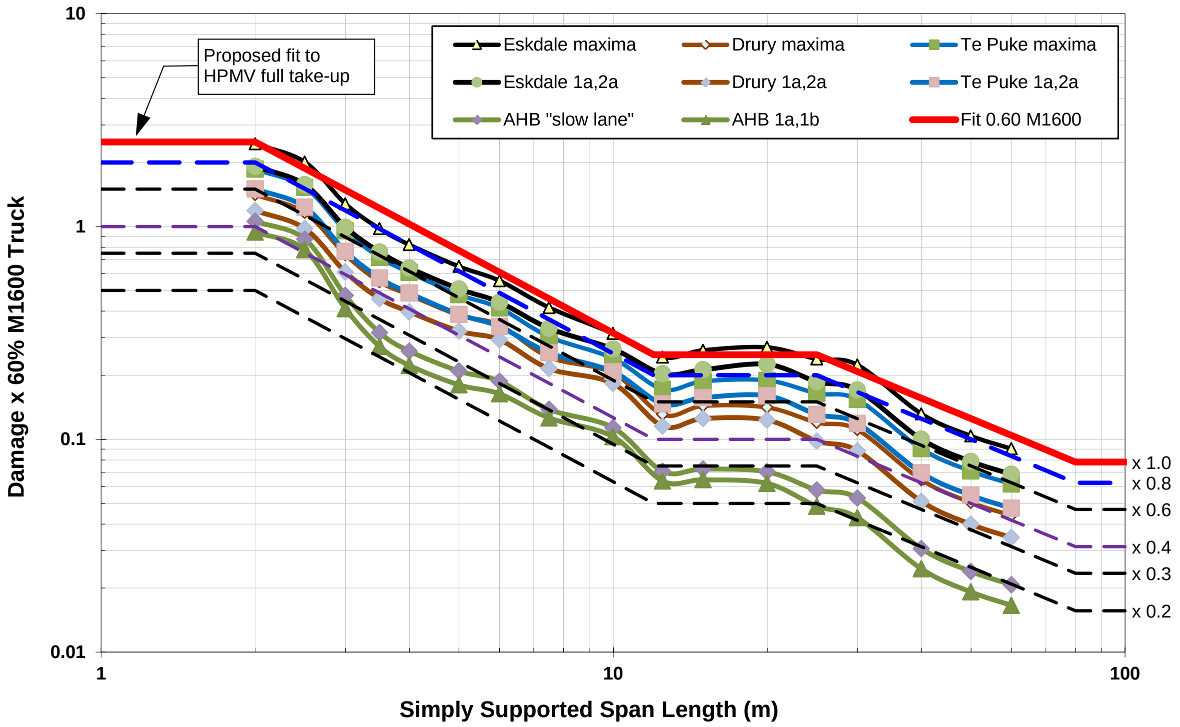
9 Route types and fatigue loading adjustments

9.1 Route factor approach (AS 5100.2)

The route factor in AS 5100.2 clause 6.9 applies a scale factor to the cycle counts per heavy vehicle that are applicable to the most heavily loaded route type. This is the only means provided in AS 5100.2 to vary the fatigue loading according to the expected heavy vehicle mix, as the other important parameter (initial daily truck count per lane) would follow from the project brief or estimates supported by traffic data.

A similar approach could be applied to the New Zealand WIM data, by estimating the reduction factors to be applied to the fitted equivalent cycle count relationship shown in figures 8.1 or 8.2. Figure 9.1 shows a selection of envelope results (for shear or moment) with full HPMV take-up relative to the 0.6xM1600 loading, and the proposed fit lines scaled by a range of factors.

Figure 9.1 Equivalent damage (cycles) per truck relative to 0.6xM1600 effects



In figure 9.1, the '1a, 2a' lines (not previously shown in figure 8.1) represent the HPMV evaluations with efficiency gains applied (trip counts reduced according to payload increase factor). The 'maxima' lines reflect full utilisation of the additional freight capacity (no trip savings, but increased freight volume) to represent the future scenario where full HPMV take-up has occurred and daily truck counts would already allow for trip savings. In the shorter term, prior to significant HPMV take-up, the case 1a and 1b lines are a guide to the route factor relevant to current heavy vehicle counts.

For the proposed truck-and-trailer fatigue vehicle (option C – 530kN 8-axle truck-and-trailer), figure 9.2 shows the equivalent damage results for the same datasets as figure 9.1, with the proposed fit line (see section 8.3.3) and same scale factors as in figure 9.1.

Comparing the relationships between the WIM site results and scaled fit lines in figures 9.1 and 9.2 indicated that route factors estimated for the M1600 loading should also be suitable for the truck-and-trailer option.

Figure 9.2 Equivalent damage (cycles) per truck relative to 530kN truck-and-trailer effects

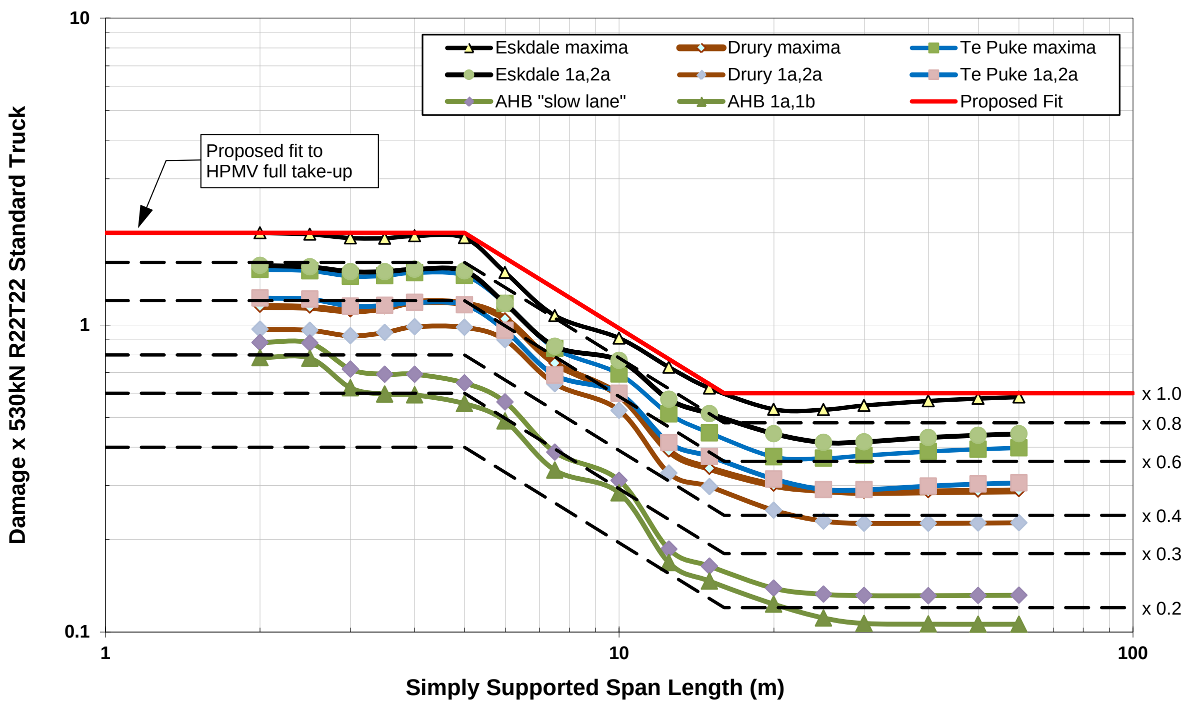


Table 9.1 summarises the estimated route factors applicable to the WIM site vehicle spectra, with the route types they represent, for the current loading or with full HPMV take-up. Matching the 0.6xM1600 results was not essential at spans less than 4m because the A160 axle loading was more critical, so the proposed route factors were selected based on fits for spans over 4m. The HPMV route factor values (estimated for the 0.6xM1600 option) were also suitable for the 530kN truck-and-trailer vehicle.

Table 9.1 Route factor summary for WIM sites (relative to proposed fit to 0.6xM1600 vehicle loading, or option C 530kN 8-axle truck-and-trailer)

WIM site	Transport Agency route classification	Freight profile	HPMV route factor	Current factor	
				0.6M1600	Option C
Eskdale	Regional strategic	Logging route with high directional bias	1.0	0.52	0.47
Te Puke	National strategic, high volume	General freight, route towards port	0.8	0.43	0.39
Drury	National strategic, high-volume motorway	General freight, motorway	0.6	0.42	0.40
AHB	National strategic, high-volume urban motorway (with 2 'slow' lanes selected)	Urban high-volume motorway with low proportion of long-distance freight	0.35	0.25 (L>3m)	0.21 (L>3m)

The 'current' factors in table 9.1 were derived for the standardised vehicle spectra representing current loading (see table 6.7). These were useful for comparison with estimated current loading spectra at other sites. The effect of upgrading most fully laden combination vehicles to HPMVs was also apparent.

The Transport Agency (2013d) state highway classifications categorise each route based on a variety of selection criteria: freight volume (HCV counts), traffic volume, population centres, major port and airport access, tourist journeys, and strategic lifeline status. For bridge fatigue loading, the freight volume criteria are most important, but other indicators such as port access would influence the future higher mass vehicle content.

The heavy traffic data collection and analysis for this study (see chapter 4 and appendix H) included samples of classified data from all state highway classes (see appendix D, table D.1). The proportions of vehicles in each class were used to make adjustments to the reference WIM site spectra, assuming that the weight distribution within each vehicle set was adequately represented by the WIM site spectra. The results of that analysis are shown in table 9.3. Many of the telemetry sites in this table show directional bias in the long-vehicle counts, and the more heavily loaded direction is indicated by the 'Direction considered' column. For example, site 76 Hikuae is in a forestry area where 8-axle truck-and-trailers travelling westbound were replaced by a similar number of additional eastbound 4-axle trucks (indicating piggy-backing trailers in one direction). Therefore, the Eskdale (eastbound) dataset was selected as an appropriate fit, then adjusted for the differences in vehicle set mix (see appendix D, table D.2).

Table 9.3 also includes results for WIM site data not directly represented by the rationalised spectra, and the directional results for the AHB with all lanes included (to provide a broader representation of urban heavy traffic). Only the 0.6xM1600 vehicle option was used for the table 9.3 evaluations.

An indicative route factor for the possible future HPMV mix is also shown, based on adopting a factor for a similar route from the WIM site estimates summarised in table 9.1. Truck-and-trailer content (see appendix D, table D.1) is a key indicator determining the appropriate WIM site and potential growth with HPMVs.

9.2 Summary

The state highway classification did not appear to be a reliable guide as to appropriate route factors and heavy vehicle counts, so local knowledge and heavy traffic forecasts may be needed to guide the selection of an applicable route type and associated factor. Table 9.2 summarises the route factor estimates with HPMV take-up included.

Table 9.2 Route factor summary (relative to proposed fit to 0.6xM1600 or 530kN 8 axle truck-and-trailer fatigue vehicle loadings) with HPMV take-up

Route description	Route factor
Routes with an exceptionally high proportion of fully loaded long vehicles in one direction; eg logging, dairy factory, bulk aggregate supply, and port access routes	1.0
Typical freight routes, national and regional strategic routes	0.8
Motorways, other rural freight routes	0.6
High-volume urban motorways	0.4
Urban roads	0.3

These factors were also relevant to the full M1600 vehicle and A160 axle fatigue loadings specified in AS 5100.2 (Option A in section 8.3.1).

Table 9.3 Estimated route factors (relative to proposed 0.6xM1600 fit) at Transport Agency telemetry sites with classified count data

Telemetry site no.	State highway	Site name	Region	Highway class	Comments on route usage (if known) – one lane each direction unless noted	ADTT (2011)	Direction considered	Spectra basis	Current factor	Indicative HPMV factor
108	35	Hamanatua Bridge	Gisborne	RS	Logging route, new WIM site from 2012 Highest truck-and-trailer % content	471 (2012)	Southbound	Eskdale	0.54	1.0
71	45	Ohawe Beach Rd	Taranaki	RD	Near SH3 intersection and Fonterra's 2nd-largest dairy factory (Whareroa)	419	Eastbound	Te Puke	0.53	1.0
14	33	Paengaroa	Bay of Plenty	RS	Rotorua–Tauranga, logging and port traffic	582	Northbound	Te Puke	0.46	0.8
33	27	Kaihere	Waikato	RC	An alternative long-haul freight route to the Waikato Expressway (SH1N)	871	Southbound	Drury	0.45	0.8
16	3	Te Kuiti	Waikato	RS	Long-haul freight route, AKL–WLG courier route, near SH4 intersection	673	Northbound	Drury	0.44	0.8
51	1N	Tokoroa	Waikato	NS HV	WIM site, long-haul freight	1384	Southbound	Te Puke	0.43	0.8
52	1S	Waipara	Canterbury	NS	WIM site, long-haul freight	1135	Southbound	Te Puke	0.37	0.8
26	2	Ormond	Gisborne	RC		257	Southbound	Te Puke	0.37	0.8
37	4	Horopito	Manawatu-Wanganui	RD	Long-haul freight route, AKL–WLG courier route	298	Southbound	Drury	0.36	0.6
11	73	Springfield	Canterbury	RS		196	Eastbound	Drury	0.33	0.6
47	1N	Paekakariki	Wellington	NS HV	Main highway north of Wellington	1797	Southbound	Drury	0.32	0.6
27	1S	Milton	Otago	RS		798	Both	Drury	0.32	0.6
45	1S	Gore	Southland	RS		496	Southbound	Drury	0.31	0.6
80	2	Clareville	Wellington	RS	South of Masterton	585	Both	AHB	0.30	0.6
76	25A	Hikuae	Waikato	RD	Forestry area, holiday destinations	259	Westbound	Eskdale	0.30	0.6
15	5	Tarukenga	Bay of Plenty	RS	North of Rotorua	631	Southbound	Drury	0.29	0.6
	1N	AHB	Auckland	NS HV	WIM site spectra fits to total for all 8 lanes, to represent urban routes	6370	Northbound	AHB NB	0.19	0.4
							Southbound	AHB SB	0.15	0.3

Notes:

a) Highway classification key: HV=high volume (>1200 HCV/day); NS=national strategic (>800 HCV/day); RS=regional strategic (>400 HCV/day or lifeline); RC=regional connector (>400 HCV/day or lifeline); RD=regional distributor.

b) See the maps included in appendix A for locations.

c) ADTT counts related to total heavy vehicle counts for both directions, including 2-axle heavy vehicles that do not fall into the strict definition of HCVs (see appendix I for definitions). Spectra were estimated for the more heavily loaded direction at the telemetry site, as indicated in the table.

10 Fatigue loading and design implementation

This section outlines the proposed guidelines for application of the fatigue loading options presented in chapters 6 and 8, combined with growth assumptions discussed in chapter 7 and the route variations presented in chapter 9. As mentioned in the introduction (section 1.4), fatigue design criteria for bridges comprise three separate elements:

- a vehicle loading spectrum comprising either a single vehicle, a selection of common vehicle types, or site-specific vehicle records, together with the repetition counts over the design fatigue life
- analysis procedure(s) to determine the corresponding design stress ranges and cycle counts for the selected vehicle loading spectrum
- material-specific fatigue life calculation methods for the assessment of components.

The guidelines below have been adapted from international codes, primarily AS 5100, but with several variations to incorporate 'best practices' adapted from other codes – particularly the Eurocodes with the UK modifications. A summary of the key differentiators between codes is provided in appendix B.

10.1 Key parameters for fatigue design

10.1.1 Intended design fatigue life for steel bridges

The design fatigue strengths (for constant amplitude stress ranges) specified in steel codes are generally based on mean experimental values minus 2 standard deviations (on logarithmic scales). Eurocode EN 1993-1-9 notes that the fatigue strengths were calculated for a 95% probability of survival with 75% confidence level. This implies that probabilities of fatigue cracking within the design fatigue life are expected to be 5% or less, and that expiry of the design fatigue life does not necessarily imply the end of the structure's service life. The assumptions for design fatigue life vary between codes (see appendix B).

It is proposed that design fatigue lives for New Zealand bridges should follow the AS 5100 (and AASHTO) assumptions – ie 75 years, assuming an inspection and maintenance regime to provide a 100-year service life (similar to the damage-tolerant approach in the Eurocode EN 1993-1-9).

Further, we recommend that the steel code is the appropriate place to consider additional reliability requirements, via the fatigue strength reduction factor; eg AS 5100.6 specifies ϕ=0.7 (or less) for non-redundant load paths.

If appropriate for exceptional cases, a project design brief may add a requirement for longer design fatigue lives than the 75 years noted above. However, it should be noted that reductions in fatigue strength through the ϕ factor would have a much more significant effect than increases in target design lives.

10.1.2 Lifetime vehicle counts and loading growth

As discussed in section 7.4.2, the growth allowance from AS 5100.2 is proposed as a minimum for the design of new road bridges. This allowance provides for:

- year-one daily truck counts plus 4% average geometric growth rate in fatigue damage over 75 years
- both volume growth and long-term average mass increase through the geometric growth rate.

Where a longer fatigue design life is required (in exceptional cases only, as suggested in section 10.1.1), the additional truck counts should consider the growth in annual loading. It is suggested that a minimum of 60% increase in design cycle counts would be necessary for a 100-year design fatigue life (ie 25 more more years at future volumes and vehicle masses).

With design cycle counts based on 4% geometric growth rate over 75 years, the aggregate fatigue damage allowed for would be approximately 440 times the first-year estimate. In contrast, the UK and Eurocode approaches are typically based on truck counts being at the road capacity from day one, but do not allow for further growth in average vehicle mass.

10.1.3 Dynamic load allowances for fatigue design

The AS 5100.2 approach to dynamic load allowances for fatigue design is to adopt the same factors (α) as used for strength design live loads (30% for the M1600 vehicle, 35% for the triple-axle set, 40% for the A160 axle). This compares with 15% in the AASHTO code (applied to a smaller vehicle with static weights at 'average' levels), and the factors in the Canadian code, which include this 15% allowance (see section 2.3.5).

The Eurocodes and BS 5400: part 10 do not add a general dynamic load allowance in the fatigue load models because the damage equivalent vehicle spectra derived from WIM records were considered to include a certain amount of dynamic impact for 'good' surface quality in the axle loads (Sedlacek et al 2008). The damage equivalence factors (λ) applied to the FLM3 standard vehicle model in the steel bridge Eurocode EN 1993-2 were derived from models that included dynamic response effects. Separate analyses for the road roughness dynamic effects on orthotropic decks (short spans) indicated damage equivalent impact factors for *local* effects in the range 1.1–1.2 for 'good' pavements and 1.3 for 'average' pavements (Sedlacek et al 2008). For the UK vehicle spectra model (FLM4), no additional general dynamic allowance is specified.

Eurocode 1 (EN 1991-2) specifies an additional dynamic load factor near expansion joints (1.30 decreasing linearly to 1.0 at 6.0m from the joint), which is similar to the factor in BS 5400: part 10 (1.25).

Based on the Eurocode approach and information in the background document (Sedlacek et al 2008), the dynamic allowances in the AS 5100.2 are considered unrealistically high for fatigue design, and it appears reasonable to propose that for the fatigue loadings derived in the present study using WIM data, the minimum additional dynamic allowance should be as follows:

- 30% within 6m of expansion joints
- no additional allowance elsewhere if the bridge surfacing will be maintained in good condition.

However, as additional dynamic amplification factors for fatigue loads generally follow from the code design live load allowances, it may be necessary to adjust the base fatigue loading to compensate for this if close alignment to AS 5100.2 is required. The high dynamic amplification factors in AS 5100.2 are partly offset by a stress-reduction factor, as discussed below.

10.1.4 AS 5100.2 fatigue stress range reduction factor

The fatigue load models in AS 5100.2, clause 6.9, apply only 70% of the maximum stress range for the A160 axle load or the M1600 moving vehicle. This reduction is not related to calibration of the base cycle count per vehicle relationships (as illustrated in figure 5.5).

The reasons given in the AS 5100.2 commentary and the Standards Australia committee notes (Boully 2003) for this factor are as follows:

- Actual stresses in a component at service load levels are generally less than the theoretically calculated values because of alternative load paths (such as bridge barriers) and the magnitude of actual components in comparison with line elements used to represent them in analysis.
- The actual lateral position of heavy vehicles varies and does not generally coincide with the critical lateral position.
- The actual load distributions per beam are generally less than calculated values, particularly if published distribution factors are used rather than grillage analysis.
- The actual dynamic load allowance is generally less than the design value.

The Standards Australia committee notes (Boully 2003) indicate that the factor was based on the combined effects of the above considerations, and no single factor for each contribution was identified.

There are other possible contributions to differences between damage based on measured stress ranges and damage calculated using the M1600 vehicle loading, including the fact that the basis of the cycle counts is the theoretical moment effects on simply supported beams, whereas an accurate analysis using a design vehicle spectrum may yield less conservative results.

For the New Zealand fatigue design criteria, the grounds for applying a uniform reduction factor of 0.7 (or a higher factor) have not been established, and it is apparent that variations in the degree of structural modelling refinement would need to be considered. Accordingly, a reduction factor of 0.7 is considered inappropriate in the proposed New Zealand context for the following reasons:

- It is normal practice to use 2D or 3D grillage or finite element models for detailed design, rather than line beam analysis with distribution factors.
- It is not evident that actual stress values are significantly less than those estimated using a good model for particular bridges (Roberts and Heywood 2000).
- It is proposed to centre the vehicle in design lanes rather than use the worst-case position.
- Not all structure types and components would be particularly sensitive to variation in the transverse position, and the assumed stress reductions may be less than presumed. For local actions, a statistical distribution of transverse position can be considered if the effect is significant (as per Eurocode 1).
- It is proposed that the application of additional dynamic loading allowance is limited to the 6m lengths adjacent to expansion joints as per Eurocode 1.
- The proposed fatigue vehicle cycle counts can be better tuned to the New Zealand loading at medium to long spans, compared with the AS 5100.2 design cycle count equation.
- If the proposed alternative fatigue design vehicle (530kN truck-and-trailer) is adopted, the applicability of a reduction factor intended for use with the M1600 vehicle is uncertain.
- If it is decided that the 0.7 factor should be retained along with the dynamic load allowance and general methodology (including cycle count formulae) as specified in AS 5100.2, the net effect would be reasonably neutral, except that an additional impact factor near expansion joints should be considered, as noted in 10.1.3 above.

There remains a good case for incorporating a stress-reduction allowance in some form, but there is no published literature available to justify a fixed allowance, and further research would be necessary to provide guidance. Structural model refinements to better reflect stiffness at service load levels and include contributions by non-structural elements could be allowed for fatigue analysis.

The following changes to the AS 5100.2 approach are proposed for the New Zealand fatigue design loading:

- Do not apply the 0.7 factor, but use appropriate analysis models and vehicle positioning.
- Limit the dynamic loading allowance application to lengths with 6m of expansion joints.

The net effect of this approach, compared with the AS 5100.2 fatigue load model, may be an increase in the fatigue vehicle loading effects, because $0.7(1+\alpha)=0.7(1+0.3)=0.91<1.0$ for the M1600 vehicle. However, a more conservative scaling factor is appropriate given the proposal to centre the vehicle in design lanes rather than using the worst-case transverse position as required by AS 5100.2.

Note: Variations in the 0.7 reduction factor and 1.3 dynamic factor applied to stress ranges for the M1600 vehicle could have a substantial effect on fatigue life estimates due to the 3rd or 5th powers, and could be more significant than variations in other parameters such as route factor or fatigue design life.

10.1.5 Proportion of heavy vehicles in one lane

The AS 5100.2 fatigue loadings for interstate and rural routes with two or more lanes in one direction place 100% of the heavy vehicles in one direction in whichever design lane gives the maximum effect for the component under consideration. On urban routes with two or more lanes in one direction, the number of vehicles per lane is 65% of the total in that direction.

From the limited available data for New Zealand motorways:

- the Drury WIM site data (two lanes each way) confirms that 100% is appropriate for the outside lanes
- the AHB data (Myers and Beamish 2011) indicates that up to 80% of HCVs used one lane when there were two lanes open, or a maximum of 60% with three or more lanes open
- data excluding the outer lane of the AHB northbound WIM site (off-ramp only) and the inner-most (tidal flow) lane indicates a share of up to 45% in any of the three continuing lanes.

These findings indicate that the lane-share assumption for urban routes in AS 5100.2 may need to be modified, recognising that although the AHB configuration is unique, lane usage by heavy traffic on other motorway bridges will be influenced by upstream and downstream connections, and may vary over the life of the structure.

It is proposed that the allowances for heavy vehicles per lane for urban routes be amended as follows:

- 100% in one lane where only one lane is available to trucks
- 80% in one lane where only two lanes are available to trucks, or 65% in the accompanying lane
- 65% in any lane for other configurations
- 45% in an adjacent lane in the same direction where effects from two lanes are to be combined (total of 110% considering that future growth in the other lane may be less constrained). A 65%/45% ratio compares with a 60%/40% ratio for dual-carriage motorways in the UK National Annex to Eurocode EN 1991-2.

10.2 Standard fatigue vehicle models

For the standard vehicle options discussed in section 8.3, and the proposed guidelines above, the proposed cycle count formulae are summarised in table 10.1 below. Proposed route factors for HPMV higher mass capable routes are listed in table 9.2.

The stress ranges to be considered with these cycle counts are the maximum peak–peak stress ranges at a component, for a passage of the fatigue vehicle or axle set across the structure.

Guidelines for the calculation of the stress range and the combination of effects from multiple lanes are provided in section 10.3.

No guidance is provided for application of the Eurocode FLM3 vehicle (EN 1991-2) because calibration of the Eurocode fatigue load models to fit future higher mass vehicles was not part of the scope of this study.

Table 10.1 Fatigue stress cycle counts for fatigue vehicle options

Fatigue design load	Equivalent cycles per truck	× design life multiplier × daily counts × route factor
Option A: 0.7×M1600×(1+α)	$0.125L^{-0.5}$	$\times\ 16\times10^4 \times \begin{pmatrix}\text{number of heavy vehicles}\\ \text{per lane per day for}\\ \text{first year of service}\end{pmatrix} \times \begin{pmatrix}\text{route}\\ \text{factor}\end{pmatrix}$
Option B: 0.6×M1600	2.5 for L ≤2m $6.1L^{-1.28}$ for 2m<L <12m 0.25 for 12m ≤L ≤25m $6.25L^{-1}$ for 25m<L <80m, or 0.08 for L ≥80m	
Option C: R22T22 530kN	2.0 for L ≤5m 10/L for 5m<L <16.67m, or 0.6 for L ≥16.67m	
Axle sets: A160 (160kN) or a tandem set (230kN)	0.25	

where L is the effective span length as defined in AS 5100.2:

1 for positive bending moments and end shear, L is the actual span length in which the bending moment or shear force is being considered
2 for negative moment over interior supports, L is the average of the adjacent span lengths
3 for reactions, L is the sum of the adjacent span lengths
4 for cross-girders, L is twice the longitudinal spacing of the cross-girders.

For option A, the accompanying axle loading with applicable dynamic allowance would be 0.7×M1600×(1+0.4) = 0.98×M1600, which is approximately the same as the one proposed to accompany the New Zealand-specific options B and C.

The design life multiplier for daily counts (16×10^4) is calculated from 365 days/year, 4% per annum compound growth for 75 years, and rounded down (from 163,750).

10.3 Stress range calculations for standard vehicle models

10.3.1 Methods of application and analysis

It is envisaged that the design vehicle will be applied to bridge deck analysis models, using an influence line or influence surface approach to derive the maximum stress ranges at details requiring fatigue evaluation. The M1600 vehicle has a variable spacing between the 2nd and 3rd triple-axle set, and a single triple-axle set is to be considered where that is more severe. Similarly, if an alternative vehicle is selected it is expected that axle sets will be omitted where they have a relieving effect (in continuous spans) so that short vehicles are adequately covered in the enveloping process. Analysis software packages can automate the above steps.

There are two variations to be considered – aligned with the three fatigue vehicle options set out above (section 10.2):

- Option A – adopt AS .2 without modification (10.3.2 below)
- Option B (or C) – amend AS 5100.2 section 6.9 for use with New Zealand fatigue loadings (10.3.3 below).

The proposed details are described below.

10.3.2 AS 5100.2 procedure

- One axle load or vehicle is placed within any design traffic lane to maximise the fatigue effects for the component under consideration.
- The standard 3.2m wide design lanes may be located in any transverse position across the carriageway, including the shoulders.
- The maximum peak-to-peak stress range at a component is evaluated for the transverse position that maximises the fatigue effects (not the centre of the lane). This does not mean the difference between the maximum and minimum envelope values obtained from software using influence surfaces, as those values may be for different transverse positions of the same vehicle, which may overestimate the maximum stress range for a single passage of the fatigue vehicle.
- The variable middle-axle spacing for the M1600 vehicle has no upper limit, which means that peak stress ranges in continuous spans may occur with six axle parts of the M1600 vehicle placed near the centres of adjacent spans. This is conservative.
- Effects from adjacent lanes are not accumulated.
- Typically, 100% of the heavy vehicles in one direction (or 65% for multilane urban routes) are placed in whichever design lane gives the maximum effect for the component under consideration.

This procedure is simple to apply but has potential weaknesses:

- Cumulative effects from vehicles in adjacent or opposing lanes are not considered.
- Effects in transverse members may be underestimated.
- Not all multiple presence situations would be covered. Placing 100% of the heavy vehicles in one direction in the worst position might partly address that.

10.3.3 Proposed improvements for New Zealand fatigue loading

It is suggested that the best practices from the Eurocodes and UK National Annex should be adapted for use with the proposed New Zealand fatigue design loading. The procedures would be similar to AS 5100, except for the following:

- Design lanes and widths generally would be based on the *Bridge manual* (NZ Transport Agency 2013c).
- The fatigue vehicle or axle set would be centred in design lanes for general actions (or marked traffic lanes where defined – an amendment included in clause 3.2.6 of the Bridge Manual. However, possible future carriageway reconfigurations would need to be considered).
- For local effects (eg decks), the notional lanes would be anywhere on the carriageway. A statistical distribution of transverse position could be considered if the effect is significant (as per Eurocode 1).
- Adjacent lane (or opposing direction) effects would be combined for significantly affected components (eg transverse girders, box structures), using a Miner's summation.
- The effect of side-by-side running (multiple presence), combined with additive stress ranges for opposing lanes (eg transverse bracing with stresses of opposite sign from two lanes), could be addressed by using the modification factor specified in the UK National Annex to BS EN1991-2, section NA.2.26 (multiply the damage summation by a factor $K_b.Z$ where K_b = ratio of maximum stress range for single vehicles in lane 2 to the maximum for single vehicles in lane 1, and Z=1.0 for loaded length L ≤3.0m, 1.5 for L ≥20m, and varying linearly with log L for L between 3m and 20m). This would provide for a small proportion of cycles at up to double the stress range for a single vehicle (amongst many other possible infrequent combinations).
- The proportions of heavy vehicles in each lane would be modified as proposed in 10.1.5.
- Multiple presence effects for vehicles in the same lane are considered to be adequately covered by the length of the M1600 design vehicle and form of the design cycle count equations. This is not directly addressed by the alternative truck-and-trailer vehicle, but the proposed design cycle count equations are somewhat conservative fits to the results including the maximum-size HPMV vehicles. No further allowance is proposed.

10.4 Steel design code recommendations

The Transport Agency *Bridge manual* (2013c) adopted AS 5100.6 for the design of steel and composite bridge superstructures, including fatigue design. A revision to this code by a joint Australian and New Zealand committee is currently in progress (committee chair S Hicks, pers comm, 31 Jan 2013) and is proposed to be designated AS/NZS 5100.6. There will be opportunities in this process to address matters arising from current Transport Agency research projects.

As noted in 10.1.1 above, the steel code is the appropriate place to consider additional reliability via the fatigue strength reduction factor. It is recommended that the steel code committee include additional guidance on selection of appropriate fatigue strength reduction factors, considering the assumptions in AS 5100.2 regarding fatigue design life.

11 Summary and conclusions

11.1 New Zealand requirements

The stated aim of this project was to determine a fatigue loading spectrum that is wholly appropriate for use in New Zealand and to develop a process, or amend an existing process, for applying this to the design of road bridges. The fatigue design criteria considered in this study are generally applicable to the design of steel or composite steel–concrete bridge structures only, but the current vehicle loading spectra would also be relevant to fatigue assessment of reinforced and pre-stressed concrete bridge structures.

The 3rd edition of the Transport Agency's *Bridge manual* (published in May 2013) confirmed that *AS 5100.6 bridge design, part 6*: *steel and composite construction* (Standards Australia 2004c) is the appropriate design standard for bridge superstructures. The present study references AS 5100.6 for fatigue life calculation methods and defers to the standards committee(s) for specification of appropriate material-dependent resistance factors. Usage of compatible fatigue design provisions in other standards such as the Eurocodes is also possible.

A separate research project (Taplin et al 2013) has proposed a new vehicle loading standard for New Zealand road bridges based on the SM1600 live load model in *AS 5100.2 bridge design, part 2: design loads* (Standards Australia 2004a). This was taken as a strong indication that adoption or modification of the AS 5100.2 vehicle fatigue load model should be provided for in the New Zealand loadings. Accordingly, options for adopting the M1600 fatigue vehicle and associated methods of application from AS 5100.2 have been included in this project.

11.2 Fatigue load models

Standardised vehicle spectra based on the seven most common heavy vehicle types have been developed to represent the heavy vehicle fleet prior to the introduction of higher mass limits. Four variations of the vehicle proportions are provided, to cover urban highways, motorways, rural freight routes, and exceptional situations with very high proportions of vehicles at maximum load in one direction (such as logging truck and dairy factory routes). These spectra are intended for assessment of bridges under current loading, and were the starting point for estimates of higher mass vehicle effects.

Single-vehicle fatigue load models are preferred for ease of use, compared with vehicle spectrum models, and are included in all the international codes reviewed in this study. The North American and Australian codes specify modified versions of the design live load vehicles, while fatigue load models in the UK and European codes specify different vehicles. All single-vehicle fatigue load models require separate analysis, so choosing a vehicle already included in live load models for serviceability and ultimate design would not reduce design effort.

The equivalent cycles of single fatigue vehicle actions per heavy vehicle vary with span length. It is important to understand that the single-vehicle load models use a single stress range value for each detail under consideration, calculated as the maximum stress range for one passage of the vehicle across the bridge. The cycle count variation with span length accounts for the increased numbers of stress cycles arising from axles or axle sets on shorter spans. A calibration process is required to select an appropriate scale factor for the single-vehicle weights, together with the cycle count relationship to span length and component locations.

Higher mass vehicles (HPMV) will significantly increase bridge fatigue loadings because fatigue damage in steel bridges generally increases with the 5th power of axle set or vehicle weight, whereas potential reductions in vehicle counts for the same freight task are a linear function of maximum payload. There was no conclusive information regarding future interest levels and take-up rates for the new limits, so estimates of fatigue loading increases have adopted the more optimistic assessments of interest level (Stimpson 2012).

Three standard fatigue vehicle options were shortlisted and calibrated to the estimated fatigue loadings, including the full forecast take-ups of HPMV higher mass limits on approved freight routes.

The fatigue vehicle options were as follows:

A unmodified M1600 fatigue vehicle with factors and cycle formulae as specified in AS 5100.2 (effectively the status quo as per the Bridge Manual 3rd edition)

B 60% of the M1600 vehicle, with modified cycle count formulae tuned to fit the New Zealand fatigue loadings with HPMV included

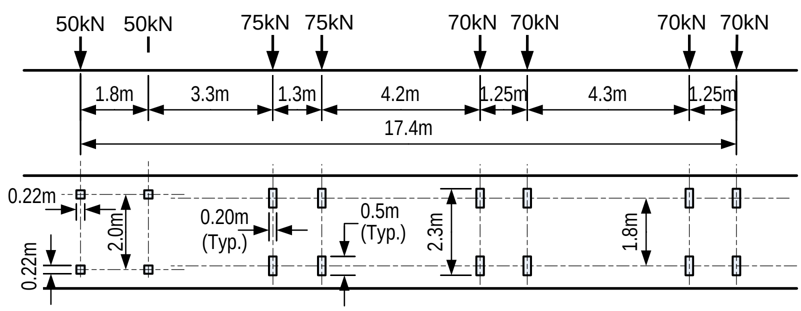
C 530kN 8-axle truck-and-trailer (similar to maximum-weight HPMVs) with cycle count formulae tuned to fit the New Zealand fatigue loadings with HPMV included.

The 60% scale factor for option B is intended to reduce the M1600 vehicle effects on short spans down to service levels, and the 530kN truck-and-trailer is similar to maximum-weight HPMV vehicles.

The unmodified M1600 fatigue vehicle (option A) was found to be a poor but safe-sided fit to the New Zealand loading estimates (for HPMV routes) at span lengths over 5m. Both M1600 vehicle options (A and B) are considered to have significant disadvantages as they are a poor fit to effects on short spans and may overestimate effects on continuous spans.

Options A and B always require a separate axle fatigue load model to represent effects on short spans. The A160 axle fatigue loading specified in AS 5100.2 is an adequate fit to the New Zealand loading estimates for bending moments in 4m spans because it generates similar effects to axle set loads, but it gives inconsistent results for shorter spans. For very short span components and deck slabs, a 230kN tandem-axle set provides consistent fits at spans less than 5m, and is a suitable replacement for the A160 axle with the same cycle counts. The option C vehicle includes tandem axles, and consistent fits at spans less than 5m can be achieved without requiring an additional axle fatigue load model.

Figure 11.1 Option C 530kN 8-axle truck-and-trailer vehicle



The option C vehicle shown in figure 11.1 is more representative of New Zealand vehicles, provides a more consistent fit over a wide range of span lengths, and may require less analysis effort than the M1600 vehicle options. Accordingly, this study finds that the 530kN 8-axle truck-and-trailer (option C) is preferred for a New Zealand-specific fatigue vehicle, based on the technical merits outlined above.

11.3 Variations in fatigue loading with route type

The route factors defined in AS 5100.2 were found to be a suitable method for allowing for the different heavy vehicle mixes on various road types.

The state highway classifications (NZ Transport Agency 2013d) are not a reliable guide regarding selection of appropriate route factors and current heavy vehicle counts, so local knowledge and heavy traffic forecasts will be needed to guide selection of the fatigue loading parameters. The route type factor estimated in this research project for the rural highways with the highest fatigue loadings was the same as for the Australian interstate highways, but heavy vehicle volumes were relatively low. For typical strategic freight routes and motorways the factors were lower (0.8 or 0.6).

This study has not attempted to provide guidance on forecasting the heavy vehicle counts for the first year of operation of a new bridge, and it is expected that suitable information would be provided by the Transport Agency or included in project design briefs.

11.4 Long-term growth allowances

Fatigue loading growth allowances must change in response to the government policy to allow higher mass vehicles with heavier axles, and in consideration of the anticipated future mass increases in the longer term (Taplin et al 2013) as well as long-term increases in freight volumes.

The factors to consider in choosing the growth allowance are as follows:

- The base fatigue vehicle loading allows for potential take-up of the HPMV higher mass limits.
- The growth multipliers incorporated in the AS 5100.2 cycle count formulae (4% per annum geometric growth for 75 years – a total of 440 times the first-year loading estimate) represent the *minimum* that should be considered in a New Zealand fatigue loading model to include both volume growth and average mass growth at arithmetic rates, eventually constrained by saturation flows and upper limits on legal axle weights.
- The AS 5100.2 commentary notes that a 75-year fatigue design life is compatible with a 100-year design life. The reasons given relate to the existence of an inspection and maintenance regime to control possible long-term damage and the low probability of failure at the theoretical fatigue design life.
- Fatigue strength reduction factors specified in material codes would address the ability to inspect and maintain the structure over the design working life.

Accordingly, the proposed fatigue loadings for New Zealand incorporate the same long-term vehicle count multipliers assumed in AS 5100.2. However, the Transport Agency could consider specifying longer fatigue loading periods by exception, allowing for the expected future increases in annual fatigue stress cycle counts beyond the 75-year period.

11.5 Analysis assumptions and dynamic amplification

The fatigue loading in AS 5100.2 includes a uniform 0.70 stress-reduction factor to account for conservatism in the fatigue loading parameters and method of application. The dynamic load allowance applied to the fatigue load is the same as that used for strength design. These assumptions are significantly different from other international codes, and there is insufficient evidence to justify their inclusion in fatigue loadings tailored to New Zealand bridges. However, it is evident that the unmodified

AS 5100.2 fatigue loadings and methods of application (option A) are generally safe-sided, except where components are significantly affected by loadings in two adjacent lanes or opposing directions, or by additional impact effects near expansion joints.

The modifications to the design fatigue vehicle and methods of application proposed for the New Zealand loading (fatigue load model options B and C) have been adapted from UK and Eurocode practice, and include allowances for multiple-lane effects and additional impact near expansion joints.

Further research, including field testing, would be necessary to investigate possible stress-reduction factors suited to New Zealand bridges designed to current and future loadings, if further refinement of the recommended procedures is deemed appropriate.

12 Recommendations

Fatigue design criteria for bridges comprise:

- a spectrum of standard vehicles, or an equivalent single vehicle plus a design axle or axle set (which may be part of the design vehicle)
- cycle counts for the fatigue vehicle(s) representing the expected service loading over the design life of the structure
- analysis procedures to determine the corresponding design stress ranges
- a material-specific design code for the fatigue life calculation method.

A spectrum of representative vehicles is the more accurate approach for detailed assessments but requires additional calculation effort compared with the single-vehicle methods.

It is recommended that the Transport Agency amend the Bridge Manual 3rd edition to provide guidance on fatigue loadings for New Zealand road bridges of steel or steel composite construction, based on clause 6.9 of *AS 5100.2 bridge design, part 2: design loads* (2004a), with modifications according to one of the single fatigue vehicle options and associated application methods listed in table 12.1 below.

Table 12.1 Standard fatigue vehicle options

Option	Vehicle, axle set	Recommended modifications to the AS 5100.2 analysis procedures
A	$0.7 \times M1600 \times (1+\alpha)$, $0.7 \times A160 \times (1+\alpha)$	• Generally unchanged, but it is recommended that the dynamic load allowance (α) be increased by 0.3 at sections within 6m of expansion joints.[a] • The AS 5100.2 requirement to place the vehicle or axle load within any design lane to maximise the fatigue effects is an important consideration for the 0.7 factor and should not be varied (as it is in the current Bridge Manual). Further modifications may be necessary to address combined effects from adjacent lanes.
B	0.6×M1600, A160 or 230kN tandem set	• Cycle counts for 0.6×M1600 tuned to New Zealand loadings (see table 10.1). • Dynamic amplification factor of 1.3 applied within 6m of expansion joints.[a] • Fatigue vehicle or axle set centred in design lanes. • Other modifications as listed in section 10.3.3 to address combined effects from adjacent lanes.
C	R22T22–530kN, Optional 230kN tandem set	• Cycle counts for R22T22 vehicle tuned to New Zealand loadings (see table 10.1). • Dynamic amplification factor of 1.3 applied within 6m of expansion joints.[a] • Fatigue vehicle or axle set centred in design lanes. • Other modifications as listed in section 10.3.3 to address combined effects from adjacent lanes.

a) Applied as recommended in Eurocode EN 1991-2:2003.

There is a trade-off required between close alignment with AS 5100.2 and a standard vehicle model that aligns with the most common large vehicles in New Zealand (truck-and-trailers), and appropriately represents loading on short, medium and long span lengths and transverse girders. It should be noted that analysis cases for fatigue design are normally separate from live load cases for strength design and exclude the uniformly distributed portion, so there is no significant benefit from choosing a vehicle included in the design live load model and no disadvantage from selecting a new vehicle.

Option C – R22T22 530kN truck-and-trailer (see figure 11.1) is the preferred standard fatigue vehicle model from a technical standpoint, as it is more representative of New Zealand vehicles and provides a more consistent fit to fatigue effects over a wide range on span lengths. It is recommended that this fatigue vehicle model be included in the Bridge Manual.

The recommended modifications to AS 5100.2 procedures for options B and C allow for combined lane effects to address a potential deficiency in the unmodified AS 5100.2 procedures. Should the Transport Agency wish to adopt option A (the status quo) with minimal modification of the AS 5100.2 fatigue loading specifications, it is further recommended that additional investigation be carried out to confirm suitable additions to allow for combined effects from multiple lanes on susceptible components such as cross beams, transoms and transverse bracing.

The recommended route factors for the cycle counts set out in table 10.1 are listed in table 9.2. The factors allow for estimated take-up of higher vehicle mass (HPMV) limits and differ from previous recommendations (eg in Clifton 2007).

The cycle count formulae refer to daily heavy vehicle counts per lane for the first year of service. Heavy vehicles are defined by the Transport Agency as vehicles with mass over 3500kg. These include buses and MCV in addition to HCV as defined in the EEM (NZ Transport Agency 2010b). It should be noted that the accuracy of heavy vehicle percentages reported in annual traffic data summaries (NZ Transport Agency 2013a) can vary significantly and calibration against a suitable reference site based on counts for vehicles with three or more axles is recommended. It is recommended that the Transport Agency assess the adequacy of heavy vehicle count information available to designers.

Guidance on the proportions of heavy vehicles per lane for urban highways is provided in section 10.1.5.

It is recommended that *AS 5100.6 bridge design, part 6: steel and composite construction* is adopted for fatigue design, with reference to Eurocode 3 (EN 1993-1-9 and EN 1993-2) for guidance on additional detail categories not yet included in AS 5100.6. It is anticipated that the AS/NZS 5100.6 committee preparing a future revision to AS 5100.6 will add guidance on selection of resistance factors, to differentiate between safe-life and damage-tolerant design approaches, considering the consequences of failure and the ability to inspect and maintain the structure.

12.1 Bridge Manual implementation and dissemination

The format of the fatigue loading recommendations to be included in a future amendment to the Bridge Manual requires consideration by the Transport Agency regarding confirmation and acceptance of the design fatigue vehicle option, growth allowances, and proposed implementation methods.

The Bridge Manual amendment would also cover other recommendations given above relating to the estimates of fatigue loading, and could provide guidance on selection of heavy vehicle counts.

The effect of the proposed future live load standards (Taplin et al 2013) on bridge designs and the relative impact of the proposed fatigue loadings on bridge construction costs have not been evaluated.

Case studies on typical bridge designs (for both existing loading standards and proposed future live loading) are recommended to inform decisions on adoption of the proposed loadings and design fatigue vehicle selection. It is suggested that additional matters considered in the case studies could include:

- the impact on construction costs of providing increased design life
- the effect of standardising fatigue loadings (eg fewer route factors)
- an assessment of the calculation effort required for the proposed vehicle options

- an assessment of conservatism for real bridge designs introduced by the standard fatigue vehicle approach, as compared to evaluation with detailed vehicle spectra and the resulting stress spectra
- the additional steel weight (or savings) for the approaches considered
- the implications for fabrication – whether additional conservatism or less refinement would result in the need to avoid easily fabricated details that may have shorter fatigue lives (such as fillet-welded joints rather than full-penetration butt welds).

These case studies should provide worked examples to assist with dissemination to bridge designers.

12.2 Recommendations for future work

The vehicle spectra provided in chapter 6 are applicable to heavy vehicle mixes prior to the introduction of higher mass limits. It is recommended that these be reviewed and amended when suitable data, including HPMV take-up, is available. Spectra relevant to future traffic mixes on HPMV routes may be needed for evaluation of complex structures and materials other than structural steel. This information would also be important for ongoing assessments of fatigue-prone structures and forecasts of renewal requirements.

Further work to enhance the project outputs could include the following:

- A review of the possible implications for concrete structure design could be carried out, using the vehicle spectrum models for current traffic and with HPMV included.
- If sensitivity tests on design outcomes with higher fatigue loadings (from the case studies noted in section 12.1 above) do not indicate significantly higher construction costs, it may be expedient to further rationalise the fatigue loading, or recommend a safe-life approach to reduce future long-term inspection and maintenance requirements.
- Application of a fixed stress-reduction factor has not been recommended, in the absence of published research to support this. If sensitivity tests indicate that refinement of the fatigue loading recommendations would be beneficial, then further research comparing actual stress levels in real bridges to calculated values may be warranted, wherever opportunities arise. Such research could also consider the corresponding dynamic factors, which in practice are difficult to separate from reduction factor estimates.

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Appendix A NZ Transport Agency heavy vehicle data collection

The NZ Transport Agency publishes annual reports on traffic volumes (State highway traffic data booklet) and WIM data analysis on their website. Processed and filtered data is made available through the TMS database.

The present vehicle classification scheme (denoted NZTA 2011) (NZ Transport Agency 2013e) is set out in table A.1, with the corresponding spectrum vehicle sets adopted in this study (see chapter 6). The Austroads classifications (Standards Australia 2007) and EEM classes (NZ Transport Agency 2010) are also listed in table A.1 for comparison.

The maps shown in figures A.1 and A.2) for the North and South Island telemetry sites show the locations of permanent traffic-counting sites and the rural WIM sites.

The maps also indicate the state highway classifications (NZ Transport Agency 2013d).

Table A.1 NZTA 2011 vehicle classification scheme

EEM class	Spectra set	NZTA class	Aust-roads	Type group	PAT types	Description	Config. code	Axles
Car	–	1	–	Car	8	oo very short (motorbike)		2
Car & LCV	–	2	1	Car	10,13	o-o car or LCV		2
		3	2	Car	11,15	o-o--o car/LCV towing trailer		3
					12,16	o-o--oo car/LCV towing tandem trailer		4
					14	o-o--o-o (car towing car)		4
Bus & MCV	1	4	3	Rigid	20	o-o (wheelbase 2m - 4m)	R11	2
					21	o--o (wheelbase 4m - 8.5m)	R11	2
				T&T	300	o--o--o (truck towing light trailer)		3
					401	o--o--oo (truck towing light trailer)		4
Bus & HCV1	2	5	4	rigid	31	o--oo	R12	3
					301	o-oo (tractor without semi-trailer)		3
					34	oo--o	R21	3
			6	Artic	30	o--o--o (incl. artic bus)	R11T1	3
			4	T&T	402	o--oo---o (truck towing light trailer)		4
					44	oo-o--o	R21T1	4
					503	o--oo--oo (truck towing light trailer)		5
HCV1	3	6	5	Rigid	45	oo--oo	R22	4
					47	o--ooo	R13	4
					511	oo--ooo (heavy truck)	R23	5
		7	7	Artic	41	o-o--oo	A112	4
					42	o-oo--o	R12T1	4
				T&T	40	o--o-o--o	R11T11	4
HCV2	4	8	8	Artic	50	o-o--o-o--o		5
					53	o-oo--oo	A122	5
					57	o-o--ooo		5
				T&T	52	o--oo-o--o	R12T11	5
		9	9	Artic	69	o-oo--ooo	A123	6
					68	oo--oo--oo (incl. car transporter)	R22T2	6
					747	o--ooo---ooo	A133	7
					791	o-oo---oooo	A124	7
					713	oo-oo—ooo	A223	7
					826	oo-oo—oooo	A224	8
					847	o--ooo---oooo	A134	8
	5	10	10	T&T	63	o--oo-o—oo	R12T12	6
					66	oo--oo-o—o	R22T11	6
					61	o-o--o-o--oo	A111T12	6
					62	o-oo---o-o-o (was type 621)		6
				A Train	622	o-o--oo-o--o		6
		11	10	T&T	731	o-oo--o-o—oo	A121T12	7
					751	o--oo--oo-oo (truck and trailer)	R12T22	7
				B Train	751	o-oo--oo--oo (no clear distinction from T&T)	B1222	7
			11	A Train	74	o-oo--oo-o—o	A122T11	7
	6	12	10	T&T	77	oo--oo-o—oo	R22T12	7
					771	oo-o--oo—oo		7
					891	oo--oo-oo—oo	R22T22	8
					915	oo-oo--oo-ooo	R22T23	9
					1020	oo--ooo--oo--ooo	R23T23	10
				B Train	914	oo-oo--ooo-oo	B2232	9
					1020	oo-oo--ooo-ooo	B2233	10
					1133	oo-oo-oooo-ooo or oo-oo-ooo-oooo	B2243, B2234	11
	7	13	11	A Train	85	o-oo--oo-o—oo	A122T12	8
					89	o-oo--ooo-o—o	A123T11	8
					810	o-oo--ooo--o-oo	A123T12	9
			10	B Train	811	o-oo--oo—ooo (B1223, R12T23 or Transporter)	R12T23	8
					851	o-oo-ooo—oo	B1232	8
					951	o-oo–ooo–ooo	B1233	9
					1032	o-oo–ooo–oooo	B1234	10
–	–	14	–	Unclassified	999	Everything else is omitted from NZTA database		any

Figure A.1 North Island state highways and telemetry site locations (Source: PDF supplied by G Wen)

Figure A.2 South Island state highways and telemetry site locations (Source: PDF supplied by G Wen)

Appendix A references

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Appendix B International design code summary

The provisions and methodologies from a number of international bridge design codes are summarised and compared here. The standards reviewed were:

- AS 5100.2–2004: design loads
- AS 5100.5–2004: concrete
- AS 5100.6–2004: steel and composite construction
- Eurocode 1 EN 1991-2:2003: traffic loads on bridges and the UK Annex
- Eurocode 2 EN 1992-2:2005: design of concrete structures – concrete bridges, and UK Annex
- Eurocode 3 EN 1993-2:2006: design of steel structures – steel bridges, and the UK Annex
- Eurocode 4 EN 1994-2:2005: design of composite steel and concrete structures – general rules and rules for bridges
- CAN/CSA-S6-00: Canadian highway bridge design code, 2000 (CHBDC)
- BS 5400, part 10: 1980: code of practice for fatigue
- AASHTO LRFD bridge design specifications 2007 (SI units) and 2010 (US units)

The tables in section B.2 compare the details of the criteria for the important aspects that need to be addressed in the preparation of fatigue design criteria for New Zealand bridges, under the following headings:

- vehicle fatigue loading spectra
- stress cycle analysis procedures
- material-specific fatigue design procedures – structural steel
- material-specific fatigue design procedures – reinforced and pre-stressed concrete bridges
- material-specific fatigue design procedures – composite structural steel with reinforced concrete decks.

B.1 Key differentiators between codes

The key differentiators between the codes are summarised in the following tables, with conclusions and matters arising.

Table B.1 Design life

Codes	Intended design fatigue life for steel bridges
AS 5100, AASHTO, CHBDC	• 75 years – AS 5100 assumes an inspection and maintenance regime to provide 100-year service life (similar to the damage-tolerant approach in Eurocodes)
Eurocodes	• 100 years, with choice of safe-life approach (ie acceptable reliability without need for regular in-service inspections) or damage-tolerant approach (ie acceptable reliability that a structure will perform satisfactorily for its design life with an inspection and maintenance regime for detecting and correcting fatigue damage)
BS 5400: part 10, EC3 UK Annex	• 120 years, with acceptable probability that it will not require repair (ie safe life)

Conclusion:

Unless the Transport Agency requires the higher levels of protection afforded by a safe-life approach, there does not appear to be a reason to differ from AS 5100. If appropriate for special structures, a longer design life could be specified in project-specific requirements, and the strength reduction factor can be used to address reliability levels.

Table B.2 Fatigue load models

Codes	Fatigue load models
AS 5100.2	• Fatigue vehicle – 0.7 x M1600 (4 x 252kN triple-axle sets) or standard axle (112kN). • Cycles based on current ADTT with ~4% compound growth and a span-length-dependent reduction factor relating expected heavy traffic mix to damage equivalent cycles of the fatigue vehicle.
AASHTO	• Standard truck – 0.75 x HS20 (244kN semi-trailer). • Cycles based on average ADTT over life or recommended lane capacity values. Alternatively, 1.50 x HS20 is used to check for unlimited life (similar to Eurocode FLM2 below).
CHBDC	• Standard truck – 0.52 x CL-625 (325kN B-Double) or 0.62 x tandem set (155kN total). • Cycles based on average ADTT over life or recommended lane capacity values.
Eurocodes	• FLM1 – 70% of SLS design live load, FLM2 – (5 very heavy frequent truck types) are used to check for unlimited life; ie stress range less than the CAFL for steel. • FLM3 – fatigue vehicle (2 tandem sets, 120kN/axle), various damage equivalence adjustments are specified in the material codes, average truck weight of 260kN is specified in the UK Annex. • FLM4 – set of 5 standard trucks (max. 450kN truck-and-trailer), or in the UK Annex an updated 23 vehicle spectrum similar to BS 5400: part 10. • FLM5 – site-specific recorded traffic data, with dynamic amplification factor for road roughness. • Cycles for motorway slow lanes are based on running at lane capacity for the entire design life.
BS 5400: part 10	• Standard fatigue vehicle (with 4 x 80kN axles), damage equivalence adjustments are specified for the standard spectrum, span length, and multiple presence. • Standard load spectrum – set of 25 standard typical trucks with up to 3 weights (high, medium, low) for common types. • Cycles for motorway slow lanes are based on running at lane capacity for the entire design life.

Conclusion:

Best practice (BS 5400, Eurocodes) is to provide a design vehicle load spectrum in addition to a standard vehicle method suitable for steel bridges. The Australian and two North American codes all adopt the vehicle specified for the design live loads and base the cycle counts on estimated ADTT over the 75-year life. The Australian code is unique in its use of a very high vehicle loading with a lower variable cycle count.

Table B.3 Dynamic load allowances

Codes	Additional Dynamic load allowance
AS 5100.2	• 40% for axle load, 35% for M1600 axle set, 30% for M1600 vehicle (same as for the design live load).
AASHTO	• 75% at deck joints,15% elsewhere (compared to 33% for design live load).
CHBDC	• No additional allowance, dynamic effects are considered in the load factors (table B.2).
Eurocodes, BS 5400: part 10	• Road roughness allowance incorporated in load through use of WIM data, additional 30% factor applied within 6m of expansion joints (tapering to zero). • The UK vehicle spectrum represents recorded vehicle and axle weight data with good pavement condition and is considered sufficient without further addition. • The Eurocode 3 simplified fatigue design procedure for steel bridges incorporates allowances for bridge response.

Conclusion:

AS 5100.2 is unusual, as the North American codes apply a reduced allowance to vehicle loads or allow for dynamic effects in the base fatigue load models.

Comments:

- AS 5100.2 may not adequately address requirements for expansion joints. The Eurocode approach (additional factor near joints) has merit.
- A general allowance of 30% (in AS 5100.2) is higher than the other codes but sits between the values recommended for 'good' and 'medium' road roughness allowances in the Eurocode FLM5 model if vehicle weight spectra are derived from static weights.

Table B.4 Stress range calculations

Codes	Fatigue load application and stress range calculation procedure
AS 5100.2	• One axle load or vehicle placed within any design traffic lane to maximise the fatigue effects for the component under consideration (including shoulders). • The maximum peak-peak stress range at a component is evaluated for the number of cycles specified in the fatigue load model (varying with span length). • Effects from adjacent lanes are not accumulated. • A fixed reduction factor of 0.7 is applied to the fatigue loading to compensate for a number of conservative assumptions.
AASHTO, CHBDC	• One standard truck placed in any lane, maximum peak-peak stress range at a component is evaluated for the number of repetitions specified in the fatigue load model. • Cycles per vehicle depends on span length and component position. • The stress range is doubled for assessing unlimited life.
Eurocodes	• One vehicle at a time, placed centrally in notional lanes for global effects or anywhere on the carriageway for local effects. • A Miner's summation is used to combine damage for each stress range and accumulate contributions from adjacent lanes. • A simplified procedure using the single fatigue vehicle (FLM3) is available for steel bridges. • The maximum peak-peak stress range at a component is evaluated, with the specified modification factors that account for span length and multiple cycles per vehicle.
UK Annex to Eurocode	• As for Eurocodes but with additional requirements for use of the vehicle spectrum method to account for multiple presence (convoys and side-by-side running).
BS 5400: part 10	• One vehicle at a time, placed within 300mm of centres of marked lanes to maximise the stress range.

Codes	Fatigue load application and stress range calculation procedure
	• A Miner's summation is used to combine damage for each stress range and accumulate contributions from adjacent lanes. • The single-vehicle method provides adjustments for multiple presence and alternating lane sequence, giving a higher stress range. • No explicit guidance is provided for multiple presence adjustment in the vehicle spectrum method though it 'should' be accounted for.

Comments:

- Best practice: Eurocode with the UK Annex and either the standard fatigue vehicle model (FLM3) for steel and steel–concrete composite structures, or the vehicle spectrum model (FLM4) generally.
- There is provision for National Annexes to modify the damage equivalence factors for the Eurocode standard fatigue vehicle model, but the only adjustment provided in the steel code (EN 1993-2) for typical truck weight distribution is the average gross weight – a calibration study would be necessary to confirm the number for New Zealand heavy traffic incorporating future legal vehicle mass increases. It would also be necessary to adopt clauses from several structural Eurocodes to use this particular method.
- The Australian and North American code methods are similar, and have the advantage of simplicity – all adopt the vehicle specified for the design live loads and base the cycle counts on estimated ADTT over the 75-year life. The Australian code is unique in its use of a very high vehicle loading with a lower variable cycle count. However, none of these methods directly addresses multiple presence, although the M1600 vehicle adequately covers a 2-vehicle platoon on a long span.

Conclusions:

- A standard vehicle method is the preferred approach for simplified design procedures. Multiple presence should be considered.
- The UK National Annex to EN 1991-2:2003 gives best-practice advice on the application of vehicle spectra load models.

Table B.5 Route type differentiation

Codes	Route type adjustments
AS 5100	• Cycle counts from ADTT (day one estimate) with reduction factors specified for routes other than principal highways or interstate freeways to account for traffic mix.
AASHTO, CHBDC	• Cycle counts from estimated average ADTT over design life is the only adjustment.
Eurocode 1	• Annual heavy vehicle counts per lane are specified, based on road type. • Heavy vehicle mix for FLM4 varies by route type (long haul, medium distance, local traffic). • Adjustments to FLM3 (steel code only) allow for variations in average vehicle weight.
UK Annex to EC1 BS 5400: part 10	• Annual heavy vehicle counts per lane are specified, based on road type. • No variations for route type. • Average vehicle weight for FLM3 is low (260kN), reflecting a high proportion of 2- and 3-axle trucks.

Comment:

- There is wide variation in approaches for this parameter. Selection of route type adjustments will be considered after analysis of WIM data and traffic count data on other highways.

Table B.6 Lifetime vehicle count basis

Codes	Vehicle count and growth basis
AS 5100	• Year-one daily truck counts with average fatigue damage growth based on 4% per annum compound (geometric) rate for 75 years. • A large part of the total fatigue damage growth allowance arises from long-term average mass increase.
AASHTO, CHBDC	• Based on route classification, up to 4000 trucks/lane/day with no allowance for vehicle mass growth (exceptions include certain toll roads with project-specific criteria with higher mass vehicles).
Eurocodes	• Fixed slow-lane annual counts, 5500 trucks/lane/day for high volume motorways, 1400 for medium volumes. No further allowance is made for vehicle mass growth, unless specified through modifications in the National Annexes.
UK Annex	• As for Eurocode, but with reduced average vehicle mass to reflect high proportions of rigid trucks.

Comment:

- The inherent growth allowance in AS 5100.2 is massive compared with international codes (and this is considered to be appropriate, given our developing infrastructure and vehicle standards), and may increase the average lifetime vehicle counts to levels comparable to the international codes.

Table B.7 Fatigue strength reduction factors for steel bridges

Codes	Strength reduction factor or material partial safety factor
AS 5100.6	Varies – no clear guidance other than $\phi \leq 0.7$ for non-redundant load paths, and $\phi = 1.0$ for the unlikely ideal case. The choice is left to the designer at present.
AASHTO, CHBDC	No reductions.
Eurocode 3	Range of values is specified, from $\gamma_{Mf} = 1.0$ for low-consequence, damage-tolerant design to $\gamma_{Mf} = 1.35$ for high consequence, safe-life design approach.
UK Annex to EC3	$\gamma_{Mf} = 1.10$.
BS 5400: part 10	No reductions, but S-N curves are slightly more conservative than the Eurocode.

Comment:

- Strength reduction factors applicable to the design using the AS 5100.6 clause 13 are set by the applicable standards committee and are outside the scope of this study. However, the Eurocode values and those given by NZS 3404 and AS 4100 provide some hints on selection of intermediate values.

B.2 Detailed comparison tables

The following tables provide more-detailed comparison of the various design criteria:

- vehicle fatigue loading spectra
- stress cycle analysis procedures
- material-specific fatigue design procedures – structural steel
- material-specific fatigue design procedures – reinforced and pre-stressed concrete bridges
- material-specific fatigue design procedures – composite structural steel with reinforced concrete decks.

Table B.8a Vehicle fatigue loading spectra for Australia, Europe and the UK

	Item	AS 5100.2 - 2004 section 6.9	Eurocode 1 (EN 1991-2:2003)	BS 5400, part 10: 1980
1.1	Load spectrum basis	Australian WIM Data – Grundy and Boully (2004): • Standard vehicles consistent with design live loading. • WIM data on main highways was analysed to estimate the equivalent number of standard vehicle cycles for the same fatigue damage. • The assumed fatigue damage equivalence relationship is applicable to structural steel	• European vehicle configurations with high axle weights (higher than UK load spectra), representing heavy traffic on main roads or motorways. • Load Models 1 and 2 are used only for calculation of maximum stress ranges for possible load arrangements, to check if fatigue life can be considered as unlimited. • Load Models 3, 4, and 5 are used for fatigue assessment in accordance with the applicable material codes. These are intended to have equivalent effects to typical European heavy traffic.	• Standard vehicle load spectrum representing weights and relative frequencies of commercial vehicles on 'typical trunk roads', and comprising 11 vehicle types with up to three weight bands per type (light, medium, heavy) giving 25 vehicles configurations. • Proportions taken from sample traffic counts and axle weights were averaged from 1970s weighbridge records. • Counts for less common types included in standard types on equivalent damage basis. • Vehicles under 30kN are ignored.
1.2	Intended design life	100 years, reduced to 75 years target service life considering ~2% failure probability, maintenance regime	100 years design working life.	20 years – bridge required to perform safely with acceptable probability that it will not require repair.
1.3	Standard fatigue loading models	Design axle or standard vehicle, whichever gives larger fatigue effect: a) 70% of A160 axle load (160kN x 0.7) b) 70% of M1600 vehicle excluding UDL (4 triple-axle sets, 120kN x 0.7 per axle)	Five fatigue load models: 1 Lane loading – 70% of serviceability (characteristic) design load, (2 x 210kN tandem set with 2.7kPa UDL in 1st lane, 2 x 140kN and 0.75kPa in 2nd lane, 2 x 30kN and 0.75kPa in 3rd lane, others 0.75kPa). 2 Set of 5 'frequent' trucks, total weights in range 280kN–630kN. 3 Standard fatigue vehicle (two tandem sets, 120kN per axle). 4 Set of 5 'standard' trucks, total weights in range 210kN–490kN, in proportions varying with route type. 5 Recorded traffic data with appropriate growth projections and allowance for road roughness (1.2 factor for 'good', 1.4 for 'medium' roughness). The UK National Annex replaces Model 4 with an updated version of the BS 5400 part 10 vehicle spectra (23 vehicles, common types are significantly lighter than the standard Model 4).	Standard vehicles: a) Standard load spectrum, or b) Standard fatigue vehicle (4 x 80kN dual-tyre axles at 1.8m, 6.0m, 1.8m spacings).
1.4	Additional dynamic load allowance	Applied in all cases: a) 40% for A160 axle load b) 30% for M1600 vehicle c) 35% for M1600 triple-axle set	• General dynamic allowances are included in the load model axle weights, or correction factors for Load Model 3 is provided in the material codes. • An additional 30% amplification factor is applied to loads at expansion joints, linearly decreasing to zero over 6m (similar treatment to BS 5400: part 10).	• 25% increase in the influence line for static stress at a discontinuity in the road surface (such as a joint), linearly decreasing to zero over 5m. • Thus the effect of one axle over the joint increases by 25%, but increases for adjacent axles are less so that the overall increase is less than 25%, varying with span length and vehicle type.
1.5	Vehicle placement	Axle load or vehicle placed within any design traffic lane to maximise the fatigue effects for the component under consideration	• All load models placed centrally in notional lanes for global actions, or for local effects, the notional lanes may be anywhere on the carriageway.	• Only one vehicle on the structure at a time. • Lane arrangements as marked on carriageway, vehicle placed within 300mm of lane centre to give maximum stress range.
1.6	Basis for cycle counts	Current no. heavy vehicles (Austroads classes 3 upwards) per lane per day, reduced by damage equivalence factors reflecting average fatigue damage per truck on main highways: a) 0.25 for A160 axle load b) 0.125 $L^{-0.5}$ for M1600 vehicle load, where L is the span length (sum of adjacent spans for reactions or average for negative moments); eg 0.025 for L=25m. This includes allowances for future vehicle mass growth. Applied for 75 years x 365 days x growth factor, thus: a) A160 cycles = $4x10^4$ x current heavy count b) M1600 cycles = $2x10^4$ x $L^{0.5}$ x current heavy count.	• Indicative no. of heavy vehicles per slow lane per year: 2.0x106 for roads and motorways with high flow rates, 0.5x106 for roads and motorways with medium flow rates, 0.125x106 for main roads with low heavy vehicle flows, 0.05x106 for local roads with low heavy vehicle flows. For fast lanes, 10% of the slow-lane counts (in addition) may be considered. • The UK National Annex substitutes a similar table to BS 5400 part 10. • For Load Model 3 (standard vehicle), the stress range is adjusted for damage equivalence at a standard cycle count (2 x106 in the steel code). • Adjustment factors allow for heavy traffic volume, design life, multiple presence, average vehicle weight, span length, component location; and are material dependent.	• Standard no. of commercial vehicles per lane per year ranging from 0.5x106 vehicles (two way narrow road) up to 2.0x106 (slow lanes of 3-lane motorway carriageway). • Scope for changes.
1.7	Growth allowance	The growth factor included above considers higher initial growth rates and eventual saturation levels in the slow lanes. The specified cycle counts are equivalent to 4.0% compound growth per annum for 75 years	None – the highest daily heavy vehicle counts (5500 per day for motorway slow lanes) reflect approximate road capacities.	None – the average daily heavy vehicle counts (eg 4100–5500 per day for motorway slow lanes) reflect approximate road capacities.
1.8	Treatment of	The cycle counts for routes other main highways are reduced to reflect the lower proportions of fully loaded vehicles and differences in heavy vehicle	• Load Model 4 categorises traffic types as long distance, medium distance or local traffic, but notes that a mixture may occur. The UK version makes no	• Covered by annual heavy counts varying according to road type, but no allowance for variations in vehicle weight distribution between routes.

	Item	AS 5100.2 - 2004 section 6.9	Eurocode 1 (EN 1991-2:2003)	BS 5400, part 10: 1980
	variations in traffic mix	type mix by applying a route factor to the cycle counts: • Principal interstate freeways and highways 1.0 • Urban freeways 0.7 • Other rural routes 0.5 • Urban roads other than freeways 0.3	distinction. • For Load Model 3 (standard vehicle), adjustments for the average weights of heavy vehicles are included in the steel code.	
1.9	Heavy vehicles per lane	• Interstate and rural highways – total for direction. • Urban routes with 2 or more lanes – 65% of total for direction (in any design traffic lane)	• Specified by annual heavy vehicle counts per lane.	• Specified by annual heavy vehicle counts per lane.
1.10	Multiple presence allowance	None. The length of the M1600 vehicle and variable 2nd to 3rd axle set spacing allows for closely spaced vehicles	• Model 1 – fully covered. • Model 2 – not covered. UK National Annex adds lightest vehicle in same lane at 40m separation or in the most onerous position in another lane. • Model 3 – covered by material code damage equivalence adjustments. • Models 4 and 5 – not covered. However, the UK National Annex requires damage contributions from two lanes to be combined and 20% of the traffic in convoy at 40m axle spacing, with side-by-side running also allowed for by increasing the total damage (ref NA.2.26).	• Effects of vehicle combinations are incorporated in the single standard vehicle method.
1.11	Transverse position variation	None	For local effects, the given frequency distribution of transverse vehicle position (±250mm) may be used.	Multiple paths may be considered, using the given frequency distribution of transverse vehicle position (±600mm).
1.12	Stated limitations	• Not applicable to fatigue design of expansion joints. • The design number of fatigue cycles is applicable to simply supported, continuous and cantilever spans	None.	
1.13	Comments	The 70% reduction in design vehicle loadings was based on actual stresses in a component being generally less than the theoretically calculated values because of alternative load paths (such as bridge barriers) and the magnitude of actual components in comparison with line elements used to represent them in analysis; and the actual lateral position of heavy vehicles not generally coinciding with the critical lateral position	• Centrifugal forces concurrent with vertical forces occasionally need to be considered.	• Centrifugal forces considered for substructures. • In the UK, BS 5400 has been superseded by the Eurocodes but survives for use in assessment of existing bridges through references in the Highways Agency's *Design manual for roads and bridges*.

Table B.8b Vehicle fatigue loading spectra for North America

	Item	AASHTO LRFD Bridge Design Specifications 2010	Canadian Highway Bridge Design Code (CHBDC) section 10.17
1.1	Load spectrum basis	• Standard 'fatigue truck', consistent with design live loading, is used to represent the variety of different trucks of different types and weights in actual traffic. • The constant rear-axle spacing (3-axle config.) approximates that for the 4- and 5-axle semi-trailers that do most of the damage to bridges. • Design Truck developed from WIM Data, NCHRP 299.	Standard 'fatigue truck', consistent with design live loading, is used to represent the variety of different trucks of different types and weights in actual traffic. The 'CL-W' truck is an idealised 5-axle vehicle that has been specifically calibrated to reflect a 625kN truck (the current legal limit in Canada).
1.2	Intended design life	75 years ~2.5% probability of cracking during the specified lifetime.	75 years ~2.5% probability of cracking during the specified lifetime.
1.3	Standard fatigue loading models	Design axle or standard design truck: • HL-93 design truck (o--o---o, 325kN=35+145+145) with a constant spacing of 9000mm between the 145kN axles, with load factors 1.50 for Fatigue I limit state (infinite life) or 0.75 for Fatigue II limit state (finite life). • A proposed amendment (Mertz 2013) will increase these factors to 2.0 (infinite life) and 0.80 (finite life). • State transportation departments may specify alternative (heavier) trucks for new designs (eg Illinois uses a 400kN 6-axle semi-trailer).	Standard fatigue vehicle CL-W truck, where W=625kN, and thus CL-625 is the usual designation (o-oo---o---o, 625kN = 50 + 2x125 + 175 + 150, representing a B-double configuration) • The load factor used in fatigue life evaluation is 0.52 for the vehicle effects, or 0.62 for the tandem-axle set.
1.4	Additional dynamic load allowance	• Dynamic Load allowance is applied to static load effects of the truck as per the percentages below. It is not applied to pedestrian loads or to the design lane load. • 70% for deck joints (all limit states). • 15% for all other components (fracture and fatigue limit state). • 33% for all other components (all other limit states).	• Dynamic allowance is applied as a percentage to static effects of the CL-W truck for the number of axles considered in the design lane: - 50% for deck joints - 40% where only 1 axle of the CL-W Truck is used (except for deck joints) - 30% where any 2 axles of the CL-W Truck, or axles 1, 2 and 3 are used - 25% where 3 axles of the CL-W truck, except for axles 1, 2 and 3, or more than 3 axles are used.
1.5	Vehicle placement	• For fatigue limit state only one design truck is used, regardless of the number of design lanes. The lane load shall not be considered. • Placement is dependent on the method adopted: - The AASHTO LRFD specifications provide two types of methods suitable for deck design: namely the *approximate method* #4.6.2 (also known as the equivalent strip method) and the *refined method* #4.6.3 (which includes a range of analytical methods including, but not limited to: finite element method, finite difference method, yield line method, and grillage analogy method. - The *approximate method* is an approach in which the bridge deck is split into a series of longitudinal and transverse design strips. The axles of the fatigue design vehicle are moved along the full length of each strip to obtain an envelope of demands. The evaluated extreme positive moment is then taken to apply to all positive moment regions and the extreme negative moment is taken to apply to all negative moment regions. Dynamic load allowances are then applied (as per the above item). Furthermore, to account for the fact that the method treats the longitudinal and transverse effect of wheel loads as uncoupled phenomena, live load distribution factors are applied to give the design demands. For the consideration of fatigue, the live load distribution factor applicable to one traffic lane is to be used. - For the *refined methods*: Because future traffic patterns on the bridge are uncertain, the position of the truck is made independent of both the traffic lanes and the design lanes. Instead, a single design truck shall be positioned transversely and longitudinally to maximise stress range at the detail regardless of the position of traffic or design lanes on the deck.	For the fatigue limit state, the traffic load shall be one truck only, placed at the centre of one travelled lane.
1.6	Basis for cycle counts	• Number of cycles is evaluated on the basis of the number of trucks *actually* anticipated to cross the bridge per day, in the most heavily travelled lane, in one direction, averaged over its design life (the average daily traffic – ADT – which is inclusive of all vehicle types). • Applied for 75 years x 365 days x (ADT x fraction of trucks in traffic) x fraction of trucks in a single lane x no. of stress range cycles per truck passage, where the no. of stress range cycles per truck passage is introduced in recognition that a single passage of a truck can produce more than one stress range cycle.	
1.7	Growth allowance	• Cycle counts are averaged over the design life. • No guidance provided for future growth allowance – the ADTT counts (eg 4000 per day for rural interstates) reflect approximate road capacities.	None – the ADTT counts (eg 4000 per day for CLASS A highways) reflect approximate road capacities.
1.8	Treatment of variations in traffic mix	In lieu of site-specific data, the no. of cycles for different classifications of routes are treated differently by applying the following 'fraction of trucks in traffic' (as suggested in the codes commentary) to an ADT= 20,000 vehicles, to give the following ADTTs: • rural interstate = 0.2x 20000 = 4000 vehicles • urban interstate = 0.15 x 20000 = 3000 vehicles • other rural = 0.15 x 20000 = 3000 vehicles • other urban = 0.10 x 20000 = 2000 vehicles.	In lieu of site-specific data, the no. of cycles for different classifications of routes are treated differently by applying the following ADTT values to different route classifications: • Class A = 4000 vehicles • Class B = 1000 vehicles • Class C = 250 vehicles • Class D = 50 vehicles.

	Item	AASHTO LRFD Bridge Design Specifications 2010	Canadian Highway Bridge Design Code (CHBDC) section 10.17
1.9	Heavy vehicles per lane	Fraction of truck traffic in a single lane: = 1.0 for 1 lane available to trucks = 0.85 for 2 lanes available to trucks = 0.8 for 3 lanes available to trucks.	As per AASHTO.
1.10	Multiple presence allowance	For fatigue limit state only 1 design truck is used, regardless of the number of design lanes. Multiple presence is not considered.	
1.11	Transverse position variation	• For the approx. method (equivalent strip method), the truck's axles are moved laterally along the transverse strip to obtain an envelope of demands. The extreme positive effect is then taken to apply to all positive regions and similarly the extreme negative effect is taken to apply to all negative regions. • For the refined method, the vehicle can be positioned transversely and longitudinally to maximise stress range at the detail regardless of the position of traffic or design lanes on the deck.	None – vehicle is placed centrally within the travelled lane.
1.12	Stated limitations	None noted.	None noted.
1.13	Comments	The design truck idealises 5-axle trucks as a 3-axle configuration – this simplification is not appropriate when considering deck elements such as orthotropic decks or modular bridge expansion joints. A separate manual (FHWA 2012) covers additional requirements for orthotropic steel deck bridges (using a 5-axle truck with defined wheel patch areas).	N/A

Table B.9a Stress cycle analysis procedures (Australia, Europe and the UK)

	Item	AS 5100.2 – 2004 section 6.9	Eurocode 1 (EN 1991-2:2003)	BS 5400, part 10: 1980
2.1	Assessment methods	• Simplified – maximum stress range is calculated with the standard axle or vehicle load placed within any design traffic lane to maximise the fatigue effects for the component under consideration, without vehicles in other lanes. • Damage equivalence factors are addressed for steel bridges through the variation in design cycle counts and route factors as noted in table B.8(a).	• Models 1, 2 and 3 – maximum and minimum stresses for the component under consideration are calculated for all possible load arrangements. - Treatment depends on the material code. - The approach for models 1 and 2 is similar to the BS 5400: part 10 assessment without damage calculation. • Model 3 (standard fatigue vehicle) – used for direct verification design using simplified methods accounting for annual traffic volumes and bridge span through a material-dependent adjustment factor λ_e. • Models 4 and 5 – the stress range spectra resulting from truck passages are calculated. Treatment depends on the material code. • For *steel structures* (EN 1993-2:2006), the single-vehicle method (Model 3) is fully supported using a damage equivalence factor to adjust the stress range to a value corresponding to $2x10^6$ cycles, allowing for: - span length (and mid-span vs support positions) (factor incorporates dynamic load allowances) - traffic volume and average truck weight (260kN in UK Annex) - design life (120 years in in UK Annex) - multiple lanes – factor accounts for relevant influence, vehicle counts and average truck weight in adjacent lanes. • For *composite shear stud connectors*, modifications to the damage equivalence factors given by EN 1993-2:2006 are provided in EN 1994-2:2005. • 'Informative' damage equivalence factors for *reinforcing and pre-stressing steel* are specified in EN 1992-2:2005 Annex NN, but the traffic volume factor only allows for truck mix variations in Load Model 4. • For concrete components in road bridges, there is no provision for assessment by the single-vehicle method. However, Models 1 and 2 may be used to verify unlimited life, or if a rigorous assessment is necessary, the Model 4 vehicle spectra may be used.	Assessment methods are specific to steel structures: a) Simplified – assessment without damage calculation: - standard fatigue vehicle in each lane in turn - maximum and minimum stress at a detail are the envelope values for all lanes - stress range to be less than the limiting values specified in design charts (which vary by road type, detail classification and span length to account for the difference in damage caused by the standard vehicle versus the load spectrum, and multiple presence) b) Simplified damage calculation – single-vehicle method - standard fatigue vehicle in each lane in turn - calculate each peak and trough stress, for each lane - if max. and min. stress stress values at a point occur with the vehicle in the same lane, the stress histories are processed for each lane separately; otherwise, an alternating sequence of vehicles in 2 lanes is assumed and the combined stress history is considered - for each stress range in the histories a lifetime damage factor (d_{120}) is taken from a design chart to account for the difference in damage caused by the standard vehicle versus the load spectrum - a further adjustment factor K_F, varying with span length and the ratio of stress from vehicles in adjacent lanes, is applied to the damage factor for each stress range – this accounts for the design charts being derived for a base length of 25m, more than 1 vehicle in the same lane, and vehicles in different lanes simultaneously causing stresses of the same sign or stresses of alternating opposite sign - the resulting damage contributions at a detail from all lanes and stress ranges are summed to estimate fatigue life c) Rigorous damage calculation – vehicle spectrum method: - explicit calculation of the stress spectra at a detail, for each vehicle in the spectrum traversing each lane - must account for possibility of higher stress ranges due to multiple vehicle presence and alternating sequences (factor K_F)

	Item	AS 5100.2 – 2004 section 6.9	Eurocode 1 (EN 1991-2:2003)	BS 5400, part 10: 1980
				- for assessment of existing structures, design spectra may be compiled from continuous strain monitoring and/or traffic monitoring - Miner's summation
2.2	Vehicle load positioning	Axle load or vehicle placed anywhere within any design traffic lane to maximise the fatigue effects for the component under consideration.	• For assessment of general actions (eg main girders) all fatigue load models are placed centrally in the notional load lanes. Slow lanes must be identified. • For assessment of local effects, the load models may be located anywhere on the carriageway.	• Each passage of a vehicle over the structure is a separate loading event. • Vehicle placed within 300mm of lane centre to give maximum stress range in component under consideration.
2.3	Stress range and cycle calculation	One stress cycle taken to be the maximum peak–peak stress range from the passage of the relevant fatigue design vehicle.	Steel structures (EN 1992-2:2006): The reference stress range (max. peak–peak stress range for the standard fatigue design vehicle) is converted to the damage equivalent stress range for $2x10^6$ cycles.	Evaluated for all cycles during passage of the relevant fatigue design vehicle(s), with impact where applicable: a) plates: greatest algebraic difference between principal stresses on planes not more than 45° apart in any one stress cycle b) welds: algebraic or vector difference between greatest or least vector sum of stresses in any one cycle. The stress cycle ranges for histories with two or more peaks and/or troughs are determined by the reservoir method.
2.4	Combination of lane effects	Not combined. Design vehicle load effects and relevant stress cycles are applied to each design lane independently.	Explicitly covered in Model 1 (lane loads), and in Model 3 for steel bridges – which, in effect, accumulate the damage, assuming one vehicle at a time.	Each lane traversed separately, effects from multiple lanes are combined.
2.5	Comments	• The simplifications in AS 5100.2 section 6.9 mean that for highway bridges only one stress range is calculated for each point under consideration, for the applicable fatigue vehicle(s). • Potential weakness where effects alternate for loading in different lanes – eg transverse diaphragms and bracing.	• Higher stress ranges where effects alternate for loading in different lanes are covered by Model 1. • The modifications for Model 4 in the UK Annex for side-by-side running may also cover this adequately.	• Handling of multiple presence through factor K_F as per BS 5400.10 could be considered for New Zealand, especially if an alternative procedure to AS 5100.2 is adopted. • For welds in composite shear connectors (see the example in appendix D.4.4), the simplified procedure (8.2) is available but not 8.3. Design tied to BS 5400.5.

Table B.9b Stress cycle analysis procedures (North America)

		AASHTO LRFD Bridge Design Specifications 2010	Canadian Highway Bridge Design Code (CHBDC) section 10.17
2.1	Assessment methods	Simplified – as outlined in table B.8(b).	Simplified – as outlined in table B.8(b).
2.2	Vehicle load positioning	As per the description given under Item: 'Vehicle placement' in table B.8(b)	• Only one vehicle present on the bridge. • Vehicle placed at critical locations along the centreline of a travelled lane.
2.3	Stress range and cycle calculation	• One stress cycle to be the maximum peak–peak stress range from the passage of the relevant fatigue design vehicle. • Code does not provide provisions for the use of cycle counting methods in the determination of either the number of stress cycles or the effective stress range. • For steel structures, a cycle count multiplier is specified, depending on component type and span length; eg 2.0 for transverse members spaced at 6m or less and simple girder spans with spans of 12m or less. • For cantilever beams and connections to steel deck plates (FWHA 2012) the cycle count multiplier is 5.0.	• As per AASHTO; however, for load-induced fatigue of steel bridges a reduction factor is applied. Reduction factor = 0.52 (except for the tandem-axle set on bridge decks = 0.62) • The reduction factor is applied to the evaluated stress range to account for: i) the relationship between the AASHTO design truck and the trucks causing fatigue damage ii) the relationship between the calculated fatigue stress range using the AASHTO design truck and the CHBDC design truck iii) any difference between the actual trucks that cause fatigue damage in the two jurisdictions.
2.4	Combination of lane effects	Not combined. Design vehicle is placed independently.	As per AASHTO.
2.5	Comments	N/A	N/A

Table B.10a Material-specific fatigue design procedures – structural steel (Australia, Europe and the UK)

	Item	AS 5100.6 – 2004 section 13	Eurocode 3 (EN 1993-1-9:2005, EN 1993-2:2006)	BS 5400, part 10: 1980
3.1	Fatigue design approaches	By using 75 years target service life, on the basis that inspection and maintenance will occur, the AS 5100.6 approach falls into the damage-tolerant category.	Design working life 100 years (UK National Annex = 120 years): a) damage-tolerant method: requires acceptable reliability that a structure will perform satisfactorily for its design life, provided that a prescribed inspection and maintenance regime for detecting and correcting fatigue damage is implemented b) safe-life method: requires acceptable reliability without need for regular in-service inspections.	• A comparison of the reliability levels in both BS 5400: part 10 and EN 1993-1-9 is included in *PD 6695-1-9:2008 Recommendations for the design of structures to BS EN 1993-1-9* (British Standards Institution 2008). • Safe-life approach as described in Eurocode 3.
3.2	Design fatigue life verification methods	• S-N curves relating constant amplitude stress range (S) to design life (N cycles). Underlying probability levels are as for Eurocode 3. • Other assessment methods, such as notch strain or fracture mechanics methods, are not covered.	• S-N curve derived from fatigue test data, design curves based on 95% probability of survival, for 75% confidence level (assuming a normal distribution). • Other assessment methods, such as notch strain or fracture mechanics methods, are not covered.	• S-N curves derived from fatigue test data, design curves based on two standard deviations below the mean (2.3% probability of failure assuming a normal distribution). • Other assessment methods, such as notch strain or fracture mechanics methods, are not covered.
3.3	General form of S-N curves for normal stress range	N x S^m = constant, exponent m is typically 3 for N <5 x 10^6 (straight line on log-log plot).	Same as AS 5100.6.	N x S^m = constant, exponent m is typically 3, except for the two highest classifications (m = 3.5, 4).
3.4	S-N curves are identical to:	Eurocode 3, AS 4100, NZS 3404	AS 5100.6, NZS 3404	BS 7608: 1993
3.5	Fatigue strength categories/ classifications	• Subset of Eurocode 3, ECCS recommendations (1985). • Category number indicates constant amplitude fatigue strength (MPa) at 2x10^6 cycles. • Notable omissions/discrepancies – bolted joint components with higher categories than Eurocode 3.	• Evolved from ECCS recommendations, comprehensive except for specialised applications.	• Detail Classes B, C, D, E, F, F2, G for normal stresses, Class W for weld shear stress, Class S for composite shear connector welds. Fatigue strengths generally similar to the Eurocode at 2x10^6 cycles but many subtle differences in classifications and limitations on use. Strengths are lower above 5x10^6 cycles. Significant differences for fillet welds in shear. • Orthotropic steel decks are not covered.
3.6	CAFL, aka constant stress range fatigue limit below which a crack is assumed not to propagate	Design fatigue strength at N = 5 x 10^6 cycles for normal stress.	Design fatigue strength at N = 5 x 10^6 cycles for normal stress.	Design fatigue strength at N = 1 x 10^7 cycles (joints in clean air, or adequately protected against corrosion).
3.7	Treatment of low stress cycles (below CAFL)	Exponent m changes to m+2 for N >5 x 10^6 cycles (increased fatigue life for low stress ranges).	Exponent m changes to m+2 for N >5 x 10^6 cycles.	Exponent m changes to m+2 for N >1 x 10^7 cycles (in clean air).
3.8	Strength reduction factor applied to fatigue strength values	Capacity factor ϕ = 1.0 for reference design condition where: a) detail is on a redundant load path (failure at that point alone will not lead to overall collapse of the structure) b) stress history is estimated by conventional methods (should not be assumed for the simplified method in AS 5100.2) e) load cycles are not highly irregular (excludes most bridges) d) the detail is accessible, and subject to regular inspection. The factor must be reduced when any of the above conditions do not apply (ie most highway bridges), but the values are not prescribed, except ϕ≤0.7 for non-redundant load paths. For comparison, NZS 3404:1997 would give 0.85 where conditions (a) and (d) apply.	• Partial factor for fatigue resistance γ_{Mf} (ϕ corresponds to1/γ_{Mf}) depends on design approach and consequence of failure: γ_{Mf} = 1.0 – low consequence, damage-tolerant design γ_{Mf} = 1.15 – high consequence, damage-tolerant design γ_{Mf} = 1.15 – low consequence, safe-life approach γ_{Mf} = 1.35 – high consequence, safe-life approach. • The highest value implies ϕ=0.74. • The UK National Annex to EN 1993-1-9 overrides these – γ_{Mf} = 1.1 (safe life approach only).	No reduction.
3.9	Material thickness correction	Applied to plates thicker than 25mm.	Yes, for plates thicker than 25mm.	None.
3.10	Treatment of variable stress ranges	Cumulative damage calculation based on Palmgren-Miner summation.	Cumulative damage calculation based on Palmgren-Miner summation.	Cumulative damage calculation based on Palmgren-Miner summation.

	Item	AS 5100.6 – 2004 section 13	Eurocode 3 (EN 1993-1-9:2005, EN 1993-2:2006)	BS 5400, part 10: 1980
3.11	Cut-off limit for low stress cycles?	Yes (stress ranges less than design fatigue strength at 10^8 cycles are neglected in the cumulative damage summation).	Yes (stress ranges less than design fatigue strength at 10^8 cycles are neglected in the cumulative damage summation).	No.
3.12	Exemptions from assessment	a) where all design stress ranges are less than cut-off limit b) for normal stresses where the total stress from permanent and variable loads is compressive at all times Note – guidance in other documents states that (b) is not applicable to fillet-welded details or where tensile residual stresses from welding are present.	N/A – all details subjected to cyclic loading should be checked for fatigue.	For non-welded details where variable stresses are entirely in the compression zone.
3.13	Treatment of compressive normal stresses	See above.	For non-welded details the compression portion of stress ranges may be reduced by 40%.	For non-welded details the compression portion of stress ranges may be reduced by 40%, dead load effects included in effective stress ranges.
3.14	Allowance for stress concentrations	• Included in detail categories, limitations given in descriptions. • All other stress increases for geometry variations, eccentricity moments, etc to be included in stress ranges.	• Included in detail categories, limitations given in descriptions. • All other stress increases for geometry variations, eccentricity moments etc to be included in stress ranges. • Hot-spot method can be used for selected welded joint details under combined axial force and moments.	• Included in detail categories, limitations given in notes. • Stress concentration factors are provided for unreinforced openings and re-entrant corners. • Effects of shear lag, restrained torsion and distortion, transverse moments, joint eccentricities, etc to be included in design stresses.
3.15	Workmanship requirements, allowances for imperfections	Construction tolerances implied by associated codes or as set in the detail category descriptions.	Tolerances and workmanship standards set out in EN 1090-2, material toughness requirements EN 1993-1-10.	Workmanship standards as specified by BS 5400: part 6, plus additional requirements set out in the notes on detail classifications. Residual stresses and geometric tolerances are allowed for in detail classifications.
3.16	Treatment of unclassified details	N/A	N/A	Assume lowest classifications unless fatigue test data showing higher classifications are available.

Table B.10b Material-specific fatigue design procedures – structural steel (North America)

	Item	AASHTO LRFD Bridge Design Specifications	Canadian Highway Bridge Design Code (CHBDC) section 10.17
3.1	Fatigue design approaches	• Design Working Life = 75 years • Limit State Assessment Method: method is specific to steel structures. The Fatigue Limit State shall be taken as restrictions on stress range as a result of a single design truck occurring at the number of expected stress ranges • Approach allows the achievement of either: - Finite Life: Design for specified number of cycles - Infinite Life (Design Below CAFL Threshold). • Details or components are grouped into 8 'detail' categories depending on their type and configuration, Code provides description of details, situation and illustrative examples as an aid in the identification of the detail category. • Fatigue design approaches provided for both load-induced or distortion-induced fatigue: a) Load-induced fatigue: - Stress range corresponding to the design truck (75% of HL-93) is evaluated by using ordinary elastic analysis and the principals of mechanics of materials. - Finite Life: Using S-N curve (see figure A.1), calculated effective stress range is compared to the 0.5 * Constant Amplitude Fatigue Thresholds (CAFL/2) for the applicable detail category. When evaluated stress is less than CAFL/2 the detail will theoretically provide infinite design life. - Infinite Life: Same approach as Finite life with the exception that the evaluated effective stress range is noted to be larger than CAFL/2. As a result, the fatigue life is determined in terms of number of stress range cycles per truck passage, n: where n=A x (effective stress range)^-3, where A is the detail category constant defined by the code. The total fatigue life is then calculated as = n/(365x75xADTT x fraction of truck s in a single lane). b) Distortion-induced Fatigue: - Adopted for members provided with interconnecting components such as diaphragms and cross bracing (where secondary stresses can be a significant source of fatigue crack growth). Check is in addition to the load-induced method. - Load paths that are sufficient to transmit all intended and unintended forces are provided by connecting all transverse members to appropriate components comprising the cross section of the longitudinal member. Load paths are provided by	Approach is as per AASHTO, but with the following differences: • The AASHTO design truck (75% of HL-93) is substituted with the Canadian design truck 1.00 * (CL-W). • For load-induced fatigue, as per AASHTO, the stress range corresponding to the design truck is evaluated using ordinary elastic analysis and the principals of mechanics of materials. However, the evaluated stress range is reduced by applying a reduction factor. Reduction factor = 0.52 (except for bridge decks = 0.62) (as discussed in Item 2.3).

	Item	AASHTO LRFD Bridge Design Specifications	Canadian Highway Bridge Design Code (CHBDC) section 10.17
		either attaching connection plates through either welding or bolting. - Code specifies detailing recommendations for transverse and lateral connection plates.	
3.2	Design fatigue life verification methods	S-N curve based on a lower bound to a large number of full-scale fatigue test data with a 97.5% probability of survival.	As per AASHTO.
3.3	General form of S-N curves for normal stress range	$N \times S^m$ = constant, exponent m is typically 3 (straight line on log-log plot).	As per AASHTO.
3.4	S-N curves are identical to:	CSA-S6-00, AISC and AWS S-N curves.	As per AASHTO.
3.5	Fatigue strength categories/classifications	• Components and details susceptible to load-induced fatigue cracking have been grouped into 8 'detail categories', by fatigue resistance. (A, B, B', C, C', D, E and E'). Category A is for the base material steel and has the highest fatigue strength (165MPa threshold). The fatigue strength limit subsequently decreases for the remaining categories. • A further two categories are provided for M 164M and M253M bolts in axial tension. • Categories include the consideration of orthotropic plates. • Classifications are generally similar to the Eurocode for common details, and S-N curves are similar for stress ranges above the CAFL.	As per AASHTO.
3.6	CAFL, aka constant stress range fatigue limit below which a crack is assumed not to propagate	• Constant Amplitude Fatigue Thresholds are dependent on the detail category under consideration. • The corresponding number of cycles varies by category.	As per AASHTO.
3.7	Treatment of low stress cycles (below CAFL)	No change in exponent.	As per AASHTO.
3.8	Strength reduction factor applied to fatigue strength values	None.	None.
3.9	Material thickness correction	None.	None.
3.10	Treatment of variable stress ranges	The AASHTO specification advises that the Palmgren-Miner rule can be used to account for cumulative damage.	Cumulative damage calculation based on Palmgren-Miner summation.
3.11	Cut-off limit for low stress cycles?	None.	None.
3.12	Exemptions from assessment	Members where fatigue details for which the dead load compressive stress is more than twice the maximum evaluated tensile stress (generated by the passage of 0.75* HL-93 truck) need not be considered.	At locations where the stresses resulting from the permanent loads are compressive, load-induced fatigue shall be disregarded when the compressive stress is at least twice the maximum tensile live load stress (same as AASHTO).
3.13	Treatment of compressive normal stresses	See above.	See above.
3.14	Allowance for stress concentrations	Detail categories account for stress concentrations, weld quality and other variables, which are difficult to quantify. Guidance on additional allowances for orthotropic steel decks is provided in the FWHA (2012) manual.	As per AASHTO.
3.15	Workmanship requirements, allowances for imperfections	As per AASHTO construction specifications.	All welding procedures, including workmanship, techniques, repairs and qualifications shall conform to the acceptance standards of CSA Standard W59-M, clause 1.5.4.
3.16	Treatment of unclassified details	N/A	N/A
3.17	Comments	N/A	Canadian approach is as per the AASHTO approach, with modifications made to reflect the differences in traffic conditions and vehicle types between the two jurisdictions.

Table B.11a Material-specific fatigue design procedures – reinforced and pre-stressed concrete bridges (Australia, Europe and the UK)

		AS 5100.5 - 2004	Eurocode 2 (EN 1992-1-1:2004, EN 1992-2:2005)	BS 5400, part 4: 1990
4.1	Fatigue design approach – general	• Fatigue loadings and number of stress cycles as for AS 5100.2. • Considered for bridges where the effective number of stress cycles is 500,000 or more.	• Fatigue verification required, except substructures not rigidly connected to superstructure or reinforcing and pre-stressing steel in regions where only compressive stresses occur at extreme concrete fibres under frequent load combinations. • The UK National Annex has further exceptions for deck slabs.	• Fatigue explicitly considered for welded reinforcing bars only (using BS 5400: part 10).
4.2	Exemptions from assessment	• Not specified, but the commentary notes that bridges subject to heavy traffic will usually need to remain fully pre-stressed under the effects of the fatigue design loading to meet the steel stress limits under the design fatigue loads.	• Buried arch, frame structures with min. 1.0m earth cover, foundations, retaining walls. Piers, columns, and abutments not rigidly connected to superstructure. Pre-stressing and reinforcing steel where concrete remains in compression under frequent load combinations. • The UK Annex adds local wheel load effects on slabs spanning between beam webs with: no welded or coupled rebar; span/thickness <= 18. Slabs must be composite with supporting webs and diaphragms (or length/width>3).	
4.3	Fatigue design approach – reinforcing and pre-stressing steel	• Design stress ranges in pre-stressing and reinforcing steel typically limited to 100MPa (post-tensioning in grouted steel ducts) and 150MPa (rebar, strand, or tendons in grouted plastic ducts) for $2x10^6$ stress cycles. Variation for different numbers of cycles is similar to that for structural steel with exponent m = 3 (2.5.5). Deflected strands have a lower limit (70MPa). • No strength reduction factor is specified. • Stress range for both flexural and shear reinforcement to be determined by truss analogy with variable strut angle and all shear in reinforcing.	• S-N curves (EN 1992-1-1:2004 tables 6.3N, 6.4N), with safety factor $\gamma_{S,fat}$ = 1.15 (comparable to ϕ = 0.87). • The exponent m is larger than for structural steel (for rebar m = 5 for $N<1x10^6$ or 9 for higher cycle counts). For comparison with AS 5100.5, the fatigue strength for rebar is $\Delta\sigma_{Rsk}$ = 162.5MPa at $1x10^6$ cycles and 150MPa at $2x10^6$ cycles (same, but a reduction factor must be applied, and variation with N is different). Other values at $2x10^6$ cycles limits are 171MPa for pretensioned steel and single strands in plastic ducts, 109MPa for curved tendons in steel ducts (with m = 5,7), 140MPa for curved tendons in plastic ducts or straight tendons (with m = 5,10), 70MPa for tendon splices, and 60 MPa at rebar couplers (m = 3 to 10^7 cycles, m = 5 above).	Stress range under SLS loadings limited to 325MPa for grade 460 bars and to 265MPa for grade 250 bars.
4.5	Fatigue design approach – concrete	Concrete compressive stress (including permanent effects) under the fatigue design loading limited to the smaller of $0.45f'_c$ and 18MPa, and beam web shear limited to 60% of the ULS strength for web crushing. Similar limit applied to slab flexural shear.	Limits on repetitive maximum compression stress are specified for $1x10^6$ cycles. The limit varies with both maximum and minimum compression stresses rather the range, and the fatigue strength decreases linearly with logN. Review of the formulae with typical concrete strength parameters indicates that the maximum stress limit may be significantly less than $0.45f'_c$ for high cycle counts, or that the allowable cycles at $0.45f'_c$ max. would be low (less than 100).	Not explicitly considered. A limitation on concrete compression stresses applies at SLS, eg bending stress limited to $0.5f_{cu}$ for reinforced concrete or $0.4f_{cu}$ for pre-stressed concrete ($\approx 0.45f'_c$). Note: SLS live loadings are characteristic loads with 5% exceedance probability in 120 years.
4.5	Comments	The significant difference between the S-N curves in the Eurocodes and the assumption of m = 3 in AS 5100.5 indicates that the damage equivalence applied in the fatigue loading (AS 5100.2) needs to be reviewed.	N/A	N/A

Table B.11b Material-specific fatigue design procedures –reinforced and pre-stressed concrete bridges (North America)

		AASHTO LRFD Bridge Design Specifications	Canadian Highway Bridge Design Code (CHBDC) Section 10.17
4.1	Fatigue design approach – general	Fatigue design need only be considered if the compressive stress is less than 2* the maximum tensile live load resulting from the passage of the fatigue design truck (0.75*HL-93) (ie 2*(0.75*HL-93) = 1.5*HL-93. Consideration of fatigue for welded or mechanical splices of reinforcing when number of stress cycles exceeds 1,000,000.	Code specifies that 'tack welding of reinforcing bars is not permitted since it can reduce fatigue resistance by creating a stress-raising notch effect'. Fatigue need not be considered for reinforcement in deck slabs designed by the empirical method.
4.2	Fatigue design approach – reinforcing	Fatigue design provisions for straight reinforcing bars are as per Helgason et al (1976), in which it is recommended that the stress range resulting from the fatigue load combination shall satisfy: $f_f \leq 146\text{-}0.33\ f_{min} + 55(r/h)$ where f_{min} = the minimum live load stress resulting from the fatigue load combination combined with the most severe stress from either permanent loading or (permanent loading + shrinkage + creep-induced external loads) and where r/h is the ratio of base radius to height of rolled on deformations. For welded or mechanical splices of reinforcement, limiting stress ranges are specified for different types of splices subjected to greater than 1,00,000 cycles: • grout-filled sleeve, with or without epoxy coated bar = 126MPa • cold-swaged coupling sleeves without threaded ends and with or without epoxy-coated bar: integrally forged coupler with upset NC threads; steel sleeve with a wedge; one-piece taper-threaded coupler; and single V-groove direct Butt weld = 84MPa • all other types of splices = 28MPa.	Code adopts provisions as per Helgason et al (1976) (same as AASHTO). However, code recognises the difficulties associated with the calculation of r/h and an accurate f_{min} by instead providing values that provide a lower bound stress range: a) Stress range in straight bars shall not exceed 125MPa b) The stress range at anchorages, connections, and bends shall not exceed 65MPa c) For bars containing complete joint penetration groove welds conforming to the requirements of CSA Standard W186, the stress range in the vicinity of welds shall not exceed 100MPa. For other types of welds, the stress range shall not exceed 65MPa. Code specifies that unless noted otherwise, tack welding to reinforcing bars is not permitted.
4.3	Fatigue design approach – pre-stressing tendons	Code specifies limits for stress ranges in tendons as: • 125MPa for radii of curvature in excess of 9m • 70MPa for radii of curvature less than 3.6m where linear interpolation is used for intermediate values.	Code specifies limits for stress ranges in strands: • Limits that are based on radii of curvature are as per AASHTO but with further limits specified for. • The stress range in tendons at couplers is to be less than 70MPa. • The stress range in corrugated plastic ducts is to be less than 125MPa. • The stress range in deformed and high-strength bars shall not exceed 70MPa and 90MPa respectively.
4.4	Fatigue design approach – concrete	Not considered.	Not considered.
4.5	Comments	N/A	N/A

Table B.12a Material-specific fatigue design procedures – composite structural steel beams with reinforced concrete decks (Australia, Europe, and the UK)

		AS 5100.6	EN 1994-2:2005	BS 5400, part 10: 1980, BS 5400, part 5: 1990
5.1	Fatigue design approach – general	As for structural steel components.	Structural steel components covered by EN 1993-2, reinforcing by EN 1992-2. Procedures for welded shear connectors are similar to EN 1993-2 unless noted.	Fatigue considered for welded shear connectors using BS 5400: part 10. Procedures are as for welded steel components unless noted.
5.2	S-N curves for shear connectors	Same as BS 5400: part 10, for shear stress in the weld metal attaching the shear connectors. Detail category 80 in the adjacent parent metal.	S-N curve for shear stress range in shear stud shank area gives 90MPa at $2x10^6$ cycles, with m = 8. Detail category 80 in the adjacent parent metal.	Fatigue Class S, stress range calculated on effective weld throat area. S-N curve gives 100MPa at $2x10^6$ cycles, with m = 8.
5.3	Analysis for shear connector force range	Longitudinal shear per unit length at the steel–concrete interface calculated by elastic analysis as for serviceability limit state. Axial forces not carried by ties are combined with shear.	Longitudinal shear per unit length at the steel– concrete interface calculated by elastic analysis as for serviceability limit state. Tension stiffening may by allowed for.	Longitudinal shear per unit length at the steel–concrete interface calculated by elastic analysis as for serviceability limit state.
5.4	Simplified method availability	AS 5100.2 standard fatigue vehicle.	Model 3 (standard fatigue vehicle) is supported (also Models 1 and 2).	Simplified method – fatigue vehicle without damage calculation.

Table B.12b Material-specific fatigue design procedures – composite structural steel with reinforced concrete decks (North America)

	Item	AASHTO LRFD Bridge Design Specifications	Canadian Highway Bridge Design Code (CHBDC) Section 10.17
5.1	Fatigue design approach – general	The pitch of the shear connectors are determined to satisfy Fatigue Limit State Requirements. The fatigue shear resistance of an individual shear connector is evaluated as per Slutter and Fisher (1966). The pitch is determined using the evaluated shear resistance and the shear force range. The effect of a shear connector on the fatigue resistance of the flange is investigated using the provisions for load-induced fatigue.	
5.2	Shear connectors	The fatigue shear resistance of an individual shear connector is evaluated as per Slutter and Fisher (1966).	

Appendix B references

British Standards Institution (2008) *PD 6695-1-9:2008. Recommendations for the design of structures to BS EN 1993-1-9*. London: British Standards Institution.

Helgason, T, JM Hanson, NF Somes, WG Corley and E Hognestad (1976) Fatigue strength of high-yield reinforcing bars. *National Cooperative Highway Research Program (NCHRP) report 164*. 31pp.

Mertz, D (2013) *FWHA workshop on manual for design, construction, and maintenance of orthotropic steel deck bridges*. Sacramento, 25 June 2013.

Slutter, RG and JW Fisher (1966) Fatigue strength of shear connectors. *Fritz Engineering Laboratory report no. 316.2*, Lehigh University.

Appendix C Additional WIM site fatigue load processing results

This appendix includes additional outputs from the fatigue load processing described in chapter 5 and the configuration data for the fatigue vehicles referenced in that chapter.

C.1 Current bridge fatigue loading at WIM sites – equivalent HN loading approach

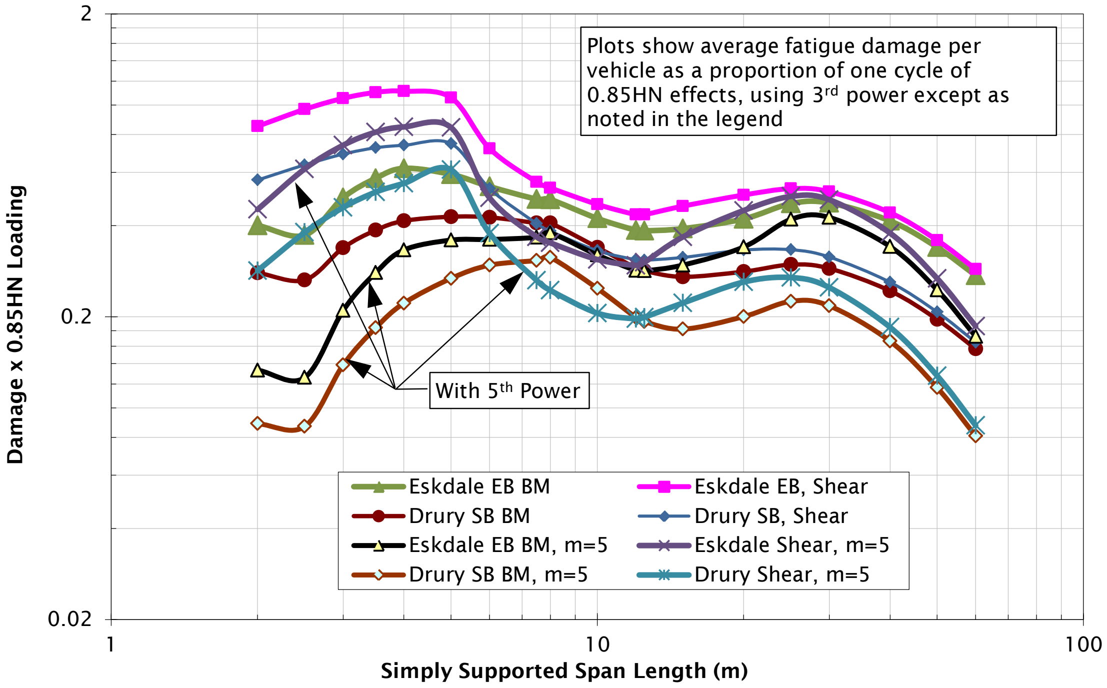
Heavy vehicle counts compiled by class for short periods are available from state highway telemetry sites (see appendix D) or can be obtained from site traffic surveys. Combining the data from classified vehicle counts with the damage breakdowns by class from a suitable WIM station (where proportions of fully laden vehicles are considered to be similar) enables estimation of site-specific fatigue loadings.

The results in appendix C were presented in a progress report for an earlier stage of this research project, prior to development of the vehicle spectrum models present in chapter 6. A more direct process is now available for estimating fatigue loading at other sites, using the vehicle spectra and vehicle set proportions at various sites (see appendix D). The appendix C results were derived from the WIM vehicle datasets and indicated less damage per vehicle on average, due to slight conservatism introduced by the fitting process (as discussed in chapter 6.4).

C.2 Fatigue loading relative to 0.85HN single-lane loading

If the moments, shear forces and reaction forces for a single lane of 0.85HN loading are used as the reference loading for calculation of average equivalent cycles per heavy vehicle (see figure C.1), it is apparent that a simple relationship between damage per vehicle and span length (of similar form to the M1600 relationship) does not exist, and there are significant differences in the form of the cycle count versus span relationships for shear force and bending moment at short spans. However, the numerical results in terms of equivalent numbers of repetitions of 0.85HN are of interest for the assessment of *current* fatigue load effects.

Figure C.1 WIM site results vs 0.85HN single-lane loading (damage equivalent cycles per heavy vehicle)



In the chart above, it is apparent that the results for the 5th-power rule remain less than, but are of similar order to, the results with the 3rd-power rule. Thus it may be advisable to adopt the 3rd-power rule at all span lengths if using equivalent repetitions of 85HN effects for fatigue assessments of existing structures designed to older loading standards, such that normal stress levels under frequent loadings may exceed the CAFL.

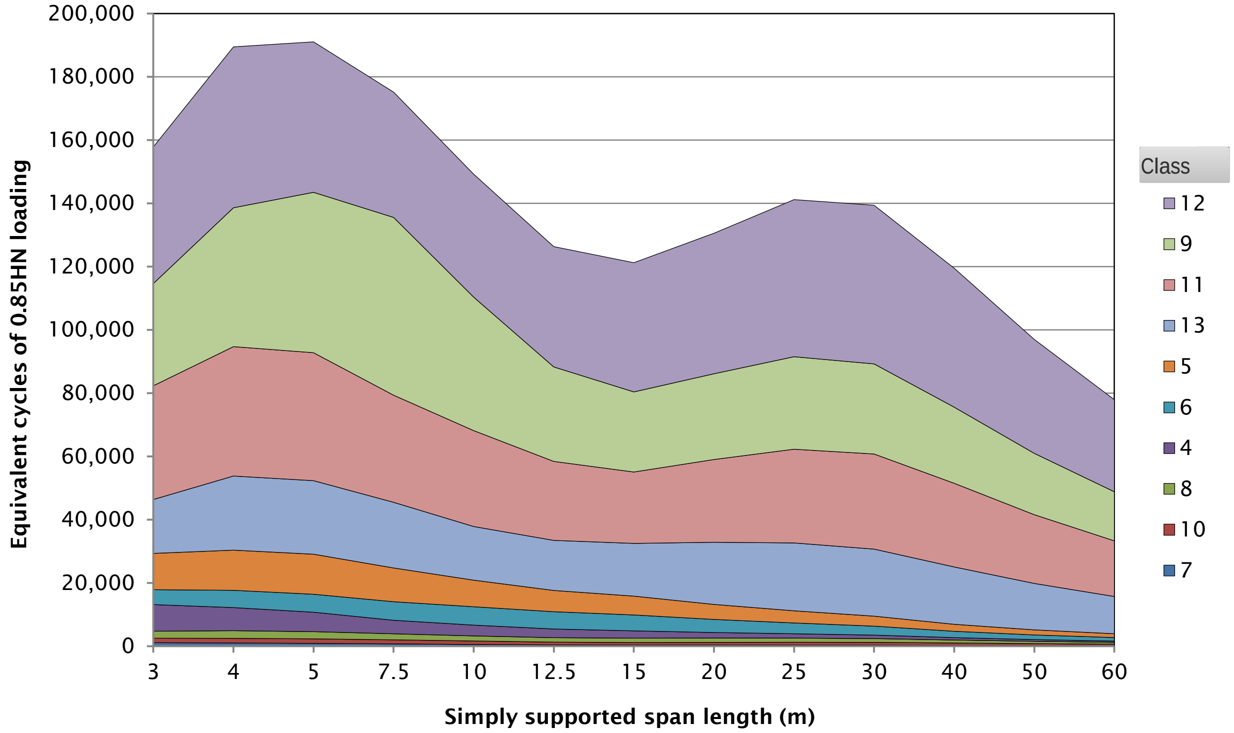
For assessment of detail categories subject to shear stress, the 5th-power rule is applicable to all stress ranges.

C.3 Fatigue loading – breakdown by vehicle class

Figure C.1 shows the fatigue loading at a few WIM sites on main highways or urban motorways, which may or may not adequately represent the damage per vehicle characteristics on other route types. Breaking down the damage summations by vehicle type shows the relative contributions, and enables more-detailed comparisons between sites. Figures C.2–C.6 show a selection of the processed results, as equivalent repetitions of 0.85HN lane load effects versus span. The corresponding tabular results (for 3rd- and 5th-power damage rules) are available on request.

Figure C.2 Drury Lane 1 NB May 2010–Mar 2011 (542,230 vehicles) vs 0.85HN loading

(a) Bending moment cycles, m = 3



(b) Shear force cycles, m = 3

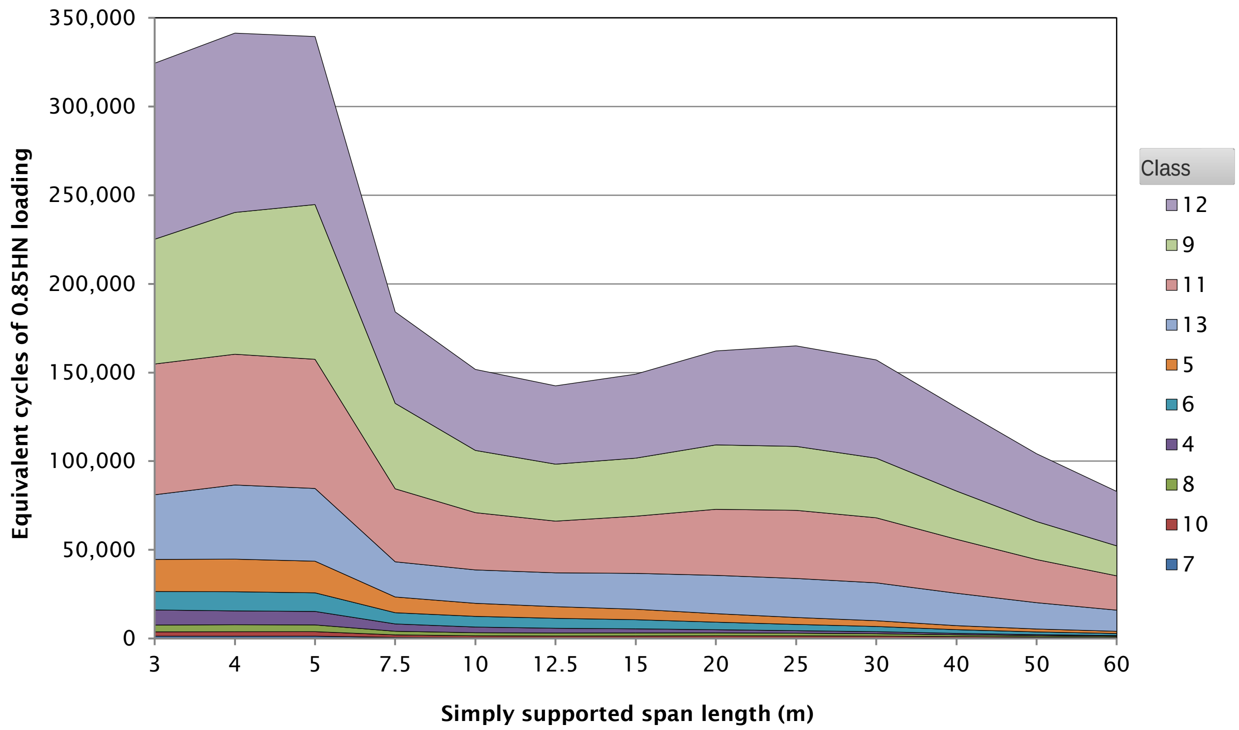
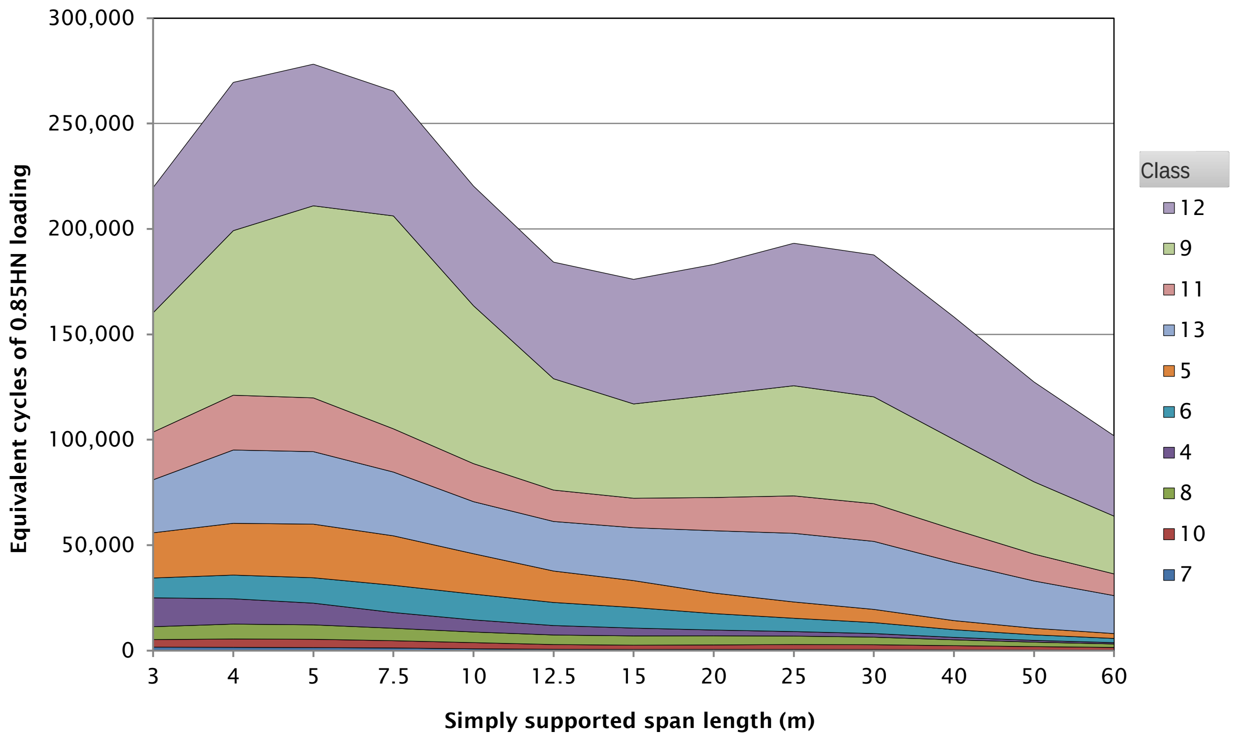
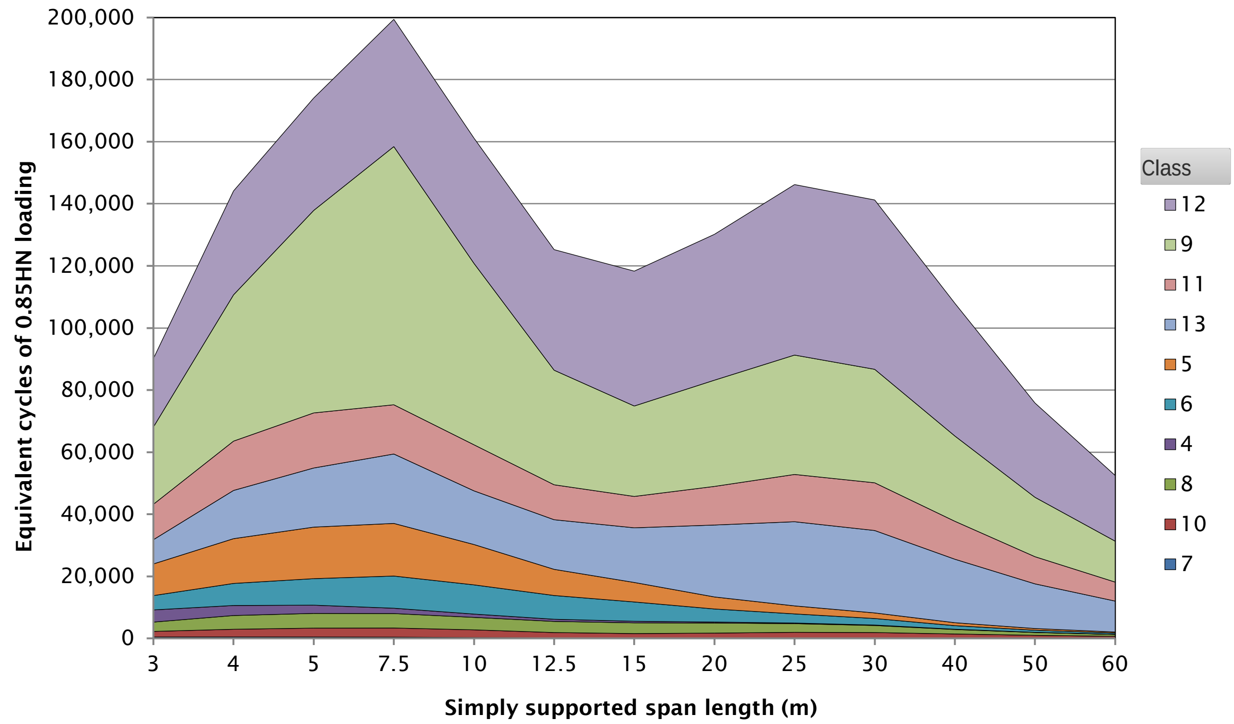


Figure C.3 Drury Lane 1 SB Jan-Dec 2011 (650,030 vehicles) vs 0.85HN loading

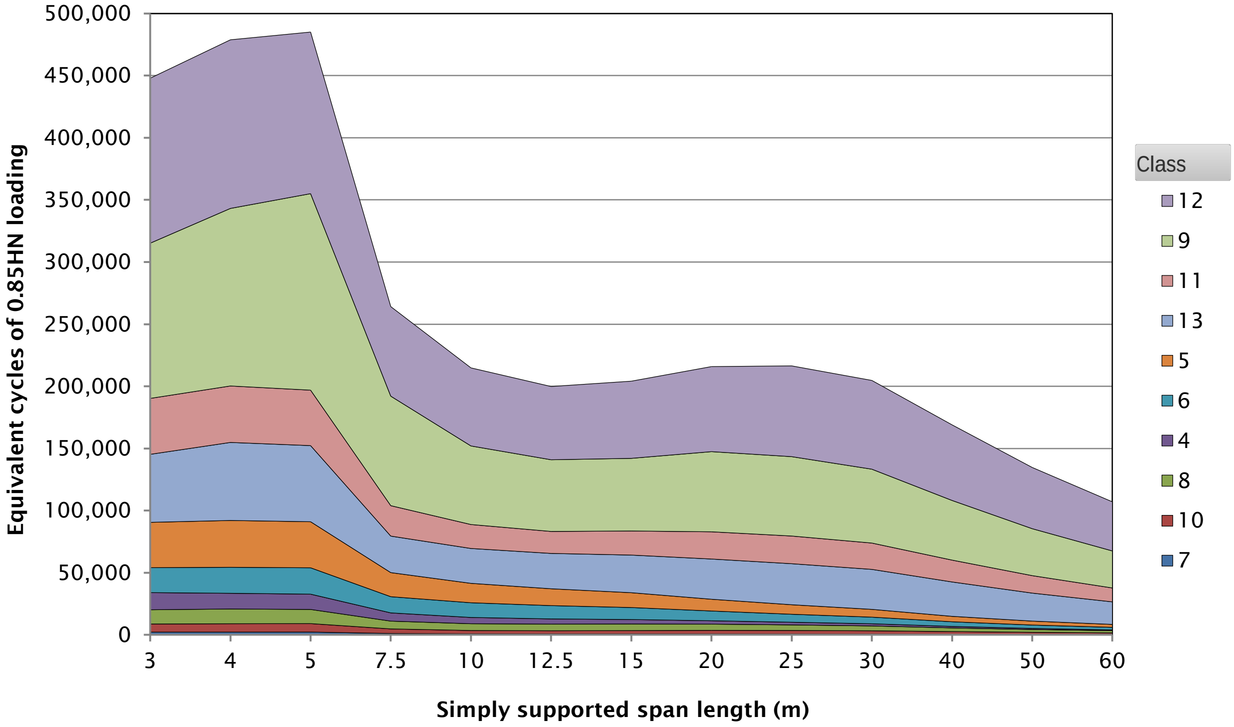
(a) Bending moment cycles, m = 3



(b) Bending moment cycles, m = 5



(c) Shear force cycles, m = 3



(d) Shear force cycles, m = 5

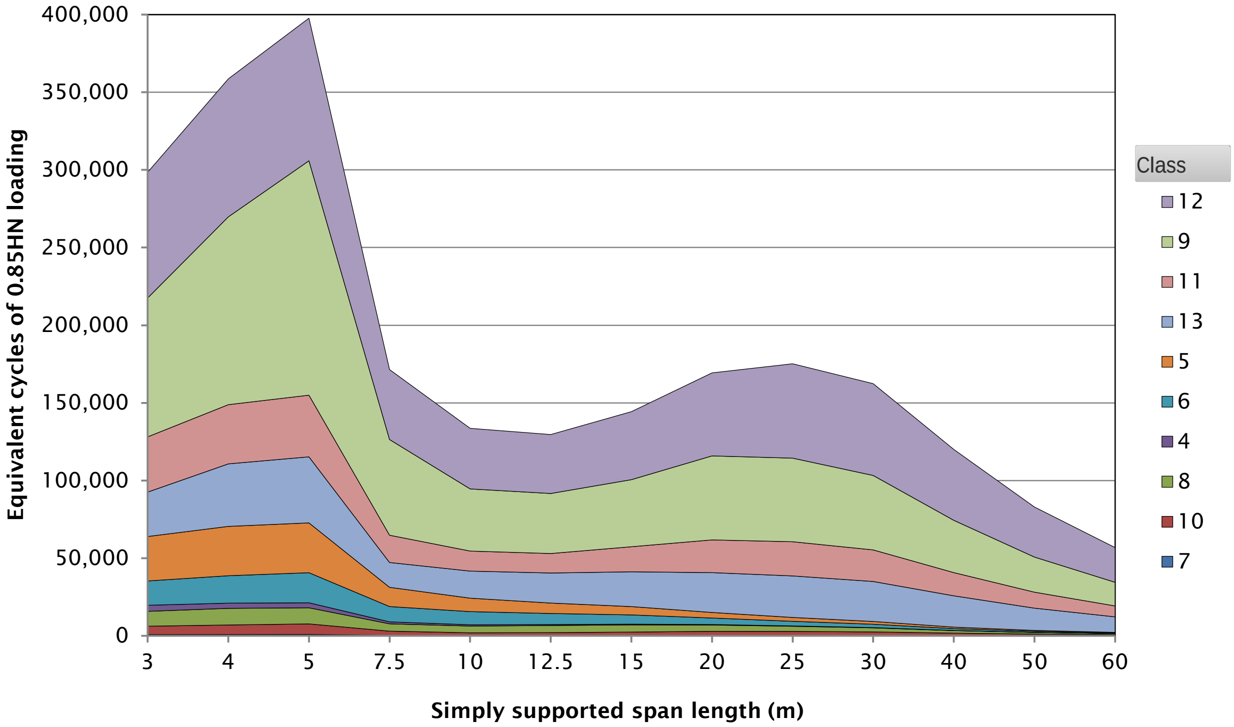
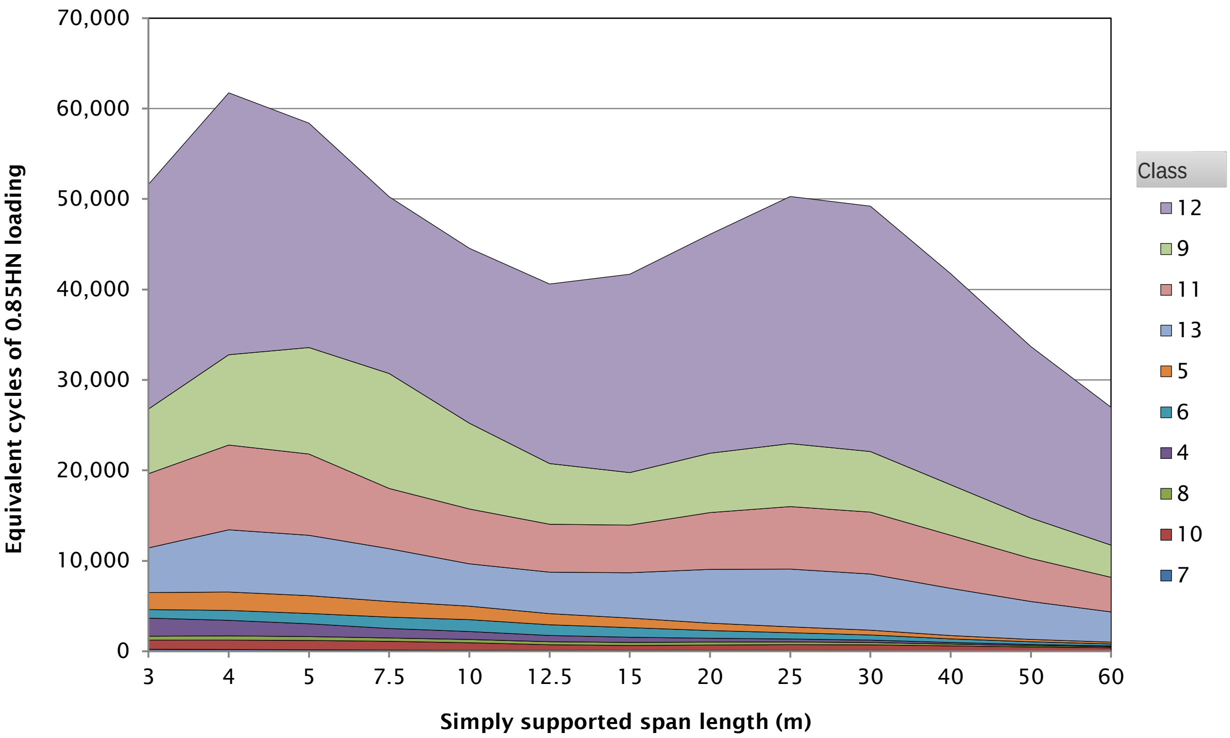


Figure C.4 Te Puke, Westbound, Jan–May 2010 (126,100 vehicles) vs 0.85HN loading

(a) Bending moment cycles, m = 3



(b) Shear force cycles, m = 3

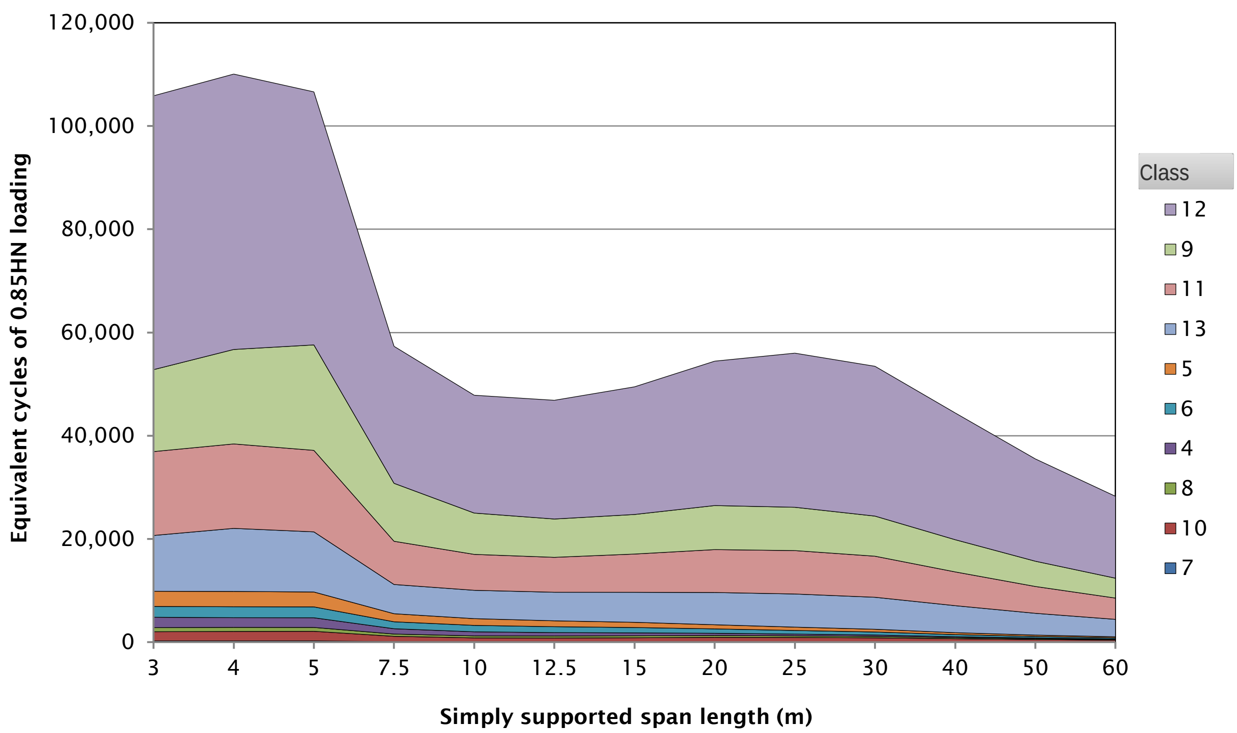
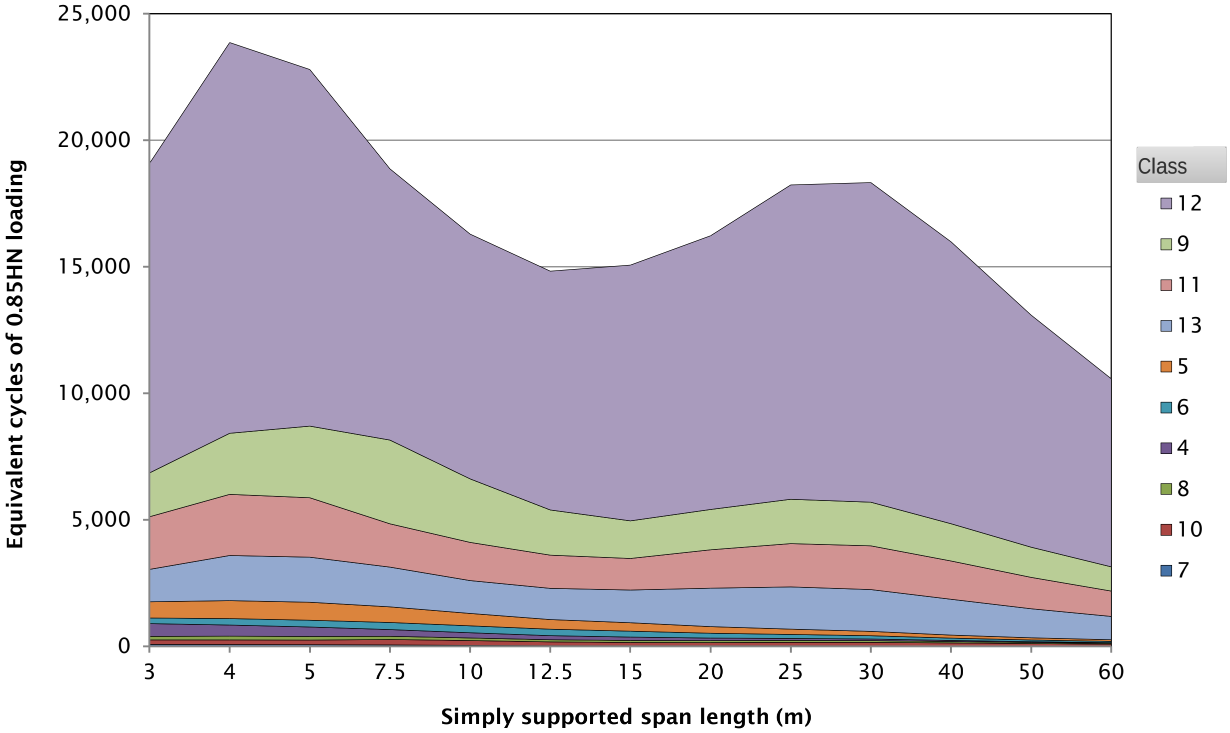


Figure C.5 Eskdale, Eastbound, Oct 2010–Feb 2011 (38,170 vehicles) vs 0.85HN loading

(a) Bending moment cycles, m = 3



(b) Shear force cycles, m = 3

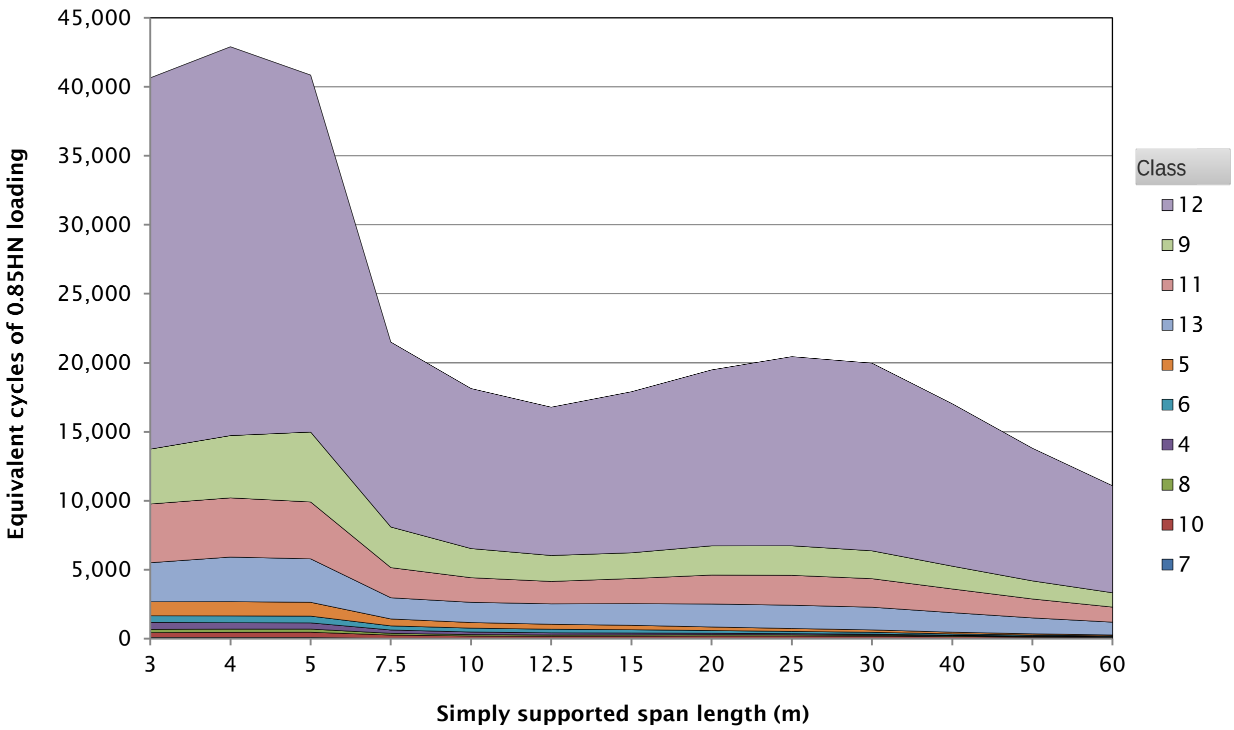
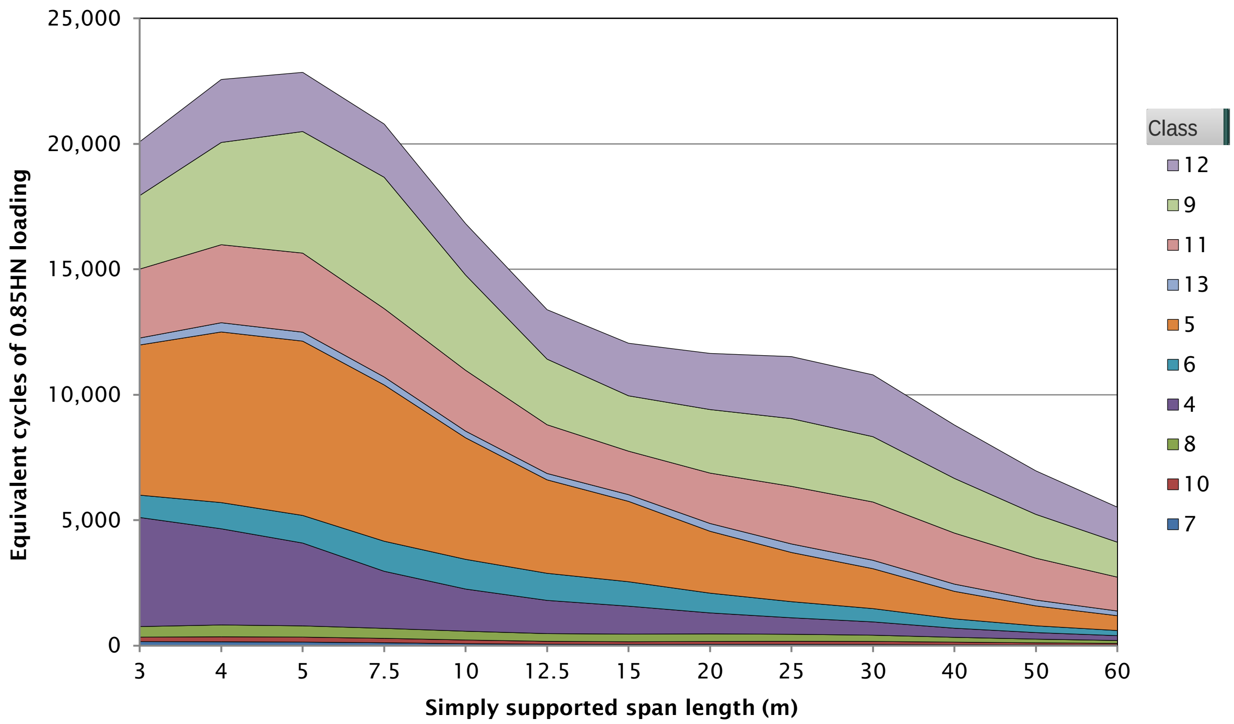
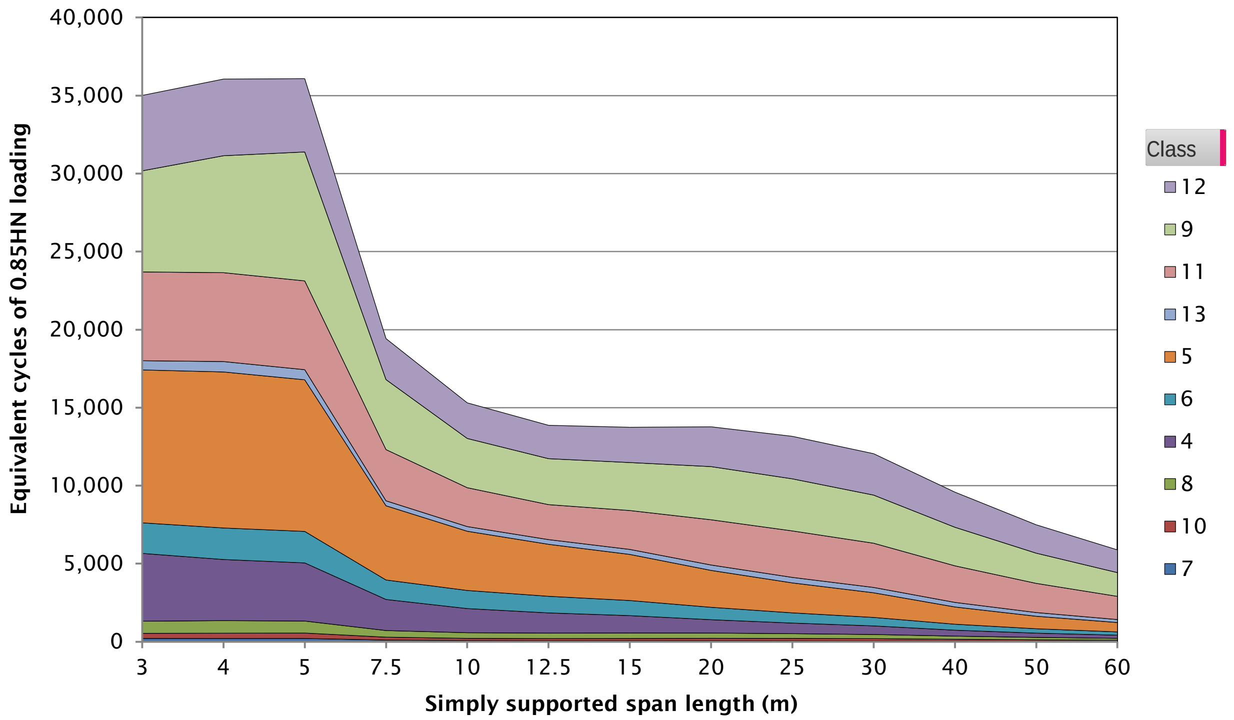


Figure C.6 AHB Northbound, Mar 2011 (89,540 heavy vehicles) vs 0.85HN loading

(a) Bending moment cycles, m = 3



(b) Shear force cycles, m = 3



C.4 Standard fatigue vehicle details

The tables below provide the dimensions and axle masses for the vehicles (other than M1600) used for the single-vehicle fatigue model comparisons (see section 5.7).

Table C.1 Miscellaneous 4- or 5-axle standard fatigue vehicles and *pro forma* vehicles

Vehicle description	Axle weight (kN) and spacing (m)											Total
	Axles	1	2	3	4	5	6	7	8	9	10	
Eurocode FLM3	4	120	120	120	120							480kN
		1.2	6	1.2								8.4m
HL-93 FWHA version	5	35	72.5	72.5	72.5	72.5						325kN
		3.7	1.22	7.78	1.22							13.9m
CL-625 (Canada)	5	50	125	125	175	150						625kN
		3.6	1.2	6.6	6.6							18.0m
T44 reduced to 39 tonne	5	42.5	85	85	85	85						383kN
		3.7	1.2	5.5	1.2							11.6m
A124 45 tonne	7	69	78.5	78.5	54	54	54	54				442kN
		3.5	1.3	4.95	1.25	1.25	1.25					13.5m
R22T22 44 tonne	8	43	43	61	61	56	56	56	56			432kN
		1.8	3.3	1.3	4.2	1.25	4.2	1.25				17.3m
R22T22 54 tonne	8	50	50	75	75	70	70	70	70			530kN
		1.8	3.3	1.3	4.2	1.25	4.23	1.25				17.4m
R23T23 57 tonne	10	49	49	54	54	54	69	69	54	54	54	560kN
		1.8	2.9	1.3	1.3	3.7	1.3	4.6	1.3	1.3		19.5m

C.5 Application of equivalent 0.85HN fatigue loadings

The results in terms of 0.85HN equivalence shown graphically in appendix C are not suitable for use in design of new structures, but may be of use for assessing fatigue loadings on existing structures under current loading. This process would be more complex than applying a single-vehicle fatigue model but may be less complex than a full vehicle spectrum method, because cycle counting of the vehicle spectrum actions is not required. The spectrum method would be more accurate because the correct S-N curves can be applied to the stress cycle results. Also, the results in this appendix were derived for mid-span bending moments or end support actions in simply supported spans, and have not been tested for other influence line forms (such as negative bending moments in multiple-span continuous girders).

The matters to be considered when estimating the current fatigue damage rates include the following:

- Heavy vehicle counts and weight characteristics:
  - review of available heavy traffic count data for the bridge site and connected routes
  - selection of a WIM site with comparable heavy vehicle mix and loading. WIM site heavy vehicle weight characteristics are presented in appendix H and the Transport Agency’s annual WIM reports
  - estimation of the applicable average daily truck counts to use for scaling the results from WIM site data. Typically, the recorded counts for 2-axle vehicles are not a reliable measure of ‘heavy’ 2-axle vehicles, and scale factors should be based on counts for vehicles with three or more axles (see table 4.3)

- lane share on multiple-lane urban routes should be considered (see section 10.1.5)

- average number of equivalent 0.85HN loading cycles per heavy vehicle using the charts above and tabular results (available on request)
- applicability of 3rd- or 5th-power results
- breakdowns of damage estimates by vehicle class
- adjustments for minor variations in vehicle class mix are possible if classified vehicle counts are available and vehicle loading characteristics for the predominant vehicle class(es) are similar to the chosen WIM site
- estimation of stress ranges under 0.85HN loading:
  - the stress ranges for use with the equivalent cycle counts would be taken from the envelope of effects under one lane of 0.85HN loading
  - other aspects of the calculation procedures would be similar to the methods for design fatigue vehicles (chapter 10).

C.6 Example – estimation of fatigue loadings for SH1 Paekakariki

This example was prepared at an earlier stage of the research project as a demonstration of how the results in terms of equivalent 0.85HN cycles might be applied to synthesise estimates of fatigue loadings at sites where classified count data is available but not measurements of vehicle weight distribution. A process using the truck weight spectra provided in table 6.7 as the base WIM data would be similar.

C.6.1 Inputs

Data for the Paekakariki site from the TMS database: hourly vehicle counts classified into classes 1–14 by the Transport Agency's NZTA 2011 classification scheme, for 350 days in the year 2011 in both directions.

Data from WIM sites (including AHB): damage spectra in term of equivalent repetitions of a standard vehicle, processed from raw data records for spans of 2–60m and summarised by vehicle class for the valid heavy vehicle classes (4–13).

C.6.2 Methodology

- Select the appropriate WIM dataset on which to base the fatigue loading estimate. The data from Drury southbound for 2011 was selected, as both situations represent traffic leaving a major city (Auckland for the Drury data and Wellington for the Paekakariki data).
- For each of the two power rules (m = 3 and m = 5) and each of moment effects (M), shear effects (V) and reaction effects (R):
  - Present the Drury data as average damage per vehicle for each span length and NZTA 2011 class, as shown in table C.2 for m = 3 and moment effects.
  - Multiply the above values by the total vehicle counts for each class from the Paekakariki site (see table C.3) to obtain the fatigue damage for the Paekakariki 350 day dataset (see table C.4).
  - Factor the results by 365/350 to estimate counts for a full year.

- Factor the results to account for vehicles in class 14 (unclassified), as this class is not included in the data processed for the Drury site. Paekakariki 2011 has a class 14 count of 8522, out of a total count of 322,433. The factor to account for class 14 is therefore 322,433/(322,433-8522) = 1.027.

The annual fatigue loading for the Paekakariki northbound direction in 2011 is shown in table C.5 and figure C.7. The average damage per vehicle is shown in comparison to AHB northbound and Drury southbound in figure C.8. This shows that the 2011 Paekakariki fatigue loading estimates with m = 3 (average per heavy vehicle) lie between the Drury and AHB results.

However, the result derived using the truck weight spectra and recommended fatigue vehicles (see table 9.3) indicates that average fatigue loading per vehicle for the Paekakariki site is estimated to be higher than the AHB site, but less than for the Drury site. This relative increase attributed to the discrete spectrum vehicle fitting and rationalisation illustrates the caution required when choosing suitable WIM data to represent the target site, and methods using the truck weight spectra are recommended.

Table C.2 Average fatigue damage per vehicle as a proportion of 0.85HN loading for Drury southbound 2011, m = 3, moment effects (equivalent to the results plotted in figure C.3a)

Span (m)	NZTA 2011 class										All classes
	4	5	6	7	8	9	10	11	12	13	
2	0.08	0.25	0.25	0.24	0.39	0.35	0.53	0.38	0.36	0.39	0.32
2.5	0.08	0.23	0.23	0.22	0.37	0.33	0.47	0.37	0.32	0.37	0.29
3	0.08	0.26	0.28	0.23	0.43	0.43	0.48	0.47	0.41	0.50	0.35
3.5	0.07	0.27	0.35	0.22	0.46	0.53	0.49	0.52	0.48	0.60	0.40
4	0.07	0.27	0.42	0.21	0.47	0.61	0.49	0.54	0.52	0.66	0.43
5	0.06	0.27	0.51	0.19	0.46	0.73	0.49	0.53	0.53	0.66	0.46
6	0.05	0.25	0.56	0.18	0.43	0.83	0.50	0.50	0.50	0.61	0.46
7.5	0.04	0.25	0.60	0.18	0.40	0.82	0.51	0.43	0.48	0.55	0.45
8	0.04	0.25	0.61	0.17	0.39	0.81	0.51	0.44	0.49	0.55	0.45
10	0.03	0.21	0.54	0.12	0.31	0.62	0.45	0.38	0.45	0.48	0.37
12	0.03	0.17	0.48	0.09	0.26	0.47	0.37	0.33	0.42	0.44	0.32
12.5	0.02	0.16	0.47	0.09	0.25	0.45	0.36	0.32	0.42	0.45	0.31
15	0.02	0.14	0.42	0.08	0.24	0.38	0.33	0.29	0.45	0.46	0.29
20	0.02	0.12	0.34	0.08	0.24	0.40	0.32	0.33	0.49	0.54	0.29
25	0.02	0.10	0.28	0.08	0.23	0.43	0.34	0.37	0.54	0.60	0.31
30	0.01	0.08	0.23	0.07	0.21	0.42	0.34	0.37	0.55	0.60	0.30
40	0.01	0.06	0.16	0.06	0.17	0.35	0.29	0.33	0.48	0.52	0.25
50	0.01	0.04	0.12	0.04	0.13	0.29	0.23	0.27	0.39	0.43	0.20
60	0.01	0.03	0.09	0.03	0.10	0.23	0.19	0.22	0.32	0.34	0.16

Table C.3 Paekakariki northbound vehicle counts, 2011 data, 350 days

NZTA 2011 class	Vehicle count	Class proportion
4	140,205	43%
5	32,851	10%
6	16,851	5%
7	2884	1%
8	1620	1%
9	42,744	13%
10	1905	1%
11	6034	2%
12	37,101	12%
13	31,716	10%
14	8522	3%
Total	**322,433**	

Table C.4 Fatigue damage as equivalent cycles of 0.85HN loading for Paekakariki northbound 2011, m = 3, moment effects (based on recorded classified counts for 350 days)

Span	NZTA 2011 class										Total
	4	5	6	7	8	9	10	11	12	13	
2	11,791	8057	4169	679	630	14,889	1016	2309	13,350	12,239	69,129
2.5	11,170	7691	3857	643	605	13,906	899	2248	11,922	11,787	64,727
3	10,526	8678	4786	654	704	18,411	917	2843	15,178	15,808	78,506
3.5	9888	8857	5954	641	752	22,656	939	3143	17,783	19,077	89,691
4	9195	8871	7028	603	768	26,096	938	3257	19,475	20,996	97,224
5	7861	8762	8561	553	748	31,200	929	3195	19,577	20,892	102,279
6	6804	8262	9406	520	699	35,516	951	3005	18,511	19,280	102,953
7.5	5762	8060	10,055	508	645	35,157	962	2621	17,933	17,508	99,214
8	5587	8135	10,205	495	634	34,475	979	2637	18,172	17,396	98,716
10	4359	6758	9058	353	495	26,357	859	2316	16,522	15,113	82,190
12	3550	5589	8021	270	421	20,043	711	1971	15,731	14,099	70,406
12.5	3445	5399	7847	259	411	19,099	688	1909	15,735	14,130	68,923
15	3071	4714	7088	223	386	16,222	622	1779	16,692	14,721	65,519
20	2565	3844	5754	231	388	17,064	618	1989	18,278	17,087	67,819
25	2166	3209	4696	224	374	18,414	657	2243	20,077	19,084	71,144
30	1828	2699	3873	205	343	17,948	646	2260	20,288	19,103	69,193
40	1321	1947	2721	162	272	15,170	551	1974	17,794	16,567	58,478
50	979	1442	1983	127	212	12,222	446	1617	14,602	13,510	47,140
60	744	1095	1489	99	167	9777	358	1306	11,809	10,882	37,726

Table C.5 Fatigue damage as equivalent cycles of 0.85HN loading, Paekakariki northbound 2011, m = 3, moment effects, factored to a full year's loading and to account for unclassified vehicles

Span	NZTA 2011 class										Total
	4	5	6	7	8	9	10	11	12	13	
2	12,630	8631	4466	727	674	15,949	1088	2473	14,300	13,110	74,049
2.5	11,965	8238	4131	688	648	14,895	963	2408	12,771	12,626	69,333
3	11,275	9295	5127	700	754	19,721	982	3045	16,259	16,933	84,093
3.5	10,592	9488	6377	686	806	24,269	1006	3366	19,049	20,435	96,074
4	9849	9502	7528	646	822	27,953	1004	3488	20,861	22,490	104,144
5	8421	9386	9170	592	801	33,421	995	3423	20,970	22,379	109,558
6	7288	8850	10,075	557	748	38,043	1019	3218	19,828	20,652	110,280
7.5	6173	8634	10,771	544	691	37,659	1031	2807	19,210	18,754	106,274
8	5985	8714	10,931	530	679	36,929	1049	2825	19,466	18,634	105,741
10	4669	7239	9703	378	531	28,233	920	2481	17,698	16,189	88,040
12	3803	5987	8592	290	451	21,469	761	2111	16,850	15,103	75,417
12.5	3690	5784	8406	277	440	20,459	737	2045	16,855	15,136	73,828
15	3290	5050	7593	239	413	17,377	666	1905	17,880	15,768	70,182
20	2748	4118	6164	248	416	18,278	662	2130	19,579	18,303	72,646
25	2320	3437	5030	240	401	19,725	704	2403	21,506	20,442	76,207
30	1958	2892	4149	220	368	19,226	691	2421	21,732	20,462	74,118
40	1415	2085	2914	174	292	16,249	590	2115	19,060	17,746	62,640
50	1049	1545	2124	136	228	13,092	478	1732	15,641	14,471	50,495
60	796	1173	1595	106	178	10,473	383	1399	12,650	11,657	40,411

Figure C.7 Fatigue damage as a proportion of 0.85HN loading, Paekakariki northbound 2011, m = 3, moment effects, factored to a full year's loading and to account for unclassified vehicles

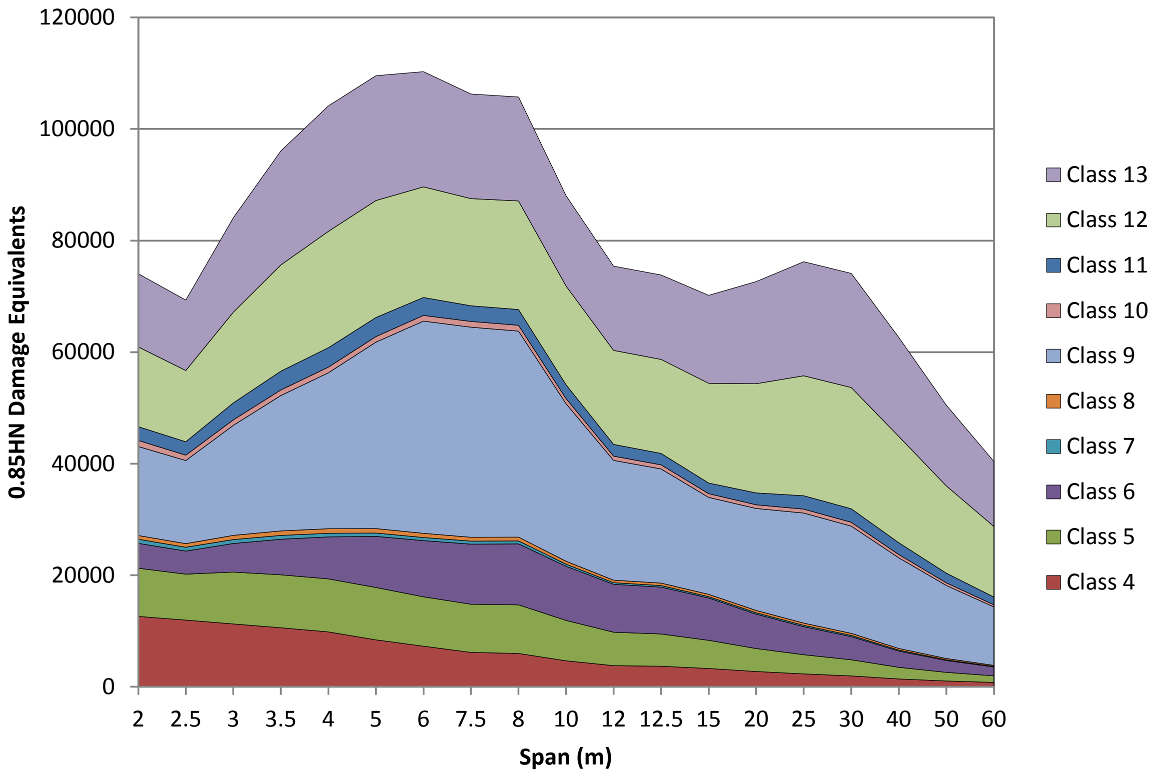
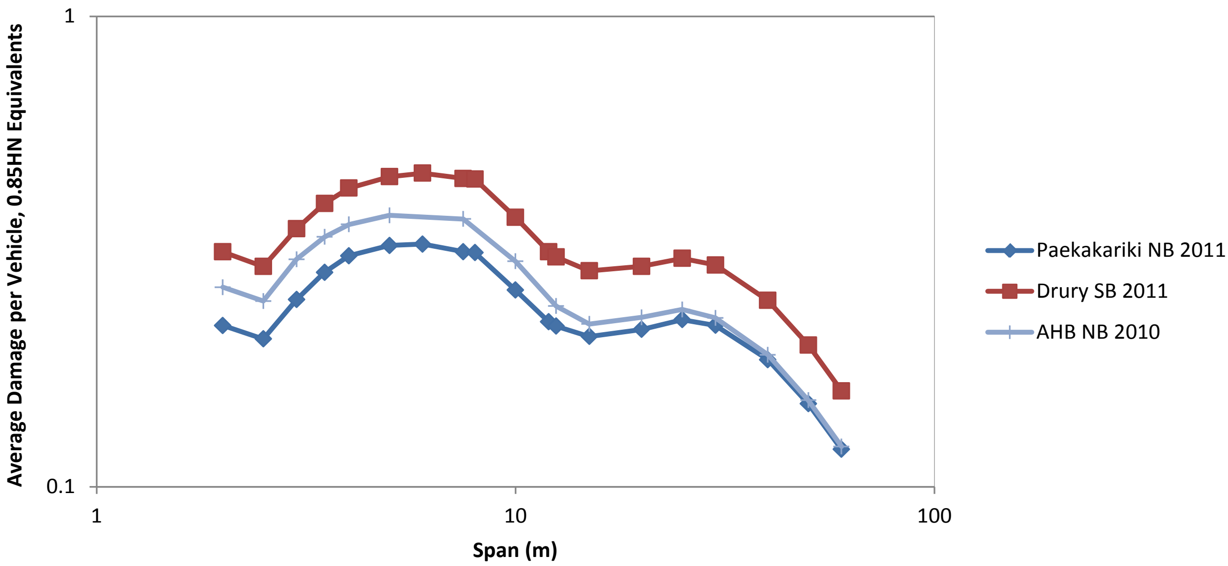


Figure C.8 Average fatigue damage per vehicle as a proportion of 0.85HN loading for Paekakariki, Drury and AHB, m = 3, moment effects



Appendix D Estimation of current fatigue loadings for other sites

The Transport Agency operates continuous traffic count stations on several state highways. Periodically (typically 1–2 weeks per year), contractors gather samples of axle-classified data to obtain estimates of the typical heavy vehicle mixes. Summaries of classified data for 2011 are presented in table D.1.

To assist with estimates of fatigue loading, these are presented in table D.2 as percentage content for the vehicle class sets used for the vehicle spectrum development reported in chapter 6.

The sample heavy vehicle mixes were analysed to estimate the equivalent fatigue loads per heavy vehicle relative to WIM site vehicle spectra and the results were shown in table 9.3.

Comments on results of particular significance are:

- The SH45-Ohawe Beach Road site is near the intersection with SH3, en route to Fonterra's Whareroa dairy factory. This factory handles the second-largest milk volume of any factory in New Zealand and it is apparent from the high truck-and-trailer content that SH45 is likely to be a significant feeder route, with the majority of truck-and-trailers and semi-trailers operating at near maximum load in one direction. However, rail is the main transport mode for that plant (including raw milk) and the SH45 heavy vehicle mix might not reflect the SH3 mix, which would include through traffic. The Eskdale WIM site data should provide an adequate fit to the SH45 mix as is, but the Te Puke spectra was chosen for estimating the site-specific effects, giving a similar effect to the Eskdale loading.
- SH5 Hamanatua Bridge WIM site appears to be dominated by logging traffic but inspection of top-end weights indicated less overloading than the Eskdale site.
- The vehicle mix at the SH33 Paengaroa site is similar to the Eskdale site, and a proportion of vehicles on that route is headed towards Tauranga and would also cross the Te Puke WIM site.
- The SH27 Kaihere site is frequently used for long-haul freight headed towards and from Tauranga (SH2), Tokoroa (SH1), and Rotorua (SH5). Its classification as a regional connector rather than a strategic route is somewhat surprising, given the relatively high freight volume, but the Waikato Expressway (SH1) is the main investment route for the region.

The methodology for estimation of equivalent fatigue loads per heavy vehicle based on the classified vehicle counts was as follows:

- Group the counts and proportions by the vehicle class sets used for the truck weight spectra (see table 6.3). The results are shown in table D.2.
- Select the appropriate direction at the counter site and the most suitable reference truck weight spectrum from table 6.7 (see notes in section 6.8 and appendix section E.1.2).
- Form an estimate of the current truck weight spectrum by changing the vehicle set mix percentages in the selected table 6.7 reference spectrum. The resulting standard truck counts per 100,000 vehicles was the estimate for the target counter site.
- The estimated set of standard trucks replaced raw WIM in the fatigue loading processing method described in section 5.3.
- Present the results as average equivalent cycles of a chosen single fatigue vehicle per heavy vehicle.
- An efficient implementation of the above steps, use pre-calculated damage equivalent moments and shears calculated for the standard spectrum vehicles at all span lengths.

Table D.1 Vehicle classifications for WIM and other sites

Site (see appendix A for location maps)	Traffic Direction (Inc = increasing, Dec = decreasing route position)	Data Collection Period	AADT (2011)	AADT Heavy Vehicles (2011)	Average vehicles per day for selected period	Average heavy vehicle counts for selected period		Heavy vehicle classes percent of total heavy traffic (%)						
						count/day	% of total	class 4 Truck with or without light trailer 2-4 axles	class 5 Truck with/without trailer, artic 3-4 axles	class 6 Heavy truck 4-5 axles	class 9 Artic 6-8 axles	classes 11+12 T&T 7-11 axles	class 13 A/B train 8-10 axles	Others
WIM sites														
National Strategic (high volume)														
SH1N AHB	Northbound	01/03/2007-31/03/2007			83,213	3184	3.8	50.4	20.0	4.9	6.6	9.6	1.0	7.4
		01/03/2011-31/03/2011			81,266	3120	3.8	48.8	22.6	4.5	7.1	8.7	0.8	7.5
	Southbound	01/03/2007-31/03/2007			83,549	3135	3.8	48.3	19.2	4.5	5.9	9.1	1.0	12.0
		01/03/2011-31/03/2011			76,054	3080	4.1	48.4	21.6	4.2	6.9	8.3	0.8	9.7
	Both		158,199	7910										
SH1N Drury	Northbound	01/01/2005-30/09/2005			20,137	2055	10.2	27.8	9.9	5.1	14.4	24.8	6.8	11.2
		01/05/2010-31/03/2011			20,477	2148	10.5							
	Southbound	01/01/2011-31/12/2011			20,151	2013	10.0	26.7	9.7	5.1	16.1	25.7	6.2	10.5
	Both		41,794	4190										
SH2 Te Puke	Westbound	01/01/2005-30/06/2005			9203	841	9.1	28.1	8.0	4.6	11.0	34.3	6.1	7.9
		01/11/2007-31/12/2007			10,787	967	9.0							
		01/01/2010-31/05/2010			9849	936	9.5							
	Both		18,767	1891										
SH1N Tokoroa	Northbound	01/11/2005-31/12/2005			4415	712	16.1	17.8	6.7	5.3	11.6	38.0	9.2	11.4
		01/01/2010-31/07/2010			4398	680	15.5							
		01/01/2011-30/06/2011			4304	668	15.5							
	Southbound	01/08/2011-31/12/2011			4441	796	17.9	17.8	6.3	8.8	11.8	34.3	8.9	12
	Both		8503	1384										
National Strategic														
SH1S Waipara	Northbound	01/01/2007-28/02/2007			4385	515	11.7	25.2	5.4	10.9	8.7	30.4	11.2	8.2
	Southbound	01/11/2010-31/05/2011			3981	571	14.3	28.6	5.2	3.6	9.3	31.7	9.9	11.8
		01/09/2011-31/12/2011			3736	670	17.9							
	Both		7502	1135										
Regional Strategic														
SH5 Eskdale (Logging truck route)	Eastbound	01/10/2010-28/02/2011			1997	289	14.5	20.8	6.1	3	9.1	**44.1**	6.2	10.6
	Westbound	01/10/2010-28/02/2011			1979	291	14.7	17.8	6.2	**26.2**	9.4	25.6	7.3	7.5
	Both		3647	596										
Regional Distributor														
SH35 Hamanatua (Sites 100/108, Logging trucks)	Inc (Southbound)	01/03/2012-31/03/2012	-	-	2122	232	10.9	26.5	3.6	2.0	1.4	**62.6**	1.2	2.7
	Dec (Northbound)	01/03/2012-31/03/2012			2120	242	11.4	30.1	6.0	**48.0**	1.3	11.0	1.2	2.4
Other sites														
Sites with HCV count at least 400 per day														
National Strategic (high volume)														
SH1N Paekakariki (Site 47)	Northbound	2011			11626	921	7.9	43.5	10.2	5.2	13.3	13.4	9.8	4.6
	Southbound				11581	874	7.5	40.3	10.6	2.9	14.1	17.1	10.5	4.5
			23,219	1797	23208	1795	7.7	41.9	10.4	4.1	13.7	15.2	10.2	4.6
Regional Strategic														
SH3 Te Kuiti (Site 16)	Inc (Southbound)	10/11/2012-16/11/2012			2029	463	22.8	35.2	5.1	2.7	13.3	28.4	11.6	3.7
	Dec (Northbound)				2014	388	19.2	21.5	6.2	2.8	17.1	35.9	13.2	3.4
	Both		4064	673	4043	851	21.0	28.4	5.6	2.7	15.2	32.1	12.4	3.5
SH33 Paengaroa (Site 14, Logging truck route)	Inc (Southbound)	30/11/2012-06/12/2012			1838	293	16.0	25.7	5.7	2.6	11.8	**46.4**	4.8	2.9
	Dec (Northbound)				1936	356	18.4	24.3	7.4	**24.0**	11.5	26.2	4.3	2.4
	Both		3991	582	3774	649	17.2	25.0	6.6	13.6	11.7	36.0	4.5	2.7
SH1S Milton (Site 27)	Inc (Southbound)	13/01/2011-19/01/2011			3366	435	12.9	32.7	10.1	7.1	8.7	28.7	7.4	5.3
	Dec (Northbound)				3482	408	11.7	27.2	17.2	5.1	7.4	29.4	6.1	7.6
	Both		6149	798	6849	843	12.3	29.9	13.8	6.1	8.0	29.1	6.7	6.5
Regional Connector														
SH27 Kaihere (Site 33)	Inc (Southbound)	01/11/2011-07/11/2011			2200	483	22.0	21.0	5.1	4.1	16.9	32.2	16.4	4.3
	Dec (Northbound)				2182	509	23.3	28.6	6.0	3.9	15.3	29.1	13.5	3.6
	Both		4356	871	4383	992	22.6	24.8	5.5	4.0	16.1	30.7	14.9	4.0
Regional Distributor														
SH45-Ohawe Beach Road (Site 71)	Inc (Eastbound)	24/11/2011-30/11/2011			2080	290	13.9	15.3	3.7	2.4	15.3	57.4	1.9	4.0
	Dec (Westbound)				2075	297	14.3	17.7	3.4	1.8	11.4	55.8	0.6	9.4
	Both		3737	419	4155	587	14.1	16.5	3.5	2.1	13.4	56.6	1.2	6.7
Sites with HCV count less than 400 per day														
National Strategic														
SH5 Tarukenga (Site 15)	Inc (Eastbound)	19/11/2011-25/11/2011			2678	313	11.7	41.2	11.4	6.1	6.3	26.7	3.6	4.8
	Dec (Westbound)				2516	370	14.7	46.6	11.5	6.1	5.9	21.4	4.0	4.6
	Both		5155	631	5194	683	13.1	43.8	11.5	6.1	6.1	24.1	3.8	4.7
SH2 Clareville (Site 80)	Inc (Westbound)	20/06/2011-26/06/2011			5154	304	5.9	50.6	14.8	6.8	4.1	17.0	1.6	5.1
	Dec (Eastbound)				5108	289	5.7	48.8	14.2	12.1	5.0	12.8	2.3	4.7
	Both		10,706	585	10262	594	5.8	49.7	14.5	9.5	4.6	14.9	2.0	4.9
SH58 Pauatahunui East (Site 73)	Inc (Eastbound)	23/08/2011-29/08/2011			6868	360	5.2	70.2	11.7	3.4	1.9	3.5	0.7	8.6
	Dec (Westbound)				6932	393	5.7	72.0	11.5	3.5	2.8	2.4	1.1	6.7
	Both		13,753	645	13800	753	5.5	71.1	11.6	3.4	2.3	2.9	0.9	7.6
SH1S Gore (Site 45)	Inc (Southbound)	07/02/2011-13/02/2011			2219	251	11.3	26.4	13.2	5.8	4.3	35.3	6.0	9.1
	Dec (Northbound)				2231	287	12.9	34.9	5.7	8.3	5.2	35.3	7.7	2.9
	Both		4016	496	4449	538	12.1	30.7	9.4	7.1	4.7	35.3	6.9	6.0
Regional Strategic														
SH94-Te Anau (Site 94)	Inc (Westbound)	13/05/2011-19/05/2011			425	55	13.0	78.1	17.0	1.3	1.3	1.8	0.0	0.5
	Dec (Eastbound)				394	75	19.0	39.3	39.9	7.1	0.6	0.6	0.0	12.6
	Both		1104	120	819	130	15.9	59.4	28.0	4.1	0.9	1.2	0.0	6.3
SH73-Springfield (Site 11)	Inc (Eastbound)	11/03/2011-17/03/2011			1019	164	16.0	59.9	3.2	3.1	5.4	19.3	3.1	6.0
	Dec (Westbound)				1040	113	10.9	43.9	5.4	3.7	5.3	22.1	2.3	17.3
	Both		1567	196	2059	277	13.4	51.8	4.3	3.4	5.4	20.7	2.7	11.7
Regional Connector														
SH2-Ormond (Site 26)	Inc (Southbound)	13/10/2011-19/10/2011			1189	122	10.3	36.6	9.3	3.0	9.7	29.8	7.1	4.4
	Dec (Northbound)				1177	128	10.9	41.1	6.7	14.5	9.3	17.4	5.2	5.8
	Both		2388	257	2366	250	10.6	38.8	8.0	8.7	9.5	23.6	6.2	5.1
Regional Distributor														
SH4-Horopito (Site 37)	Inc (Southbound)	12/11/2011-18/11/2011			812	148	18.2	36.3	4.6	2.4	13.5	24.3	14.8	4.1
	Dec (Northbound)				787	200	25.4	58.2	3.1	2.1	8.5	15.5	9.0	3.6
	Both		1890	298	1599	348	21.8	47.1	3.9	2.3	11.0	20.0	11.9	3.8
SH25A-Hikuae (Site 76)	Inc (Eastbound)	1/11/2011-7/1/2011			1413	127	9.0	59.3	8.0	13.9	2.2	13.8	0.1	2.6
	Dec (Westbound)				1367	119	8.7	58.7	8.6	5.9	1.9	22.3	0.1	2.5
	Both		3228	259	2780	246	8.8	59.0	8.3	10.0	2.1	18.0	0.1	2.6

Table D.2 Vehicle set proportions for short-duration samples at traffic-counter sites

					Increasing Direction								Decreasing Direction								Both Directions							
			2011	2011	Set 1	Set 2	Set 3	Set 4	Set 5	Set 6	Set 7	Daily	Set 1	Set 2	Set 3	Set 4	Set 5	Set 6	Set 7	Daily	Set 1	Set 2	Set 3	Set 4	Set 5	Set 6	Set 7	Daily
No.	SH	Site	AADT	ADTT	4	5	6+7	8+9	10+11	12	13	Count	4	5	6+7	8+9	10+11	12	13	Count	4	5	6+7	8+9	10+11	12	13	Count
11	73	Springfield	1567	196	60%	3%	4%	8%	7%	15%	3%	164	44%	5%	6%	12%	12%	18%	2%	113	53%	4%	5%	10%	9%	16%	3%	277
14	33	Paengaroa	3991	582	26%	6%	**4%**	13%	9%	**38%**	5%	293	24%	7%	**25%**	13%	8%	**19%**	4%	356	25%	7%	15%	13%	9%	28%	5%	649
15	5	Tarukenga	5155	631	41%	11%	8%	7%	5%	23%	4%	313	47%	12%	7%	8%	3%	19%	4%	370	44%	12%	8%	8%	4%	21%	4%	683
16	3	Te Kuiti	4064	673	35%	5%	4%	15%	6%	23%	12%	463	22%	6%	4%	19%	7%	29%	13%	388	29%	6%	4%	17%	6%	26%	12%	851
26	2	Ormond	2388	257	37%	9%	**4%**	11%	5%	**26%**	7%	122	42%	7%	**17%**	11%	5%	**13%**	5%	128	40%	8%	11%	11%	5%	19%	6%	250
27	1S	Milton	6149	798	33%	10%	9%	10%	3%	27%	8%	435	28%	18%	8%	9%	3%	28%	6%	408	31%	14%	8%	10%	3%	28%	7%	843
33	27	Kaihere	4356	871	21%	5%	5%	19%	7%	27%	16%	483	29%	6%	5%	17%	7%	23%	14%	509	25%	6%	5%	18%	7%	25%	15%	992
37	4	Horopito	1890	298	36%	5%	3%	16%	3%	22%	15%	148	59%	3%	3%	10%	2%	14%	9%	200	49%	4%	3%	13%	2%	18%	12%	348
45	1S	Gore	4016	496	28%	14%	8%	7%	2%	36%	6%	251	35%	6%	9%	6%	3%	33%	8%	287	32%	9%	8%	7%	3%	34%	7%	538
47	1N	Paekakariki	23,219	1797	41%	11%	4%	15%	3%	15%	11%	874	45%	10%	6%	14%	3%	12%	10%	921	43%	11%	5%	15%	3%	14%	10%	1795
71	45	Ohawe Beach Road	3737	419	15%	4%	4%	17%	3%	56%	2%	290	18%	3%	4%	15%	6%	54%	1%	297	17%	4%	4%	16%	5%	55%	1%	587
73	58	Pauatahunui East	13,753	645	73%	12%	5%	4%	2%	3%	1%	360	75%	12%	5%	4%	1%	2%	1%	393	74%	12%	5%	4%	2%	2%	1%	753
76	25A	Hikuae	3228	259	60%	8%	**15%**	3%	3%	**12%**	0%	127	59%	9%	**7%**	2%	4%	**19%**	0%	119	59%	8%	11%	3%	3%	15%	0%	246
80	2	Clareville	10,706	585	51%	15%	8%	6%	4%	15%	2%	304	49%	14%	13%	7%	3%	11%	2%	289	50%	15%	10%	6%	4%	13%	2%	594
94	94	Te Anau	1104	120	78%	17%	2%	2%	0%	2%	0%	55	43%	44%	10%	3%	0%	0%	0%	75	58%	32%	6%	2%	0%	1%	0%	130

Notes:

a) See appendix A for maps showing the telemetry site locations by number.

b) The 2011 AADT numbers and % heavy were taken from the 2007–2011 data booklet (Wen 2012) and the ADTT values were calculated: ADTT = AADT x % heavy /100.

c) The vehicle classes included in each vehicle set were as listed in table 6.3.

d) The sample periods used to compile the vehicle set proportion data and average daily counts are listed in table D.1.

Appendix D references

Wen, G (2012) *State Highway Traffic Data Booklet 2007–2011*. Wellington: NZ Transport Agency.

Appendix E Standard vehicle spectra usage

E.1 Vehicle spectrum usage

The vehicle spectra set out in chapter 6 were developed to fit WIM data in 2010/11, prior to the issue of higher mass HPMV permits for those routes. It would be premature to provide guidance on suitable spectra representing the future vehicle mix, so it is considered that application of the current spectra should be limited to the assessment of existing structures on non-HPMV routes. It is envisaged that codified procedures for the use of vehicle spectra in BS 5400: part 10 or Eurocode EN 1991-2 will be applicable, but route-specific annual heavy vehicle counts would be required.

E.1.1 General guidance

The UK National Annex to Eurocode 1 (EN 1991-2) provides suitable guidance on the use of a vehicle spectrum model. Key points are as follows:

- Stress cycles for passages of each vehicle are assessed and counted using a rainflow counting procedure or reservoir method (EN 1993-1-9 or BS 5400: part 10).
- Fatigue damage at a component is assessed for one or two lanes (not more).
- Vehicles are placed centrally in notional lanes for global actions on main girders; lanes can be anywhere on the carriageway for most adverse local effects. A statistical distribution of transverse position may be used.
- A Miner's summation is used to combine effects of all stress ranges.
- Multiple presence in the same lane is covered by 20% of traffic assumed to be in convoys, with 40m front-to-rear axle spacing (no further guidance is provided on how this would be implemented).
- Side-by-side running is allowed for by applying an adjustment factor $K_b.Z$ to total damage, where:
    - K_b = ratio of maximum stress range for single vehicles in lane 2 to the maximum for single vehicles in lane 1, and
    - Z = 1.0 for loaded length L ≤3.0m, 1.5 for L ≥20m, and varying linearly with log L for L between 3m and 20m.

E.1.2 Requirements for New Zealand traffic

In the absence of specific guidance, the UK National Annex provisions noted above are considered appropriate, but further information for New Zealand heavy traffic and roads is required.

a) Heavy vehicle counts

The fitted spectra are presented as counts per 100,000 heavy vehicles (mass greater than 3.5 tonne), whereas fatigue assessments require the appropriate annual counts per lane for the bridge structure and time period to be evaluated. Current average daily count data for the WIM sites have been summarised in chapter 4 of this report (per direction), and in the Transport Agency annual WIM reports (which include totals for both directions over several years).

Count data from several Transport Agency telemetry sites on other routes have been summarised for this report (see appendix D), but it should be noted that heavy vehicle percentages for many sites included in the Transport Agency annual State Highway Traffic Data booklets are not accurate, as they may be derived from length-based classifications or assumed percentage values, and the correct proportion of 'heavy' 2-axle vehicles varies widely.

Therefore, it is recommended that axle-classified heavy vehicle count data is used to estimate current annual heavy vehicle counts for the application of the standardised vehicle spectra. Counts for vehicles with three or more axles should be used to determine the scaling factors applied to the vehicle spectra in chapter 6, tables 6.6 and 6.7.

b) Heavy vehicle counts per lane

The requirements in AS 5100.2 clause 6.9 may be appropriate (100% of directional heavy vehicle count in one lane for rural highways and expressways, or 65% for urban routes with two or more lanes in one direction). Thus for urban motorways, 65% of the heavy vehicle count would be placed in the more adverse lane, with 35% in an adjacent lane. This compares with the 60:40 split implied by BS 5400: part 10 for dual carriageways. However, refer to section 10.1.5 of this report for further guidance.

c) Dynamic load factor allowance

An amplification factor should be applied to static vehicle weight data to account for pavement roughness. A value of 1.2 for 'good' pavements (as recommended for Eurocode 1 FLM 5) is considered to be overly conservative because the spectra-fitting process for the table 6.7 data has already introduced a degree of conservatism through:

- selecting WIM data for the more adverse directions
- the normal dynamic scatter in WIM data included in the damage equivalent axle loadings targeted by the spectra
- rationalisation of vehicle weight band proportions.

No amplification factor is applied to the UK standard vehicle spectrum specified in the UK National Annex.

Considering the above, the necessity for an amplification factor is debatable and should not be considered in isolation from other parameters and the history of the surfacing condition.

However, it is recommended that a 1.3 amplification factor is applied to loads in the vicinity of expansion joints as specified in Eurocode 1 (decreasing to 1.0 over 6.0m).

d) Heavy traffic growth

Guidance on past and future heavy traffic growth rates is provided in chapter 7 of this report.

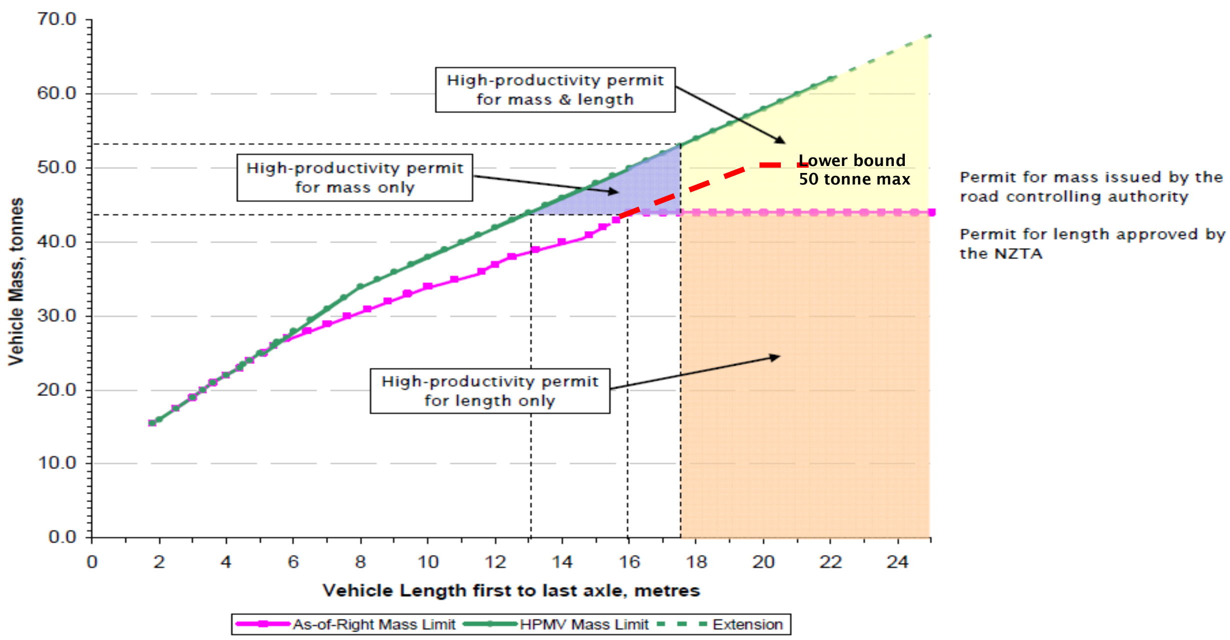
The characteristics and history of the bridge route should be considered and the adopted historic growth rate of fatigue loading should not be more than 5% compound unless supported by assessment of the applicable heavy traffic data.

Appendix F Estimated fatigue loading increases following HPMV introduction

F.1 Review of the HPMV project reports on business case and pavement effects

The 2010 amendment to the VDAM rule introduced increased gross and axle set mass limits for approved vehicles. Uptake of the new limits has been restricted by route availability, due to concerns with bridge capacities (and additional pavement damage). The bridge capacity studies (Waldin 2012) indicated that the full HPMV effects are comparable to 0.90HN on spans up to 25m and 0.95HN over 25m (which are the assessment loadings included in the amended Transport Agency Bridge Manual). Thus, the overall span effects increase by around 10%.

Figure F.1 Current and HPMV bridge formulae (NZ Transport Agency 2010)



The particular concern that was examined in this study, which is not covered in the bridge live load capacity investigations, was the increased fatigue loading on short spans. Under the Class 1 limits, maximum axle set masses on combination vehicles are constrained by the 44-tonne gross mass limit. Under the new rule, tandem-axle set mass on truck-and-trailers could increase by around 25%, which corresponds to an increase in fatigue damage of up to 200% on short spans.

Table F.1 Comparison of axle set mass limits

Axle set type	Class 1 limit (tonne)	HPMV limit (tonne)	Future vehicles[a]
Single, standard tyre	6.0	6.0	8 tonne?
Single, twin tyre	8.2	8.8	10 tonne?
Tandem, twin tyre	14.5 or 15.0 (space>1.3m)	15.0 or 16.0 (space>1.3m)	18 tonne?
Triple, twin or single large tyre	18.0 (spaces ≥1.25m)	19.0 (spaces ≥1.25m)	27 tonne
Quad, twin or single large tyre	20.0	22.0 (only 1 steering axle)	32 tonne

a) Taplin et al (2013).

The aggregate increases in fatigue loading will be less than the extreme values indicated by increases in axle mass limits, as the evaluation must consider:

- reductions in the number of trips required to move the same freight task
- that new or modified vehicles with longer lengths and more axles would be required to fit the maximum limits, and these are not suitable for all routes and applications
- that potential increases for existing vehicles would be less, to comply with the amended bridge formula and technical requirements
- proportions of volume-constrained ('cube-out') versus fully laden ('mass-out') vehicles
- empty or partly laden vehicles on the return trips
- cube-out vehicles that may take up the 'as-of-right' length increases to add around 10% payload
- the level of interest and the time needed to upgrade the vehicle fleet.

Prior to the introduction of the higher mass limits, several reports were prepared (NZ Transport Agency 2010; Hunter 2010a; Hunter 2010b; Hunter 2010c), including details of the heavy fleet and varying assessments of likely take-up and the cube-out proportion. The Transport Agency (2010) funding and investment guidelines appear to take a rather pessimistic view of potential take-up, as follows:

- The dominant vehicle for line-haul freight routes, as represented by the WIM site data, is assessed at 80% cube-out (ie only 20% higher mass take-up potential), with likely take-up estimated as 14% of the current fleet on core routes.
- The WIM site data indicates mass-out proportions (within about 10% of the 44t limit) for truck-and-trailers in the higher loaded direction to be in the range 40–80%, using the proportions assigned to the upper weight spectrum band as a guide.
- An inspection of current HPMV permit approvals and applications summary (NZ Transport Agency 2013) indicates a significant level of interest in take-up of the full mass limits by existing vehicles. Table F.2 indicates 1253 truck-and-trailers, which would be 14% of the total fleet of 9075 (NZ Transport Agency 2010), though some could be the same vehicle in multiple regions. The number of vehicles with permits and actually operating at higher mass is not known.

Table F.2 HPMV permit approvals and applications in progress as at April 2013

Vehicle type	Approved	In progress	Grand total
A224	197	43	240
B1222	2		2
B1232	35	11	46
B1233	79	4	83
B2223, B2233	2		2
B2243	23		23
R12T22	91	41	132
R22T22	689	100	789
R22T23	212	102	314
R23T23	16	2	18
Grand total	**1346**	**303**	**1649**

F.2 Review of the 50MAX project reports on business case and pavement effects

The 50MAX option is a lower mass limit HPMV (50 tonnes) with longer lengths to conform to the extrapolated Class 1 bridge formula and one or two extra axles provided to reduce pavement impacts. It is proposed that existing 7–8-axle truck-and-trailers and B-Trains may upgrade to this standard, while minimising the additional infrastructure upgrade costs. Therefore, this would be the fall-back position on other routes that controlling authorities do not propose to upgrade (in the short term). The axle set mass increases would be less than for the full HPMV case, and evaluation is necessary to estimate the potential increases in fatigue loading.

The key document for this study is *Business case for lower bound high productivity motor vehicles* (Stimpson 2012). This study proposed three scenarios (pessimistic, base case and optimistic) for 50MAX take-up (only), as though the full HPMV option was unavailable.

Key points of relevance to the fatigue study are as follows:

- The business case scope was limited to lower bound HPMVs (50 tonnes maximum), and therefore did not consider the proportion of the fleet that would opt to rebuild/convert to full HPMV capability (an option for carriers in regions with full HPMV-capable routes).
- Logging truck-and-trailers would not upgrade to 50MAX because the longer lengths prevent piggy-backing the empty trailer. B-Trains (with new trailers) were not considered.
- Fonterra advised that turning-circle restrictions in North Island farms and fleet standardisation would make 50MAX less feasible, so the base scenario included only the South Island for the dairy sector (1/3 of the fleet). The optimistic scenario assumed 100% take-up in the dairy sector.
- The ultimate demand by B-Trains plus truck-and-trailers on line-haul routes was assessed as 70% (with 30% cube-out). With the recommended 55% loading ratio (45% returning empty) assumed in the pavement studies, this indicated 70% x 0.55 = 39% fully laden. This figure is consistent with the Drury WIM site spectra upper band proportion (40%).
- An upgrade/replacement rate of 15% pa was assumed in the base case (17.5% optimistic), thus full take-up by 2020 was considered feasible.
- The base case excluded areas of the rural sector and used a slightly lower conversion rate for the line-haul sector. The end result for the line-haul sector (after 7–8 years) was the same, so for bridge fatigue loadings covering all regions, only the optimistic scenario was relevant.

A report on the likely vehicle configurations by de Pont (2012) provides good data on expected empty and fully laden gross and axle weights for the 50MAX vehicles, and the corresponding payload increases. However, their assessments of changes in average ESA counts reflect averages for all WIM stations and all directions combined, so are not useful for the bridge evaluations.

F.3 US method for adjustments to vehicle weight spectra

While a general method has been used in the US to estimate shifts in truck weight and axle weight histograms arising from changes in vehicle weight limits (Fu et al 2003; Cohen et al 2003), there is insufficient New Zealand data to confirm the key parameters, and the computer software was not available for review.

However, the key principles of their algorithm for adjusting the weight histogram are of interest:

- With the recommended default parameters, 95% of vehicle counts within ±10% of the old limit are shifted up according to ratio of new to old weight limit.
- The percentage of vehicles to be shifted decreases linearly to zero at ±20% of the old weight limit, so that there is minimal or no shift of either cube-out or excessively overweight vehicles.
- Weight increases for each histogram band are proportional to the increase in ‘practical maximum’ weights for the vehicle classes (gross limits considering axle set maxima, etc).
- Adjustments are made for reductions in loaded and empty trip counts.
- There is provision for considering exogenous shifts (through truck-type shifts, general growth or increased competitiveness versus other modes).

The methodology set out in Fu et al’s report (2003) appears to be more a robust method for evaluating increased pavement damage costs than the methods applied in the previous New Zealand studies that used average ESA counts. Their method preserves most of the existing variation in top end loading and dynamic effects that would be excluded by applying the unmodified HPMV *pro forma* vehicle weights.

For our study, the above principles suggested a simplified approach using the upper mass bands of the standardised vehicle spectra (all counts, or a reduced proportion) as the vehicles to be shifted.

F.4 Adopted method for adjusting fatigue spectra and loading to cover HPMV shift

F.4.1 Average increases in per-vehicle effects

- Evaluate vehicle moments, shears, reactions on simply supported spans for standardised Class 1 vehicles (44-tonne maximum), and a range of replacement HPMV *pro forma* vehicles (both full and lower bound vehicles). Existing Class 1 vehicles are based on average (WIM) dimensions and axle mass shares, and future higher mass options include existing dimensions and the longer length maximum weights. The 50MAX truck-and-trailer and B-Train *pro forma* vehicles are based on lower bound HPMV vehicle configurations proposed by de Pont (2012) and the higher mass options are derived from a discussion paper by Waldin (2011), with adjustments to fit average dimensions and conform to the published rule for all axle groupings. Vehicle configurations are listed in appendix F.3.
- Determine ratios of equivalent moments, shears, etc including all cycles (with 5th-power rule) between the Class 1 vehicles and their higher mass replacements/upgrades. These ratios vary with span length and can be presented as damage ratios (increase in equivalent repetitions of a fixed fatigue vehicle) or equivalent vehicle mass ratio (5th root of the damage ratio) for a fixed repetition count.
- It is assumed that these ratios reflecting the change in effects from the Class 1 mass limits to the new higher mass limits can be applied to the effects of fully laden vehicles in the vehicle spectra, thereby preserving the existing variance in dynamic effects and loading. This will be conservative if there is improved compliance with the mass limits (which should occur if the existing 1.5-tonne prosecution tolerance is removed). However, we have taken the pessimistic view of no improvement, as an effective enforcement regime is not yet in place.

F.4.2 Trip savings through increased payload capacity

Two extremes can be considered:

a) Constant freight task – fully laden vehicle counts are reduced in proportion to the payload gain, which should consider tolerance usage and the smaller increases available to cube-out vehicles with longer trailers. This scenario is referred to as 'Efficiency gain' in the pavement impact studies (Hunter 2010b) and presumes that all loads are divisible.

b) Constant vehicle counts (increased freight capacity) – designated higher mass routes may attract freight travelling via alternative routes, and therefore trip numbers are assumed to remain at current levels (in the longer term). This scenario is referred to as 'No efficiency gain' in the pavement impact studies.

It is proposed that the constant freight task scenario would apply initially, as assumed in the 50MAX business case study, but that the constant vehicle count scenario should be considered in conjunction with potential full HPMV take-up in the longer term (on the approved routes).

F.4.3 HPMV take-up rates (10-year time frame)

The various HPMV studies generally assume a 10-year take-up period for the full higher mass limits (from 2010) and the lower bound (50MAX) base scenario assumes that a 15%pa conversion rate is achievable (from 2013). Thus an approximately linear take-up rate to 2020 is implied.

For the bridge fatigue design loading estimates it is appropriate to adopt the more conservative achievable take-up targets for the designated HPMV routes. Therefore we propose to base the vehicle mass growth increase rates on:

- full take-up achieved in 2020, with linear growth rate from 2010 to 2020
- interest levels as indicated by the optimistic scenario for the lower bound (50MAX) business case (Stimpson 2012)
- full higher mass limits on main highways (and other designated higher mass routes)
- lower bound (50 tonne) limits on other highways.

F.4.4 Longer term vehicle mass growth (beyond 2020)

The investigations for the new higher mass limits began prior to 2000, regulation changes were introduced in 2010, and a further 10-year period is allowed for full adoption – in total, a period of 20+ years for this change. Previous changes to average vehicle weights through increasing numbers of axles and new configurations occurred over similarly long periods (the previous increase to 44 tonnes occurred in 1989). Beyond the 10-year frame, it is anticipated for the purpose of fatigue load growth estimates that the progression will continue through:

- a trend from current lengths to longer HPMVs with more axles
- routes not currently suitable for higher mass vehicles being upgraded eventually, allowing the lower bound vehicles to carry higher masses
- general adoption of higher axle mass limits for all vehicles as of right, as originally proposed for the 2010 amendment.

Thus, there is scope for further ongoing growth within the new HPMV axle mass limits for an uncertain period. Taplin et al's bridge live loading research project (2013) considered future vehicle configurations with heavier axles than the new HPMV limits (as indicated in the axle mass limit table above) but did not speculate on time frames. The increases they envisaged for twin-steer, triple- and quad-axle sets exceeded 40%.

In this study, we assessed the average mass and damage growth rates for the 10-year HPMV roll out period noted above and considered them to be indications of potential long-term growth rates.

F.4.5 Implementation of adjustments for higher mass vehicles

Based on the optimistic take-up scenario (Stimpson 2012), we assumed that all vehicle counts in the higher mass bands of the proposed standard vehicle spectra for truck-and-trailers, B-Trains and semi-trailers (vehicle sets 4, 5, 6 and 7 in table 6.7) are candidates for higher mass upgrades or replacements. The spectra counts already include allowances for directional bias, unladen vehicles and cube-out vehicles, and therefore it was considered that the only required adjustments to these counts would be the trip savings for equal freight task.

The evaluations considered vehicle upgrade scenarios for the most common truck types in each spectrum vehicle set, as set out in table F.3. It is anticipated that these shifts will adequately represent the range of possible changes, or indicate the trend for the longer length vehicles beyond 57 tonnes.

For each combination of Class 1 vehicle and new replacement vehicle set out in table F.3, the increase in fatigue loading effects were evaluated as described in section F.4.1 above. The trip savings noted in F.4.2 above (see section F.6 for details) were applied as scale factors reducing the ratios of damage per vehicle. The ratios of equivalent moments and the corresponding damage ratios (with trip savings) are plotted against span length on the following pages.

Table F.3 Representative Class 1 vehicles to HPMV vehicle type changes

			Representative vehicle shifts from Class 1, 44-tonne max.								
	Higher mass option	Length changes	Sets 1–3	Set 4		Set 5		Set 6		Set 7	
				Old	New	Old	New	Old	New	Old	New
1	Full HM	No change	N/A	A224	48t[a]	R12T22	49t	R22T22	52t	B1232	51t
2	Full HM	Longer trailers	N/A	A224	48t[a]	R12T22	52t	R22T22	55t	B1232	B1233 57t
3	50MAX	Longer trailers	N/A	N/A		R12T22	R22T23 50t	R22T22	R22T23 50t	B1232	B1233 50t
4	Full HM + AoR[b]	No change	+6% mass	A224 48t, others +6% mass (mid-band)		Changes as for full HM scenarios above					
5	Full HM + AoR	Longer trailers									

a) The 48t limit for A224 vehicles includes typical ISO container transporters that may have operated with overweight permits previously, and matches recently issued HPMV permits.

b) For the future as-of-right (AoR) axle mass increases to the HPMV limits, the average increase in legal mass (with no increase to steer axles) would be less than 6%. This increase is applied to the upper bands for sets 1–3 and the middle band for set 4 (which includes cube-out and mass-out 5- or 6-axle semi-trailers).

The proportions of vehicles in the upper weight bands that are considered to be higher mass limit candidates are indicated in table F.4.

Table F.4 Potential HPMVs – proportions of total heavy vehicle counts

Spectrum Vehicle Set			Proportion of Total Heavies			Proportion in Upper Band (with directional bias)			Potential HPMVs (Percentage of Heavies)		
Set	Configuration	Upper band	Drury	Eskdale	Te Puke	Drury	Eskdale	Te Puke	Drury	Eskdale	Te Puke
4	5-8 axle Artics	420 kN	20%	11%	13%	30%	30%	30%	6.0%	3.4%	3.9%
5	Single steer Truck+Trailer	450 kN	8%	7%	10%	75%	75%	75%	6.1%	5.6%	7.1%
6	twin steer Truck+Trailer	450 kN	20%	43%	27%	40%	80%	70%	8.0%	34.0%	19.0%
7	B-Train (single steer)	450 kN	8%	7%	6%	55%	55%	55%	4.6%	4.0%	3.4%
			56%	69%	56%				24.7%	47.0%	33.5%

Due to the substantial directional bias for heavy traffic heading towards ports and timber mills, and for bulk aggregate supply routes, the proportions in the upper bands can exceed the average values assumed in the pavement damage and business case studies. The SH1 Drury data shows the least bias and 44% of heavies are rigid trucks, and this site therefore has the lowest expected proportion of potential HPMV candidates (25%). At current volumes (around 4000 heavies/day), that implies up to 500 trips per day in either direction with full take-up of HPMV options.

F.4.6 Aggregation of single-vehicle changes using standardised vehicle spectra

The changes in vehicle spectra fatigue loadings (in terms of repetitions of the 0.85HN effects) were estimated by multiplying the results for the spectra vehicles by the damage ratios determined for the representative vehicle shifts. This scaling preserved the effect of the spread in the recorded weight data above and below the Class 1 mass limits, and was limited to the upper mass bands.

This calculation gave the total changes in fatigue damage (per 100,000 vehicles in the current population), which could then be applied to the tabulated and plotted results for current loading (eg figure 6.4). This was repeated for moment and shear effects using all fitted spectra (5th-power damage rule). Selections of the results relative to M1600 vehicle loading are presented in the following pages.

F.5 Results – with potential higher mass limit take-up

The following pages show the results for the calculations described above, covering:

1. ratios of damage equivalent moments (single repetition) for the heavier vehicles compared with the 44-tonne vehicles they replace (see figures F.2–F.4)
2. corresponding fatigue damage ratios, assuming the same total freight tonnage (see figures F.5–F.7)
3. a selection of plots of damage equivalence as M1600 repetitions per truck versus length, with and without the HPMV shifts (see figures F.8–F.13, compared with 5th-power results in figure 6.4)
4. a tabular summary of the damage increase factors by span length range – these are not tied to a particular design fatigue vehicle
5. estimates of the damage growth rates (fatigue loading increase per annum) for potential uptake over a 10-year period
6. growth rate summary.

Figure F.2 Moment ratio – Class 1 vs higher mass vehicles, no length change

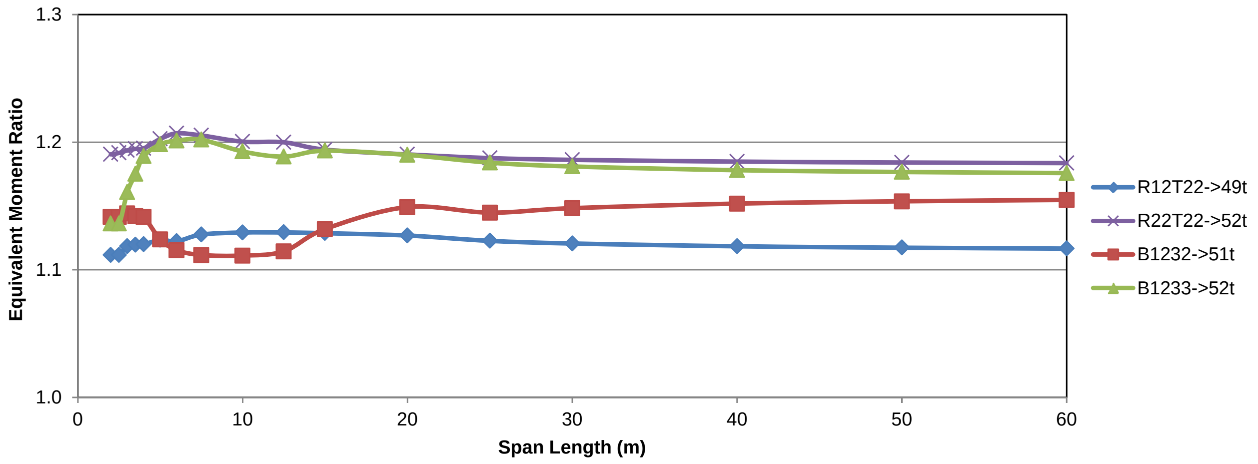


Figure F.3 Moment ratio – Class 1 vs longer higher mass vehicles

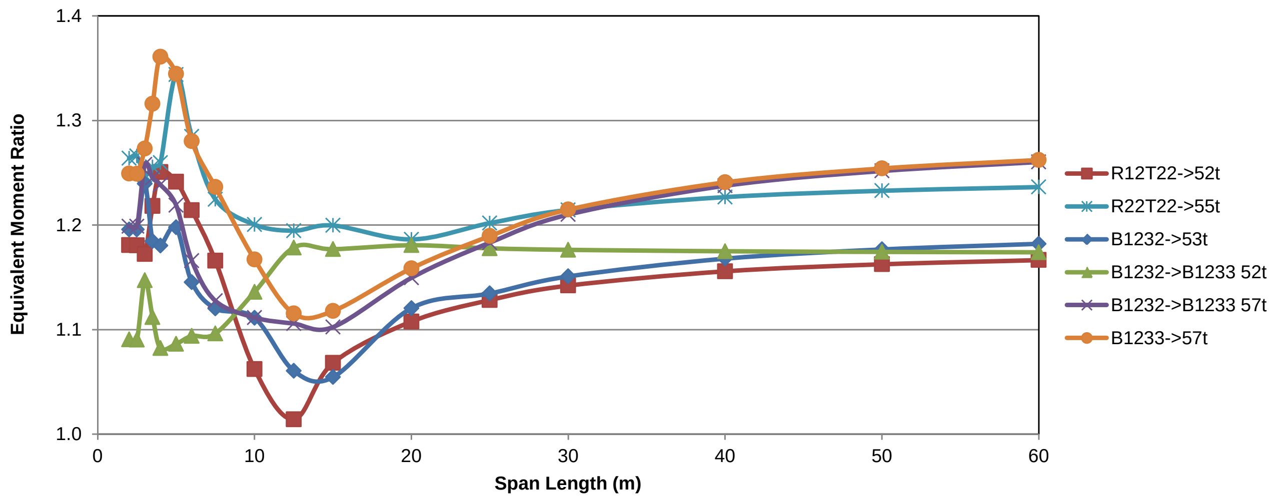


Figure F.4 Moment ratio – Class 1 vs 50MAX vehicles (lower bound)

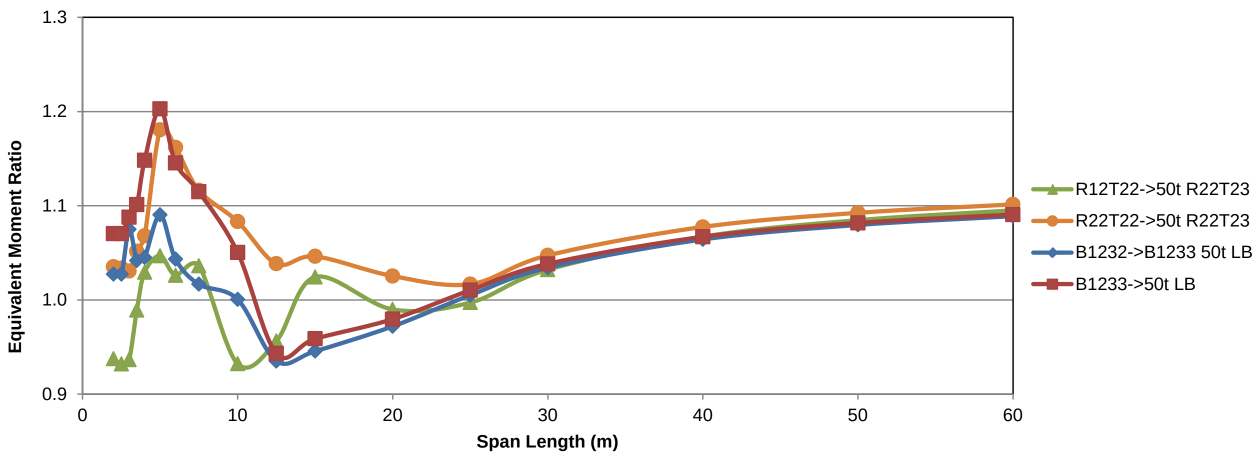


Figure F.5 Damage ratio with trip savings – Class 1 vs higher mass vehicles, no length change

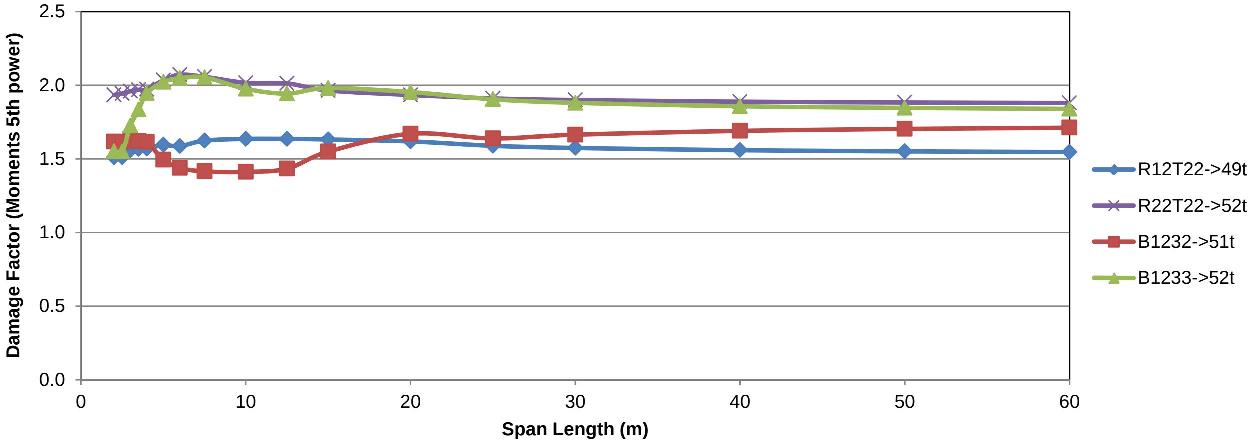


Figure F.6 Damage ratio with trip savings – Class 1 vs longer higher mass vehicles

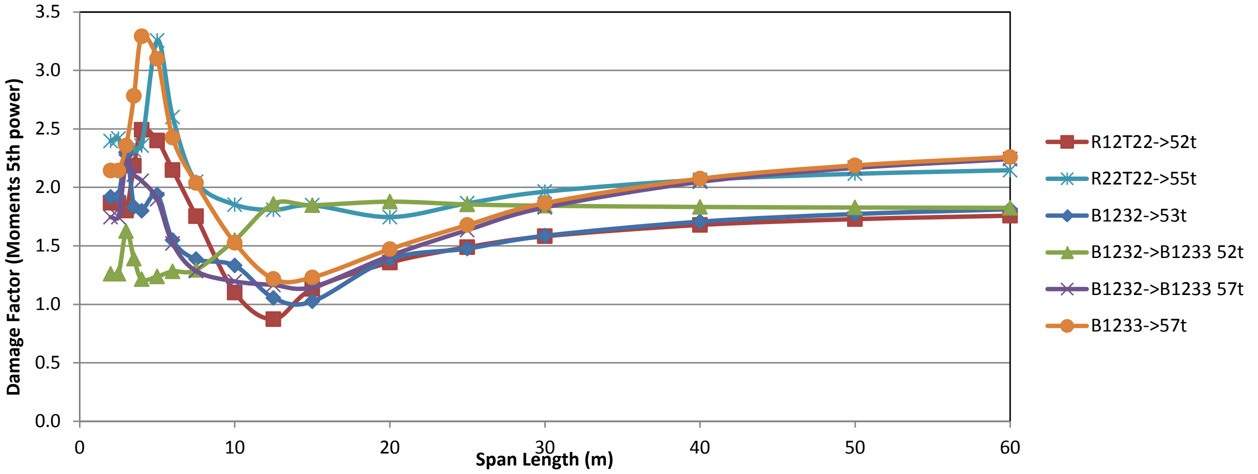


Figure F.7 Damage ratio with trip savings – Class 1 vs 50MAX vehicles (lower bound)

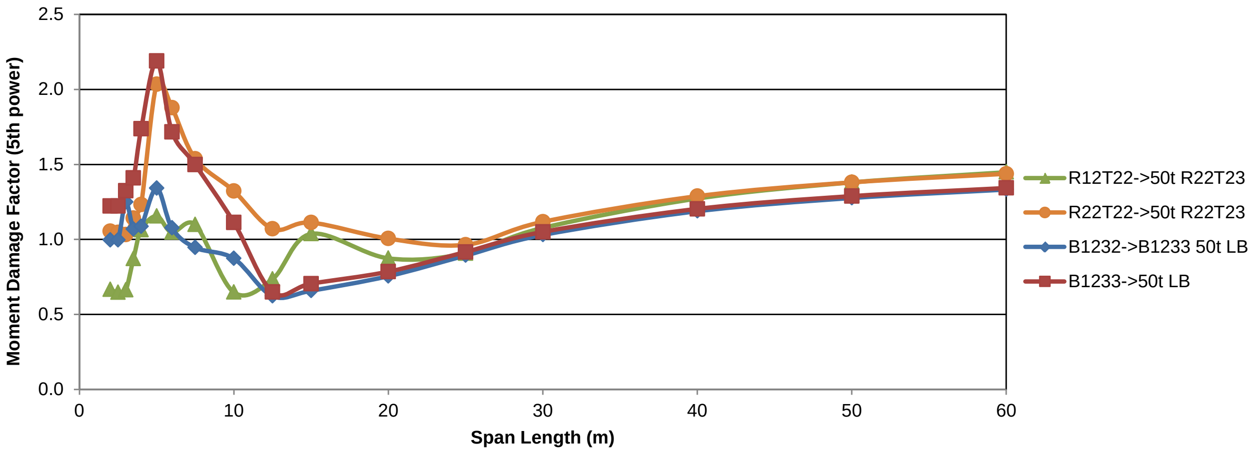


Figure F.8 Case 1a, existing vehicle lengths with max GVM, reduction in trip counts to equalise freight task, bending moment results

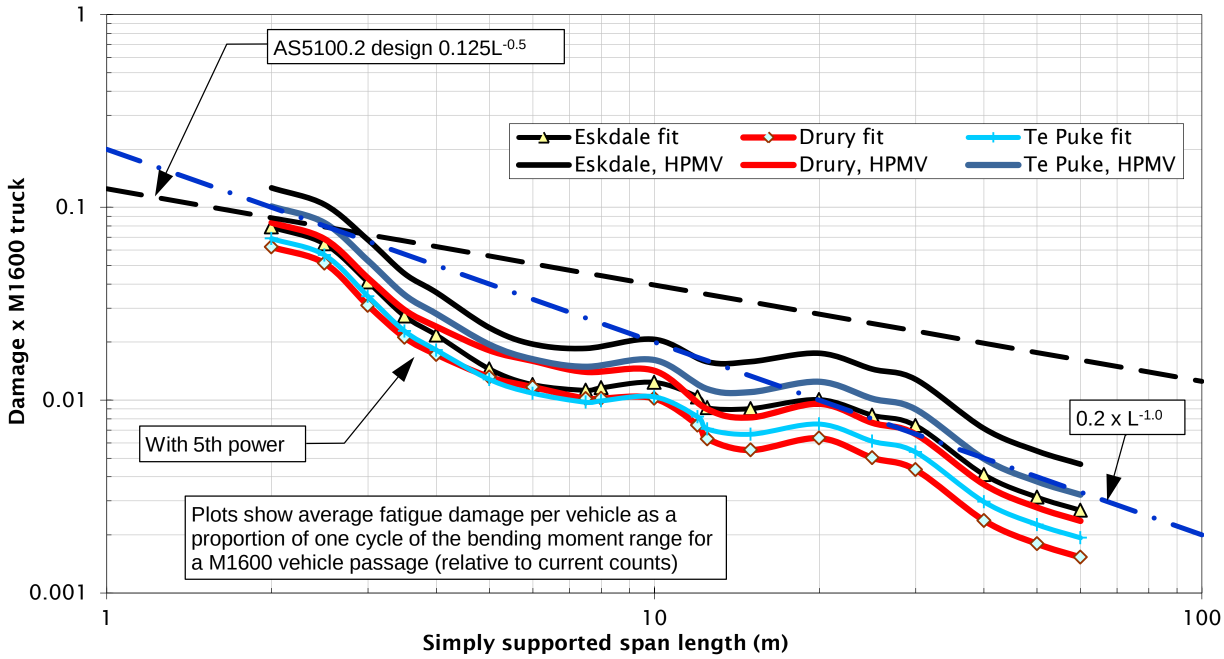


Figure F.9 Case 2a, full take-up of longer length options with max GVM, reduction in trip counts to equalise freight task, bending moment results

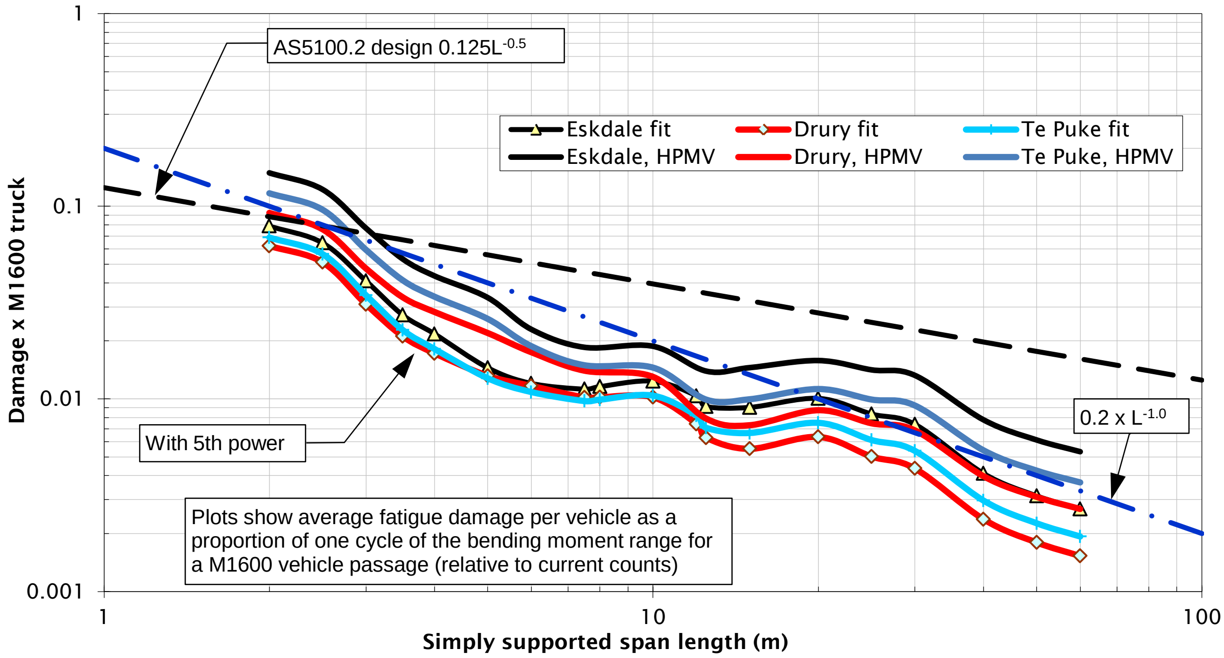


Figure F.10 Case 1b, existing vehicle lengths with max GVM, no reduction in trip counts, bending moment results

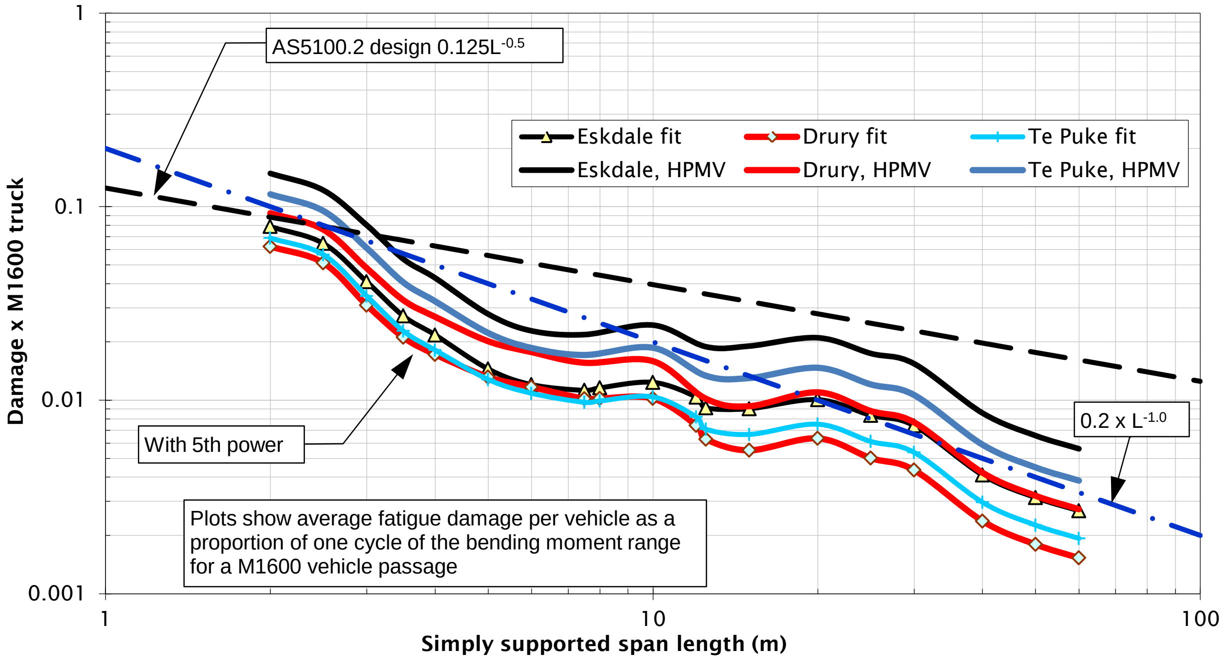


Figure F.11 Case 2b, longer vehicles with max GVM, no reduction in trip counts, bending moment results

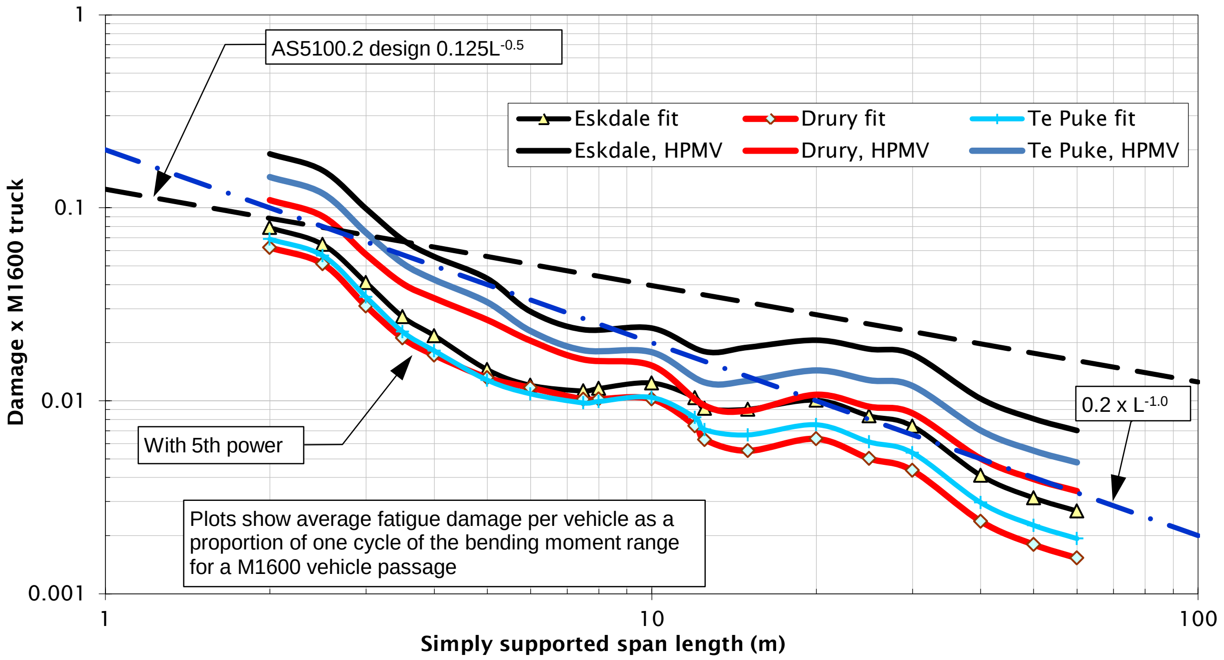


Figure F.12 Case 2a, full take-up of longer length options with max GVM, reduction in trip counts to equalise freight task, shear force results

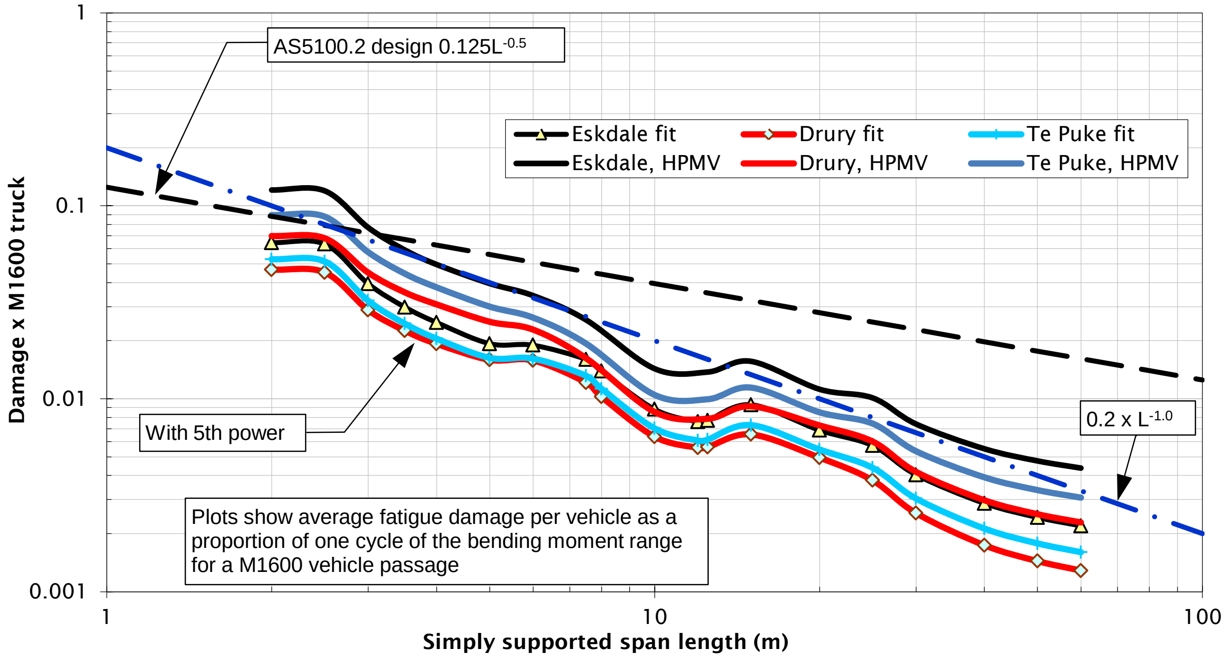


Figure F.13 Case 1b, existing lengths with max GVM, no reduction in trip counts, shear force results

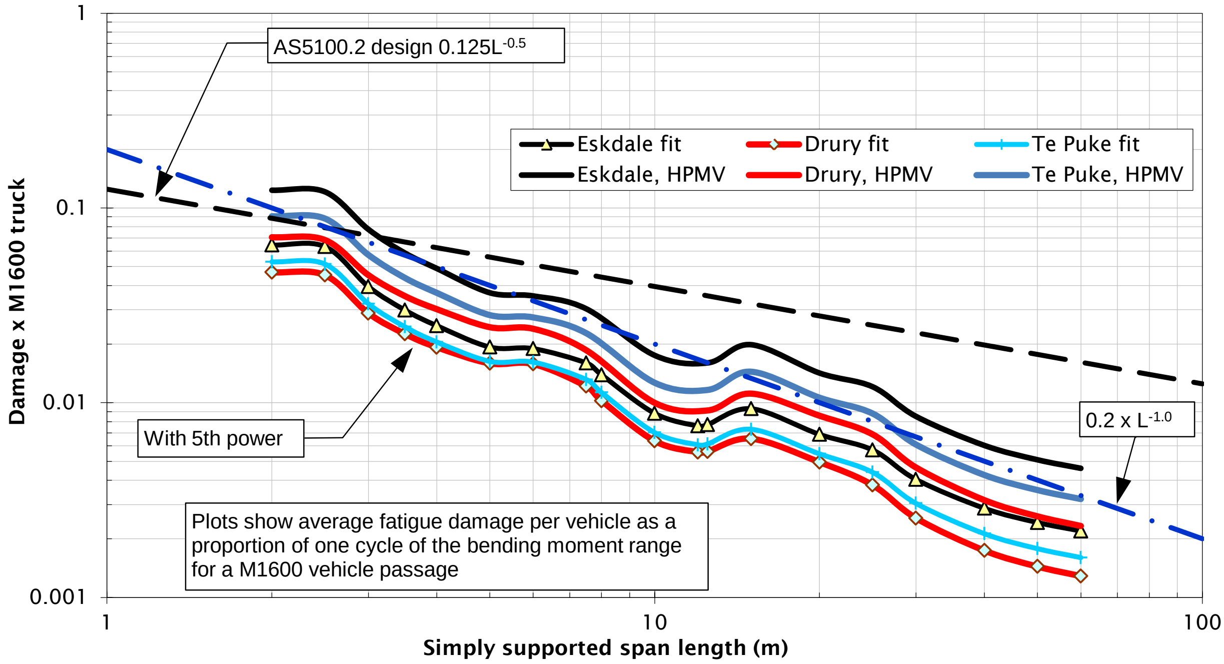


Table F.5 Summary of HPMV uptake analysis results

Case No.	Fleet interest scenario	Typical Vehicle Mass Change Type	Trip saving	Productivity Gain			Action	Damage increase factors											
								SH1 Drury				SH5 Eskdale				SH2 Te Puke			
				Drury	Eskdale	Te Puke		<10m	10-15m	20-30m	40-60m	<10m	10-15m	20-30m	40-60m	<10m	10-15m	20-30m	40-60m
1a	Optimistic, Full HM limits	Wt incr only	Yes - const freight	-3.5% trips	-8.1% trips	-5.3% trips	Moment	1.39	1.48	1.53	**1.55**	1.66	**1.75**	1.74	1.74	1.54	1.65	**1.67**	1.67
							Shear	1.40	1.49	**1.58**	1.57	**1.66**	1.77	1.76	1.75	1.55	1.67	1.69	**1.69**
2a	Optimistic, Full HM limits	Wt & length Incr		-5.0% trips	-11.2% trips	-7.5% trips	Moment	1.67	1.33	1.58	**1.76**	**2.31**	1.61	1.79	1.98	**2.03**	1.50	1.72	1.91
							Shear	1.60	1.40	**1.64**	1.78	**2.05**	1.78	1.83	1.99	1.85	1.62	1.76	**1.92**
3	50 Max, optimistic	Wt & length Incr		-2.0% trips	-4.8% trips	-3.2% trips	Moment	1.17	0.99	1.05	**1.27**	**1.51**	1.12	1.09	1.37	**1.35**	1.05	1.08	**1.35**
							Shear	1.09	0.97	1.07	**1.27**	1.27	1.06	1.11	**1.37**	1.18	1.01	1.09	**1.34**
1b	Optimistic, Full HM limits	Wt incr only	No - increase capacity	+4.6% gross	+8.7% gross	+6.8% gross	Moment	1.56	1.69	1.77	**1.79**	1.97	**2.11**	2.09	2.09	1.79	1.96	1.98	**1.99**
							Shear	1.57	1.70	**1.82**	1.81	1.97	**2.13**	2.11	2.10	1.79	1.98	**2.01**	2.00
2b	Optimistic, Full HM limits	Wt & length Incr		+7.4% gross	+13.3% gross	+10.6% gross	Moment	1.99	1.61	1.98	**2.23**	**2.97**	2.10	2.36	2.61	**2.53**	1.91	2.22	2.48
							Shear	1.92	1.71	2.06	**2.26**	**2.61**	2.31	2.41	2.63	2.31	2.05	2.28	**2.49**
4	Full HM + AoR axle wt incr	Wt incr only		+5.5% gross	+9.2% gross	+7.5% gross	Moment	1.63	1.73	1.79	**1.81**	2.00	**2.12**	2.10	2.10	1.84	1.99	2.00	**2.00**
5	Full HM + AoR axle wt incr	Wt & length Incr		+8.4% gross	+13.8% gross	+11.3% gross	Moment	2.06	1.66	2.01	**2.25**	**3.00**	2.11	2.37	2.62	**2.59**	1.94	2.24	2.49
max Increment arising from AoR increase in addition to full HM limits								**4.7%**	3.7%	2.3%	1.2%	1.8%	1.5%	0.7%	0.3%	3.1%	2.5%	1.3%	0.6%

Comments:

1 For 10–20m spans, the effect of increasing loads with current vehicle lengths is more severe than using bigger loads on longer lengths.

2 For longer spans, the GVM increase is the significant factor and the highest increases would occur with full take-up of the maximum-length vehicles.

3 At short spans, the effect of increasing the length to allow maximum axle set weights is more severe, even when payload adjustments are included.

4 50MAX is not applicable to logging T&T; therefore the Eskdale 50MAX figures would not apply to that route and others with significant logging vehicle content. Up to 35% increase in damage rate is assessed for short spans on other routes (in the more heavily loaded direction.

5 The largest potential increases affect short spans on the routes with high proportions of fully laden vehicles heading toward ports and/or timber mills.

6 Adding the effect of the previously proposed general increase in axle weight limits after full HPMV take-up adds 3–5% at short spans. Impact on urban routes may be higher because eligible rigid vehicles would be a much larger proportion of the fleet.

7 Damage increase factors are based on 5th-power fatigue damage summations for the vehicle spectrum.

F.6 Standard vehicle details

The tables below provide the dimensions and axle masses for the vehicles used in the HPMV evaluations.

Table F.6 Typical 44-tonne truck-and-trailers and higher mass HPMV versions

Vehicle Description	Axles	GVM	Wheel	Axle mass (tonne)										Axle spacing (m)								
		(tonne)	base	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9
A224 Class 1	8	44	15.9	4.5	4.5	7.5	7.5	5	5	5	5			1.8	2.6	1.3	6.3	1.3	1.3	1.3		
A224 ISO container	8	48	15.9	5	5	8	8	5.5	5.5	5.5	5.5			1.8	2.6	1.3	6.3	1.3	1.3	1.3		
R12T22 Class 1	7	44	16.5	5.8	6.7	6.7	6.2	6.2	6.2	6.2				4.0	1.3	5.5	1.3	3.2	1.3			
R12T22 full short	7	49	16.5	6	7.5	7.5	7	7	7	7				4.0	1.3	5.5	1.3	3.2	1.3			
R12T22 full long	7	52	18.0	6	8	8	7.5	7.5	7.5	7.5				4.0	1.3	5.5	1.3	4.6	1.3			
R22T22 Class 1	8	44	17.3	4.4	4.4	6.2	6.2	5.7	5.7	5.7	5.7			1.8	3.3	1.3	4.2	1.3	4.2	1.3		
R22T22 full short	8	52	17.3	5	5	7.5	7.5	6.75	6.75	6.75	6.75			1.8	3.3	1.3	4.2	1.3	4.2	1.3		
R22T22 full long	8	55	18.6	5	5	7.5	7.5	7.5	7.5	7.5	7.5			1.8	3.3	1.3	4.4	1.3	5.2	1.3		
R22T23 lower bound	9	50	20.0	4.8	4.8	6.7	6.7	6	6	5	5	5		1.8	3.3	1.3	4.5	1.3	5.2	1.3	1.3	
R23T23 full short	10	57	19.5	5	5	5.5	5.5	5.5	7	7	5.5	5.5	5.5	1.8	2.9	1.3	1.3	3.7	1.3	4.6	1.3	1.3
B1232 Class 1	8	44	17.5	5.3	6.2	6.2	5.7	5.7	5.7	4.6	4.6			3.7	1.3	4.3	1.3	1.3	4.3	1.3		
B1232 full short	8	51	17.5	5.4	7	7	6.33	6.33	6.33	6.3	6.3			3.7	1.3	4.3	1.3	1.3	4.3	1.3		
B1232 full long	8	53	18.5	5.4	7.3	7.3	6.33	6.33	6.33	7	7			3.7	1.3	4.8	1.3	1.3	4.8	1.3		
B1233 Class 1	9	44	17.7	5.4	6.1	6.1	5.2	5.2	5.2	3.6	3.6	3.6		3.6	1.3	3.7	1.3	1.3	3.9	1.3	1.3	
B1233 lower bound	9	49.6	20.0	5.4	6.5	6.5	5.7	5.7	5.7	4.7	4.7	4.7		3.6	1.3	5	1.3	1.3	5	1.3	1.3	
B1233 full short	9	51.6	17.7	5.4	7.03	7.03	6.25	6.25	6.25	4.47	4.47	4.47		3.6	1.3	3.7	1.3	1.3	3.9	1.3	1.3	
B1233 full long	9	57	19.5	5.5	8	8	6.33	6.33	6.33	5.5	5.5	5.5		3.7	1.3	4.6	1.3	1.3	4.7	1.3	1.3	

Comments:

- Current dimensions and axle mass distribution are based on WIM data for average 44-tonne vehicles at the AHB and Drury sites. Tractor steer-axle weights increase only slightly with GVM.
- The 'full' HPMVs use existing dimensions (short version) or longer trailers (long version). All combinations of axle set masses conform to the new limits for combined mass versus length.
- The 'lower bound' versions are the '50MAX' alternative configurations with no change to the rigid truck or tractor dimensions.

Table F.7 Preliminary proposals for additional standard spectrum vehicles

Vehicle Description	Axles	GVW	Wheel	Axle weight (kN)								Axle spacing (m)						
		(kN)	base	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7
5HM o-oo--oo--oo	7	490	16.5	60	75	75	70	70	70	70		4.0	1.3	5.5	1.25	3.2	1.25	
6HM oo--oo-oo--oo	8	530	17.4	50	50	75	75	70	70	70	70	1.8	3.3	1.3	4.2	1.25	4.3	1.25
7HM o-oo--ooo--oo	8	530	17.5	55	75	75	65	65	65	65	65	3.7	1.3	4.3	1.3	1.3	4.3	1.3

If a modified standard vehicle spectrum is required for detailed assessments, it will be necessary to add additional weight bands to the 7–8-axle standard vehicles. The vehicles in table F.7 are proposed, with no increases in lengths compared to existing spectra vehicles.

These are preliminary versions derived from the 'short' HPMV configurations listed in table F.6 and may not adequately cover the fatigue effects of actual HPMV vehicles if significant take-up of the longer maximum-weight vehicles occurs. The proposed axle weights should be reviewed when sufficient data is available to confirm the appropriate weights and vehicle set proportions. The '6HM' vehicle is the option C standard fatigue vehicle discussed in chapter 8.

F.7 Efficiency gains

The potential payload gains at maximum vehicle weights (table F.8) were used to assess the average reduction in trip counts (constant total freight task assumption). Because these adjustments were only applied to the top bands of the spectra, the average efficiency gains (and average vehicle mass increases) for all similar vehicles were less than the gains indicated in table F.8.

Table F.8 Estimated efficiency gains for the selected HPMV *pro forma* vehicles

Class 1 vehicle					HPMV upgrade options				
Description	GVM	Tol[a]	Empty	Payload	Description	GVM	Empty	Payload	Gain
A224 Class 1	44	1.5	18	27.5	A224 ISO container	48	18	30	9%
R12T22 Class 1	44	1.5	17	28.5	R22T23 lower bound	50	19	31	9%
					R12T22 full short	49	17	32	12%
					R12T22 full long	52	17	35	23%
R22T22 Class 1	44	1.5	18	27.5	R22T23 lower bound	50	19	31	13%
					R22T22 full short	52	18	34	24%
					R22T22 full long	55	18	37	35%
					R23T23 full short	57	20	37	35%
B1232 Class 1	44	1.5	18	27.5	B1233 lower bound	49.5	18	31.5	15%
					B1232 full short	51	18	33	20%
					B1232 full long	53	18	35	27%
					B1233 full short	51.6	18	33.6	22%
					B1233 full long	57	18	39	42%
B1233 Class 1	44	1.5	18	27.5	B1233 lower bound	49.5	18	31.5	15%
					B1233 full short	51.6	18	33.6	22%
					B1233 full long	57	18	39	42%

a) Maximum current vehicle weights (with HPMV permits) were frequently above 44t and therefore we assumed that the prosecution 'Tolerance' would form part of the 'normal' maximum payload. No tolerance has been added to the HPMV payloads.

b) The lower bound HPMV vehicle configurations report (de Pont 2012) was the primary source of empty weights for Class 1 existing and lower bound vehicles.

Appendix F references

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Appendix G Fatigue damage growth scenarios

G.1 Growth in fatigue loading over HPMV take-up period

Table G.1 combines the fatigue damage growth factors from table F.5 with the 3% per annum forecast growth rate in freight task or heavy vehicle counts (see section 7.2.8). An equivalent arithmetic (linear) growth rate was calculated for average vehicle gross mass (relative to the current vehicle mix, ignoring trip savings that would inflate the average across a lesser number of vehicles).

Table G.1 Growth factor estimates for 10-year take-up of HPMV higher mass limits (from 2010/11)

	Site					
	Drury		Eskdale		Te Puke	
Calculation step	**Short span**	**Medium span**	**Short span**	**Medium span**	**Short span**	**Medium span**
With efficiency gains (trip savings)						
Damage increase factor (constant freight)	1.67	1.53	2.31	1.83	2.03	1.92
Linear growth rate for 10-year transition	6.7% pa	5.3% pa	13.1% pa	8.3% pa	10.3% pa	9.2% pa
Add 3% pa freight task growth (10 yrs)	11.7% pa[a]	9.9% pa	20.1% pa	13.8% pa	16.4% pa	14.9% pa
Equiv. vehicle mass growth rate (10 yrs)	1.1% pa[b]	0.9% pa	1.8% pa	1.3% pa	1.5% pa	1.4% pa
With constant vehicle count proportions (use capacity increase)						
Damage increase factor (constant count)	1.99	1.77	2.97	2.41	2.53	2.28
Linear growth rate for 10-year transition	9.9% pa	7.7% pa	19.7% pa	14.1% pa	15.3% pa	12.8% pa
Add 3% pa number growth (10 yrs)	15.9% pa	12.9% pa	28.6% pa	21.3% pa	22.9% pa	19.6% pa
Equiv. vehicle mass growth rate (10 yrs)	1.5% pa	1.2% pa	2.4% pa	1.9% pa	2.0% pa	1.8% pa
Lower bound – 50-tonne max. with efficiency gains						
Span length range:	<10m	≥30m	<10m	≥30m	<10m	≥30m
Damage increase factor (constant freight)	1.17	1.27	Results not applicable. This site is dominated by logging vehicles, which are unsuitable for longer trailers with existing trucks.		1.35	1.34
Linear growth rate for 8-year transition	2.2% pa	3.4% pa			4.3% pa	4.3% pa
Add 3% number growth (8 yrs)	6.6% pa	8.1% pa			9.4% pa	9.3% pa
Equiv. vehicle mass growth rate (8 yrs)	0.4% pa	0.6% pa			0.8% pa	0.8% pa

Note: Linear growth rate calculation examples:

a) (1.67x1.30 – 1.0)/10 = 0.117 (11.7% pa)

b) $(1.67^{0.2} - 1.0)/10 = 0.011$ (1.1% pa)

G.2 Fatigue growth rate estimates – summary

The potential rates of fatigue damage over the HPMV take-up period for the optimistic scenarios are summarised below.

Scenario 1 – optimistic take-up over 10 years, 3% pa freight task growth with trip savings

		Short spans	Medium spans
Annual damage growth rates:	SH1 Drury	12% pa	10% pa
	SH2 Te Puke	16% pa	15% pa
	SH5 Eskdale	20% pa	14% pa

Scenario 2 – high growth, optimistic take-up over 10 years, 3% pa general freight task growth plus usage of additional fleet capacity

		Short spans	Medium spans
Annual damage growth rates:	SH1 Drury	16% pa	13% pa
	SH2 Te Puke	23% pa	20% pa

Scenario 3 – 50MAX only, full take-up over 8 years, 3% pa freight task growth

		<10m spans	≥30m spans
Annual damage growth rates:	SH1 Drury	6.6% pa	8.1% pa
	SH2 Te Puke	9.4% pa	9.3% pa

G.3 Caution for 50MAX evaluations

For spans in the 10–25m range, the assessment showed there would be no net increase in fatigue damage rate under the 50MAX scenario provided that the estimated trip savings occur in practice. However, short span components such as stringers, floor beams and decks would be likely to have increased fatigue damage rates under the 50MAX scenario.

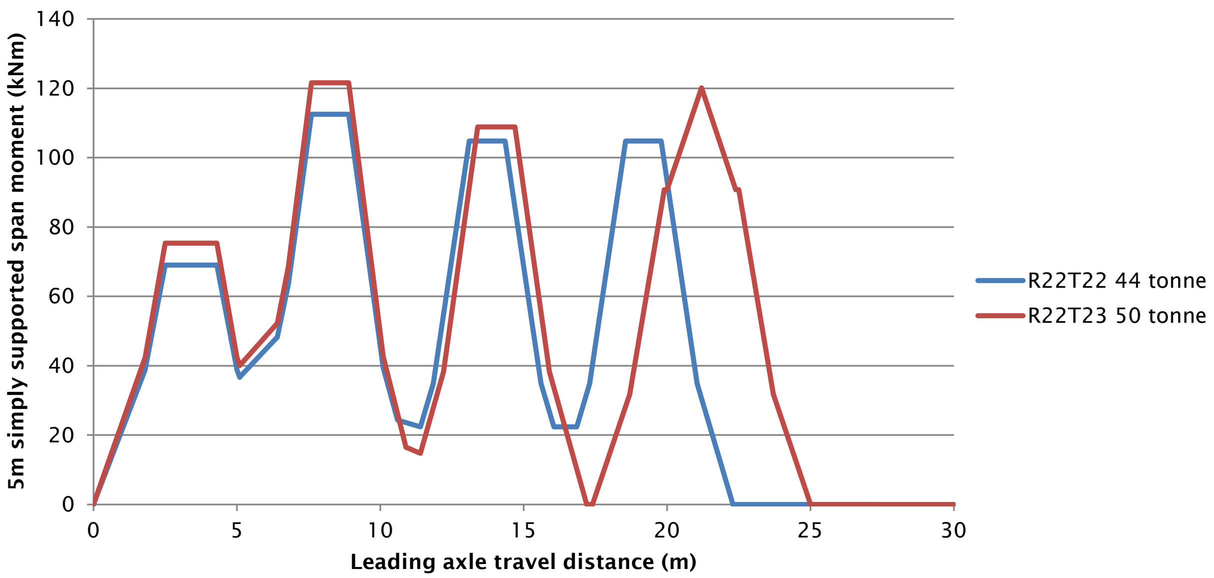
This finding contrasts with the pavement assessments (Jones 2012), which found no net increase in ESA counts. In our research, there were several differences in methodology that contributed to this dissimilarity:

- A 5th-power damage rule was used for steel bridges (versus 4th-power for pavements).
- The heavier axle sets (particularly the trailer triple-axle set) increased the average peak moments and shears on short spans.
- Peak-to-trough stress ranges (represented by bending moments and shear forces) were the important variable rather than axle set weights. At certain span lengths (around 5m) the increased trailer axle set spacings tended to lower the trough values between axle sets, which further increased the 5th-power stress range summation. Figure G.1 illustrates this point, and the same effect was seen in the full HPMV evaluations for short spans.
- The pavement studies made pessimistic assumptions about the vehicle types that could upgrade to 50MAX, limiting the scope to existing R22T22 and B1232 vehicle combinations. Stimpson (2012) and de Pont (2012) allowed for a wider range of vehicle configurations to upgrade. Our research included existing R12T12, R12T22 and B1233 counts in the potential upgrade counts.

- Our research assumed directional bias to maximise loading effects on individual girders, whereas the pavement studies captured the averages for both directions in order to aggregate total pavement costs. For bridges, the fatigue repair requirements may be limited to one direction but strengthening requirements would apply to the entire deck.
- The pavement evaluations relied on equivalent axle counts (de Pont 2012) that were calculated using data from all WIM sites combined over a fixed time period. Therefore, the averages were biased toward the busiest site (SH1 Drury), whereas the results for this study used separate weight distributions for each site.

Thus, evaluations of the potential fatigue impacts of 50MAX vehicles on bridge decks should consider the axle set effects on bridge spans, which differ from the average effects on pavements.

Figure G.1 Bending moments for Class 1 and 50MAX truck-and-trailers crossing a 5m span



G.4 Other comments

- The Australian data for 2002 on the Hume Highway (Grundy 2002b) shows annual growth figures for fatigue damage per truck of over 12% at short spans and 12–15% for medium spans. The estimates for the New Zealand sites (before adding volume growth) are of a similar order.
- The analysis of the HPMV-modified fatigue loadings in terms of M1600 loading shows that the damage increases apply at all span lengths and that the AS 5100.2 design equation for cycle count variation with span length (inversely proportional to square root of span length) is not appropriate.
- For design of new structures, where stress cycles for legal vehicles will be below the CAFL, the evaluations based on 5th-power equivalence results are relevant at all span lengths.
- For assessment of older structures, maximum stress cycles for legal vehicles might exceed the CAFL and the damage increase factors may decrease.
- Similarly, if vehicle mass limits continue to increase beyond the new HPMV limits, stress ranges for future vehicles may exceed the CAFL for bridges designed to current standards. Thus, indefinite growth in damage rate using a 5th-power rule would not be appropriate.

G.5 AS 5100.2 long-term growth assumptions

The cycle counts specified in AS 5100.2 clause 6.9 allow for:

- 75-year fatigue design life
- 4% compound growth rate in equivalent cycle counts

Thus the total cycle count is approximately 440 x year-1 count.

The BD-090 committee notes (Grundy 2002b) indicate that this was derived by considering:

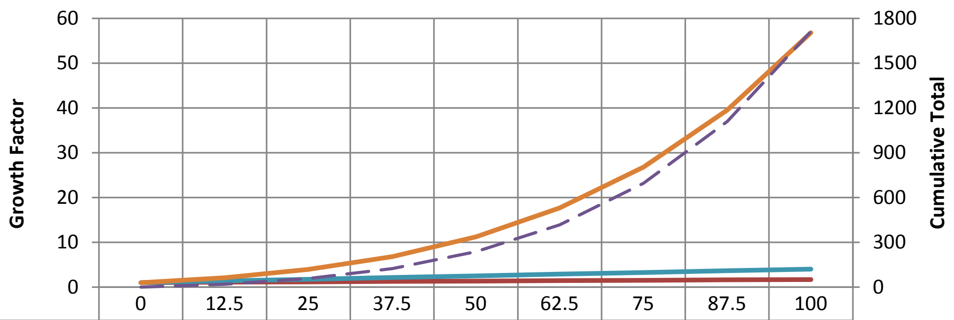
- year 2000 as the base year
- a linear increase in truck counts (per slow lane) from 1500 to 4000 per day over 50 years (3.3% pa initially), capped at 4000 thereafter
- axle mass increasing by 33% (from a 6-tonne average to an 8-tonne average) over 12 years, then stabilising.

G.6 Long-term growth assumptions for New Zealand

The preceding material shows that estimated HPMV take-up coupled with volume growth rates similar to the forecast GDP growth rate results in damage growth rates over 10% pa initially (as observed in the Australian data from 2000 to 2001). In the longer term it is assumed that there would an upper bound on axle mass limits as is assumed in the live load study (Taplin et al 2013, see table F.1), the AS 5100 model, and the surveyed international codes. Therefore in the longer term a lower average growth rate for equivalent mass could be considered, with an eventual cap. As a minimum, the vehicle mass growth rate applicable to the 50MAX (lower bound HPMV) scenario should be assumed, as this option will be available on most roads. The current average dual-tyre axle masses are up to 6.0 tonnes at the New Zealand WIM sites (5th-power weighted average). A 30% average mass increase beyond a 10-year initial HPMV take-up period might increase the average axle to 8.0–8.4 tonnes.

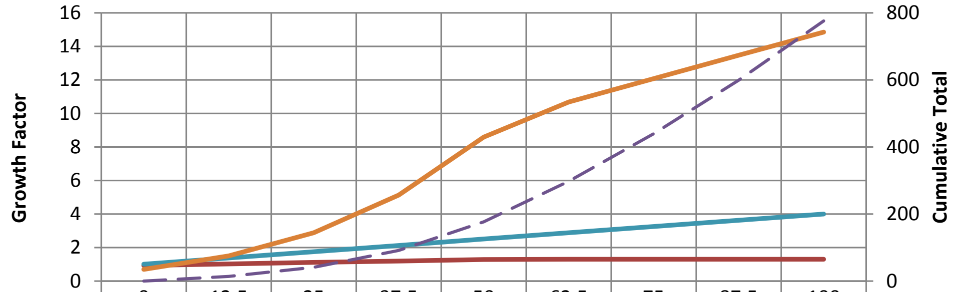
Some alternative scenarios are presented here.

a) Uncapped – 0.7% pa average linear vehicle mass growth, 3% pa linear volume growth:



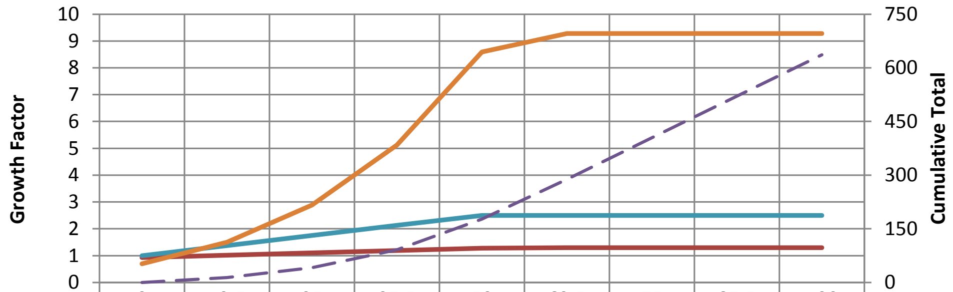
	0	12.5	25	37.5	50	62.5	75	87.5	100
Mass Factor	1.00	1.09	1.18	1.26	1.35	1.44	1.53	1.61	1.70
Volume Factor	1.00	1.38	1.75	2.13	2.50	2.88	3.25	3.63	4.00
Damage factor (m=5)	1	2.1	3.9	7	11	18	27	40	57
cumulative (x year 1)	0	19	57	124	237	417	695	1109	1711
equiv compound rate		7.3%	6.3%	5.7%	5.4%	5.1%	4.8%	4.6%	4.4%

b) Capped mass growth – 0.7% pa average linear vehicle mass growth with 10-year HPMV take-up period (starting at 0.93 factor) and capped at 30% further growth, 3% pa linear volume growth:



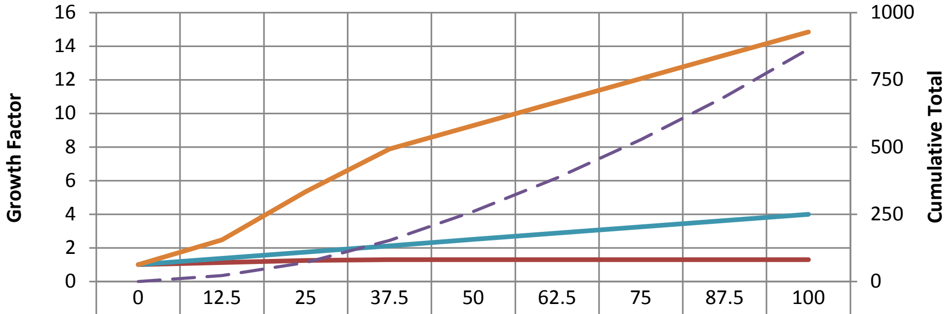
	0	12.5	25	37.5	50	62.5	75	87.5	100
Mass Factor	0.93	1.02	1.11	1.19	1.28	1.30	1.30	1.30	1.30
Volume Factor	1.00	1.38	1.75	2.13	2.50	2.88	3.25	3.63	4.00
Damage factor (m=5)	0.7	1.5	2.9	5	9	11	12	13	15
cumulative	0	14	41	91	177	297	439	599	776
equiv compound rate		1.6%	3.9%	4.4%	4.5%	4.3%	4.0%	3.6%	3.4%

c) Capped mass and volume growth – 0.7% pa average linear vehicle mass growth as for (b), 3% pa linear volume growth from 1600 to 4000 trucks/day/lane after 50 years:



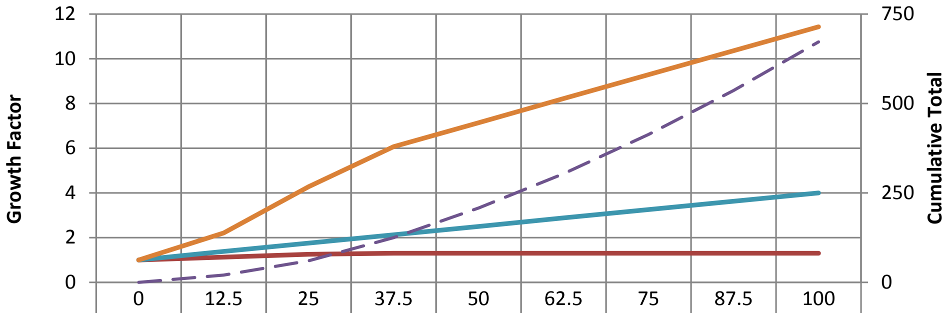
	0	12.5	25	37.5	50	62.5	75	87.5	100
Mass Factor	0.93	1.02	1.11	1.19	1.28	1.30	1.30	1.30	1.30
Volume Factor	1.00	1.38	1.75	2.13	2.50	2.50	2.50	2.50	2.50
Damage factor (m=5)	0.7	1.5	2.9	5	9	9	9	9	9
cumulative	0	14	41	91	177	289	405	521	637
equiv compound rate		1.6%	3.9%	4.4%	4.5%	4.2%	3.8%	3.4%	3.1%

d) Capped mass growth – 1.0% pa average vehicle mass growth with no initial take-up period, 3% pa linear volume growth.



	0	12.5	25	37.5	50	62.5	75	87.5	100
Mass Factor	1.00	1.13	1.25	1.30	1.30	1.30	1.30	1.30	1.30
Volume Factor	1.00	1.38	1.75	2.13	2.50	2.88	3.25	3.63	4.00
Damage factor (m=5)	1.0	2.5	5.3	8	9	11	12	13	15
cumulative	0	22	71	153	261	385	527	687	864
equiv compound rate		9.2%	7.8%	6.7%	5.7%	4.9%	4.3%	3.9%	3.5%

e) Capped mass growth, higher stress ranges above CAFL – as for (d) but using a 4th-power damage rule (average value, as highest stress ranges may be in the 3rd-power S-N curve range while the 5th power rule applies to lower stress ranges):



	0	12.5	25	37.5	50	62.5	75	87.5	100
Mass Factor	1.00	1.13	1.25	1.30	1.30	1.30	1.30	1.30	1.30
capped vol factor	1.00	1.38	1.75	2.13	2.50	2.88	3.25	3.63	4.00
Damage factor (m=4)	1.0	2.2	4.3	6	7	8	9	10	11
cumulative	0	20	60	125	208	304	413	536	672
equiv compound rate		7.8%	6.7%	5.8%	5.0%	4.3%	3.8%	3.5%	3.1%

G.7 Summary

From the five scenarios shown above, we can observe the following:

- An ongoing compound growth rate for damage is necessary to adequately represent a combination of mass and volume growth.
- Scenario (b) 0.7% pa capped vehicle mass growth with 3% pa volume growth fits the AS 5100.2 multiplier (440 x base year).
- Uncapped mass limit growth would result in much higher damage at 75+ years.
- The scenarios generally support the AS 5100.2 approach (~4% compound damage growth rate) but at lower assumed mass growth rates than Grundy's example, due to the preference for the 5th-power

damage rule. Thus if the optimistic HPMV take-up scenarios are to be covered, a higher growth rate should be assumed (eg 4.3% over 75 years from scenario (d)).

- A 100-year fatigue design life would require 60–75% more design cycles (roughly 10–12% reduction in stress range for the fatigue vehicle) compared to the 75-year life used in AS 5100.2.
- Even with low assumptions for growth rate, the 100-year multipliers exceed the AS 5100.2 allowance.

Appendix G references

de Pont, J (2012) Lower bound HPMVs – vehicle configurations. Transport Engineering Research New Zealand Limited (TERNZ) report to NZTA. Accessed 19 June 2014. www.nzta.govt.nz/vehicle/your/50max/docs/report-of-vehicle-configurations.pdf

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Jones, A (2012) *Lower bound HPMVs: analysis of pavement impacts*. Accessed 19 June 2014. www.nzta.govt.nz/vehicle/your/50max/docs/lb-hpmv-analysis-of-pavements-summary-report.pdf

Stimpson, D (2012) *Business case for lower bound high productivity motor vehicles*. Accessed 16 June 2014. www.nzta.govt.nz/vehicle/your/50max/docs/lower-bound-hpmv-business-case.pdf

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Appendix H Heavy vehicle data collection, analysis and validation summary

H.1 Introduction

This appendix presents the findings of the data validation exercise undertaken at step 3 of this research project (see the outline in section 3.1) and summarises the heavy traffic characteristics for each site. The findings include recommendations on which datasets are suitable for use in deriving fatigue loadings.

H.2 Heavy vehicle data collection

H.2.1 NZ Transport Agency WIM sites

The NZ Transport Agency owns eight WIM stations on the state highway network, including the two AHB stations managed by Beca and Auckland Motorway Alliance (AMA) personnel for the Auckland Harbour Bridge Alliance. Outputs from the Transport Agency systems (excluding the AHB WIM systems at present) are available from the Transport Agency's TMS database, while the AHB data is maintained in a dedicated database system (AHBWIM) located at the AMA offices, with back-up copies held by Beca and the Transport Agency. The details of the eight WIM sites owned by the Transport Agency are shown in table H.1, and a map of the locations of the five non-AHB WIM sites for which data is available is given in appendix A.

Table H.1 Details of Transport Agency-owned WIM stations in New Zealand

Site ref.	ID code	Location name	Highway position	Inception date	Lanes	Comments
01N00463	48	Drury	01N-0461/2.24	Jan 2001	4	
00500259	101	Eskdale	005-0249/10.26	Jul 2010	2	
00200176	49	Te Puke	002-0171/4.4	Jan 2000	2	
01N00628	51	Tokoroa	01N-0625/3.5	Jan 2000	2	
01S00285	52	Waipara	01S-0284/0.6	Jan 2000	2	
03500321	108	Hamanatua Bridge	035-0321/0.091	Nov 2011	2	Raw data unavailable at time of review
01N18423		AHB Southbound	01N-0414/9.0	Dec 2000	5	4 lanes until 2006
01N28423		AHB Northbound	01N-0414/8.6	Jun 2006	5	4 lanes 1996–2000

H.2.2 WIM data download from the Transport Agency's TMS database

The methodology outlined in chapter 3 of this research report required sufficient representative samples of data from WIM sites to determine current fatigue loadings. It was desirable, though not essential, to obtain long periods of data that covered the range of seasonal variations.

A subset of the years with available data was therefore selected for raw data downloading, with reference to the days of accepted data (see annex H.1) and the annual summary reports obtained from the TMS database (annex H.2 presents the annual distributions by vehicle type). The weight-related annual summary tables (axle set weight distributions, ESA counts, and gross mass distributions by vehicle type) were also downloaded and are available in spreadsheet form but were found to be of little use, due to apparent weight calibration discrepancies for portions of the annual data.

The two most recent years (2011 and 2010) were selected for detailed analysis, along with 2005 and 2007 to provide information on recent growth trends. The years 2008 and 2009 were deliberately avoided, as there had been a noticeable short-term decline in vehicle counts resulting from economic factors, as indicated by the national state highway heavy traffic volume index for heavy vehicles (Wen 2013). The AHB data indicated significant peaks in 2005–2007, followed by a decline following completion of major infrastructure projects and the general economic downtown in 2008.

Approximately 10 million heavy vehicle records were downloaded from the TMS database for the five WIM sites for which raw data was available (Drury, Eskdale, Te Puke, Tokoroa and Waipara) and used to establish a database (using Microsoft Access). Data from the AHB WIM was already available in processed form for periods of particular interest.

H.2.3 Other Transport Agency data collection sites

Classified vehicle counts were needed to estimate fatigue loading at a selection of other routes. Sites with data available in TMS included:

- an axle classifier system (piezo strip) at SH1 Paekakariki (continuous)
- short periods of classified counts at a few sites in each region.

The status of the available data was investigated later in the study, and summarised counts have been provided in appendix D.

H.3 WIM data validation

From experience with the AHB WIM systems, issues were anticipated with use of raw or processed WIM data (such as incorrectly classified vehicles, length errors, hardware faults and calibration errors). The data received from the Transport Agency via the TMS database was therefore evaluated using our existing validation tools in order to identify the presence and extent of validity issues, and to identify usable data for fatigue loading.

It was possible that the minor type classification errors would not be detected through the above screening process. However, the proposed bridge fatigue load processing method using the filtered raw vehicle records to determine average damage per heavy vehicle did not rely on accurate type identification, other than excluding light vehicles.

H.3.1 Invalid record tagging

A set of validation rules was applied to all raw data records for all five sites for the selected years (2005, 2007, 2010 and 2011), and any records that did not comply were tagged as invalid. The rules used were as follows (% of records tagged given in brackets):

- Speed outside the range 30–140 km/hr (0.04%): May indicate a misread. Alternatively, if the speed is genuinely high or low, length and weight readings are often inaccurate.
- Length >25m or <2m (0.002%): Indicates a misread. Should be excluded from bridge loading calculations, but may be accepted for axle weight tallies.
- Wheelbase >25m or <1m (0.004%): Indicates a misread.
- Overhang (length–wheelbase) <1m or >10m (0.7%): Indicates a misread.
- Any axle <1000kg (3%): For a heavy vehicle record, this indicates either a light vehicle concatenated to a valid truck record or dynamic effects changing the distribution within an axle set. These may be

usable for fatigue load evaluations but should be excluded when characterising loadings by vehicle class.

- Any axle >16000kg (0.008%): This may indicate an intermittent hardware fault or incorrectly doubled axle weight (where the system detects a problem in one pad and attempts to compensate by doubling the measured weight). These records should be excluded from bridge loading evaluations.

The total percentage of records tagged as invalid was 3.8%. These rules excluded most vehicles that were not suitable for characterising the bridge span loading effects, but many of the 'invalid' records were still applicable for axle weight-related effects and were retained for processing.

H.3.2 Steer-axle weights and selection of datasets for further analysis

The average weight of the steer axles for 6-axle articulated vehicles (PAT type 69 o-oo—ooo) was calculated and compiled by site, lane and month, and is shown in figures H.1–H.5. The steer-axle weight of this vehicle type is not significantly affected by payload and provided the general fleet remains the same there should be minimal variation in average recorded weight. From historic Transport Agency records and close monitoring of the AHB sites, the expected range for laden vehicles is 5.0–5.1 tonnes +/- 0.1 tonne either way. Values outside this range are treated with suspicion, and may indicate calibration errors. Sudden changes not associated with calibration setting changes are an indication of equipment problems.

Figure H.1 Average type 69 steer-axle weight by month, Drury

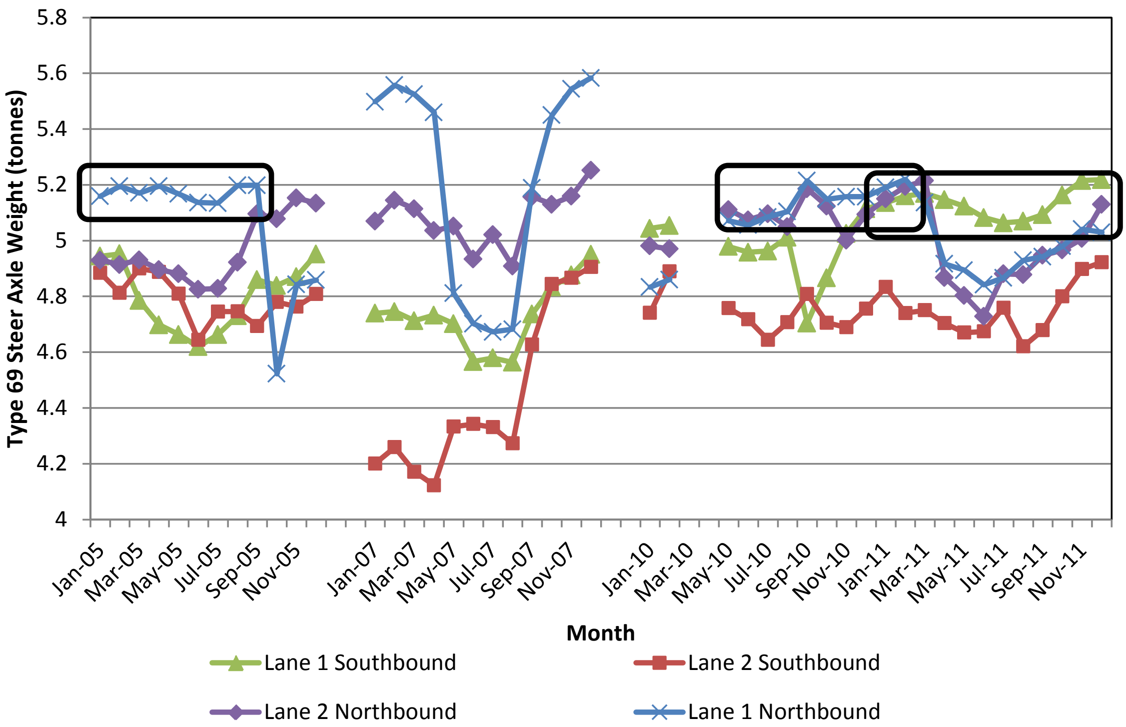


Figure H.2 Average type 69 steer-axle weight by month, Eskdale

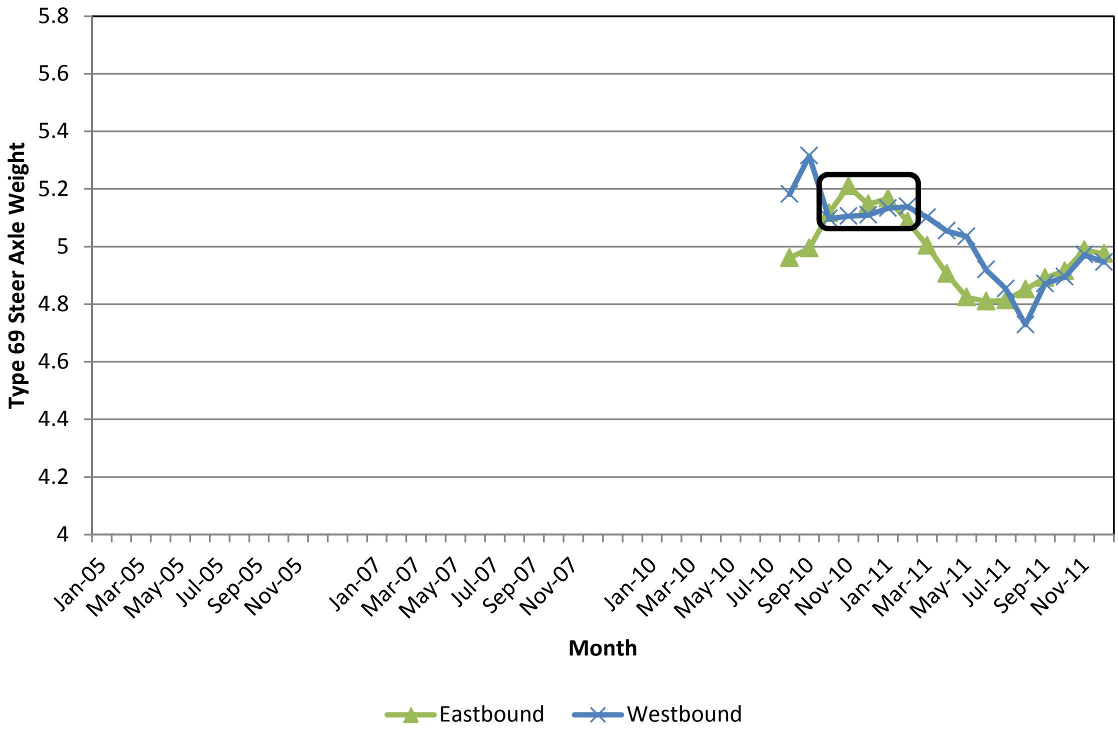


Figure H.3 Average type 69 steer-axle weight by month, Te Puke

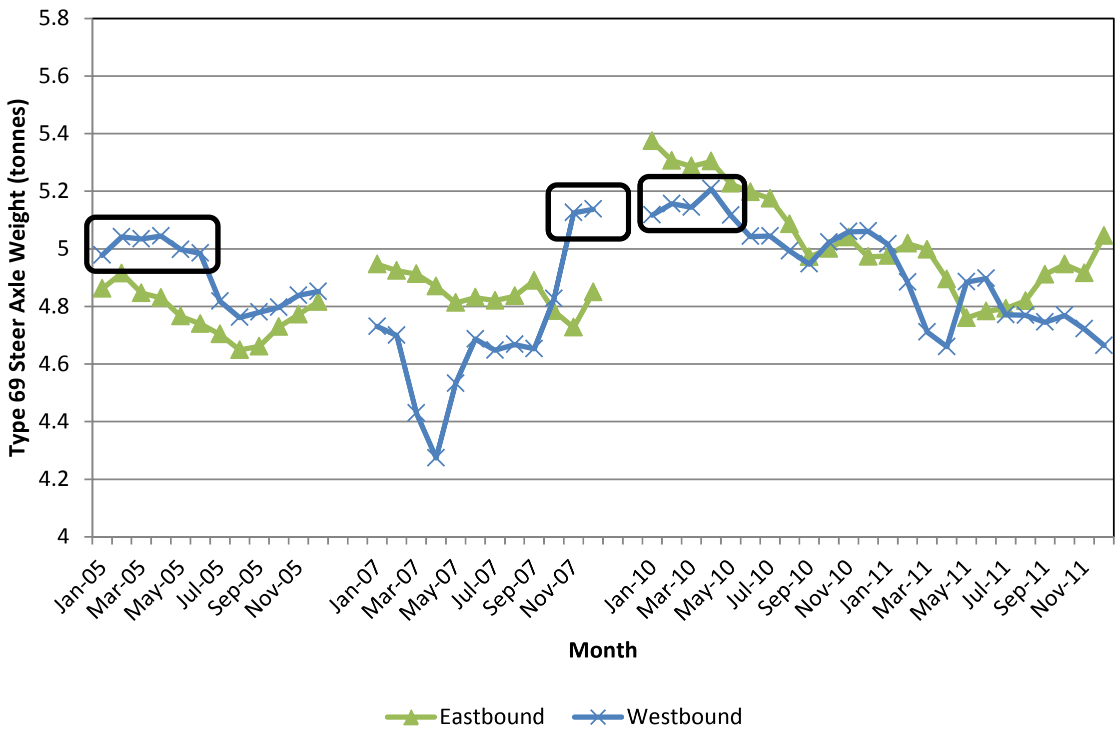


Figure H.4 Average type 69 steer-axle weight by month, Tokoroa

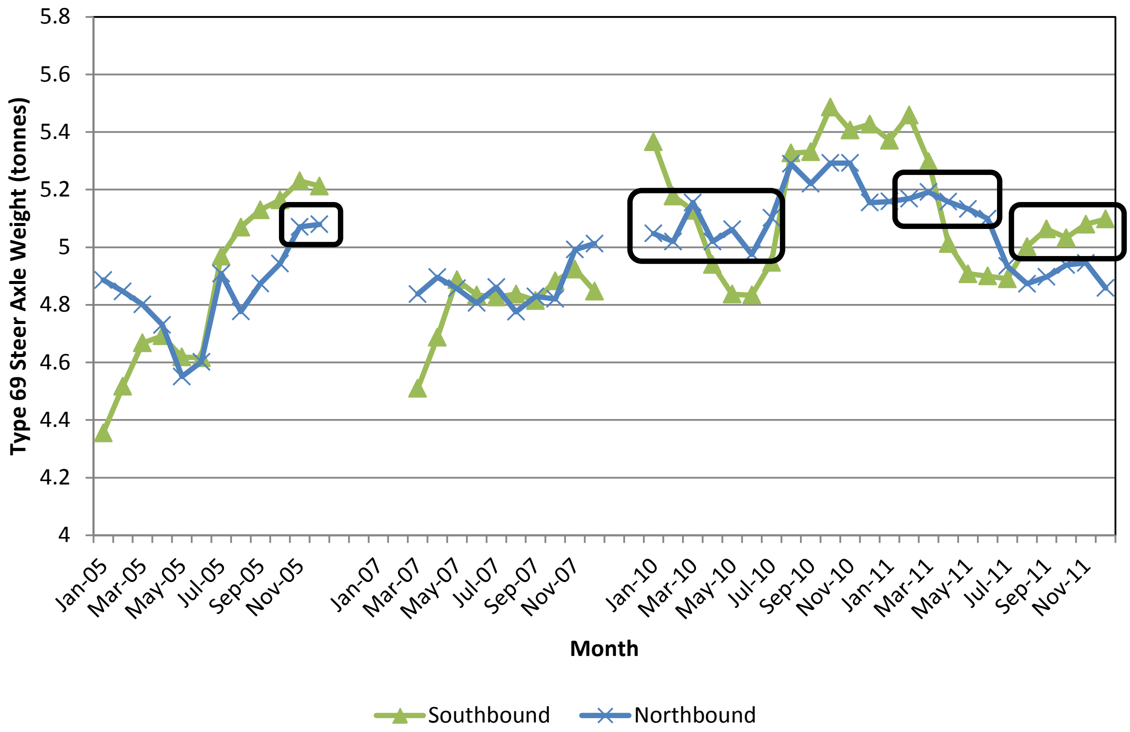
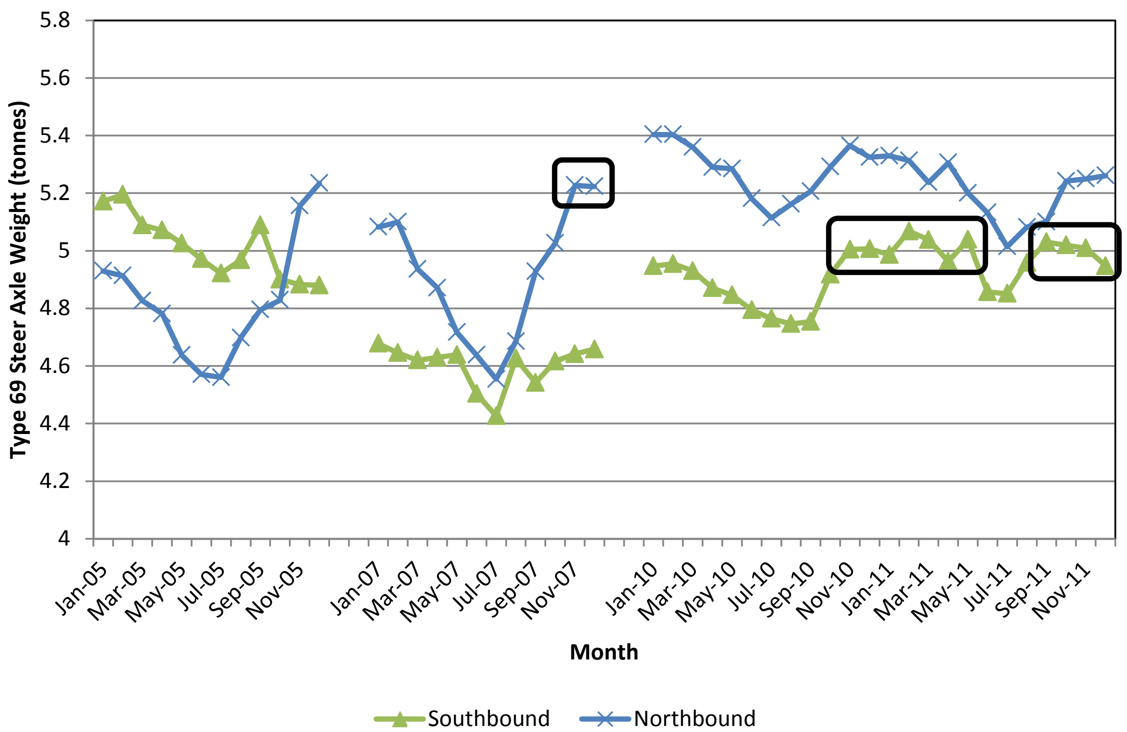


Figure H.5 Average type 69 steer-axle weight by month, Waipara



The type 69 steer-axle weights at all sites showed substantial variation from the expected range over the years analysed, as can be seen in figures H.1–H.5.

The data from Waipara (see figure H.5) also appears to show seasonal variations, with troughs present at around July each year. This could indicate that temperature effects were not being adequately compensated for at this site, which may have compromised the data's validity for deriving fatigue loadings. It was also noted from inspection of Google Streetview images that the pavement cracking around the induction loops was evident at time of capture (January 2010).

Subsets of the data (particular lanes over particular time periods) show steer-axle weights sufficiently consistent and close to the expected values to be used for bridge fatigue loading evaluations. The steer-axle weight data was therefore used as the basis for selecting valid datasets for further analysis. This selection principle was validated by comparing weight distributions for specific truck types from the AHB and Drury WIM sites that are known to make trips across both sites (eg type 751, which is dominated by bulk aggregate carriers supplying Auckland, including the North Shore). The directional bias of the weight data was also used as a guide for data selection, as the direction with more empty vehicles was considered less important for fatigue load estimation. The more heavily loaded directions were found to be as given in table H.2, with the AHB also given for comparison.

Table H.2 Directional bias in loading

Site	Higher loading direction	Major freight destination(s)
SH1 Drury	Northbound (2005) Southbound (2010/11)	Auckland
SH1 Tokoroa	Northbound	Auckland, Hamilton, Tauranga
SH2 Te Puke	Westbound	Tauranga (port)
SH5 Eskdale	Eastbound	Napier (port, timber mill)
SH1 Waipara	Unclear	Picton, Christchurch
SH1 AHB	Northbound	North Shore

The accepted valid datasets are listed in table H.3 and indicated by boxes in figures H.1–H.5. The selected datasets represented approximately 20% of the downloaded heavy vehicle records. The percentage of records tagged as invalid in the data validation process (see section H.3.1) are also given in table H.3.

Table H.3 Datasets selected for further analysis

Site	Lane	Time period	Heavy vehicles	Average type 69 steer-axle weight (tonnes)	% tagged as invalid
Drury	1 northbound	01/01/2005–30/09/2005	499,353	5.17	2.7%
Drury	1 northbound	01/05/2010–31/03/2011	558,678	5.14	2.9%
Drury	1 southbound	01/01/2011–31/12/2011	659,074	5.14	1.4%
Waipara	Northbound	01/01/2007–28/02/2007	17,308	5.09	6.0%
Waipara	Southbound	01/11/2010–31/05/2011	114,173	5.02	3.6%
Waipara	Southbound	01/09/2011–31/12/2011	65,590	5.00	4.2%
Tokoroa	Northbound	01/11/2005–31/12/2005	40,323	5.07	2.9%
Tokoroa	Northbound	01/01/2010–31/07/2010	129,961	5.06	6.2%
Tokoroa	Northbound	01/01/2011–30/06/2011	120,920	5.15	3.3%

Site	Lane	Time period	Heavy vehicles	Average type 69 steer-axle weight (tonnes)	% tagged as invalid
Tokoroa	Southbound	01/08/2011–31/12/2011	102,945	5.06	3.8%
Te Puke	Westbound	01/01/2005–30/06/2005	107,790	5.01	1.6%
Te Puke	Westbound	01/11/2007–31/12/2007	48,793	5.13	7.2%
Te Puke	Westbound	01/01/2010–31/05/2010	131,116	5.15	3.8%
Eskdale	Eastbound	01/10/2010–28/02/2011	39,377	5.14	3.1%
Eskdale	Westbound	01/10/2010–28/02/2011	40,093	5.12	1.2%
Total			**2,016,420**	**5.13**	**3.3%**

H.4 Characteristics of data selected for further analysis

Further analysis of the datasets listed in table H.3 was undertaken in order to gain an understanding of the characteristics of the data, and to provide recommendations regarding which datasets are suitable for processing to derive fatigue loading information.

H.4.1 Average daily vehicle counts

Table H.4 shows the average vehicle counts and heavy vehicle counts per day for each of the selected datasets, with AHB and Paekakariki (axle classifier site ID 47 on SH1 north of Wellington) for comparison. These counts include the invalid vehicle types that were not included in the WIM data downloaded from the TMS database (NZ Transport Agency class 14) and therefore include all heavy vehicles.

In order to enable comparison with other sites that lack WIM equipment, the heavy vehicle counts shown in table H.4 are presented as heavy vehicle counts for both 2+ and 3+ axles. The WIM equipment is able to distinguish light and heavy vehicles settings clearly, whereas other counter sites can only identify 'heavies' from axle spacing or length-based classification. Use of the 3+ axle counts avoided the uncertainty in the classification of 2-axle vehicles and directly related to counts for HCVs plus 3-axle buses (the Transport Agency EEM (2010) defines HCVs as heavy commercial vehicles with three or more axles, excluding Passenger Transport vehicles). Further details of the Transport Agency classification schemes are provided in appendix A.

The variations in traffic volume and composition between sites are apparent in table H.4, and these are related to the nature of the routes on which the sites are located:-

Drury: Located just south of Auckland on SH1 and carries almost all north–south traffic at this point, and therefore has the second highest traffic volume of all the sites. The heavy vehicle percentage content of the traffic stream is moderate, reflecting the freight that travels on the main highway as well as the relatively high volumes of lighter vehicles. The freight task includes long-haul inter-city traffic and bulk aggregate supplies from the south, but excludes the routes from the nearest major quarry at Drury and the steel mill.

Eskdale: Located on the comparatively minor SH5, and has the lowest traffic volume of the WIM sites. The high content of heavy vehicles reflects the presence of forestry activity in the area, but the main route between the Pan Pacific mill and the port is on SH2 north of the SH5 junction and therefore loading on SH2 may be higher.

Te Puke: Located on SH2 between the port of Tauranga and the mostly small-town/rural eastern North Island. The traffic volumes here are moderate, as are the heavy vehicle proportions, most of which is likely to reflect freight (including timber products) to the port.

Tokoroa: Has relatively low traffic volumes despite being on SH1, likely due to the availability of alternative routes. The heavy traffic percentages are high, however, due to being on a long-haul freight route and the proximity of the Kinleith pulp and paper mill south of Tokoroa.

Waipara: Also has relatively low traffic volumes compared with the other WIM sites, and is located north of Christchurch. The heavy traffic volumes are relatively high, possibly because of the agriculture and wineries in the region, in addition to Christchurch–Picton freight.

AHB: High-volume 8-lane urban motorway with highest traffic volumes, but lowest heavy traffic percentage contents, reflecting its location within a major city and the resulting domination of the traffic stream by lighter vehicles. The maximum daily heavy vehicle counts per lane are less than the Drury site, and thus the Drury site has the highest ‘slow’ lane heavy counts.

Table H.4 Average daily vehicle counts for selected datasets

Dataset	All vehicles	Heavy vehicles with ≥2 axles		Heavy vehicles with ≥3 axles	
		Count	%	Count	%
Drury Jan–Sep 2005, northbound	20,137	2055	10%	1443	7.2%
Drury May 2010–Mar 2011, northbound	20,483	2148	10%	1553	7.6%
Drury Jan–Dec 2011 southbound	20,957	2094	10%	1459	7.0%
Eskdale Oct 2010–Feb 2011, eastbound	1997	289	14%	234	12%
Eskdale Oct 2010–Feb 2011, westbound	1979	291	15%	241	12%
Te Puke Jan–Jun 2005, westbound	9203	841	9.1%	597	6.5%
Te Puke Nov–Dec 2007, westbound	10,787	967	9.0%	667	6.2%
Te Puke Jan–May 2010, westbound	9849	936	9.5%	697	7.1%
Tokoroa Nov–Dec 2005, northbound	4415	712	16%	514	12%
Tokoroa Jan–Jul 2010, northbound	4398	680	15%	571	13%
Tokoroa Jan–Jun 2011, northbound	4304	668	16%	562	13%
Tokoroa Aug–Dec 2011, southbound	4441	796	18%	622	14%
Waipara Jan–Feb 2007, northbound	4385	515	12%	384	8.8%
Waipara Nov 2010–May 2011, southbound	3981	571	14%	421	11%
Waipara Sep–Dec 2011, southbound	3736	670	18%	404	11%
AHB Mar 2007, southbound	82,597	3104	3.8%	1589	1.9%
AHB Mar 2007, northbound	84,337	3203	3.8%	1571	1.9%
AHB Mar 2011, southbound	76,055	3059	4.0%	1567	2.1%
AHB Mar 2011, northbound	81,267	3094	3.8%	1573	1.9%
Paekakariki 2011, northbound	11,626	921	7.9%	521	4.5%
Paekakariki 2011, southbound	11,581	874	7.5%	522	4.5%

At the urban highway sites (AHB and Paekakariri) it is evident that doubling the observed counts for 3+-axle vehicles to obtain the total heavy counts (as recommended in the UK National Annex to Eurocode 1 – British Standards Institution 2008) is a satisfactory approximation. At the other sites, the average 2-axle heavy vehicle counts add 25–45% to the 3+-axle totals.

H.4.2 Heavy vehicle proportions by PAT type

The analysis that follows was based on the classification of vehicles into PAT types, the 10 most common of which are shown in table H.5.

Table H.5 Description of the 10 most common PAT types

PAT type	Axle configuration	Short code	Description
20	o-o	R11	Short truck
21	o--o	R11	Rigid truck or bus
31	o--oo	R12	Rigid truck or bus
45	oo--oo	R22	Rigid truck
69	o-oo--ooo	A123	Articulated truck
751	o-oo--oo--oo	R12T22	Truck-and-trailer, or B-Train
791	o-oo---oooo	A124	Articulated truck
826	oo-oo--oooo	A224	Articulated truck
851	o-oo--ooo--oo	B1232	B-Train
891	oo--oo-oo--oo	R22T22	Truck-and-trailer

The heavy vehicle proportions by PAT type for the 10 most common PAT types are presented in table H.6, with the counts and proportions for all PAT types included in annexes H.2 and H.3. It can be seen that the proportions of each vehicle type vary between sites, time periods and directions. However, all datasets except Drury and westbound at Eskdale had type 891 (R22T22) as the most common heavy vehicle and R11 (a 2-axle truck) as the second most common. At Drury, R11 was the most common type, and type 891 was the second most common. At Eskdale, the most common westbound heavy vehicle type was 45 (a 4-axle truck), due to many type 891 logging vehicles piggybacking empty trailers on the truck for their return journey.

In general, type 891 (a twin-steer truck-and-trailer) was used for general freight and logs, while type 751 (with single-steer truck) was most commonly used by bulk carriers (such as tipper trucks hauling aggregates and the like), but also by flat-bed truck-and-trailers.

The counts for newer types with 8–10 axles were much smaller, but growing. The annual summary tables (totals for all lanes and months in annex H.2) show the trends since 2000, but counts for some of the new types were not reported until they were added to the WIM configurations, and usage of a few types was inconsistent. We note the following:

- Many of the (small) counts for odd configurations arose from classification errors (misreads) such as concatenated or spit vehicles.
- Introduction of new types 300, 301, 401, 402 and 503 in 2011 to separate light trailers improved usability of the count data for this study but has created inconsistencies with previous years.
- The counts for types 61, 62 and 621 were combined, as these have all been used for the o-oo---o-o-o configuration at various times (tractor and semi-trailer with three widely spaced axles, a common heavy plant transporter rig). Type 69 also captured some of these (triple-axle spacings <2.2m).
- Type 1020 captured new HPMV types R23T23, B2233 and probably B2234 if any (11 axles).

Table H.6 Proportions of heavy vehicles (>3.5 tonnes) by PAT type for selected datasets

Site and direction	PAT type								
	20 & 21 (R11)	31 (R12)	45 (R22)	69 (A123)	791 (A124)	826 (A224)	751 & 891 (R12T22 & R22T22)	851 (B1232)	Other
Drury NB	27.8%	9.9%	5.1%	10.4%	1.9%	2.1%	24.8%	6.8%	11.2%
Drury SB	26.7%	9.7%	5.1%	9.0%	2.8%	4.3%	25.7%	6.2%	10.5%
Eskdale EB	20.8%	6.1%	3.0%	4.0%	1.2%	3.9%	44.1%	6.2%	10.6%
Eskdale WB	17.8%	6.2%	26.2%	3.8%	1.2%	4.4%	25.6%	7.3%	7.5%
Te Puke WB	28.1%	8.0%	4.6%	8.1%	0.9%	2.0%	34.3%	6.1%	7.9%
Tokoroa NB	17.8%	6.7%	5.3%	5.6%	2.3%	3.7%	38.0%	9.2%	11.4%
Tokoroa SB	17.8%	6.3%	8.8%	4.7%	2.3%	4.8%	34.3%	8.9%	12.0%
Waipara NB	25.2%	5.4%	10.9%	5.5%	3.2%	0.0%	30.4%	11.2%	8.2%
Waipara SB	28.6%	5.2%	3.6%	3.7%	2.8%	2.8%	31.7%	9.9%	11.8%

H.4.3 GVM distribution of heavy vehicles by PAT type

Figures H.6–H.20 show the GVM distribution of heavy vehicles by PAT type for the 10 most common PAT types. Once again, variations are apparent over time and between different sites and lanes. However, all datasets show a peak in heavy vehicle counts in the region of 40–50 tonnes, which represents the fully loaded vehicles, and includes significant numbers of vehicles exceeding the 44-tonne legal limit at all sites. This peak is dominated by type 891 vehicles, with the exception of the pre-2008 Drury period (where type 751 counts are higher). This reduction at Drury is likely to be due to the downturn in construction activity in the region from 2008, but is offset by growth in the type 826 and 891 proportions. The second most common type (2-axle vehicles) is found almost exclusively below 15 tonnes in all datasets (compared with the 14.2-tonne legal limit).

At the Eskdale site, the behaviour described in section H.4.2 (where type 891 vehicles are reconfigured as type 45 on their westbound journey) is visible as a much higher peak of type 45 vehicles (at 15–18 tonnes) accompanied by a lower peak of type 891 vehicles in the westbound dataset. This has implications for estimation of multiple presence effects at this site and other sites with logging traffic (eg a type 891 truck one way concurrent with type 45 in the opposing direction).

At the Tokoroa site, a decrease in type 20 vehicles is accompanied by an increase in type 21 vehicles. This indicates that the change may be due to a change in processing rules for the WIM data (rather than a genuine change in traffic composition), as types 20 and 21 are distinguished from each other only by their axle spacing. The directional bias in the numbers of type 891 vehicles at this site may be due to these vehicles taking alternative routes when heading south.

The Waipara data shows significant seasonal variation (in both calibrations and vehicle weight distribution) and it is likely that 2011 heavy traffic was affected by the disruption to normal activity following the Christchurch earthquakes.

For comparison, the corresponding charts for the AHB WIM sites for March 2007 and 2011 are shown in figures H.21–H.28. As the data for these sites is so dominated by 2- and 3-axle vehicles, each chart is also produced in a version that omits these smaller vehicles.

The GVM distribution for all PAT types for a representative dataset from each site is available on request.

It should be noted that the length of datasets selected for further study was limited by apparent discrepancies in weight calibration. At some sites, the time periods were insufficient to cover the extent of seasonal variations at all sites, and this should be taken into account when estimating the bridge fatigue loading effects.

Figure H.6 GVM distribution by PAT type, Drury Jan–Sep 2005, Lane 1 northbound

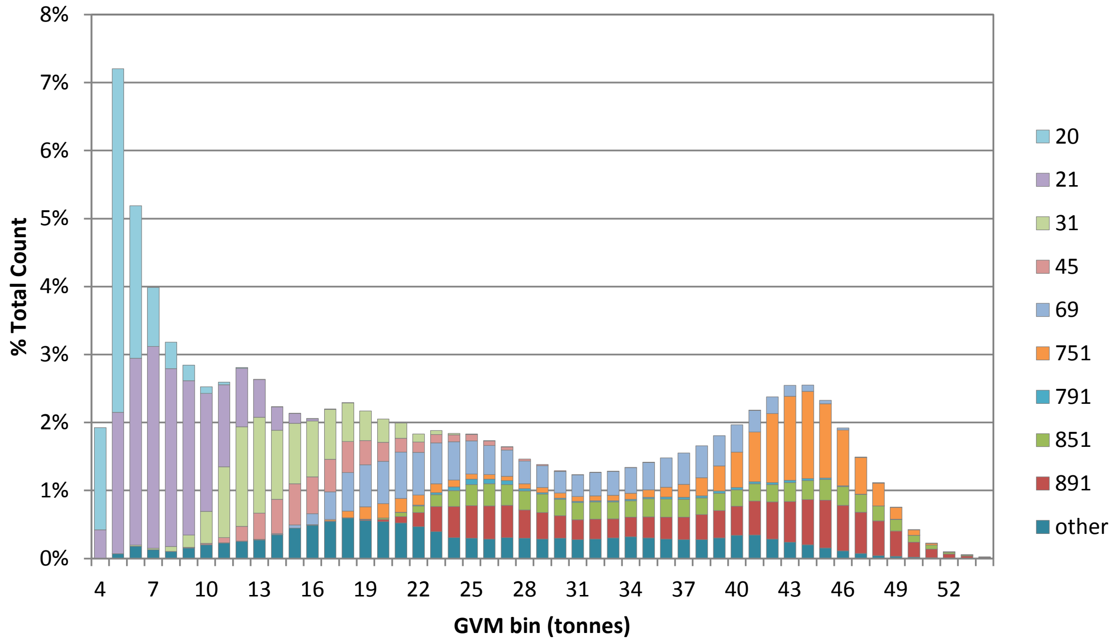


Figure H.7 GVM distribution by PAT type, Drury May 2010–Mar 2011, Lane 1 northbound

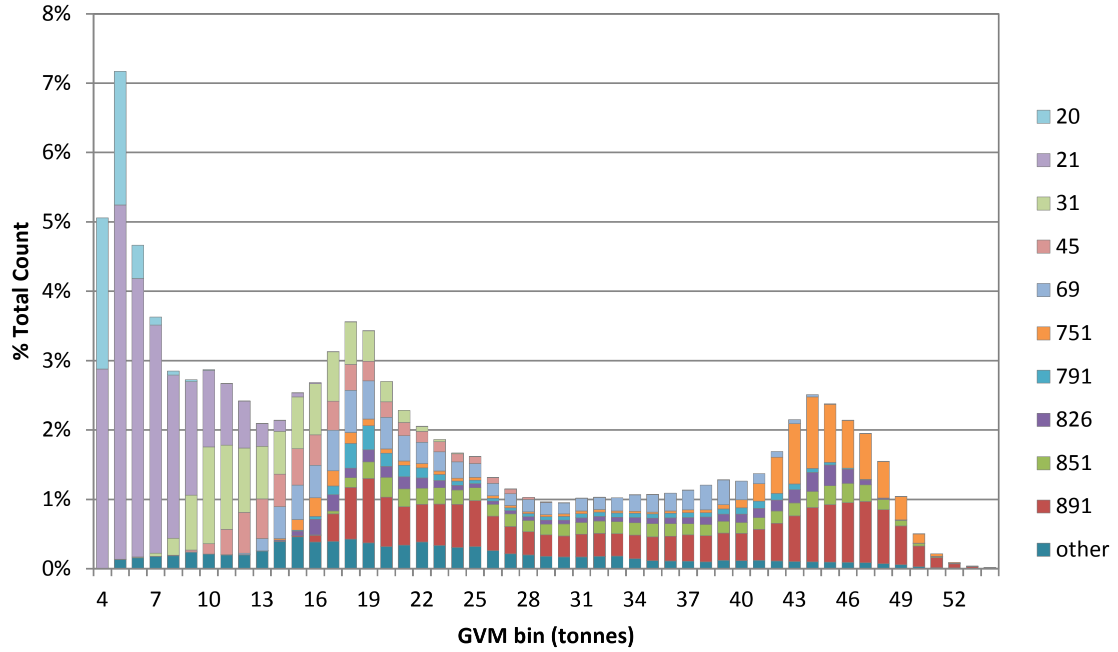


Figure H.8 GVM distribution by PAT type, Drury Jan–Dec 2011, Lane 1 southbound

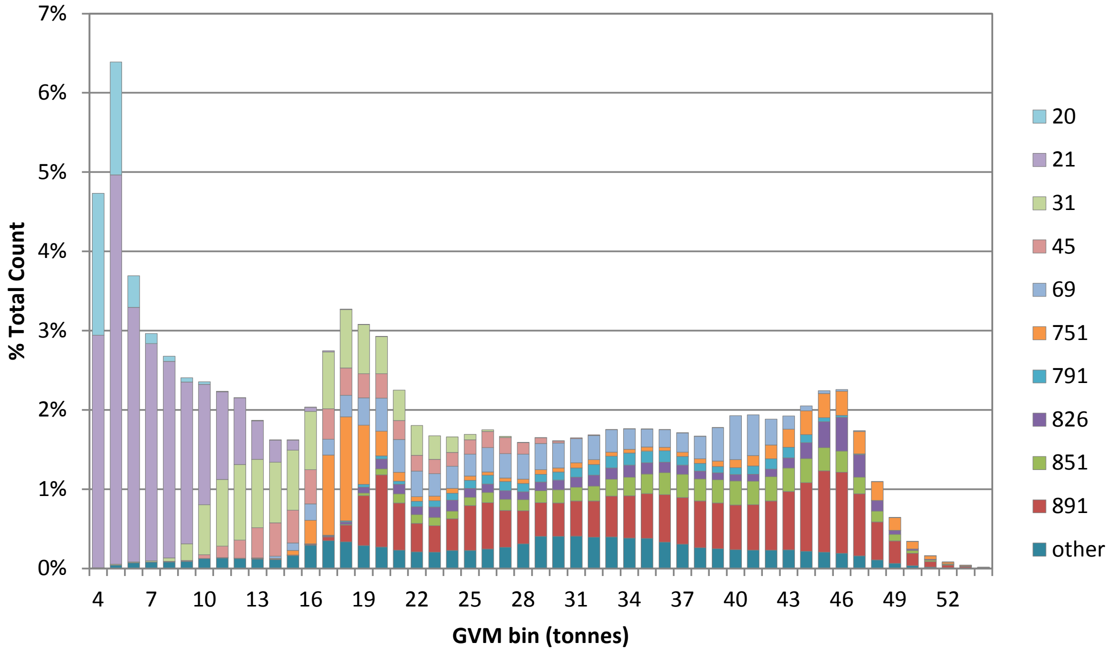


Figure H.9 GVM distribution by PAT type, Eskdale Oct 2010–Feb 2011, westbound

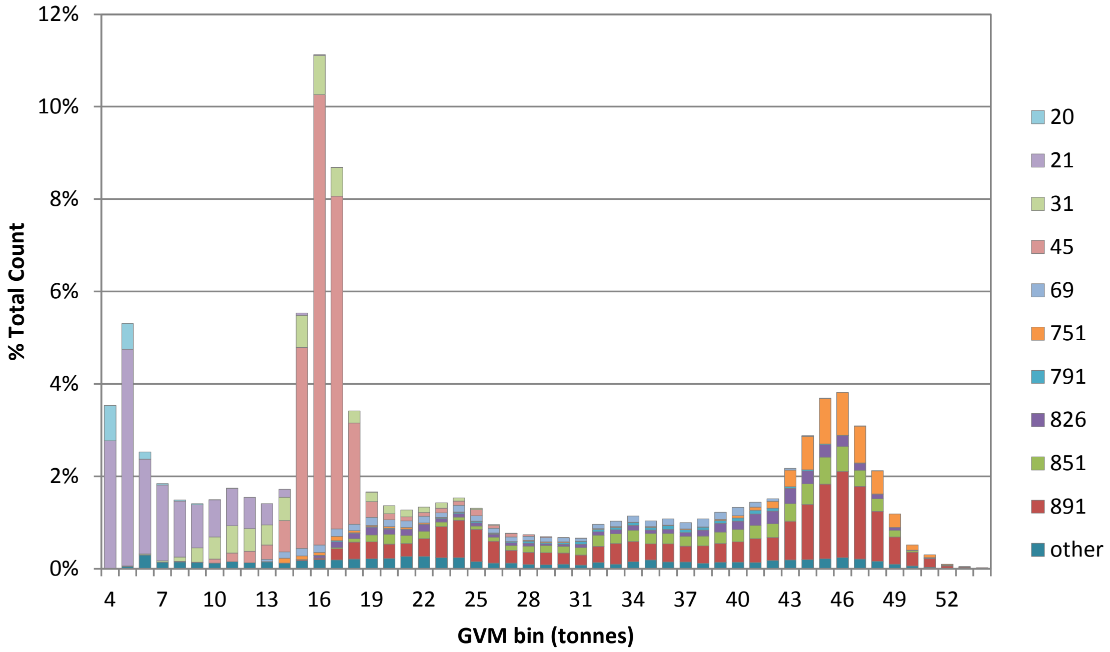


Figure H.10 GVM distribution by PAT type, Eskdale Oct 2010-Feb 2011, eastbound

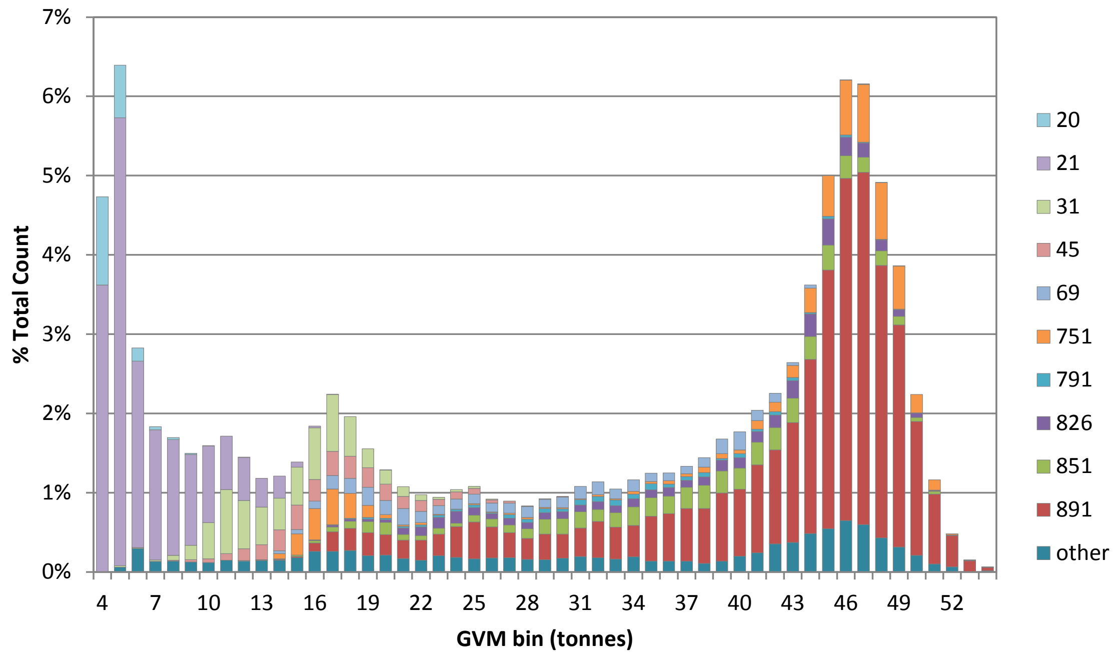


Figure H.11 GVM distribution by PAT type, Te Puke Jan-Jun 2005, westbound

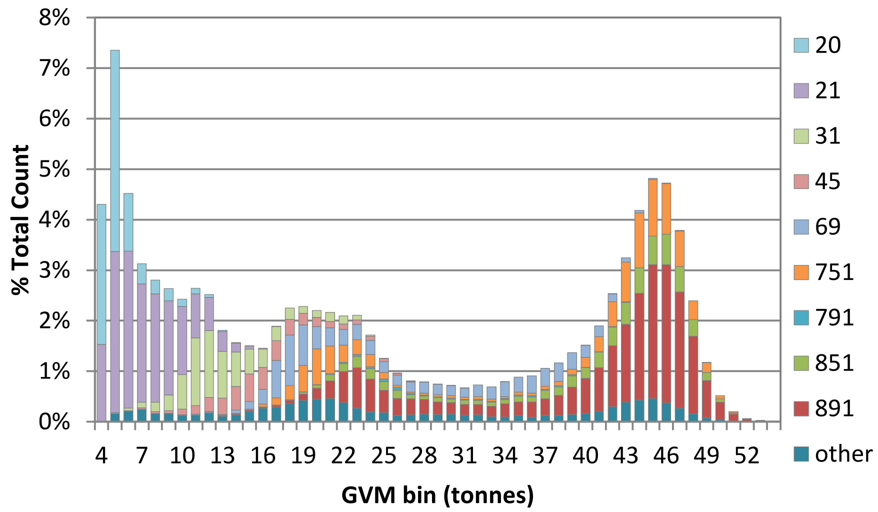


Figure H.12 GVM distribution by PAT type, Te Puke Nov–Dec 2007, westbound

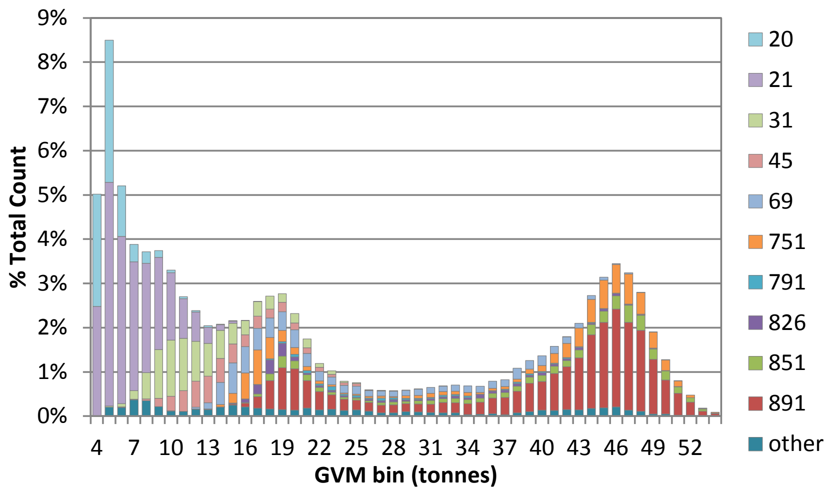


Figure H.13 GVM distribution by PAT type, Te Puke Jan–May 2010, westbound

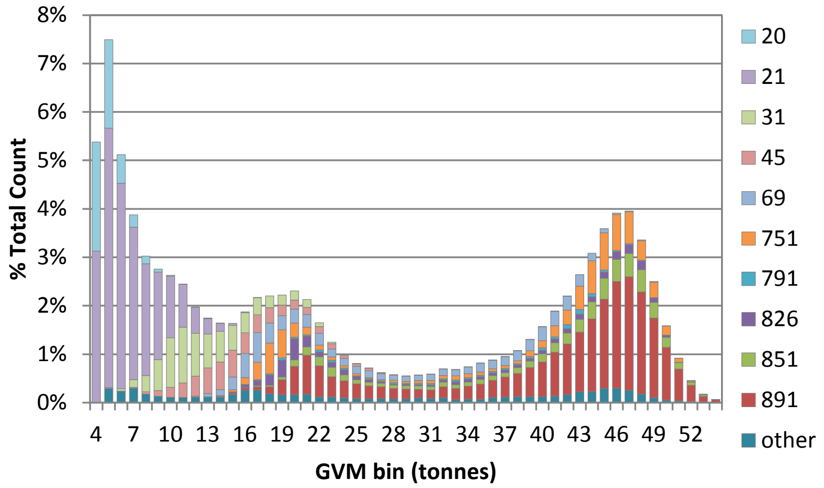


Figure H.14 GVM distribution by PAT type, Tokoroa Nov–Dec 2005, northbound

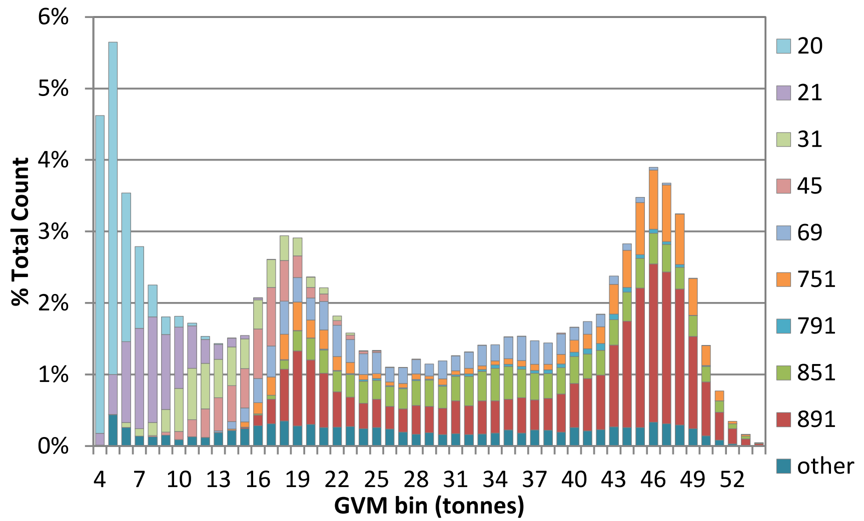


Figure H.15 GVM distribution by PAT type, Tokoroa Jan–Jul 2010, northbound

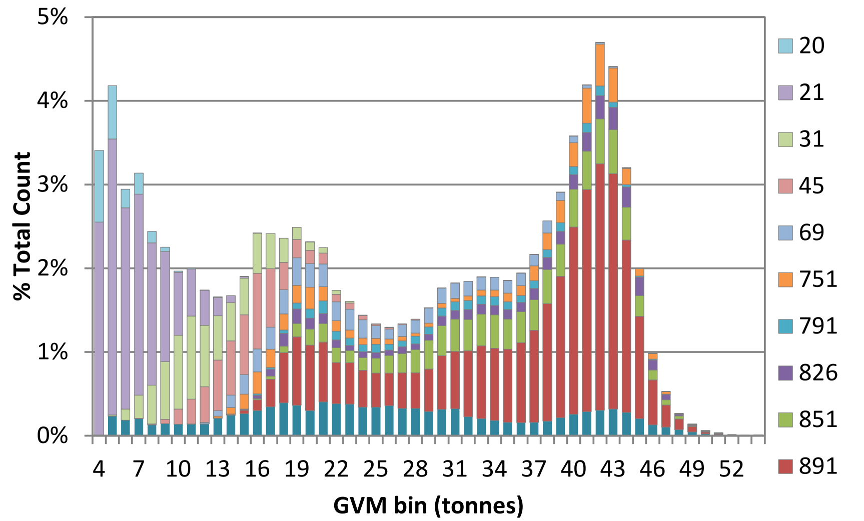


Figure H.16 GVM Distribution by PAT type, Tokoroa Jan–Jun 2011, northbound

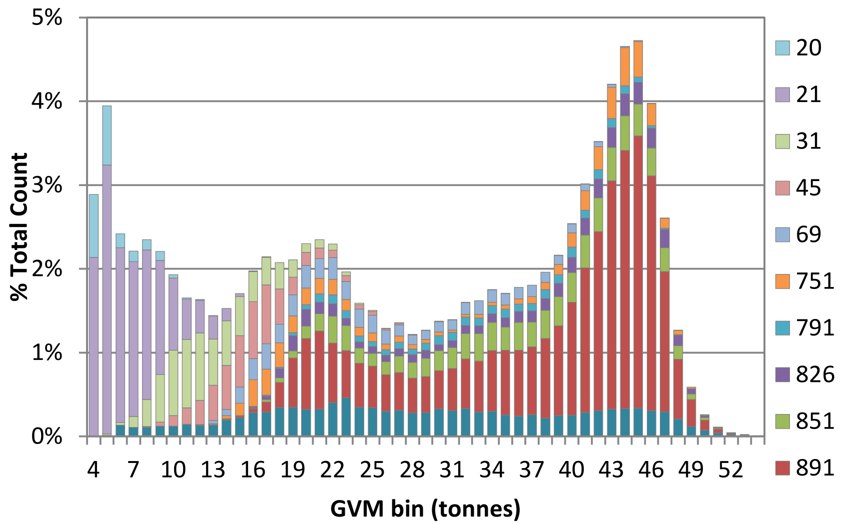


Figure H.17 GVM distribution by PAT type, Tokoroa Aug–Dec 2011, southbound

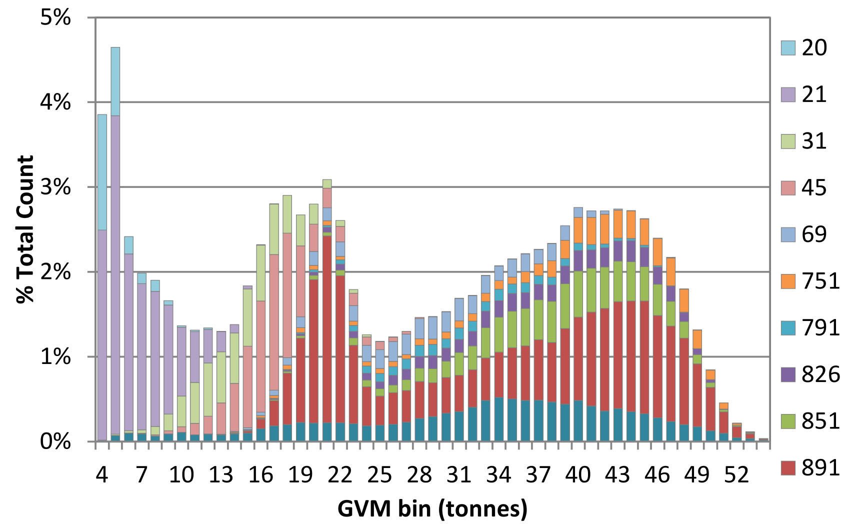


Figure H.18 GVM distribution by PAT type, Waipara Jan–Feb 2007, northbound

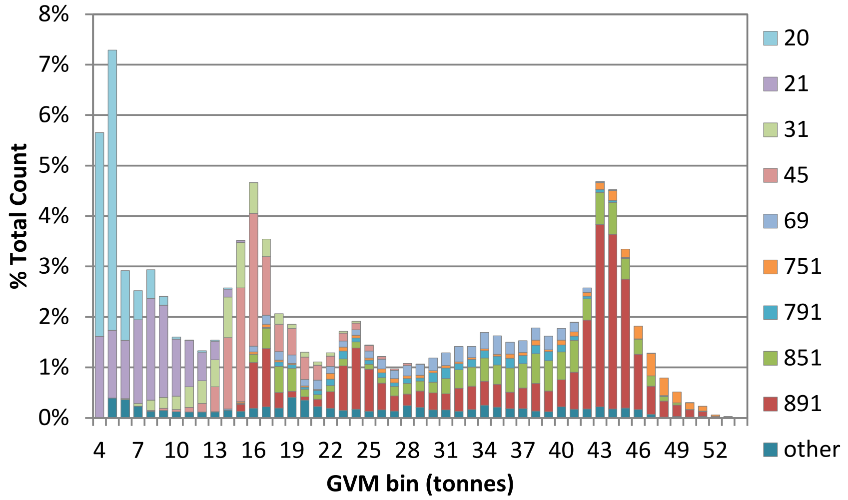


Figure H.19 GVM distribution by PAT type, Waipara Nov 2010–May 2011, southbound

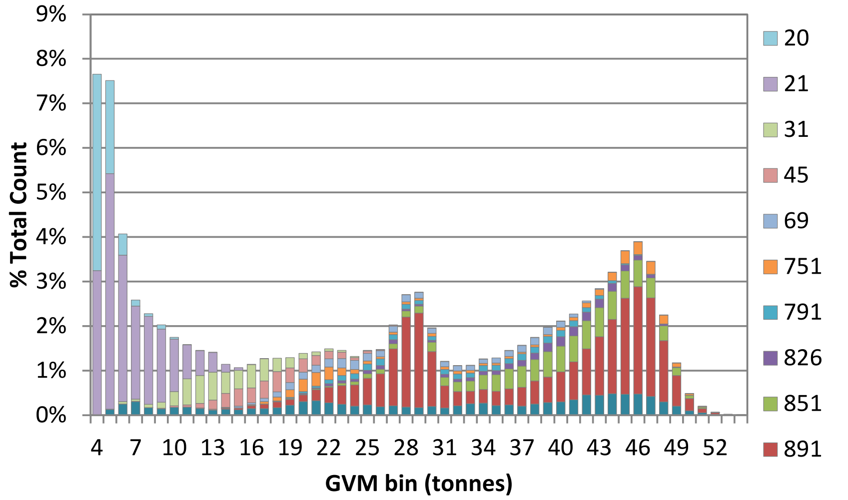


Figure H.20 GVM distribution by PAT type, Waipara Sep–Dec 2011, southbound

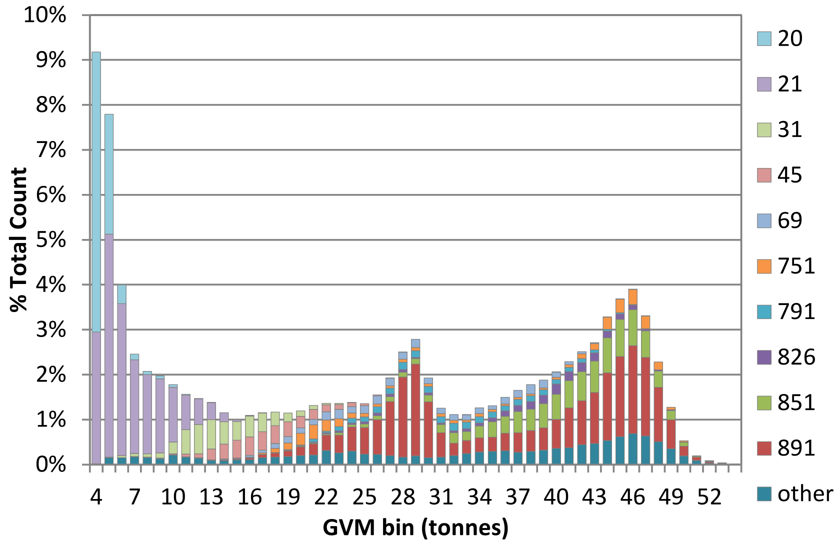


Figure H.21 GVM distribution by PAT type, AHB Mar 2007, southbound

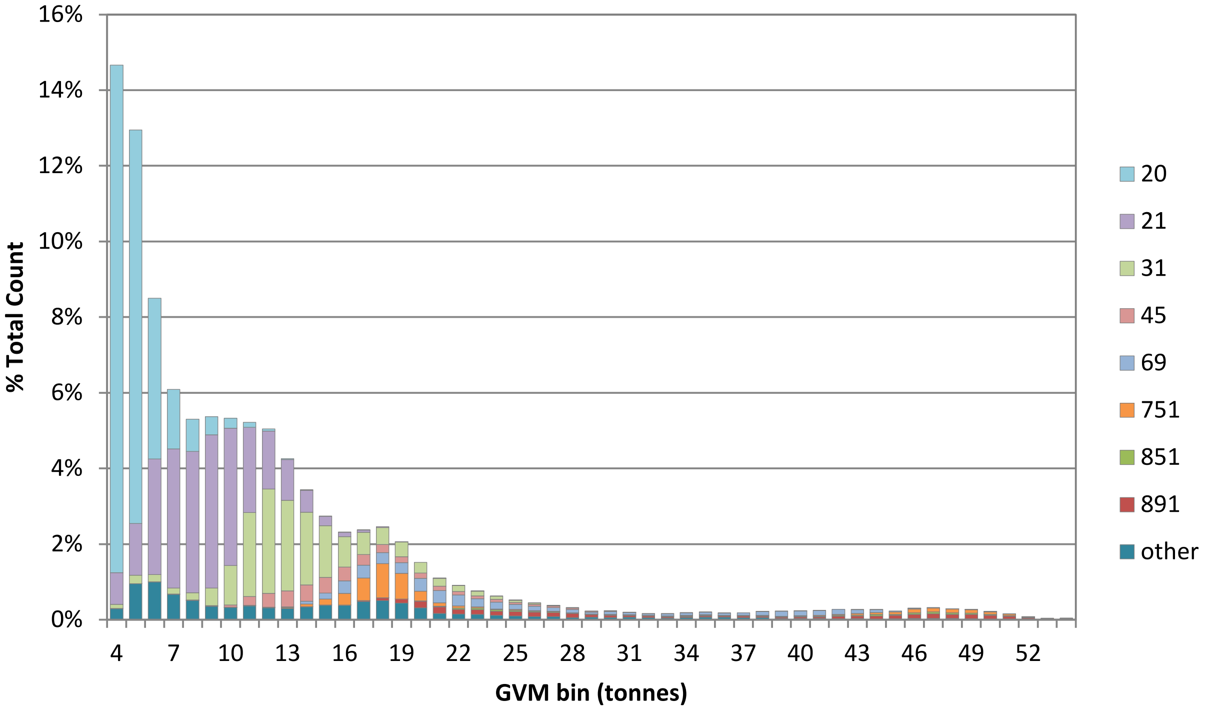


Figure H.22 GVM distribution by PAT type, AHB Mar 2007, southbound, >3 axles

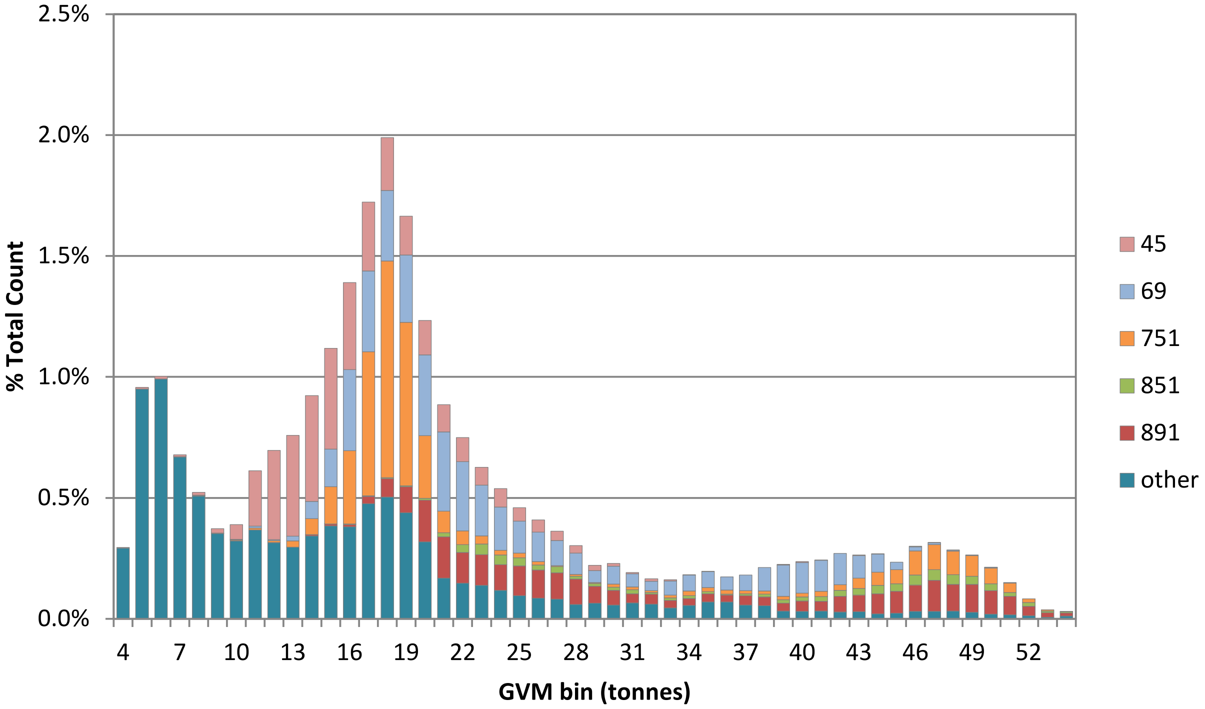


Figure H.23 GVM distribution by PAT type, AHB Mar 2011, southbound

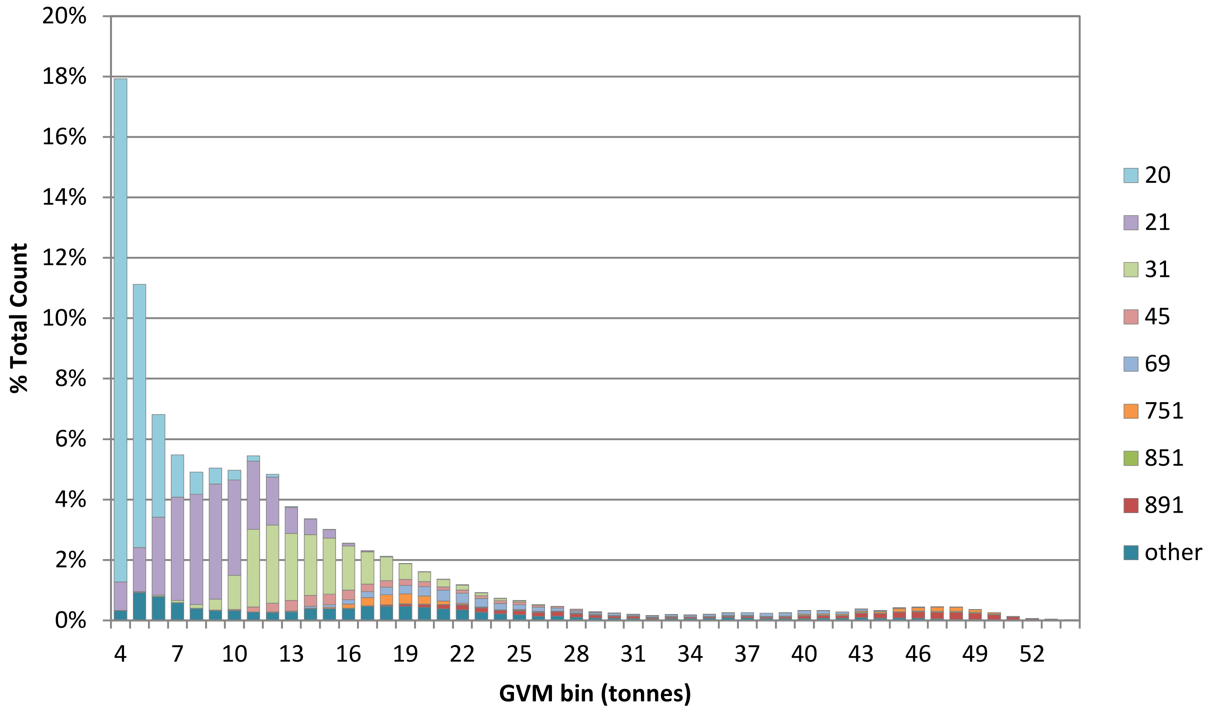


Figure H.24 GVM distribution by PAT type, AHB Mar 2011, southbound, >3 axles

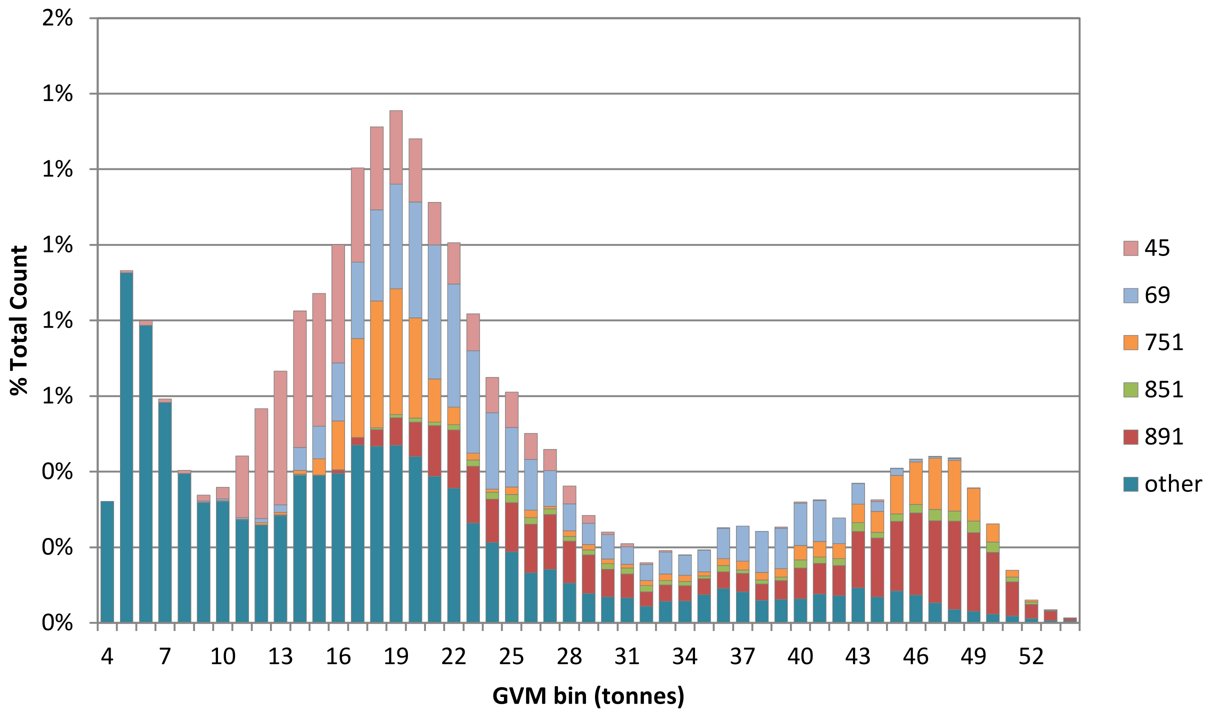


Figure H.25 GVM distribution by PAT type, AHB Mar 2007, northbound

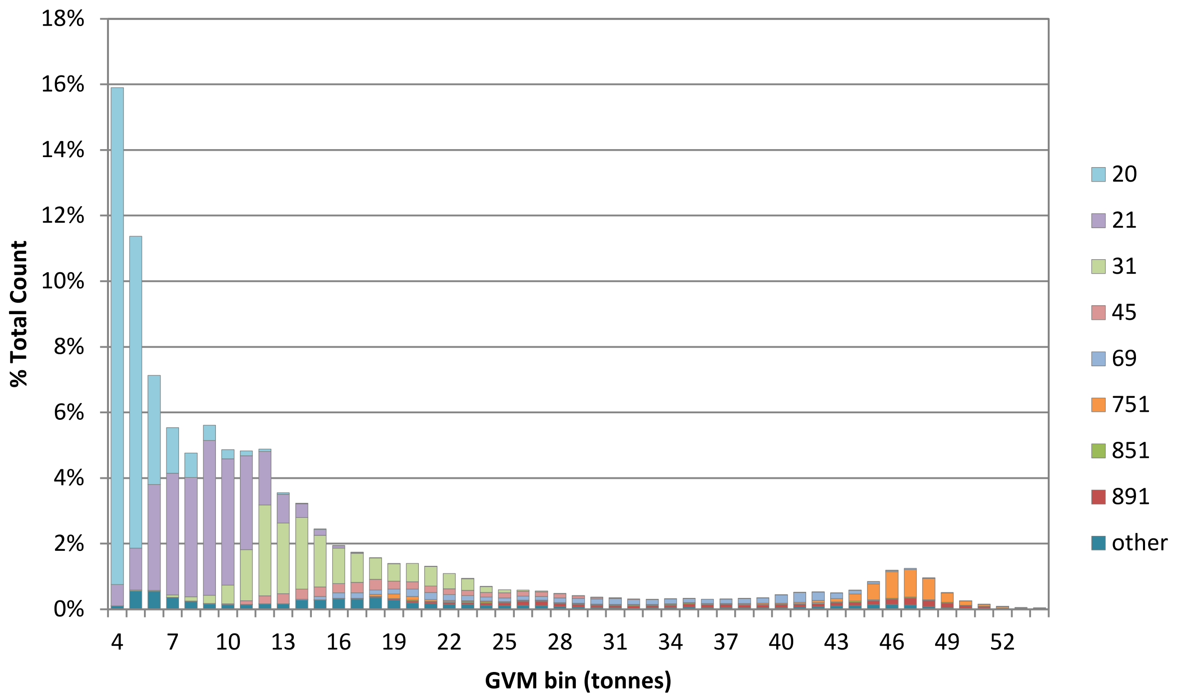


Figure H.26 GVM distribution by PAT type, AHB Mar 2007, northbound, > 3 axles

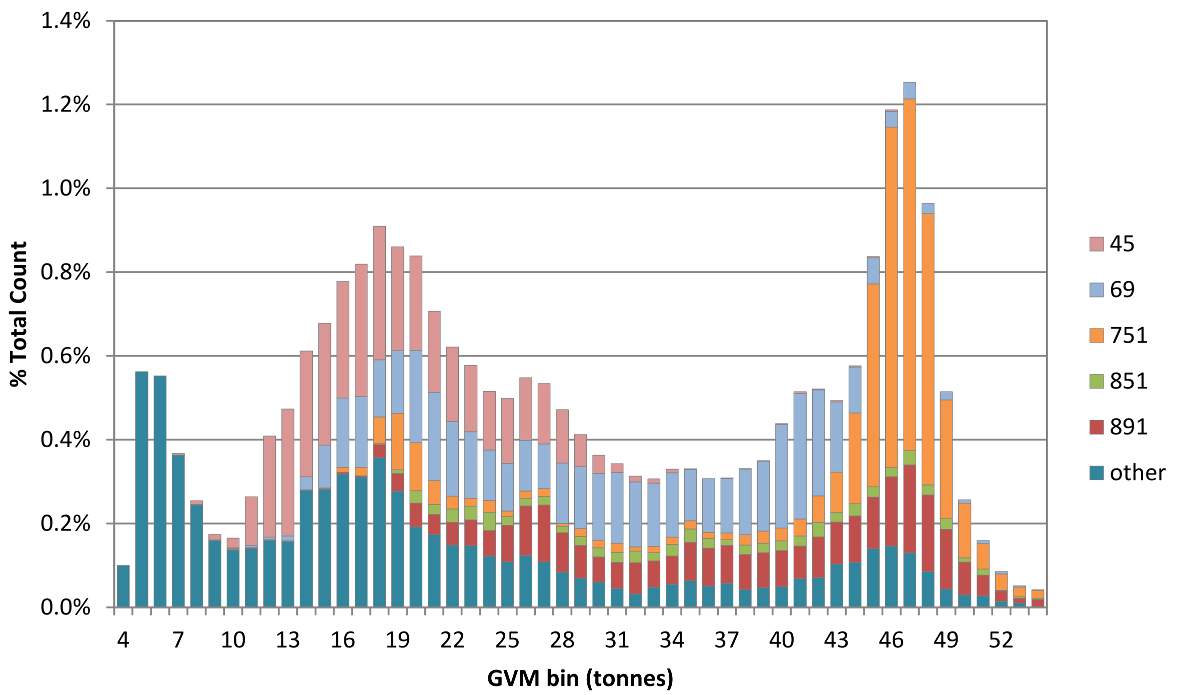


Figure H.27 GVM distribution by PAT type, AHB Mar 2011, northbound

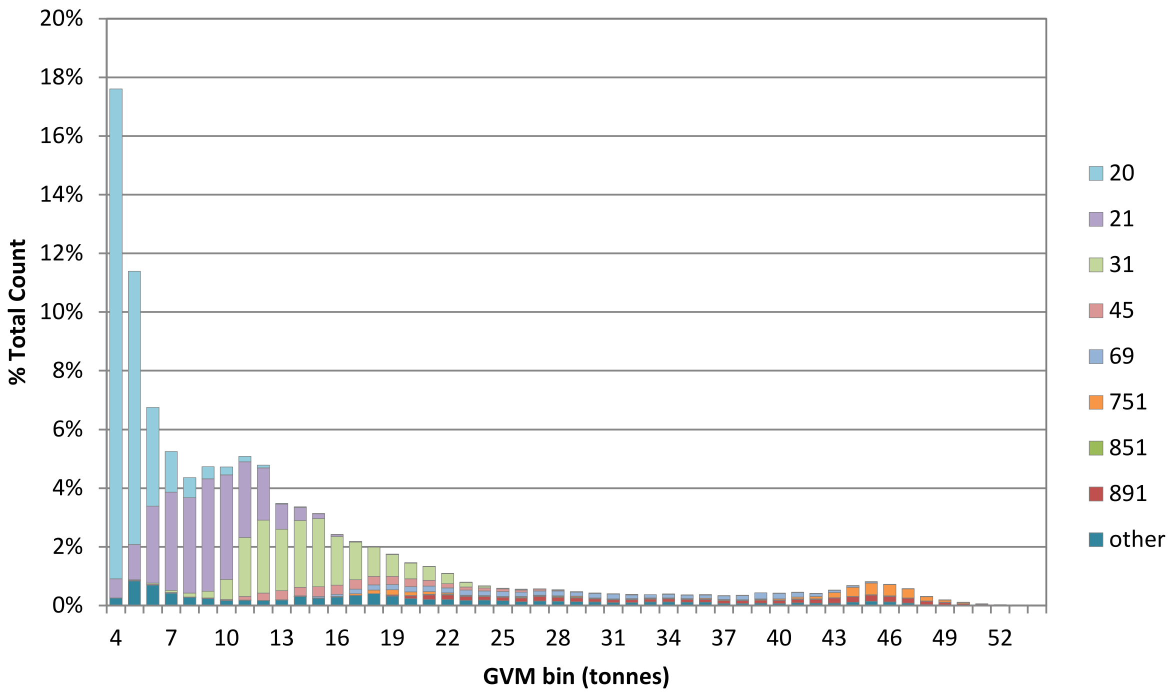
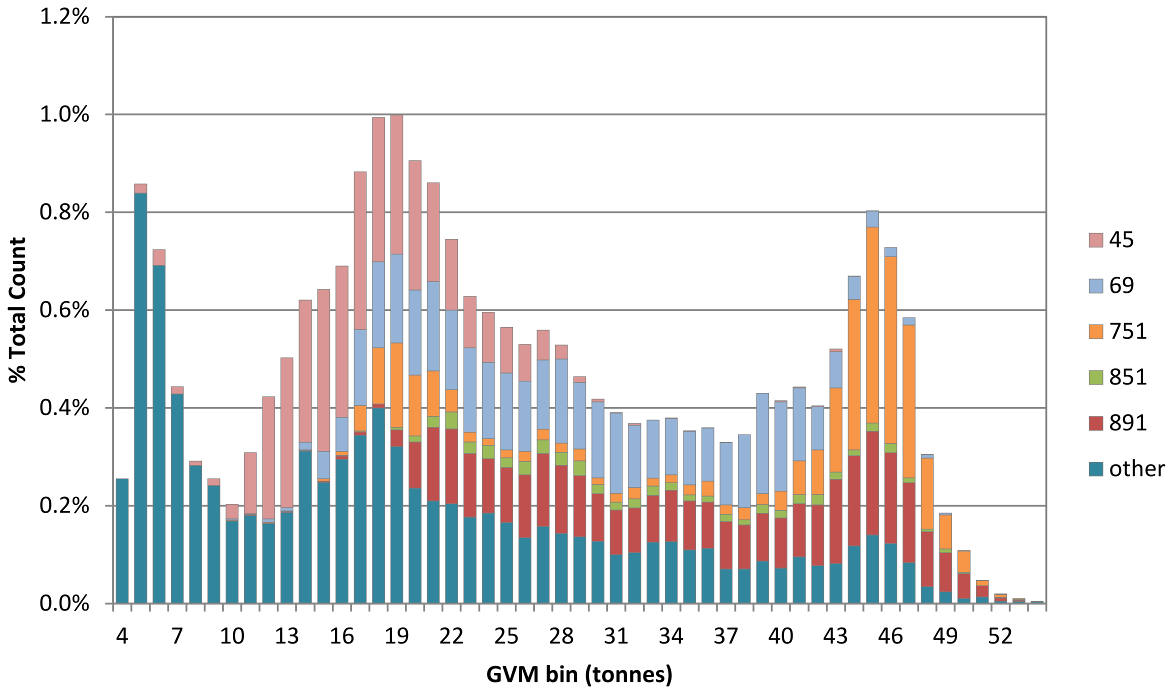


Figure H.28 GVM distribution by PAT type, AHB Mar 2011, northbound, >3 axles



H.4.4 GVM and length statistics

Annex H.4 gives the heavy vehicle mass and length statistics (count, minimum, maximum, average, and standard deviation) by PAT type, for the selected datasets. Given the highly skewed form of the mass distributions, the mass statistics are not directly usable but give a general indication of vehicle total and average tonnages on the WIM site routes.

H.4.5 Axle and axle set weights

Figure H.29 shows the distribution of axle weights for the combined data from all selected datasets (except Drury southbound), for both single-tyre and dual-tyre axles. Similar charts are given in annex H.5 for each dataset individually.

Figure H.29 Axle weights, all selected datasets

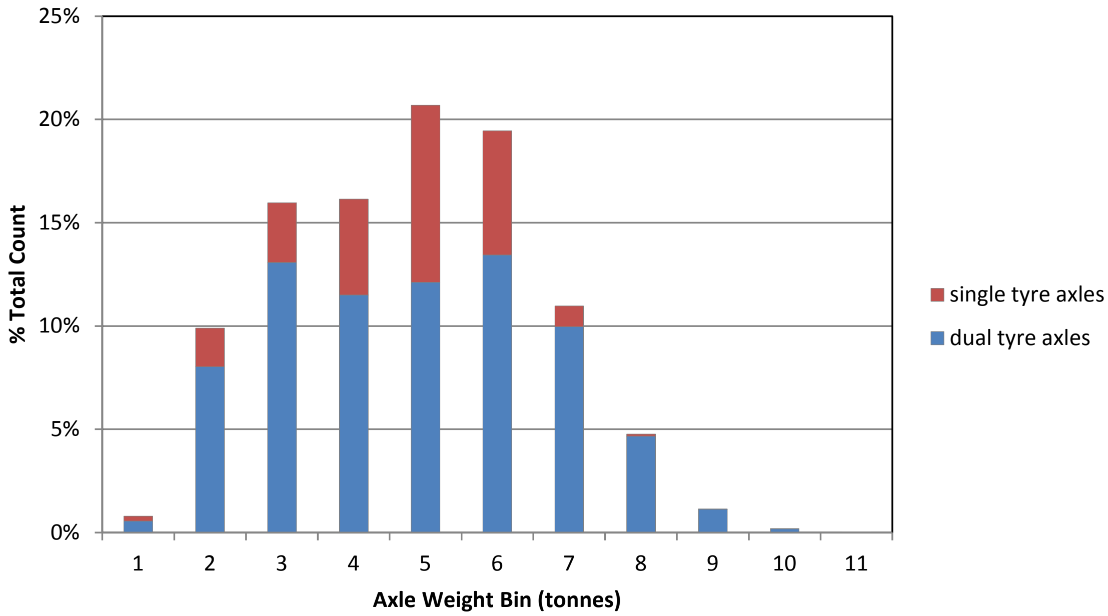
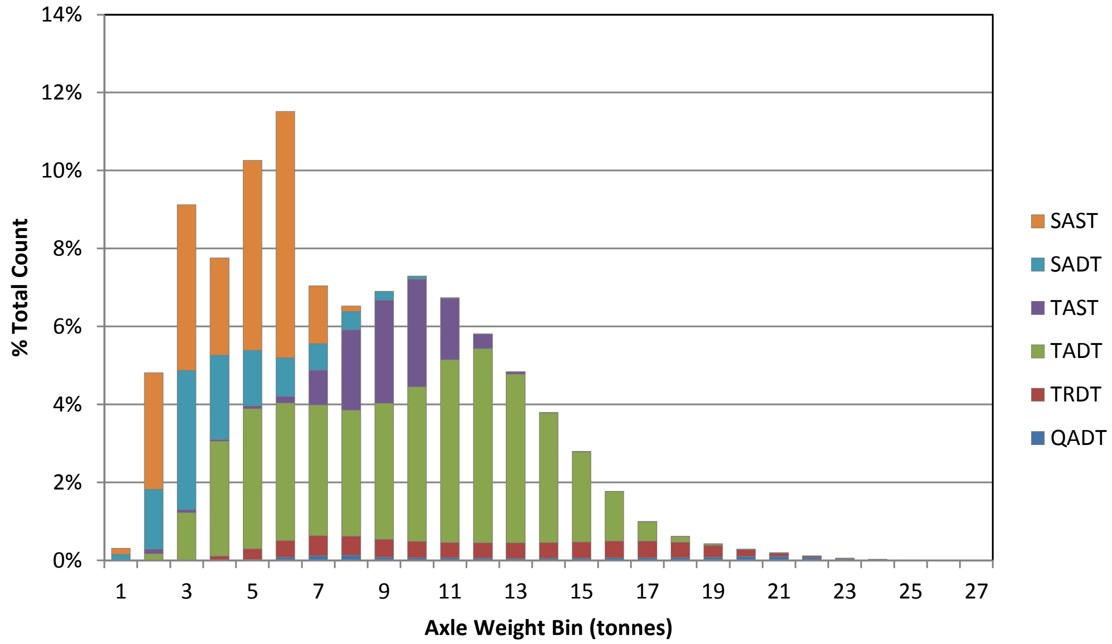


Figure H.30 shows the weight distribution of the six axle set types for the combined data from all datasets. An axle set consists of all axles spaced closer than 2.2m. The axle set types shown are SAST (single axle, single tyres), SADT (single axle, dual tyres), TAST (tandem axle, single tyres), TADT (tandem axle, dual tyres), TRDT (triple axle, dual tyres) and QADT (quadruple axle, dual tyres). Charts for each dataset are presented individually in annex H.6.

These distributions are considered when estimating counts for fatigue design axle loads.

Figure H.30 Histogram of axle set weights, all selected datasets



H.5 Summary

This review of heavy vehicle weight data from the Transport Agency's WIM sites for the years 2005, 2007, 2010 and 2011 has found the following:

- There is a small percentage of erroneous vehicle records included in the TMS database, which must be excluded from the bridge fatigue load calculations.
- There appears to be considerable variation in weight calibration accuracy over time and between lanes at all sites. Only 24% of the downloaded raw datasets were deemed usable for further processing (using the average type 69 steer-axle weights as a guide).
- Weight distributions are directionally biased, and the more heavily loaded direction will be more important for fatigue design loadings.
- Heavy vehicle counts in either direction are generally well matched, but at sites with logging traffic (SH5 Eskdale) directional counts by vehicle type are affected by empty trailers carried on the back of the truck for return (unladen) trips.
- The annualised heavy vehicle type distribution tables in annex H.2 provide a means to extend shorter term processed weight data to an annual basis, provided that discrepancies in light vehicle counts (through calibration and classification errors) and directional counts are addressed.
- There are sufficient periods of weight data available at all sites to characterise fatigue loadings per heavy vehicle, but these will need to be compiled by vehicle class to enable adjustments for annualised counts, as noted above.
- The general applicability of the selected datasets for use in fatigue loading estimates is unclear from inspection of the weight distributions and vehicle counts alone, and data from all sites may prove useful for comparing the various route types.

The conclusion of the data validation task was that all of the selected datasets listed earlier in table H.3 should be carried forward to the next step of this investigation. However, since no additional information regarding verification of WIM system calibration accuracy was available, the dataset selection for the fatigue load estimates had to rely on the indicators referred to in this appendix, and the fatigue load processing outcomes (see section 5 of this report) to support that conclusion.

The final selection of datasets for the vehicle spectrum model (see table 6.1 in the report) was supported by close scrutiny of the vehicle weight characteristics for each dataset (see section H.4), and the chosen datasets excluded periods when relatively low average type 69 steer-axle weights (indicating potentially low weight readings) were recorded. On that basis, we concluded that the chosen datasets should provide a sufficient representation of the weight characteristics of the heavy vehicle population crossing the WIM sites in 2010–2011.

Appendix H references

British Standards Institution (2008) *UK National Annex to Eurocode 1: actions on structures, part 2: traffic loads on bridges*. London: British Standards Institution.

NZ Transport Agency (2010) *Economic evaluation manual* (vol 1). Wellington: NZ Transport Agency.

Wen, G (2013) *State Highway Traffic Data Booklet 2008–2012*. Wellington: NZ Transport Agency.

Annex H.1 Accepted data by WIM site

The number of days per year of accepted WIM data for the sites in the Transport Agency's TMS database are listed below (as of February 2012). The day counts are relevant to annual summary tables in the following appendices, which record total counts for accepted days in a calendar year.

Table HA.1.1 Number of days of accepted data for WIM sites in the TMS database

Location	Site ref.	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Drury	01N00463	0	312	340	324	272	357	364	340	243	365	260	349
Eskdale	00500259	0	0	0	0	0	0	0	0	0	0	147	333
Te Puke	00200176	337	318	358	345	213	316	317	314	309	337	362	297
Tokoroa	01N00628	347	314	353	332	285	365	316	246	229	363	362	362
Waipara	01S00285	350	297	365	355	366	363	364	296	287	365	362	359

Annex H.2 TMS annual summaries – HMV distribution by PAT type

Table HA.2.1 TMS annual summaries

Drury			HMV Distribution by PAT Type																	
			Total Count									% Distribution								
PAT Type	Class	Description	2000	2004	2005	2006	2007	2008	2009	2010	2011	2000	2004	2005	2006	2007	2008	2009	2010	2011
20	4	o-o (Wheelbase 2m - 4m)	126953	141568	116127	134379	128277	134922	69343	49320	73556	12.3%	16.1%	8.3%	9.3%	8.9%	9.2%	4.9%	5.3%	5.2%
21	4	o--o (Wheelbase 4m - 8.5m)	144928	111023	254896	258663	265185	295786	316092	206491	320439	14.0%	12.7%	18.2%	17.9%	18.4%	20.2%	22.6%	22.1%	22.6%
300	4	o--o--o (truck towing light trailer)	0	0	0	0	0	0	0	0	10615	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.7%
401	4	o--o--oo (truck tow light 2 ax trailer)	0	0	0	0	0	0	0	0	8762	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.6%
30	5	o-o--o	19056	17294	19724	21783	23207	28035	21350	14194	3438	1.8%	2.0%	1.4%	1.5%	1.6%	1.9%	1.5%	1.5%	0.2%
31	5	o--oo	111059	89904	144996	154909	153267	139669	135040	90043	135817	10.7%	10.2%	10.4%	10.7%	10.6%	9.6%	9.6%	9.6%	9.6%
34	5	oo--o	1100	1023	2897	3617	2826	402	267	250	444	0.1%	0.1%	0.2%	0.2%	0.2%	0.0%	0.0%	0.0%	0.0%
44	5	oo-o--o	79	31	106	186	212	82	36	25	20	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
301	5	o--oo (tractor without semi-trailer)	0	0	0	0	0	0	0	0	2351	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%
402	5	o--oo---o (truck tow light 1 ax trailer)	0	0	0	0	0	0	0	0	3295	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%
503	5	o--oo--oo (truck tow light trailer)	0	0	0	0	0	0	0	0	273	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
45	6	oo--oo	42606	38300	67917	73787	76417	72061	73216	47694	71824	4.1%	4.4%	4.9%	5.1%	5.3%	4.9%	5.2%	5.1%	5.1%
47	6	o--ooo	108	0	0	0	110	57	25	27	41	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
511	6	oo--ooo (heavy truck)	0	0	0	0	0	0	0	0	576	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
40	7	o--o-o--o	7972	4130	5285	5284	5604	7352	8431	4855	0	0.8%	0.5%	0.4%	0.4%	0.4%	0.5%	0.6%	0.5%	0.0%
41	7	o-o--oo	20431	17205	29965	26812	25663	28048	26676	17442	12668	2.0%	2.0%	2.1%	1.9%	1.8%	1.9%	1.9%	1.9%	0.9%
42	7	o-oo--o	1370	1047	1882	2586	2393	1027	1061	1093	690	0.1%	0.1%	0.1%	0.2%	0.2%	0.1%	0.1%	0.1%	0.0%
50	8	o-o--o-o--o	0	0	0	0	0	0	0	0	43	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
52	8	o--oo-o--o	8385	4221	11035	8364	7906	4076	3642	3324	5510	0.8%	0.5%	0.8%	0.6%	0.5%	0.3%	0.3%	0.4%	0.4%
53	8	o-oo--oo	23636	16313	29144	24533	23116	19984	17073	12107	19043	2.3%	1.9%	2.1%	1.7%	1.6%	1.4%	1.2%	1.3%	1.3%
57	8	o-o--ooo	0	0	0	0	0	0	0	0	1202	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%
64	9	oo-oo--oo	0	0	0	0	0	0	0	0	1	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
68	9	oo--oo--oo	0	1208	651	749	850	6520	12189	9050	14345	0.0%	0.1%	0.0%	0.1%	0.1%	0.4%	0.9%	1.0%	1.0%
69	9	o-oo--ooo	161747	118286	176182	175044	163298	146152	123991	84036	124160	15.6%	13.5%	12.6%	12.1%	11.3%	10.0%	8.8%	9.0%	8.7%
713	9	oo-oo--ooo Tri Artic	0	0	0	0	864	2454	1552	3308	11925	0.0%	0.0%	0.0%	0.0%	0.1%	0.2%	0.1%	0.4%	0.8%
747	9	o--ooo---ooo	0	121	289	372	478	216	255	128	275	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
791	9	o-oo---oooo	0	7360	11533	18324	20209	33644	41514	26845	38386	0.0%	0.8%	0.8%	1.3%	1.4%	2.3%	3.0%	2.9%	2.7%
826	9	oo-oo--oooo Quad Artic	0	0	0	0	3581	25551	53204	36414	59761	0.0%	0.0%	0.0%	0.0%	0.2%	1.7%	3.8%	3.9%	4.2%
847	9	o--ooo---oooo	0	1002	557	429	439	833	1422	1192	1327	0.0%	0.1%	0.0%	0.0%	0.0%	0.1%	0.1%	0.1%	0.1%
61/62/621	10	o-o--o-o--oo/o-o--oo-o--o/o-oo--o-o--o	695	783	1960	1478	1851	1539	998	814	1256	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%
63	10	o--oo-o--oo	31359	16039	30336	19816	16742	11355	8448	5387	9094	3.0%	1.8%	2.2%	1.4%	1.2%	0.8%	0.6%	0.6%	0.6%
65	10	oo--o-o--oo	0	0	0	0	0	0	1	0	0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
66	10	oo--oo-o--o	1619	831	2915	2955	3032	2042	1372	803	815	0.2%	0.1%	0.2%	0.2%	0.2%	0.1%	0.1%	0.1%	0.1%
622	10	o-o--oo--o-o	0	0	0	0	0	0	0	0	24	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
74	11	o-oo--oo-o--o	1249	36	108	131	184	13	7	34	7	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
78	11	o--ooo-o--oo	8	0	0	0	59	3	0	0	0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
731	11	o-oo--o-o--oo	177	597	3110	1472	1299	37	0	0	0	0.0%	0.1%	0.2%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%
751	11	o-oo--oo--oo	89461	76711	149563	146925	142605	117027	111055	71196	101289	8.6%	8.7%	10.7%	10.1%	9.9%	8.0%	7.9%	7.6%	7.1%
77	12	oo--oo-o--oo	34791	16030	27973	23078	21762	14500	14717	8106	12060	3.4%	1.8%	2.0%	1.6%	1.5%	1.0%	1.1%	0.9%	0.8%
771	12	oo-o--oo--oo	0	0	0	0	0	0	0	0	2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
891	12	oo--oo-oo--oo	105209	113318	188692	214519	226813	242935	237569	165368	251332	10.2%	12.9%	13.5%	14.8%	15.7%	16.6%	17.0%	17.7%	17.7%
914	12	oo-oo--ooo-oo B Train	0	0	0	0	0	589	1481	1770	1745	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.2%	0.1%
915	12	oo-oo--oo-ooo T&T	0	0	0	0	0	3	205	749	2855	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.2%
1020	12	oo-oo-ooo-ooo B Train	0	0	0	0	0	118	92	38	2775	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%
85	13	o-oo--oo-o--oo	99	58	32	26	47	0	0	0	0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
89	13	o-oo--ooo-o--o	13	100	525	384	316	16	0	0	0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
811	13	o--oo--oo--ooo (B train)	0	0	0	0	0	0	0	0	1327	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%
851	13	o-oo--ooo--oo	101974	74873	107537	108552	100887	100876	96336	57581	85249	9.8%	8.5%	7.7%	7.5%	7.0%	6.9%	6.9%	6.2%	6.0%
951	13	o-oo-ooo-ooo	0	7769	12702	18474	20899	23396	22888	16315	29622	0.0%	0.9%	0.9%	1.3%	1.5%	1.6%	1.6%	1.7%	2.1%
1032	13	o-oo-ooo-oooo B Train	0	0	0	0	0	1	0	0	1	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Total			1036084	877181	1398639	1447631	1440398	1461321	1401548	935999	1420240	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Table HA.2.2 TMS annual summaries

Eskdale

			HMV Distribution by PAT Type			
			Total Count		% Distribution	
PAT Type	Class	Description	2010	2011	2010	2011
20	4	o-o (Wheelbase 2m - 4m)	434	4767	0.5%	2.5%
21	4	o--o (Wheelbase 4m - 8.5m)	12355	29178	15.5%	15.2%
300	4	o--o--o (truck towing light trailer)	0	1161	0.0%	0.6%
401	4	o--o--oo (truck tow light 2 ax trailer)	0	1492	0.0%	0.8%
30	5	o-o--o	544	256	0.7%	0.1%
31	5	o--oo	4675	10719	5.9%	5.6%
34	5	oo--o	68	131	0.1%	0.1%
44	5	oo-o--o	2	10	0.0%	0.0%
301	5	o--oo (tractor without semi-trailer)	0	211	0.0%	0.1%
402	5	o--oo---o (truck tow light 1 ax trailer)	0	342	0.0%	0.2%
503	5	o--oo--oo (truck tow light trailer)	0	48	0.0%	0.0%
45	6	oo--oo	13251	31025	16.6%	16.2%
47	6	o--ooo	3	18	0.0%	0.0%
511	6	oo--ooo (heavy truck)	0	13	0.0%	0.0%
40	7	o--o-o--o	139	0	0.2%	0.0%
41	7	o-o--oo	1444	1448	1.8%	0.8%
42	7	o-oo--o	53	29	0.1%	0.0%
50	8	o-o--o-o--o	0	7	0.0%	0.0%
52	8	o--oo-o--o	266	444	0.3%	0.2%
53	8	o-oo--oo	733	1902	0.9%	1.0%
57	8	o-o--ooo	0	154	0.0%	0.1%
68	9	oo--oo--oo	432	948	0.5%	0.5%
69	9	o-oo--ooo	3034	6978	3.8%	3.6%
713	9	oo-oo--ooo Tri Artic	412	819	0.5%	0.4%
747	9	o--ooo---ooo	5	2	0.0%	0.0%
791	9	o-oo---oooo	937	2160	1.2%	1.1%
826	9	oo-oo--oooo Quad Artic	3472	8033	4.3%	4.2%
847	9	o--ooo---oooo	27	28	0.0%	0.0%
61/62/621	10	o-o--o-o--oo/o-o--oo-o--o/o-oo--o-o--o	295	676	0.4%	0.4%
63	10	o--oo-o--oo	225	694	0.3%	0.4%
66	10	oo--oo-o--o	10	48	0.0%	0.0%
74	11	o-oo--oo-o--o	0	1	0.0%	0.0%
751	11	o-oo--oo--oo	4769	10244	6.0%	5.3%
77	12	oo--oo-o--oo	1982	3963	2.5%	2.1%
771	12	oo-o--oo--oo	0	2	0.0%	0.0%
891	12	oo--oo-oo--oo	23511	57433	29.4%	29.9%
914	12	oo-oo--ooo-oo B Train	228	435	0.3%	0.2%
915	12	oo-oo--oo-ooo T&T	24	140	0.0%	0.1%
1020	12	oo-oo-ooo-ooo B Train	13	111	0.0%	0.1%
811	13	o--oo--oo--ooo (B train)	0	251	0.0%	0.1%
851	13	o-oo--ooo--oo	5531	12331	6.9%	6.4%
951	13	o-oo-ooo-ooo	1002	3262	1.3%	1.7%
Total			79876	191914	100.0%	100.0%

Table HA.2.3 TMS annual summaries

Te Puke

			HMV Distribution by PAT Type																	
			Total Count									% Distribution								
PAT Type	Class	Description	2000	2004	2005	2006	2007	2008	2009	2010	2011	2000	2004	2005	2006	2007	2008	2009	2010	2011
20	4	o-o (Wheelbase 2m - 4m)	81261	44227	44610	41399	40395	27783	15806	25994	15018	17.1%	13.8%	9.2%	9.9%	7.7%	5.5%	3.1%	4.3%	2.9%
21	4	o--o (Wheelbase 4m - 8.5m)	57160	44745	73852	15772	93929	107480	120266	136021	110396	12.0%	13.9%	15.2%	3.8%	17.9%	21.2%	23.7%	22.5%	21.0%
300	4	o--o--o (truck towing light trailer)	0	0	0	0	0	0	0	0	2977	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.6%
401	4	o--o--oo (truck tow light 2 ax trailer)	0	0	0	0	0	0	0	0	2771	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.5%
30	5	o-o--o	7496	3399	4774	4067	4338	4933	5250	5865	360	1.6%	1.1%	1.0%	1.0%	0.8%	1.0%	1.0%	1.0%	0.1%
31	5	o--oo	48076	26141	43936	44776	45752	43083	42876	51161	43723	10.1%	8.1%	9.0%	10.7%	8.7%	8.5%	8.4%	8.5%	8.3%
34	5	oo--o	421	167	191	171	181	233	971	205	226	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	0.2%	0.0%	0.0%
44	5	oo-o--o	103	2	2	14	12	25	162	13	9	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
301	5	o--oo (tractor without semi-trailer)	0	0	0	0	0	0	0	0	1384	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.3%
402	5	o--oo---o (truck tow light 1 ax trailer)	0	0	0	0	0	0	0	0	911	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%
503	5	o--oo--oo (truck tow light trailer)	0	0	0	0	0	0	0	0	212	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
45	6	oo--oo	27224	24717	39666	40182	45802	40569	47313	53355	57448	5.7%	7.7%	8.1%	9.6%	8.7%	8.0%	9.3%	8.8%	10.9%
47	6	o--ooo	1510	0	0	0	15	29	66	3	15	0.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
511	6	oo--ooo (heavy truck)	0	0	0	0	0	0	0	0	59	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
40	7	o--o-o--o	6052	1724	2388	2075	2338	2033	1568	1838	0	1.3%	0.5%	0.5%	0.5%	0.4%	0.4%	0.3%	0.3%	0.0%
41	7	o-o--oo	5292	4177	6416	6386	5893	6389	6368	8401	2725	1.1%	1.3%	1.3%	1.5%	1.1%	1.3%	1.3%	1.4%	0.5%
42	7	o-oo--o	388	106	239	414	400	261	528	224	19	0.1%	0.0%	0.0%	0.1%	0.1%	0.1%	0.1%	0.0%	0.0%
50	8	o-o--o-o--o	0	0	0	0	0	0	0	0	1	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
52	8	o--oo-o--o	3515	1101	1540	939	882	827	776	598	818	0.7%	0.3%	0.3%	0.2%	0.2%	0.2%	0.2%	0.1%	0.2%
53	8	o-oo--oo	8246	3445	4591	3481	3650	3251	4395	4375	2862	1.7%	1.1%	0.9%	0.8%	0.7%	0.6%	0.9%	0.7%	0.5%
57	8	o-o--ooo	0	0	0	0	0	0	0	0	170	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
68	9	oo--oo--oo	0	609	1089	1119	1210	1177	1564	1352	1164	0.0%	0.2%	0.2%	0.3%	0.2%	0.2%	0.3%	0.2%	0.2%
69	9	o-oo--ooo	40168	31870	47127	39728	40394	39915	38042	44681	37844	8.4%	9.9%	9.7%	9.5%	7.7%	7.9%	7.5%	7.4%	7.2%
713	9	oo-oo--ooo Tri Artic	0	0	0	0	970	1824	2125	647	1945	0.0%	0.0%	0.0%	0.0%	0.2%	0.4%	0.4%	0.1%	0.4%
747	9	o--ooo---ooo	0	2	0	8	41	52	56	73	38	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
791	9	o-oo---oooo	0	945	2897	3572	5098	4860	5304	6407	7136	0.0%	0.3%	0.6%	0.9%	1.0%	1.0%	1.0%	1.1%	1.4%
826	9	oo-oo--oooo Quad Artic	0	0	0	0	7468	12489	16356	22915	20299	0.0%	0.0%	0.0%	0.0%	1.4%	2.5%	3.2%	3.8%	3.9%
847	9	o--ooo---oooo	0	123	677	510	272	730	1255	1983	1561	0.0%	0.0%	0.1%	0.1%	0.1%	0.1%	0.2%	0.3%	0.3%
61/62/621	10	o-o--o-o--oo/o-o--oo-o--o/o-oo--o-o--o	363	300	524	590	651	449	460	462	489	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%
63	10	o--oo-o--oo	12479	6865	8683	7685	7517	4014	3390	6295	5682	2.6%	2.1%	1.8%	1.8%	1.4%	0.8%	0.7%	1.0%	1.1%
65	10	oo--o-o--oo	0	0	0	0	0	6	51	0	0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
66	10	oo--oo-o--o	495	348	265	368	485	666	491	343	387	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%
622	10	o-o--oo--o-o	0	0	0	0	0	0	0	0	9	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
74	11	o-oo--oo-o--o	3929	808	123	90	45	299	243	64	0	0.8%	0.3%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%
78	11	o--ooo-o--oo	1757	0	0	0	1	0	0	0	0	0.4%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
731	11	o-oo--o-o--oo	16	6	13	12	3	2	0	0	0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
751	11	o-oo--oo--oo	58735	35134	54848	58481	54482	51498	43496	51888	44643	12.4%	10.9%	11.3%	14.0%	10.4%	10.1%	8.6%	8.6%	8.5%
77	12	oo--oo-o--oo	18487	7363	10492	7799	7247	5883	5878	6515	6228	3.9%	2.3%	2.2%	1.9%	1.4%	1.2%	1.2%	1.1%	1.2%
771	12	oo-o--oo--oo	0	0	0	0	0	0	0	0	11	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
891	12	oo--oo-oo--oo	67052	62072	104541	104238	118459	114655	112842	136036	125574	14.1%	19.3%	21.5%	25.0%	22.6%	22.6%	22.2%	22.5%	23.9%
914	12	oo-oo--ooo-oo B Train	0	0	0	0	0	433	935	1661	722	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.2%	0.3%	0.1%
915	12	oo-oo--oo-ooo T&T	0	0	0	0	0	0	3	23	126	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
1020	12	oo-oo-ooo-ooo B Train	0	0	0	0	0	0	3	4	32	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
85	13	o-oo--oo-o--oo	5	0	0	0	0	0	0	0	0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
89	13	o-oo--ooo-o--o	10	0	0	0	0	0	0	0	0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
811	13	o--oo--oo--ooo (B train)	0	0	0	0	0	0	0	0	20	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
851	13	o-oo--ooo--oo	25157	20389	31191	30970	33526	29528	27886	33819	26981	5.3%	6.3%	6.4%	7.4%	6.4%	5.8%	5.5%	5.6%	5.1%
951	13	o-oo-ooo-ooo	0	784	2101	2574	2426	2003	1610	1906	1852	0.0%	0.2%	0.4%	0.6%	0.5%	0.4%	0.3%	0.3%	0.4%
Total			475397	321569	486776	417420	523882	507379	508335	605127	524847	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Table HA.2.4 TMS annual summaries

Tokoroa

			HMV Distribution by PAT Type																	
			Total Count									% Distribution								
PAT Type	Class	Description	2000	2004	2005	2006	2007	2008	2009	2010	2011	2000	2004	2005	2006	2007	2008	2009	2010	2011
20	4	o-o (Wheelbase 2m - 4m)	15327	34565	56537	53115	33288	18642	11388	10740	10475	4.6%	9.6%	12.5%	12.7%	9.7%	6.1%	2.6%	2.4%	2.2%
21	4	o--o (Wheelbase 4m - 8.5m)	26950	28359	36234	32820	25601	35254	64275	65401	68368	8.1%	7.8%	8.0%	7.8%	7.4%	11.4%	14.4%	14.4%	14.2%
300	4	o--o--o (truck towing light trailer)	0	0	0	0	0	0	0	0	2792	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.6%
401	4	o--o--oo (truck tow light 2 ax trailer)	0	0	0	0	0	0	0	0	2869	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.6%
30	5	o-o--o	3076	4696	7370	7256	4837	4326	4826	3936	777	0.9%	1.3%	1.6%	1.7%	1.4%	1.4%	1.1%	0.9%	0.2%
31	5	o--oo	28729	25902	29686	27739	22507	19710	29005	29790	30649	8.6%	7.2%	6.5%	6.6%	6.5%	6.4%	6.5%	6.6%	6.3%
34	5	oo--o	525	347	778	914	161	2435	293	348	295	0.2%	0.1%	0.2%	0.2%	0.0%	0.8%	0.1%	0.1%	0.1%
44	5	oo-o--o	152	65	169	193	21	525	11	21	38	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%	0.0%	0.0%	0.0%
301	5	o--oo (tractor without semi-trailer)	0	0	0	0	0	0	0	0	426	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%
402	5	o--oo---o (truck tow light 1 ax trailer)	0	0	0	0	0	0	0	0	1040	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%
503	5	o--oo--oo (truck tow light trailer)	0	0	0	0	0	0	0	0	90	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
45	6	oo--oo	17694	22933	29880	26270	22022	19370	29403	30143	31855	5.3%	6.3%	6.6%	6.3%	6.4%	6.3%	6.6%	6.7%	6.6%
47	6	o--ooo	332	0	0	0	5	107	9	8	15	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
511	6	oo--ooo (heavy truck)	0	0	0	0	0	0	0	0	64	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
40	7	o--o-o--o	2016	2031	2485	2353	1621	1609	1529	1250	0	0.6%	0.6%	0.5%	0.6%	0.5%	0.5%	0.3%	0.3%	0.0%
41	7	o-o--oo	4831	4862	5706	5143	4753	4861	7619	6872	3901	1.4%	1.3%	1.3%	1.2%	1.4%	1.6%	1.7%	1.5%	0.8%
42	7	o-oo--o	434	373	868	1270	316	654	303	312	51	0.1%	0.1%	0.2%	0.3%	0.1%	0.2%	0.1%	0.1%	0.0%
50	8	o-o--o-o--o	0	0	0	0	0	0	0	0	27	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
52	8	o--oo-o--o	4086	3015	2821	1814	1050	900	976	760	766	1.2%	0.8%	0.6%	0.4%	0.3%	0.3%	0.2%	0.2%	0.2%
53	8	o-oo--oo	11412	4714	5366	5227	3011	3250	3354	3640	3725	3.4%	1.3%	1.2%	1.2%	0.9%	1.1%	0.8%	0.8%	0.8%
57	8	o-o--ooo	0	0	0	0	0	0	0	0	199	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
68	9	oo--oo--oo	0	125	349	452	156	3034	5951	6165	6762	0.0%	0.0%	0.1%	0.1%	0.0%	1.0%	1.3%	1.4%	1.4%
69	9	o-oo--ooo	39369	36678	42242	35093	26748	20211	23567	23550	23424	11.8%	10.1%	9.3%	8.4%	7.8%	6.6%	5.3%	5.2%	4.8%
713	9	oo-oo--ooo Tri Artic	0	0	0	0	237	333	260	1562	2741	0.0%	0.0%	0.0%	0.0%	0.1%	0.1%	0.1%	0.3%	0.6%
747	9	o--ooo---ooo	0	26	8	8	8	44	155	74	60	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
791	9	o-oo---oooo	0	1901	3198	4007	4064	5218	12680	10783	11452	0.0%	0.5%	0.7%	1.0%	1.2%	1.7%	2.8%	2.4%	2.4%
826	9	oo-oo--oooo Quad Artic	0	0	0	0	1960	4955	16603	18807	22381	0.0%	0.0%	0.0%	0.0%	0.6%	1.6%	3.7%	4.2%	4.6%
847	9	o--ooo---oooo	0	265	375	208	208	61	170	384	266	0.0%	0.1%	0.1%	0.0%	0.1%	0.0%	0.0%	0.1%	0.1%
61/62/621	10	o-o--o-o--oo/o-o--oo-o--o/o-oo--o-o--o	1148	518	866	788	615	459	551	595	686	0.3%	0.1%	0.2%	0.2%	0.2%	0.1%	0.1%	0.1%	0.1%
63	10	o--oo-o--oo	6517	3638	4336	4644	3667	3154	3921	3728	3588	1.9%	1.0%	1.0%	1.1%	1.1%	1.0%	0.9%	0.8%	0.7%
65	10	oo--o-o--oo	0	0	0	0	0	49	33	7	2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
66	10	oo--oo-o--o	825	464	980	1234	489	692	488	311	286	0.2%	0.1%	0.2%	0.3%	0.1%	0.2%	0.1%	0.1%	0.1%
622	10	o-o--oo--o-o	0	0	0	0	0	0	0	0	13	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
74	11	o-oo--oo-o--o	1583	63	18	37	0	9	12	81	9	0.5%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
78	11	o--ooo-o--oo	484	0	0	0	4	0	0	0	0	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
731	11	o-oo--o-o--oo	1483	64	280	479	98	12	0	0	0	0.4%	0.0%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%
751	11	o-oo--oo--oo	46264	31044	33664	26248	20878	19191	25532	26701	26611	13.8%	8.6%	7.4%	6.3%	6.1%	6.2%	5.7%	5.9%	5.5%
77	12	oo--oo-o--oo	18634	11667	11772	9939	6027	4923	7333	5977	5612	5.6%	3.2%	2.6%	2.4%	1.8%	1.6%	1.6%	1.3%	1.2%
771	12	oo-o--oo--oo	0	0	0	0	0	0	0	0	31	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
891	12	oo--oo-oo--oo	53598	91294	114670	118390	112824	93957	137002	142411	153503	16.0%	25.2%	25.3%	28.3%	32.8%	30.5%	30.8%	31.5%	31.8%
914	12	oo-oo--ooo-oo B Train	0	0	0	0	0	126	522	703	742	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.2%	0.2%
915	12	oo-oo--oo-ooo T&T	0	0	0	0	0	0	61	441	2106	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.4%
1020	12	oo-oo-ooo-ooo B Train	0	0	0	0	0	36	74	32	371	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%
85	13	o-oo--oo-o--oo	260	2	2	12	0	0	0	0	0	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
89	13	o-oo--ooo-o--o	169	38	92	139	30	13	0	0	0	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
811	13	o--oo--oo-ooo (B train)	0	0	0	0	0	0	0	0	450	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%
851	13	o-oo--ooo--oo	48478	44500	53371	43009	35396	30099	42973	41522	41974	14.5%	12.3%	11.8%	10.3%	10.3%	9.8%	9.7%	9.2%	8.7%
951	13	o-oo-ooo-ooo	0	7458	9480	9844	11212	9832	14139	15682	21638	0.0%	2.1%	2.1%	2.4%	3.3%	3.2%	3.2%	3.5%	4.5%
1032	13	o-oo-ooo-oooo B Train	0	0	0	0	0	0	0	0	1	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Total			334376	361607	453603	418645	343814	308051	445018	452737	483131	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Table HA.2.5 TMS annual summaries

Waipara			HMV Distribution by PAT Type																	
			Total Count									% Distribution								
PAT Type	Class	Description	2000	2004	2005	2006	2007	2008	2009	2010	2011	2000	2004	2005	2006	2007	2008	2009	2010	2011
20	4	o-o (Wheelbase 2m - 4m)	25964	36156	40550	39627	28856	25861	11016	14965	19322	12.7%	13.5%	13.7%	12.6%	11.0%	7.8%	3.3%	4.2%	5.3%
21	4	o--o (Wheelbase 4m - 8.5m)	24465	31271	30901	32900	28014	48949	68943	70178	70583	12.0%	11.7%	10.4%	10.5%	10.7%	14.7%	20.6%	19.7%	19.3%
300	4	o--o--o (truck towing light trailer)	0	0	0	0	0	0	0	0	3702	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.0%
401	4	o--o--oo (truck tow light 2 ax trailer)	0	0	0	0	0	0	0	0	3957	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.1%
30	5	o-o--o	4958	4721	5820	5502	3895	5773	7729	7191	775	2.4%	1.8%	2.0%	1.8%	1.5%	1.7%	2.3%	2.0%	0.2%
31	5	o--oo	16853	20110	19990	18410	15614	21658	20706	21677	20752	8.3%	7.5%	6.7%	5.9%	6.0%	6.5%	6.2%	6.1%	5.7%
34	5	oo--o	149	98	124	122	103	111	230	164	121	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%
44	5	oo-o--o	27	6	9	9	12	16	41	41	10	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
301	5	o--oo (tractor without semi-trailer)	0	0	0	0	0	0	0	0	839	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%
402	5	o--oo---o (truck tow light 1 ax trailer)	0	0	0	0	0	0	0	0	1096	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.3%
503	5	o--oo--oo (truck tow light trailer)	0	0	0	0	0	0	0	0	408	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%
45	6	oo--oo	10748	14666	17703	19862	16631	20315	21274	20115	19702	5.3%	5.5%	6.0%	6.3%	6.3%	6.1%	6.3%	5.6%	5.4%
47	6	o--ooo	7	0	0	0	72	172	276	212	179	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.1%	0.1%	0.0%
511	6	oo--ooo (heavy truck)	0	0	0	0	0	0	0	0	26	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
40	7	o--o-o--o	3261	783	873	953	859	1355	1590	1532	0	1.6%	0.3%	0.3%	0.3%	0.3%	0.4%	0.5%	0.4%	0.0%
41	7	o-o--oo	4155	5883	6382	6762	4991	7025	7358	7584	2940	2.0%	2.2%	2.1%	2.2%	1.9%	2.1%	2.2%	2.1%	0.8%
42	7	o-oo--o	215	116	153	157	171	203	209	186	41	0.1%	0.0%	0.1%	0.0%	0.1%	0.1%	0.1%	0.1%	0.0%
50	8	o-o--o-o--o	0	0	0	0	0	0	0	0	12	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
52	8	o--oo-o--o	1248	930	870	900	873	878	994	827	633	0.6%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.2%	0.2%
53	8	o-oo--oo	3068	3326	2933	2482	2339	2915	3149	3389	3137	1.5%	1.2%	1.0%	0.8%	0.9%	0.9%	0.9%	1.0%	0.9%
57	8	o-o--ooo	0	0	0	0	0	0	0	0	201	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%
68	9	oo--oo--oo	0	1353	1616	1781	1440	1619	2529	2882	3985	0.0%	0.5%	0.5%	0.6%	0.5%	0.5%	0.8%	0.8%	1.1%
69	9	o-oo--ooo	23586	25966	23952	19097	15173	17954	14321	14579	14691	11.6%	9.7%	8.1%	6.1%	5.8%	5.4%	4.3%	4.1%	4.0%
713	9	oo-oo--ooo Tri Artic	0	0	0	0	278	769	844	1051	1443	0.0%	0.0%	0.0%	0.0%	0.1%	0.2%	0.3%	0.3%	0.4%
747	9	o--ooo---ooo	0	75	32	24	12	26	21	13	54	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
791	9	o-oo---oooo	0	4352	7382	8346	9128	10958	8615	10241	10956	0.0%	1.6%	2.5%	2.7%	3.5%	3.3%	2.6%	2.9%	3.0%
826	9	oo-oo--oooo Quad Artic	0	0	0	0	2310	6255	9988	11701	10725	0.0%	0.0%	0.0%	0.0%	0.9%	1.9%	3.0%	3.3%	2.9%
847	9	o--ooo---oooo	0	814	699	352	113	153	207	156	107	0.0%	0.3%	0.2%	0.1%	0.0%	0.0%	0.1%	0.0%	0.0%
61/62/621	10	o-o--o-o--oo/o-o--oo-o--o/o-oo--o-o--o	125	106	166	163	120	222	172	396	571	0.1%	0.0%	0.1%	0.1%	0.0%	0.1%	0.1%	0.1%	0.2%
63	10	o--oo-o--oo	2618	2905	2546	2411	1781	2439	2224	3526	2113	1.3%	1.1%	0.9%	0.8%	0.7%	0.7%	0.7%	1.0%	0.6%
65	10	oo--o-o--oo	0	0	0	0	0	6	45	42	4	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
66	10	oo--oo-o--o	355	810	260	427	234	379	279	205	204	0.2%	0.3%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%
622	10	o-o--oo--o-o	0	0	0	0	0	0	0	0	19	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
74	11	o-oo--oo-o--o	208	55	32	8	7	6	2	3	0	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
78	11	o--ooo-o--oo	0	0	0	0	287	154	0	0	0	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%
731	11	o-oo--o-o--oo	4	0	1	2	5	0	0	0	0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
751	11	o-oo--oo--oo	13637	14842	14707	13542	11312	14310	14541	14772	15274	6.7%	5.5%	5.0%	4.3%	4.3%	4.3%	4.3%	4.1%	4.2%
77	12	oo--oo-o--oo	8970	6445	7379	8340	7305	8282	9326	8680	6431	4.4%	2.4%	2.5%	2.7%	2.8%	2.5%	2.8%	2.4%	1.8%
771	12	oo-o--oo--oo	0	0	0	0	0	0	0	0	24	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
891	12	oo--oo-oo--oo	37116	58322	75539	90676	73554	87249	84325	92500	99815	18.2%	21.8%	25.4%	28.9%	28.0%	26.3%	25.2%	25.9%	27.2%
914	12	oo-oo--ooo-oo B Train	0	0	0	0	0	21	70	183	695	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.2%
915	12	oo-oo--oo-ooo T&T	0	0	0	0	0	0	25	94	1689	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.5%
1020	12	oo-oo-ooo-ooo B Train	0	0	0	0	0	3	64	40	79	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
85	13	o-oo--oo-o--oo	106	10	8	1	1	1	0	0	0	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
89	13	o-oo--ooo-o--o	0	0	0	0	4	0	0	0	0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
811	13	o--oo--oo--ooo (B train)	0	0	0	0	0	0	0	0	32	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
851	13	o-oo--ooo--oo	22346	30411	32094	34416	29170	35952	34071	37004	36277	10.9%	11.3%	10.8%	11.0%	11.1%	10.8%	10.2%	10.4%	9.9%
951	13	o-oo-ooo-ooo	0	3426	4291	6759	7738	10168	10032	10458	13029	0.0%	1.3%	1.4%	2.2%	2.9%	3.1%	3.0%	2.9%	3.6%
1032	13	o-oo-ooo-oooo B Train	0	0	0	0	0	0	0	0	7	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Total			204189	267958	297012	314031	262402	332157	335216	356587	366660	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Annex H.3 Heavy vehicle counts by PAT type for selected periods

Table HA.3.1 Heavy vehicle counts by PAT type for selected periods (types in descending order of total count, left to right), page 1 of 4

Data Set	PAT Type:	891	21	31	69	751	851	20	45	826	791	951	77	53
Total All Data Sets	**Count**	**542320**	**520602**	**226516**	**218544**	**200980**	**185447**	**152574**	**140685**	**78969**	**55170**	**50590**	**38203**	**33342**
	% Total	**20.86%**	**20.03%**	**8.71%**	**8.41%**	**7.73%**	**7.13%**	**5.87%**	**5.41%**	**3.04%**	**2.12%**	**1.95%**	**1.47%**	**1.28%**
Drury 1SB Jan-Dec 2011	Count	120109	147842	63335	58258	47148	40178	25440	32941	28250	18120	14047	5791	8962
	% Total	18.48%	22.74%	9.74%	8.96%	7.25%	6.18%	3.91%	5.07%	4.35%	2.79%	2.16%	0.89%	1.38%
Drury 1NB Jan-Sep 2005	Count	61769	87369	48222	58793	52468	35859	50770	23205	0	3863	3952	10267	10139
	% Total	12.71%	17.98%	9.92%	12.10%	10.80%	7.38%	10.45%	4.77%	0.00%	0.79%	0.81%	2.11%	2.09%
Drury 1NB May 2010-Mar 2011	Count	98452	121975	53314	48575	42090	33846	26023	29012	21844	15683	9586	4844	6932
	% Total	18.16%	22.49%	9.83%	8.96%	7.76%	6.24%	4.80%	5.35%	4.03%	2.89%	1.77%	0.89%	1.28%
Waipara NB Jan - Feb 2007	Count	4361	2079	883	897	583	1817	2023	1767	0	522	460	146	103
	% Total	26.80%	12.78%	5.43%	5.51%	3.58%	11.17%	12.43%	10.86%	0.00%	3.21%	2.83%	0.90%	0.63%
Waipara SB Nov 2010-May 2011	Count	31339	22767	5792	4011	4459	10695	8053	3991	3213	3129	3260	2639	901
	% Total	28.48%	20.69%	5.26%	3.65%	4.05%	9.72%	7.32%	3.63%	2.92%	2.84%	2.96%	2.40%	0.82%
Waipara SB Sep - Dec 2011	Count	16391	12532	3148	2307	2554	6365	6073	2281	1645	1779	2314	1395	422
	% Total	26.09%	19.94%	5.01%	3.67%	4.06%	10.13%	9.66%	3.63%	2.62%	2.83%	3.68%	2.22%	0.67%
Tokoroa NB Nov - Dec 2005	Count	10626	3119	2296	3271	3478	4533	5180	2025	0	429	819	1048	447
	% Total	27.15%	7.97%	5.87%	8.36%	8.89%	11.58%	13.24%	5.17%	0.00%	1.10%	2.09%	2.68%	1.14%
Tokoroa NB Jan-Jul 2010	Count	38768	19137	8741	6461	6494	11036	2676	6894	5034	3079	4225	1873	871
	% Total	31.82%	15.71%	7.17%	5.30%	5.33%	9.06%	2.20%	5.66%	4.13%	2.53%	3.47%	1.54%	0.71%
Tokoroa NB Jan - Jun 2011	Count	39845	17088	7698	5750	6358	10001	2390	5682	5366	2896	5024	1488	792
	% Total	34.09%	14.62%	6.59%	4.92%	5.44%	8.56%	2.04%	4.86%	4.59%	2.48%	4.30%	1.27%	0.68%
Tokoroa SB Aug-Dec 2011	Count	28787	14947	6198	4701	5190	8806	2702	8678	4773	2281	4735	896	903
	% Total	29.08%	15.10%	6.26%	4.75%	5.24%	8.90%	2.73%	8.77%	4.82%	2.30%	4.78%	0.91%	0.91%
Te Puke WB Jan-Jun 2005	Count	25925	18760	8198	10018	11010	7078	9731	4355	0	589	476	3548	936
	% Total	24.45%	17.70%	7.73%	9.45%	10.39%	6.68%	9.18%	4.11%	0.00%	0.56%	0.45%	3.35%	0.88%
Te Puke WB Nov-Dec 2007	Count	11283	10137	4052	3468	3886	2340	3574	2164	980	455	214	603	249
	% Total	24.93%	22.39%	8.95%	7.66%	8.58%	5.17%	7.90%	4.78%	2.16%	1.01%	0.47%	1.33%	0.55%
Te Puke WB Jan-May 2010	Count	32459	29243	9844	8985	10495	7634	6547	6172	4621	1441	436	1915	963
	% Total	25.74%	23.19%	7.81%	7.13%	8.32%	6.05%	5.19%	4.89%	3.66%	1.14%	0.35%	1.52%	0.76%
Eskdale EB Oct 2010-Feb 2011	Count	14374	7161	2324	1545	2471	2383	776	1146	1502	443	429	1518	360
	% Total	37.66%	18.76%	6.09%	4.05%	6.47%	6.24%	2.03%	3.00%	3.94%	1.16%	1.12%	3.98%	0.94%
Eskdale WB Oct 2010-Feb 2011	Count	7832	6446	2471	1504	2296	2876	616	10372	1741	461	613	232	362
	% Total	19.78%	16.28%	6.24%	3.80%	5.80%	7.26%	1.56%	26.19%	4.40%	1.16%	1.55%	0.59%	0.91%

Table HA.3.2 Heavy vehicle counts by PAT type for selected periods (types in descending order of total count, left to right), page 2 of 4

Data Set	PAT Type:	41	63	68	30	52	713	40	401	915	300	914	66	847
Total All Data Sets	**Count**	**30541**	**27774**	**19707**	**16152**	**11195**	**10848**	**4231**	**3940**	**3724**	**3425**	**3032**	**2495**	**2435**
	% Total	**1.17%**	**1.07%**	**0.76%**	**0.62%**	**0.43%**	**0.42%**	**0.16%**	**0.15%**	**0.14%**	**0.13%**	**0.12%**	**0.10%**	**0.09%**
Drury 1SB Jan-Dec 2011	Count	5807	4532	6778	1476	2549	5615	0	2077	1385	1736	830	373	607
	% Total	0.89%	0.70%	1.04%	0.23%	0.39%	0.86%	0.00%	0.32%	0.21%	0.27%	0.13%	0.06%	0.09%
Drury 1NB Jan-Sep 2005	Count	9242	12306	256	5652	4653	0	1662	0	0	0	0	1211	188
	% Total	1.90%	2.53%	0.05%	1.16%	0.96%	0.00%	0.34%	0.00%	0.00%	0.00%	0.00%	0.25%	0.04%
Drury 1NB May 2010-Mar 2011	Count	6214	3324	5193	4048	2077	2548	1241	457	500	407	1005	427	677
	% Total	1.15%	0.61%	0.96%	0.75%	0.38%	0.47%	0.23%	0.08%	0.09%	0.08%	0.19%	0.08%	0.12%
Waipara NB Jan - Feb 2007	Count	200	83	95	137	42	0	23	0	0	0	0	12	9
	% Total	1.23%	0.51%	0.58%	0.84%	0.26%	0.00%	0.14%	0.00%	0.00%	0.00%	0.00%	0.07%	0.06%
Waipara SB Nov 2010-May 2011	Count	1059	858	1011	581	245	382	69	391	92	297	109	52	33
	% Total	0.96%	0.78%	0.92%	0.53%	0.22%	0.35%	0.06%	0.36%	0.08%	0.27%	0.10%	0.05%	0.03%
Waipara SB Sep - Dec 2011	Count	405	284	584	120	77	274	0	354	681	312	130	32	10
	% Total	0.64%	0.45%	0.93%	0.19%	0.12%	0.44%	0.00%	0.56%	1.08%	0.50%	0.21%	0.05%	0.02%
Tokoroa NB Nov - Dec 2005	Count	429	340	76	450	181	0	145	0	0	0	0	36	9
	% Total	1.10%	0.87%	0.19%	1.15%	0.46%	0.00%	0.37%	0.00%	0.00%	0.00%	0.00%	0.09%	0.02%
Tokoroa NB Jan-Jul 2010	Count	1649	894	1725	875	214	276	190	0	65	0	177	61	86
	% Total	1.35%	0.73%	1.42%	0.72%	0.18%	0.23%	0.16%	0.00%	0.05%	0.00%	0.15%	0.05%	0.07%
Tokoroa NB Jan - Jun 2011	Count	911	923	1576	186	154	707	0	347	410	317	157	72	92
	% Total	0.78%	0.79%	1.35%	0.16%	0.13%	0.60%	0.00%	0.30%	0.35%	0.27%	0.13%	0.06%	0.08%
Tokoroa SB Aug-Dec 2011	Count	704	515	1416	146	146	482	0	162	551	282	175	49	33
	% Total	0.71%	0.52%	1.43%	0.15%	0.15%	0.49%	0.00%	0.16%	0.56%	0.28%	0.18%	0.05%	0.03%
Te Puke WB Jan-Jun 2005	Count	1171	1840	247	856	453	0	426	0	0	0	0	41	130
	% Total	1.10%	1.74%	0.23%	0.81%	0.43%	0.00%	0.40%	0.00%	0.00%	0.00%	0.00%	0.04%	0.12%
Te Puke WB Nov-Dec 2007	Count	497	388	110	392	39	90	155	0	0	0	0	36	23
	% Total	1.10%	0.86%	0.24%	0.87%	0.09%	0.20%	0.34%	0.00%	0.00%	0.00%	0.00%	0.08%	0.05%
Te Puke WB Jan-May 2010	Count	1366	1213	282	924	128	66	284	0	4	0	288	71	510
	% Total	1.08%	0.96%	0.22%	0.73%	0.10%	0.05%	0.23%	0.00%	0.00%	0.00%	0.23%	0.06%	0.40%
Eskdale EB Oct 2010-Feb 2011	Count	439	142	186	153	126	202	20	77	10	33	82	9	9
	% Total	1.15%	0.37%	0.49%	0.40%	0.33%	0.53%	0.05%	0.20%	0.03%	0.09%	0.21%	0.02%	0.02%
Eskdale WB Oct 2010-Feb 2011	Count	448	132	172	156	111	206	16	75	26	41	79	13	19
	% Total	1.13%	0.33%	0.43%	0.39%	0.28%	0.52%	0.04%	0.19%	0.07%	0.10%	0.20%	0.03%	0.05%

Table HA.3.3 Heavy vehicle counts by PAT type for selected periods (types in descending order of total count, left to right), page 3 of 4

Data Set	PAT Type:	34	301	402	42	1020	62	731	621	61	57	811	747	511
Total All Data Sets	**Count**	**1895**	**1814**	**1712**	**1664**	**1618**	**1276**	**1208**	**975**	**918**	**674**	**646**	**410**	**341**
	% Total	**0.07%**	**0.07%**	**0.07%**	**0.06%**	**0.06%**	**0.05%**	**0.05%**	**0.04%**	**0.04%**	**0.03%**	**0.02%**	**0.02%**	**0.01%**
Drury 1SB Jan-Dec 2011	Count	176	1127	1003	294	1346	509	0	0	1	534	330	142	251
	% Total	0.03%	0.17%	0.15%	0.05%	0.21%	0.08%	0.00%	0.00%	0.00%	0.08%	0.05%	0.02%	0.04%
Drury 1NB Jan-Sep 2005	Count	1147	0	0	599	0	0	1173	728	68	0	0	129	0
	% Total	0.24%	0.00%	0.00%	0.12%	0.00%	0.00%	0.24%	0.15%	0.01%	0.00%	0.00%	0.03%	0.00%
Drury 1NB May 2010-Mar 2011	Count	139	220	284	443	37	155	0	0	371	33	70	68	58
	% Total	0.03%	0.04%	0.05%	0.08%	0.01%	0.03%	0.00%	0.00%	0.07%	0.01%	0.01%	0.01%	0.01%
Waipara NB Jan - Feb 2007	Count	9	0	0	11	0	0	0	6	0	0	0	0	0
	% Total	0.06%	0.00%	0.00%	0.07%	0.00%	0.00%	0.00%	0.04%	0.00%	0.00%	0.00%	0.00%	0.00%
Waipara SB Nov 2010-May 2011	Count	40	188	64	13	18	96	0	0	45	12	9	7	4
	% Total	0.04%	0.17%	0.06%	0.01%	0.02%	0.09%	0.00%	0.00%	0.04%	0.01%	0.01%	0.01%	0.00%
Waipara SB Sep - Dec 2011	Count	8	85	58	7	11	106	0	0	0	24	4	5	0
	% Total	0.01%	0.14%	0.09%	0.01%	0.02%	0.17%	0.00%	0.00%	0.00%	0.04%	0.01%	0.01%	0.00%
Tokoroa NB Nov - Dec 2005	Count	44	0	0	53	0	0	35	59	0	0	0	3	0
	% Total	0.11%	0.00%	0.00%	0.14%	0.00%	0.00%	0.09%	0.15%	0.00%	0.00%	0.00%	0.01%	0.00%
Tokoroa NB Jan-Jul 2010	Count	87	0	0	81	2	0	0	0	154	0	0	15	0
	% Total	0.07%	0.00%	0.00%	0.07%	0.00%	0.00%	0.00%	0.00%	0.13%	0.00%	0.00%	0.01%	0.00%
Tokoroa NB Jan - Jun 2011	Count	54	85	105	0	38	176	0	0	0	16	124	14	13
	% Total	0.05%	0.07%	0.09%	0.00%	0.03%	0.15%	0.00%	0.00%	0.00%	0.01%	0.11%	0.01%	0.01%
Tokoroa SB Aug-Dec 2011	Count	48	81	171	23	130	132	0	0	0	47	70	9	13
	% Total	0.05%	0.08%	0.17%	0.02%	0.13%	0.13%	0.00%	0.00%	0.00%	0.05%	0.07%	0.01%	0.01%
Te Puke WB Jan-Jun 2005	Count	39	0	0	37	0	0	0	109	0	0	0	0	0
	% Total	0.04%	0.00%	0.00%	0.03%	0.00%	0.00%	0.00%	0.10%	0.00%	0.00%	0.00%	0.00%	0.00%
Te Puke WB Nov-Dec 2007	Count	19	0	0	27	0	0	0	73	0	0	0	0	0
	% Total	0.04%	0.00%	0.00%	0.06%	0.00%	0.00%	0.00%	0.16%	0.00%	0.00%	0.00%	0.00%	0.00%
Te Puke WB Jan-May 2010	Count	36	0	0	42	0	0	0	0	89	0	0	14	0
	% Total	0.03%	0.00%	0.00%	0.03%	0.00%	0.00%	0.00%	0.00%	0.07%	0.00%	0.00%	0.01%	0.00%
Eskdale EB Oct 2010-Feb 2011	Count	25	13	15	17	17	46	0	0	89	2	13	2	1
	% Total	0.07%	0.03%	0.04%	0.04%	0.04%	0.12%	0.00%	0.00%	0.23%	0.01%	0.03%	0.01%	0.00%
Eskdale WB Oct 2010-Feb 2011	Count	24	15	12	17	19	56	0	0	101	6	26	2	1
	% Total	0.06%	0.04%	0.03%	0.04%	0.05%	0.14%	0.00%	0.00%	0.26%	0.02%	0.07%	0.01%	0.00%

Table HA.3.4 Heavy vehicle counts by PAT type for selected periods (types in descending order of total count, left to right), page 4 of 4

Data Set	PAT Type:	89	503	74	47	44	771	50	85	65	622	Total
Total All Data Sets	**Count**	**276**	**266**	**129**	**39**	**38**	**27**	**15**	**12**	**7**	**5**	**2599406**
	% Total	**0.01%**	**0.01%**	**0.00%**	**0.00%**	**0.00%**	**0.00%**	**0.00%**	**0.00%**	**0.00%**	**0.00%**	**100.00%**
Drury 1SB Jan-Dec 2011	Count	0	102	2	18	1	0	5	0	0	2	650029
	% Total	0.00%	0.02%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	100.00%
Drury 1NB Jan-Sep 2005	Count	272	0	26	0	31	0	0	12	0	0	486031
	% Total	0.06%	0.00%	0.01%	0.00%	0.01%	0.00%	0.00%	0.00%	0.00%	0.00%	100.00%
Drury 1NB May 2010-Mar 2011	Count	0	27	15	15	1	0	3	0	0	0	542233
	% Total	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	100.00%
Waipara NB Jan - Feb 2007	Count	0	0	1	0	1	0	0	0	0	0	16270
	% Total	0.00%	0.00%	0.01%	0.00%	0.01%	0.00%	0.00%	0.00%	0.00%	0.00%	100.00%
Waipara SB Nov 2010-May 2011	Count	0	65	1	0	0	21	3	0	6	2	110022
	% Total	0.00%	0.06%	0.00%	0.00%	0.00%	0.02%	0.00%	0.00%	0.01%	0.00%	100.00%
Waipara SB Sep - Dec 2011	Count	0	56	0	1	0	1	0	0	0	0	62835
	% Total	0.00%	0.09%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	100.00%
Tokoroa NB Nov - Dec 2005	Count	4	0	0	0	0	0	0	0	0	0	39135
	% Total	0.01%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	100.00%
Tokoroa NB Jan-Jul 2010	Count	0	0	1	0	0	0	0	0	1	0	121842
	% Total	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	100.00%
Tokoroa NB Jan - Jun 2011	Count	0	5	2	0	2	3	4	0	0	0	116871
	% Total	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	100.00%
Tokoroa SB Aug-Dec 2011	Count	0	3	0	1	0	2	0	0	0	1	98989
	% Total	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	100.00%
Te Puke WB Jan-Jun 2005	Count	0	0	42	0	1	0	0	0	0	0	106016
	% Total	0.00%	0.00%	0.04%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	100.00%
Te Puke WB Nov-Dec 2007	Count	0	0	11	1	0	0	0	0	0	0	45266
	% Total	0.00%	0.00%	0.02%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	100.00%
Te Puke WB Jan-May 2010	Count	0	0	28	1	1	0	0	0	0	0	126102
	% Total	0.00%	0.00%	0.02%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	100.00%
Eskdale EB Oct 2010-Feb 2011	Count	0	6	0	1	0	0	0	0	0	0	38167
	% Total	0.00%	0.02%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	100.00%
Eskdale WB Oct 2010-Feb 2011	Count	0	2	0	1	0	0	0	0	0	0	39598
	% Total	0.00%	0.01%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	100.00%

Annex H.4 GVM and length statistics for selected datasets

Table HA.4.1 GVM and length statistics by vehicle type for selected dataset

Drury Lane 1 Southbound, 01/01/2011-01/01/2012

NZTA 2011 Class	PAT Type	Count	Avg GVM	Min GVM	Max GVM	GVM StDev	Avg Length	Min Length	Max Length	Length StDev
4	20	25440	4456	3530	17290	1175	5.26	3.39	12.45	0.65
4	21	147842	6713	3530	19380	2601	7.92	4.35	15.50	1.53
4	300	1736	8439	3570	21440	3382	11.83	7.77	19.34	1.87
4	401	2077	9821	4680	21890	3362	14.11	8.84	20.80	2.68
5	30	1476	12312	3620	22790	2803	16.77	12.53	22.16	1.45
5	31	63335	15091	3690	29910	4084	10.32	5.82	18.20	2.15
5	34	176	13638	3720	22860	3243	10.77	7.20	14.20	1.59
5	44	1	6590	6590	6590		13.50	13.50	13.50	
5	301	1127	15545	3640	25590	5646	7.00	4.45	14.41	0.62
5	402	1003	15672	4500	32930	5314	18.23	11.21	24.69	2.84
5	503	102	18655	11570	26830	3049	16.83	11.55	19.82	2.53
6	45	32941	18111	4980	38340	5032	10.56	6.53	19.88	1.28
6	47	18	15494	10640	29360	6467	8.86	6.90	13.19	2.10
6	511	251	25716	7680	36430	3979	11.01	8.13	16.58	0.83
7	41	5807	17639	4720	38220	3753	15.85	7.97	22.82	2.23
7	42	294	15440	5530	20160	1376	16.01	8.44	17.42	0.73
8	50	5	21856	11290	28760	6421	19.26	17.75	20.68	1.12
8	52	2549	23937	8700	52100	5732	19.60	12.81	24.55	1.53
8	53	8962	25746	7470	47980	7552	14.65	9.55	22.79	2.36
8	57	534	21148	6310	33180	4639	16.59	11.95	22.14	0.78
9	68	6778	30925	9600	55910	4337	20.53	9.63	24.98	1.81
9	69	58258	29407	8060	55270	8417	16.90	11.35	24.99	1.17
9	713	5615	32334	11380	50370	7384	17.79	12.85	24.75	1.43
9	747	142	28509	15120	51320	8334	17.13	15.26	19.80	0.87
9	791	18120	32623	12960	55900	7140	18.28	15.26	24.98	0.75
9	826	28250	35318	13240	58450	9290	18.38	15.99	23.83	0.64
9	847	607	31619	15480	51860	6046	18.52	17.08	21.30	0.50
10	61	1	8830	8830	8830		21.01	21.01	21.01	
10	62	509	31727	16360	60390	8969	19.34	16.15	23.98	0.91
10	63	4532	31088	9870	52470	10420	18.67	13.81	24.65	1.55
10	66	373	26628	10230	42890	4910	19.48	14.40	22.42	1.47
10	622	2	16945	8880	25010	11406	23.84	23.19	24.48	0.91
11	74	2	30015	20440	39590	13541	20.06	19.32	20.79	1.04
11	751	47148	28288	10380	75700	12727	19.18	15.13	24.82	0.84
12	77	5791	33417	10940	53750	8079	19.96	16.07	23.41	0.93
12	891	120109	34448	10170	64220	9497	20.47	17.15	24.98	0.88
12	914	830	39021	19410	57990	8543	20.43	18.72	22.74	0.62
12	915	1385	39687	15800	53180	6837	22.35	18.79	24.89	1.30
12	1020	1346	30456	15950	50660	5267	22.28	19.17	24.66	0.74
13	811	330	38200	17750	53730	8155	19.99	18.34	24.27	0.79
13	851	40178	36244	12370	58630	7744	20.32	17.71	24.90	0.66
13	951	14047	37851	17270	70400	6009	20.96	17.38	24.92	1.03

Table HA.4.2 GVM and length statistics by vehicle type for selected dataset

Drury Lane 1 Northbound, 01/01/2005-01/10/2005 and 01/05/2010-01/04/2011

NZTA 2011 Class	PAT Type	Count	Avg GVM	Min GVM	Max GVM	GVM StDev	Avg Length	Min Length	Max Length	Length StDev
4	20	76792	4791	3500	17130	1182	5.16	3.15	12.79	0.95
4	21	209344	6904	3500	18260	2451	7.83	4.21	21.08	1.50
4	300	407	9274	3640	20700	2947	11.87	8.39	18.50	1.90
4	401	457	9395	5960	17270	2569	14.01	9.89	19.44	2.18
5	30	9700	9191	3890	23740	3625	13.32	6.23	23.23	2.82
5	31	101536	13427	4020	28810	3426	9.73	4.33	19.46	2.20
5	34	1286	12744	4630	28520	3544	10.21	4.59	14.01	1.66
5	44	32	14792	6580	22310	3582	15.08	8.30	20.53	3.87
5	301	220	11586	3960	23140	3739	6.72	4.75	7.76	0.45
5	402	284	13355	5590	28850	3765	17.72	12.23	21.45	2.94
5	503	27	17737	9430	24450	3173	14.65	13.03	18.84	1.72
6	45	52217	16183	5510	40440	4094	10.18	6.01	21.43	1.27
6	47	15	22158	9890	27570	5474	9.71	6.78	11.02	1.18
6	511	58	25623	19600	34070	4134	11.03	9.36	12.01	0.65
7	40	2903	14378	4280	32500	4406	16.63	9.70	23.94	2.46
7	41	15456	14589	4910	35720	4324	14.98	7.96	24.55	2.06
7	42	1042	16029	6290	31950	5440	15.81	7.76	23.42	2.60
8	50	3	17477	7210	24620	9116	19.76	19.50	20.22	0.40
8	52	6730	21990	8160	42160	6527	17.72	11.47	24.87	2.09
8	53	17070	21775	6360	42080	6722	14.37	8.83	23.51	2.42
8	57	33	16161	5910	23850	3905	15.46	11.61	16.48	1.08
9	68	5449	24731	9960	45690	5769	19.76	11.86	24.21	1.19
9	69	107368	26499	8250	54860	8624	16.34	10.54	24.52	1.10
9	713	2548	26544	12080	47160	8411	17.45	12.39	23.62	1.23
9	747	197	34416	15520	48660	6889	16.62	14.08	19.11	0.76
9	791	19546	27974	12980	53520	9306	17.96	15.06	23.68	0.72
9	826	21844	31282	13010	55900	11097	18.14	15.45	24.19	0.64
9	847	865	36385	15950	50650	8304	18.20	16.22	23.09	0.53
10	61	439	28099	15370	62400	7427	19.36	16.98	21.97	0.81
10	62	155	28950	16940	56080	7518	19.04	16.89	23.42	0.88
10	63	15630	30398	9270	54600	9641	17.85	12.10	24.41	1.31
10	66	1638	25255	10290	44580	6901	19.24	12.41	23.71	1.33
10	621	728	27681	15000	58950	7041	18.88	14.43	22.78	0.98
11	74	41	34817	16560	56260	8494	19.77	17.71	23.78	1.36
11	731	1173	31805	15820	55510	6874	19.50	16.85	22.31	0.70
11	751	94557	39466	11440	57700	9049	18.71	15.22	24.83	0.85
12	77	15111	30192	10990	54250	8572	19.18	15.37	23.10	1.20
12	891	160220	34641	10990	60190	10236	20.03	15.25	24.84	0.83
12	914	1005	37256	14620	63120	9578	20.10	18.44	22.56	0.61
12	915	500	35552	16900	56950	7530	21.64	19.37	24.53	1.26
12	1020	37	36154	18810	50550	9709	20.02	19.10	21.73	0.54
13	85	12	36773	21210	46700	8489	19.97	17.86	24.43	1.86
13	89	272	34044	18730	53650	6457	19.77	17.86	21.48	0.59
13	811	70	40880	17600	51770	9276	19.81	18.18	21.48	0.76
13	851	69704	34047	12710	59120	9053	19.84	16.47	24.85	0.73
13	951	13538	35083	16480	59330	8764	20.32	17.55	24.43	0.85

Table HA.4.3 GVM and length statistics by vehicle type for selected dataset

Eskdale Eastbound, 01/10/2010-01/03/2011

NZTA 2011 Class	PAT Type	Count	Avg GVM	Min GVM	Max GVM	GVM StDev	Avg Length	Min Length	Max Length	Length StDev
4	20	776	4268	3540	19040	1121	4.77	3.26	6.32	0.55
4	21	7161	6123	3530	15380	2542	7.17	4.46	13.37	1.46
4	300	33	9061	5080	16800	3015	11.51	8.17	14.76	1.84
4	401	77	10012	5810	16830	2561	15.23	9.28	19.87	2.75
5	30	153	9415	4420	19850	4090	13.05	7.94	19.25	3.18
5	31	2324	14001	4160	27200	3544	9.87	6.06	15.48	2.28
5	34	25	14983	9230	19930	3178	8.17	7.80	10.88	0.59
5	301	13	10007	6710	12620	1628	6.52	6.26	6.82	0.17
5	402	15	12842	7680	20610	3707	16.96	14.07	19.33	1.82
5	503	6	16982	14940	19580	1791	18.24	16.76	20.26	1.17
6	45	1146	16801	7450	29710	3987	9.99	6.83	12.69	1.13
6	47	1	23340	23340	23340		9.18	9.18	9.18	
6	511	1	22670	22670	22670		9.15	9.15	9.15	
7	40	20	13686	5070	23150	5585	16.39	12.76	19.72	2.24
7	41	439	12655	5000	25610	5553	14.56	8.68	20.38	2.52
7	42	17	18249	12750	24260	3301	17.03	14.87	20.18	2.19
8	52	126	22635	12520	35690	4869	17.47	13.01	20.04	2.01
8	53	360	19799	11690	40730	5439	15.15	10.81	20.34	2.71
8	57	2	7970	6870	9070	1556	14.41	14.29	14.53	0.17
9	68	186	29669	15730	38610	4601	19.86	13.18	23.58	1.24
9	69	1545	28088	11840	60360	8536	16.43	12.44	20.38	1.00
9	713	202	30945	16070	51580	7855	16.81	13.61	21.23	0.99
9	747	2	39735	38820	40650	1294	17.09	16.88	17.31	0.30
9	791	443	32826	15580	50990	7391	17.94	15.30	24.83	0.81
9	826	1502	36479	15350	52600	9017	17.81	16.74	21.46	0.46
9	847	9	37849	23930	44870	6311	17.98	17.51	18.54	0.29
10	61	89	38144	21230	63630	13447	18.96	17.44	20.64	0.56
10	62	46	34095	20400	58790	12275	19.05	17.46	22.96	0.86
10	63	142	26537	14180	45370	7583	18.70	15.55	20.70	1.20
10	66	9	29197	19180	38590	7871	17.61	16.10	18.86	1.27
11	751	2471	37312	13040	53310	13254	18.62	16.66	21.06	0.50
12	77	1518	43858	13600	53280	5720	19.51	16.76	21.36	0.52
12	891	14373	41711	12780	58720	8185	19.80	17.21	23.02	0.60
12	914	82	39066	22530	50310	6503	19.97	19.21	21.08	0.34
12	915	10	41136	20050	49720	9011	21.93	19.65	23.79	1.24
12	1020	17	45351	24220	50110	5684	19.30	18.54	20.33	0.51
13	811	13	31792	27060	40290	4004	19.55	19.16	20.11	0.26
13	851	2382	35819	13710	55990	8668	19.60	17.79	21.72	0.47
13	951	429	37749	19930	53550	6261	20.25	18.69	22.67	0.58

Table HA.4.4 GVM and length statistics by vehicle type for selected dataset

Eskdale Westbound, 01/10/2010-01/03/2011

NZTA 2011 Class	PAT Type	Count	Avg GVM	Min GVM	Max GVM	GVM StDev	Avg Length	Min Length	Max Length	Length StDev
4	20	616	4377	3530	18820	1187	4.95	3.07	6.40	0.53
4	21	6446	6321	3530	16110	2652	7.41	4.65	13.77	1.55
4	300	41	7639	3880	15170	2471	11.32	8.33	14.29	1.78
4	401	75	9598	6030	12990	2021	14.08	10.26	19.48	2.35
5	30	156	9096	4160	18690	3660	13.21	8.37	19.90	2.93
5	31	2471	14129	4500	26440	3769	9.76	6.09	13.94	2.14
5	34	24	16287	4630	20800	4268	8.45	4.79	11.64	1.40
5	301	15	15102	8660	23150	5215	6.74	6.39	6.98	0.16
5	402	12	14818	7490	21150	4732	17.74	15.57	19.39	1.22
5	503	2	14180	12720	15640	2065	18.23	16.72	19.74	2.14
6	45	10372	15872	5620	30770	1858	9.33	7.21	16.18	0.55
6	47	1	11910	11910	11910		9.69	9.69	9.69	
6	511	1	20770	20770	20770		9.67	9.67	9.67	
7	40	16	14358	7310	24550	5478	17.03	13.68	20.06	2.35
7	41	448	12434	5030	31350	5523	14.43	8.96	19.87	2.49
7	42	17	15486	11470	18280	1781	16.28	12.97	19.80	1.78
8	52	111	25543	12760	39250	6180	17.37	13.45	19.87	1.89
8	53	362	22963	10150	38700	7643	14.85	10.94	21.00	2.50
8	57	6	12647	7230	20280	5580	14.91	12.78	16.34	1.33
9	68	172	23145	15170	38520	4139	19.77	14.07	23.21	1.28
9	69	1504	27037	12080	52930	9060	16.34	12.82	19.92	0.96
9	713	206	32563	14890	52770	8857	16.84	13.93	21.03	0.94
9	747	2	43655	35950	51360	10897	17.00	16.83	17.17	0.24
9	791	461	33534	14710	47220	7169	17.89	15.38	21.10	0.48
9	826	1741	34976	14890	51050	10009	17.85	16.70	21.79	0.44
9	847	19	43208	23410	47850	6428	18.13	17.71	18.45	0.22
10	61	101	32342	18770	63370	13164	18.93	17.93	19.94	0.51
10	62	56	32271	20170	63000	12367	18.84	17.74	20.17	0.57
10	63	132	28813	14550	47950	9704	18.68	16.28	20.72	1.19
10	66	13	35887	19770	40960	7215	17.15	16.04	20.06	1.36
11	751	2295	42149	12760	52570	8797	18.64	16.37	21.11	0.51
12	77	232	35086	16330	49430	9587	19.40	16.93	20.68	0.56
12	891	7831	36936	13080	58630	10054	19.88	17.70	22.62	0.53
12	914	79	40136	19290	52140	7342	20.03	19.15	21.24	0.35
12	915	26	37482	20320	50110	8755	22.01	20.14	22.88	0.90
12	1020	19	41743	34270	48900	4582	19.39	19.10	19.89	0.20
13	811	26	44207	37920	49080	3084	19.53	18.46	20.09	0.34
13	851	2876	36728	15320	52310	8853	19.66	18.16	22.06	0.44
13	951	613	40310	18310	51900	7358	20.13	18.69	22.63	0.43

Table HA.4.5 GVM and length statistics by vehicle type for selected dataset

Te Puke Westbound, 01/01/2005-01/07/2005, 01/11/2007-01/01/2008 and 01/01/2010-01/06,

NZTA 2011 Class	PAT Type	Count	Avg GVM	Min GVM	Max GVM	GVM StDev	Avg Length	Min Length	Max Length	Length StDev
4	20	19852	4751	3500	14940	1467	5.76	3.18	12.94	0.76
4	21	58140	6540	3500	16380	2358	7.74	4.51	21.52	1.49
5	30	2172	7543	3730	20560	3249	11.68	6.44	22.18	2.29
5	31	22094	12411	3600	26860	3601	9.10	4.67	18.56	1.85
5	34	94	14420	4540	29820	5260	9.42	5.50	19.50	1.65
5	44	1	10810	10810	10810		11.28	11.28	11.28	
6	45	12690	15129	5510	46510	4168	10.12	6.93	17.58	1.16
6	47	2	16675	16600	16750	106	9.55	9.08	10.01	0.66
7	40	865	17526	4670	32510	7292	15.56	8.16	21.59	2.29
7	41	3034	11438	5010	28210	5092	13.07	8.53	21.20	2.30
7	42	106	15278	7100	25240	3685	15.49	11.80	21.03	2.60
8	52	620	23547	7710	42550	8839	16.51	12.97	23.61	1.80
8	53	2148	21589	8310	38670	6763	13.95	10.03	20.90	2.18
9	68	639	24156	9090	61890	5751	19.76	12.38	21.90	1.11
9	69	22471	26268	8100	56640	9574	16.40	11.78	23.40	0.95
9	713	156	34751	14420	49730	9652	17.34	15.03	19.22	0.83
9	747	14	32004	17830	45850	9917	16.19	15.23	16.97	0.58
9	791	2485	31547	11590	49130	8805	17.78	15.45	23.89	0.66
9	826	5601	29841	12640	52360	11653	17.52	16.17	20.34	0.57
9	847	663	42577	16700	50300	5986	17.58	15.76	19.42	0.43
10	61	89	34550	14200	64400	12093	19.16	17.14	20.71	0.80
10	63	3441	31484	10150	54260	10553	17.55	13.65	23.43	1.26
10	66	148	22623	11620	41390	5709	17.91	15.66	21.43	1.26
10	621	182	31911	13610	58530	10399	19.55	16.19	23.17	1.15
11	74	81	35917	12810	47400	9359	19.25	18.19	20.80	0.55
11	751	25390	35652	9980	67860	11979	19.17	14.48	24.76	0.88
12	77	6066	37044	10760	55380	10741	19.21	15.89	24.35	0.78
12	891	69664	39568	10410	62900	9477	19.75	16.15	24.97	0.83
12	914	288	45058	20000	57630	7112	19.61	18.59	21.25	0.39
12	915	4	38568	19900	50000	13588	19.47	19.28	19.65	0.15
13	851	17051	38342	11210	56300	9595	19.78	16.19	24.98	0.74
13	951	1126	35268	17900	55020	8198	20.06	18.23	22.01	0.80

Table HA.4.6 GVM and length statistics by vehicle type for selected dataset

Tokoroa Northbound, 01/11/2005-01/01/2006, 01/01/2010-01/08/2010 and 01/01/2011-01/0

NZTA 2011 Class	PAT Type	Count	Avg GVM	Min GVM	Max GVM	GVM StDev	Avg Length	Min Length	Max Length	Length StDev
4	20	10246	4874	3500	19950	1491	5.78	3.24	13.61	1.04
4	21	39344	6484	3500	19360	2371	7.43	4.24	20.03	1.50
4	300	317	7692	3990	18750	3075	11.88	8.53	17.56	1.34
4	401	347	9844	5130	18960	2642	14.12	10.20	19.53	2.23
5	30	1511	7791	3880	19820	3643	12.72	6.68	19.91	3.09
5	31	18735	12274	4100	26640	3630	9.40	4.90	17.74	2.08
5	34	185	12132	4210	22740	4302	9.81	4.21	19.45	2.19
5	44	2	8235	7250	9220	1393	14.18	14.12	14.25	0.09
5	301	85	9571	3960	20780	3460	6.15	4.34	7.95	0.82
5	402	105	12399	5430	24370	3891	16.06	11.72	20.01	2.55
5	503	5	19342	13550	28820	7003	14.79	14.15	15.49	0.53
6	45	14601	15263	5970	43290	3502	9.70	6.19	17.46	1.14
6	511	13	24909	16860	39870	5675	10.80	9.11	15.81	1.63
7	40	335	12100	4210	28470	4612	15.61	9.13	24.78	3.00
7	41	2989	14484	4800	28220	4783	15.02	8.22	22.37	2.30
7	42	134	16626	9280	27780	4692	16.41	8.26	20.21	2.59
8	50	4	17758	11840	25820	7017	17.20	14.84	19.82	2.43
8	52	549	20078	8830	41190	6267	17.85	12.76	24.05	1.89
8	53	2110	20033	8540	46290	4943	15.33	10.17	23.09	2.34
8	57	16	17225	7410	29690	5324	15.67	13.89	18.46	1.23
9	68	3377	25932	8470	64720	5400	19.73	10.15	24.80	1.06
9	69	15481	25487	9410	58690	8213	16.39	11.45	24.87	1.09
9	713	983	27960	10870	51270	9158	17.18	12.87	23.32	1.02
9	747	32	36788	15740	45170	8375	16.16	14.95	18.36	0.79
9	791	6404	31763	12530	51420	8028	17.56	15.09	24.70	0.82
9	826	10400	34123	12580	62640	9622	17.69	15.65	24.79	0.77
9	847	187	34318	18330	55140	8623	17.87	16.38	20.54	0.65
10	61	154	35209	13720	57380	12750	18.67	17.09	22.29	0.80
10	62	176	35888	12760	71350	13951	18.99	17.39	22.12	0.80
10	63	2157	23882	10490	54850	9168	17.66	14.52	23.41	1.34
10	65	1	30210	30210	30210		18.09	18.09	18.09	
10	66	169	26288	12700	43890	8978	18.48	14.96	21.08	1.21
10	621	59	34772	20950	59920	12699	19.07	15.64	20.36	0.86
11	74	3	37263	25530	44420	10243	20.72	19.14	22.84	1.91
11	731	35	36593	25530	45520	5393	19.56	18.11	20.56	0.57
11	751	16330	32659	11630	61750	11611	18.76	14.32	24.70	0.87
12	77	4409	34564	12580	54720	10158	18.79	15.42	24.76	0.87
12	771	3	14573	12980	16530	1803	19.35	19.11	19.59	0.24
12	891	89239	36530	10940	58200	8879	19.37	15.83	24.95	0.92
12	914	334	35628	15370	52860	9219	19.64	18.28	22.68	0.70
12	915	475	37926	19460	50930	7093	21.45	18.43	24.19	1.30
12	1020	40	37102	19820	51390	7930	20.19	18.69	23.02	1.14
13	89	4	32840	28980	38130	3845	19.74	18.90	20.60	0.70
13	811	124	42902	19570	63590	5594	19.60	17.85	22.41	0.61
13	851	25570	34354	11510	55490	8241	19.59	15.03	24.98	0.73
13	951	10068	35191	15670	56990	8222	19.86	17.07	24.84	0.94

Table HA.4.7 GVM and length statistics by vehicle type for selected dataset

Tokoroa Southbound, 01/08/2011-01/01/2012

NZTA 2011 Class	PAT Type	Count	Avg GVM	Min GVM	Max GVM	GVM StDev	Avg Length	Min Length	Max Length	Length StDev
4	20	2702	4573	3540	12430	1436	5.30	3.40	6.50	0.57
4	21	14947	6289	3530	16250	2383	7.45	4.32	14.05	1.42
4	300	280	6672	3570	17590	2596	11.82	8.39	17.04	1.35
4	401	162	10023	4540	18830	3125	14.74	9.84	19.57	2.04
5	30	146	10415	4590	20150	3350	16.66	12.84	19.00	1.53
5	31	6197	14101	3890	25440	3413	9.97	5.94	15.47	1.93
5	34	42	11927	3880	18280	2514	9.24	7.76	12.15	1.43
5	301	81	11385	3660	20660	3795	6.51	4.80	7.48	0.58
5	402	171	16718	6210	27310	5213	15.49	11.70	20.75	2.35
5	503	3	20407	18650	23450	2646	17.48	16.25	18.27	1.08
6	45	8678	16533	5350	37260	3023	9.84	6.97	15.63	0.99
6	47	1	17400	17400	17400		10.56	10.56	10.56	
6	511	13	22994	10490	32100	7358	10.70	8.71	12.46	0.89
7	41	704	17098	4720	26890	4018	15.08	9.23	20.16	2.36
7	42	23	15028	12140	21130	2371	15.10	13.85	16.34	0.47
8	52	145	23190	6830	33500	5137	18.61	13.43	21.33	1.75
8	53	903	23601	10880	52030	4776	15.85	10.53	22.55	2.36
8	57	47	20109	13810	30020	3805	16.21	14.07	18.76	0.81
9	68	1414	32390	13440	56210	4111	20.70	13.41	24.84	1.57
9	69	4697	28851	11420	57660	6687	16.42	12.21	22.47	1.07
9	713	477	32061	14830	47340	6541	16.79	13.06	21.12	0.91
9	747	9	32849	18810	43440	9200	16.44	15.43	17.51	0.79
9	791	2277	31408	12190	51770	6323	17.81	15.27	24.19	0.86
9	826	4772	36065	12230	52450	7689	17.87	16.02	22.76	0.71
9	847	33	35846	24480	49440	7736	18.06	16.70	22.08	1.05
10	62	132	39670	18210	62750	11517	18.83	15.72	22.78	0.88
10	63	515	25875	12730	53240	7588	17.96	14.73	21.76	1.63
10	66	47	25612	16250	37940	4578	18.74	15.48	21.14	1.23
10	622	1	33730	33730	33730		18.90	18.90	18.90	
11	751	5190	39003	12700	53910	8345	18.90	16.69	24.23	0.87
12	77	896	35121	13450	51050	7702	19.26	15.45	22.99	1.22
12	771	2	29570	17100	42040	17635	19.27	19.23	19.31	0.06
12	891	28782	33737	11260	61550	10709	19.64	16.69	24.99	1.18
12	914	175	40561	22070	53750	6285	20.05	18.37	23.44	0.84
12	915	550	40396	17130	53230	7142	22.15	18.40	24.82	1.18
12	1020	130	40847	22880	52820	6826	21.71	19.57	23.53	0.68
13	811	70	34820	16220	51780	8801	19.41	18.27	21.33	0.60
13	851	8806	37389	13320	55530	6768	20.03	17.64	24.95	0.92
13	951	4733	38908	14960	57560	6269	20.53	17.61	24.77	1.28
13	1032	1	38020	38020	38020		19.60	19.60	19.60	

Table HA.4.8 GVM and length statistics by vehicle type for selected dataset

Waipara Northbound, 01/01/2007-01/03/2007

NZTA 2011 Class	PAT Type	Count	Avg GVM	Min GVM	Max GVM	GVM StDev	Avg Length	Min Length	Max Length	Length StDev
4	20	2023	4680	3540	13720	1263	6.76	4.06	11.43	0.97
4	21	2079	7333	3540	14800	2535	8.67	5.84	13.88	1.44
5	30	137	6860	3820	17440	3282	12.22	6.79	20.97	3.07
5	31	883	13576	5090	25060	3296	10.92	6.24	14.87	2.29
5	34	9	11289	4810	14220	3220	10.51	6.56	11.72	1.69
5	44	1	21940	21940	21940		20.08	20.08	20.08	
6	45	1767	15937	7160	40650	2937	10.30	7.58	15.06	1.04
7	40	23	14635	5560	27340	6821	15.41	10.51	20.70	2.57
7	41	200	11323	5150	25950	5743	14.10	8.54	20.83	2.31
7	42	11	19208	15860	24280	2816	14.58	12.01	17.91	2.16
8	52	42	20950	12120	36590	5338	18.57	11.43	21.10	2.03
8	53	103	21388	12770	36050	5603	15.51	11.43	20.55	2.63
9	68	95	26226	12860	36330	4460	20.36	12.88	21.99	1.38
9	69	897	29878	13100	53870	7486	17.19	12.39	21.90	1.24
9	791	522	31222	14670	51110	7281	18.41	16.88	22.03	0.50
9	847	9	42479	34480	50260	5280	18.63	18.17	19.14	0.33
10	63	83	26756	13350	45770	9088	18.89	16.26	21.41	1.36
10	66	12	30797	21830	44010	7709	18.94	17.60	19.98	0.74
10	621	6	35907	17390	57510	13781	19.47	16.22	20.97	1.69
11	74	1	38260	38260	38260		18.79	18.79	18.79	
11	751	583	39049	14130	52680	10116	19.70	17.79	24.11	0.72
12	77	146	27315	12880	50580	11355	19.71	17.96	21.41	0.73
12	891	4361	35817	12720	52780	9998	20.33	17.94	22.22	0.74
13	851	1817	33849	14540	52430	9097	20.49	18.15	22.81	0.53
13	951	460	35822	16620	50740	7512	20.66	19.21	22.71	0.45

Table HA.4.9 GVM and length statistics by vehicle type for selected dataset

Waipara Southbound, 01/11/2010-01/06/2011 and 01/09/2011-01/01/2012

NZTA 2011 Class	PAT Type	Count	Avg GVM	Min GVM	Max GVM	GVM StDev	Avg Length	Min Length	Max Length	Length StDev
4	20	14126	4161	3500	15830	947	5.06	3.14	9.79	0.48
4	21	35299	6322	3500	16940	2440	7.14	4.27	13.57	1.23
4	300	609	8015	3770	17590	3089	11.70	8.24	16.54	1.74
4	401	745	9798	4640	25210	2789	14.11	9.53	20.03	2.17
5	30	701	8549	4150	20290	3422	13.95	7.31	21.37	3.71
5	31	8940	13658	3580	26470	3413	9.86	4.86	16.52	2.07
5	34	48	13222	3570	30610	5126	8.97	4.56	11.83	1.88
5	301	273	10812	3870	29490	5708	5.84	4.43	9.04	0.79
5	402	122	14717	5950	27800	5259	15.59	10.81	21.22	2.39
5	503	121	18017	11450	28240	3367	17.50	11.71	20.28	1.73
6	45	6271	16954	5390	39090	3545	10.09	6.94	14.26	1.25
6	47	1	10920	10920	10920		7.16	7.16	7.16	
6	511	4	21213	11650	28030	7861	10.19	9.53	10.87	0.61
7	40	69	15168	4640	27540	5261	15.60	9.17	19.91	2.38
7	41	1464	15713	4700	27360	6173	15.28	8.46	20.50	2.77
7	42	20	14935	5410	26330	6813	13.18	8.36	18.66	3.81
8	50	3	6157	5690	6870	627	21.06	18.60	22.59	2.15
8	52	322	21731	11040	38380	4847	17.66	12.68	23.23	2.17
8	53	1323	23075	7620	38550	4361	16.14	10.22	21.82	1.93
8	57	36	17153	6300	26790	6981	15.41	11.07	17.29	1.86
9	68	1595	29838	10920	45590	6633	20.05	12.62	23.63	2.26
9	69	6318	28153	9180	55510	7532	16.37	11.51	21.34	1.07
9	713	656	31769	13030	49910	8480	17.03	13.93	22.01	1.14
9	747	12	36383	28240	45160	5238	18.22	17.32	19.01	0.52
9	791	4908	32053	15130	52130	6803	17.64	15.18	24.30	0.56
9	826	4858	36782	13110	56450	7109	17.92	15.58	23.20	0.48
9	847	43	39106	23500	49120	7171	18.31	17.28	19.50	0.44
10	61	45	33506	20430	57610	11543	19.41	17.68	20.62	0.81
10	62	202	37566	21280	63350	11279	19.21	17.57	22.24	0.69
10	63	1142	31146	11010	49110	9893	17.88	14.72	21.49	1.10
10	65	6	32400	18190	40150	9903	19.38	18.74	19.89	0.51
10	66	84	27250	17010	42800	5737	18.21	14.58	22.11	1.44
10	622	2	13185	8620	17750	6456	21.27	20.49	22.06	1.11
11	74	1	37800	37800	37800		19.70	19.70	19.70	
11	751	7013	33218	10880	54690	11282	18.88	16.21	24.94	0.68
12	77	4034	40258	11000	52150	8464	19.13	15.95	23.32	0.56
12	771	22	33385	14250	40990	7369	19.85	18.74	20.74	0.45
12	891	47730	36656	10540	55950	8972	19.52	16.34	24.94	0.65
12	914	239	41266	23300	55690	5557	20.04	18.64	20.95	0.39
12	915	773	43958	13890	75450	7627	21.27	18.24	23.65	1.15
12	1020	29	43524	24920	50680	5963	20.42	19.03	22.90	1.16
13	811	13	47542	21880	67610	16201	21.07	18.94	23.12	1.35
13	851	17060	39192	13300	53240	6290	19.70	17.40	23.27	0.53
13	951	5574	39591	13230	53100	6487	19.90	17.62	23.82	0.89
13	1032	4	32613	24960	38920	6034	19.59	19.27	19.88	0.32

Annex H.5 Histograms of axle weights, individual datasets

Figure HA.5.1 Histogram of axle weights, Drury Jan-Dec 2011, Lane 1 southbound

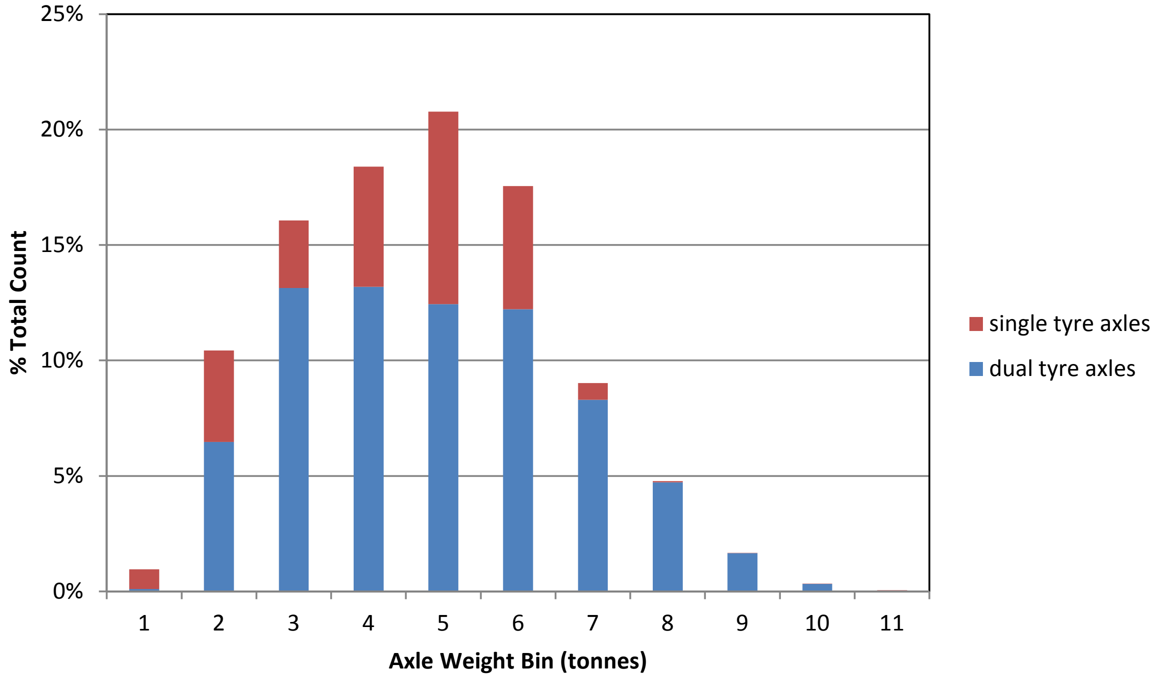


Figure HA.5.2 Histogram of axle weights, Drury Jan-Sep 2005, Lane 1 northbound

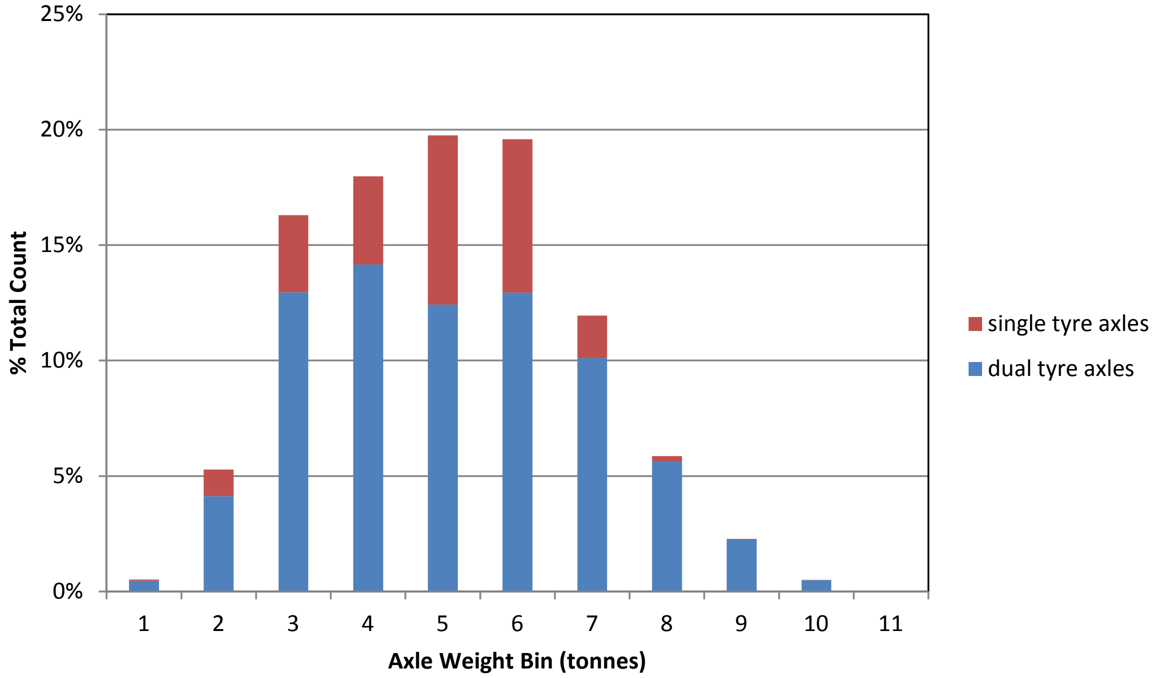


Figure HA.5.3 Histogram of axle weights, Drury May 2010–Mar 2011, Lane 1 northbound

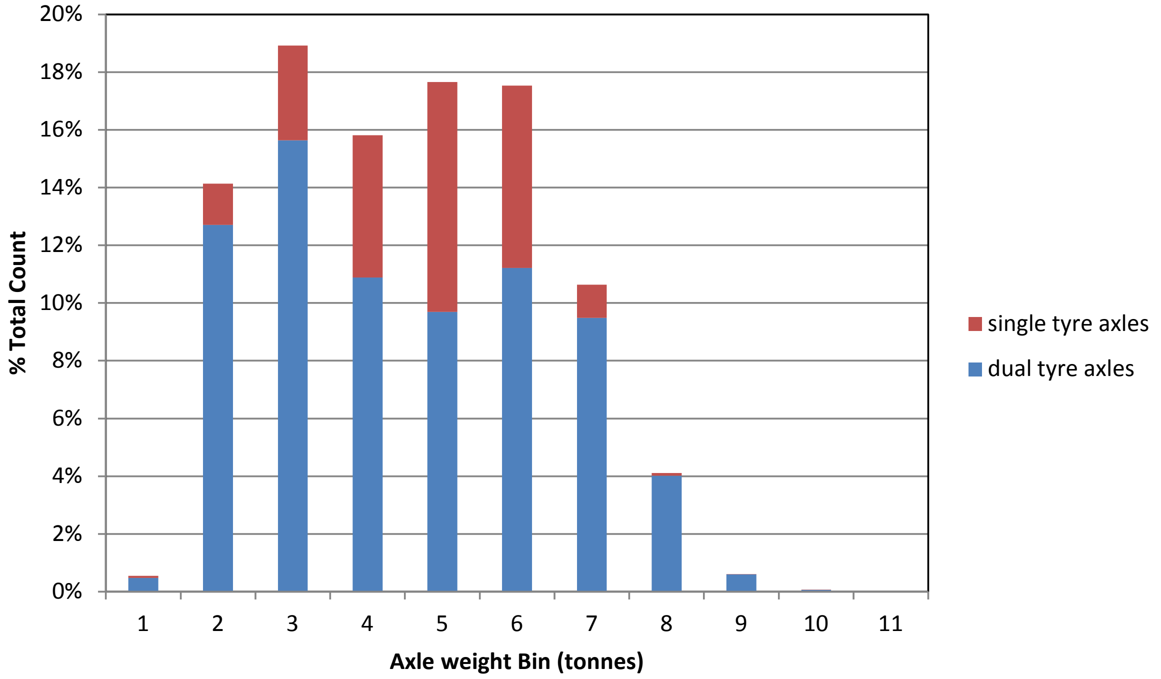


Figure HA.5.4 Histogram of axle weights, Eskdale Oct 2010–Feb 2011, eastbound

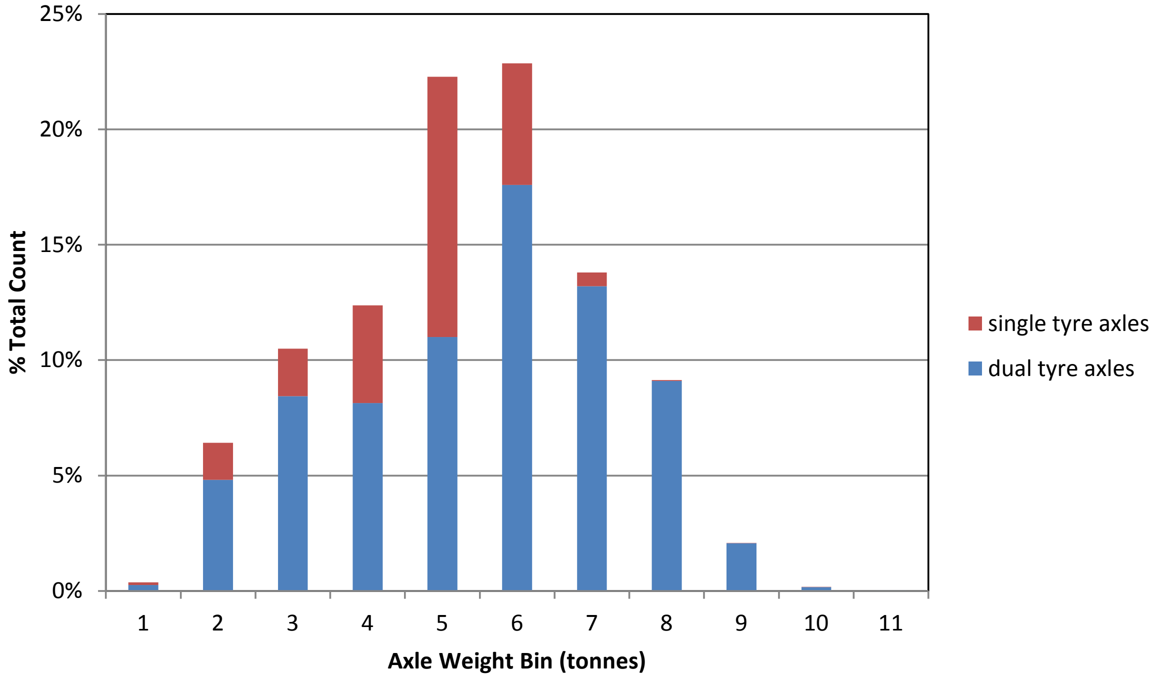


Figure HA.5.5 Histogram of axle weights, Eskdale Oct 2010–Feb 2011, westbound

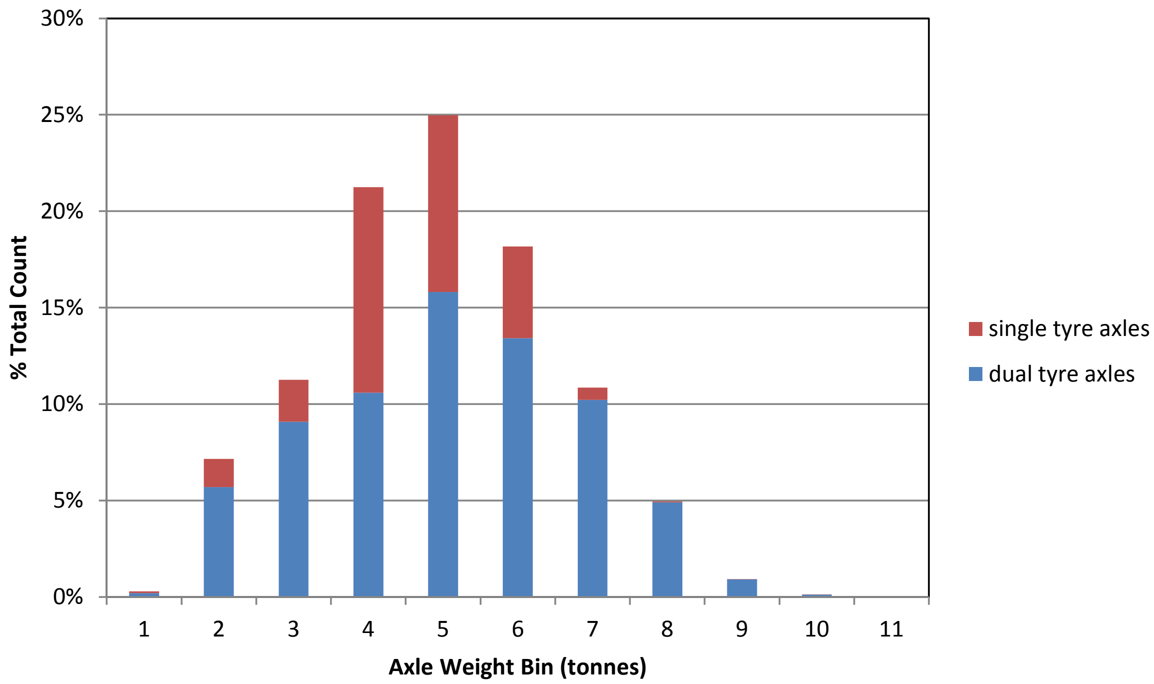


Figure HA.5.6 Histogram of axle weights, Te Puke Jan–Jun 2005, westbound

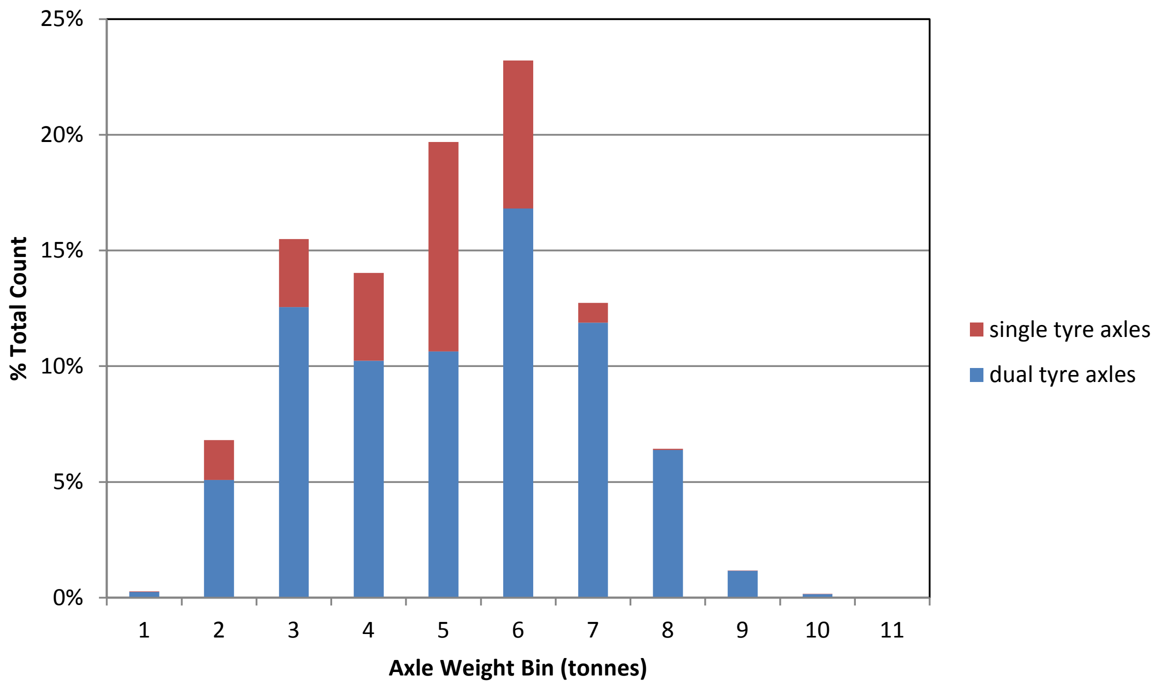


Figure HA.5.7 Histogram of axle weights, Te Puke Nov-Dec 2007, westbound

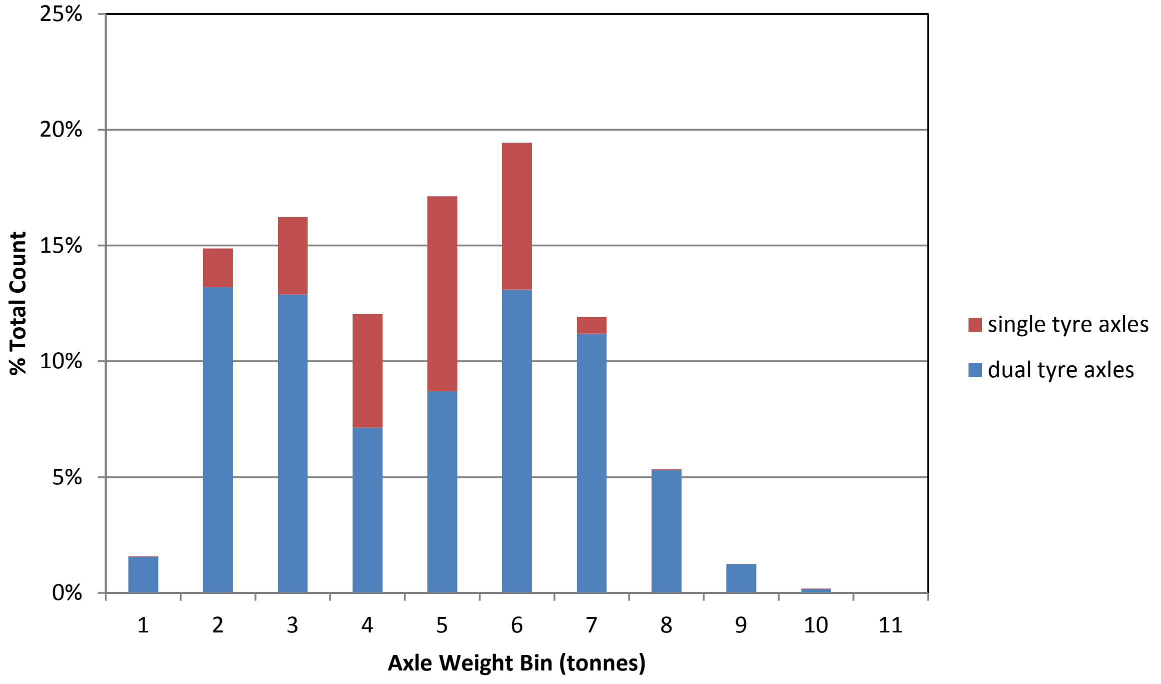


Figure HA.5.8 Histogram of axle weights, Te Puke Jan-May 2010, westbound

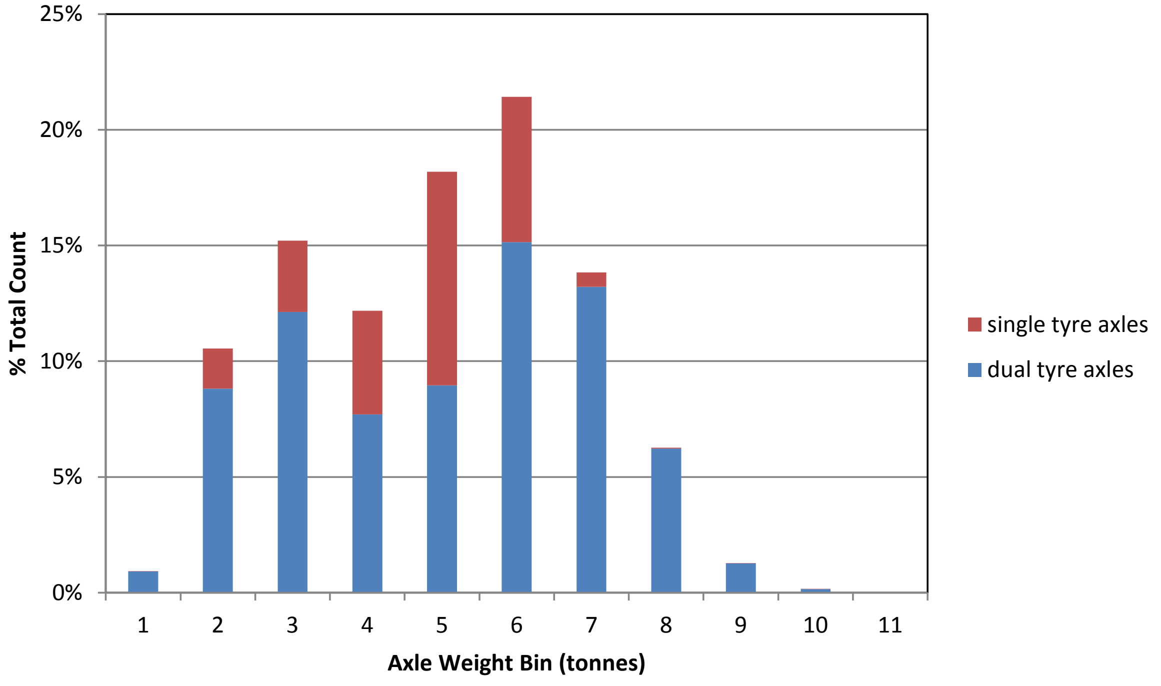


Figure HA.5.9 Histogram of axle weights, Tokoroa Nov–Dec 2005, northbound

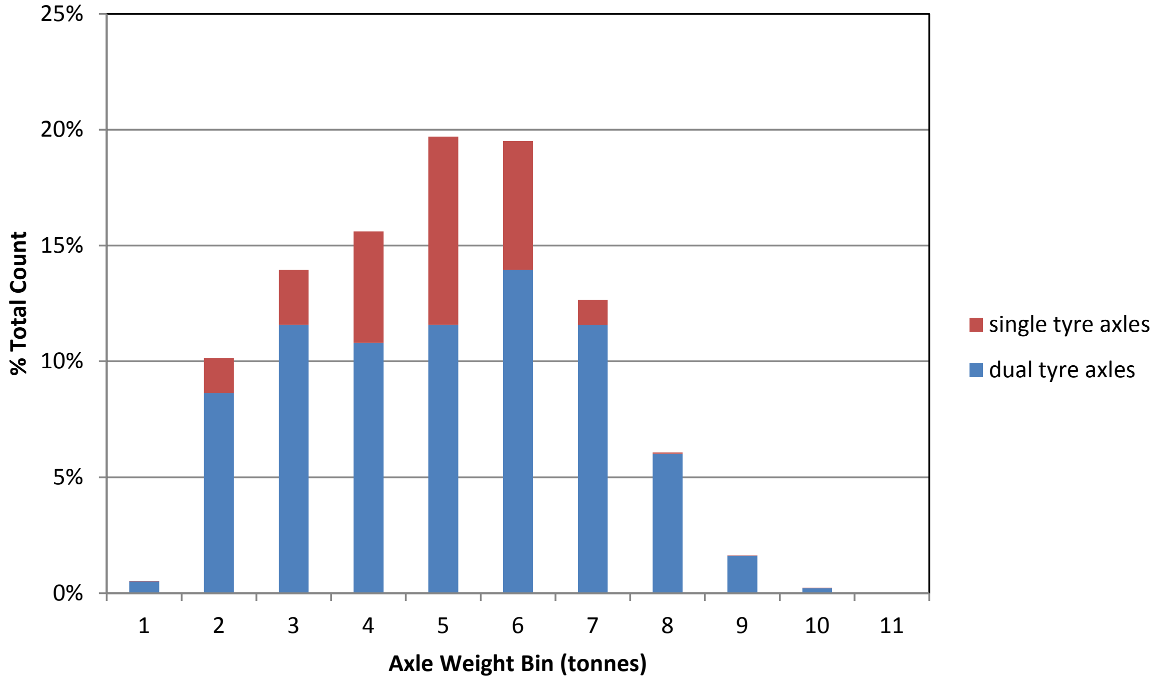


Figure HA.5.10 Histogram of axle weights, Tokoroa Jan–Jul 2010, northbound

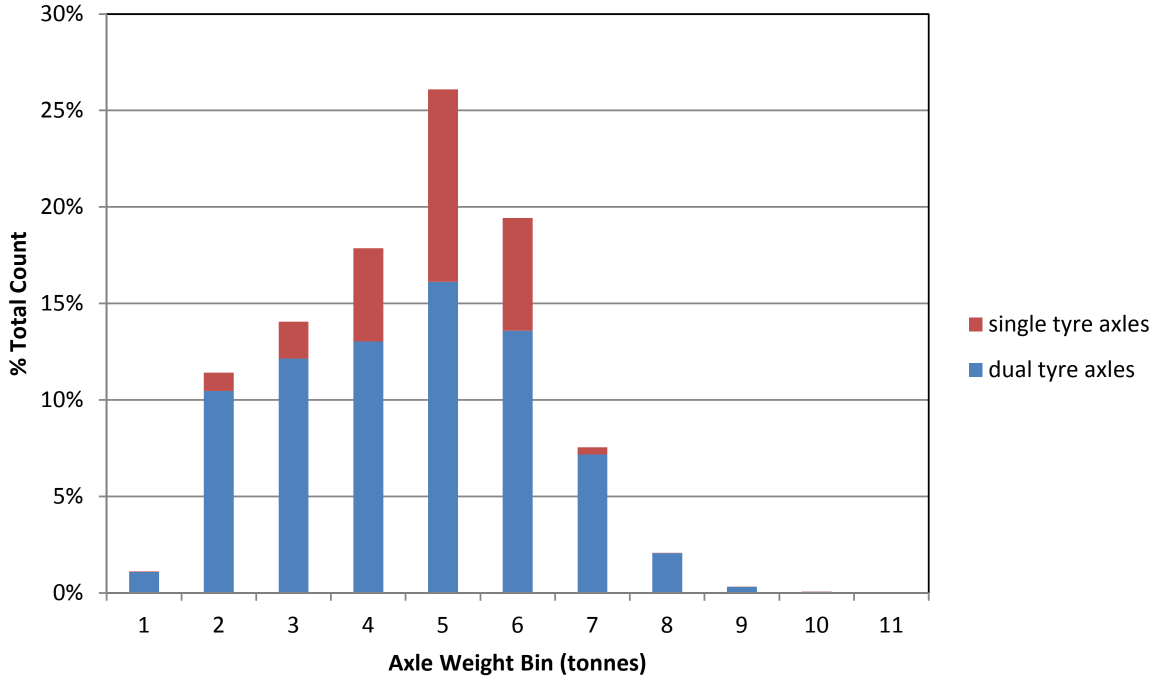


Figure HA.5.11 Histogram of axle weights, Tokoroa Jan-Jun 2011, northbound

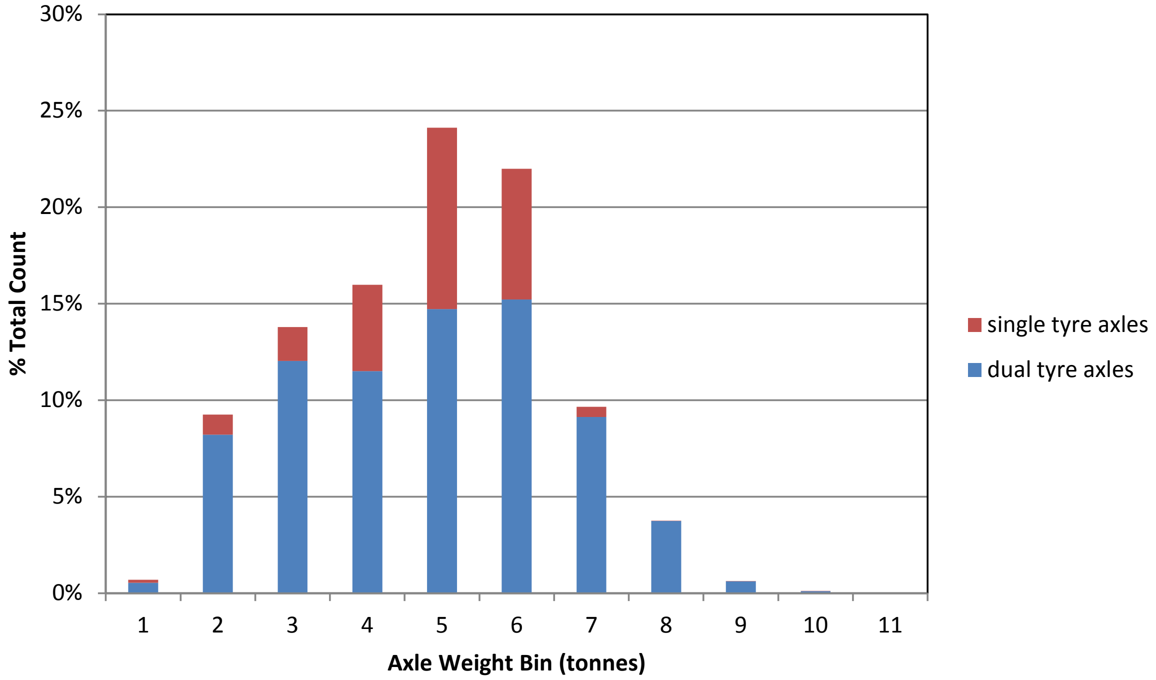


Figure HA.5.12 Histogram of axle weights, Tokoroa Aug-Dec 2011, southbound

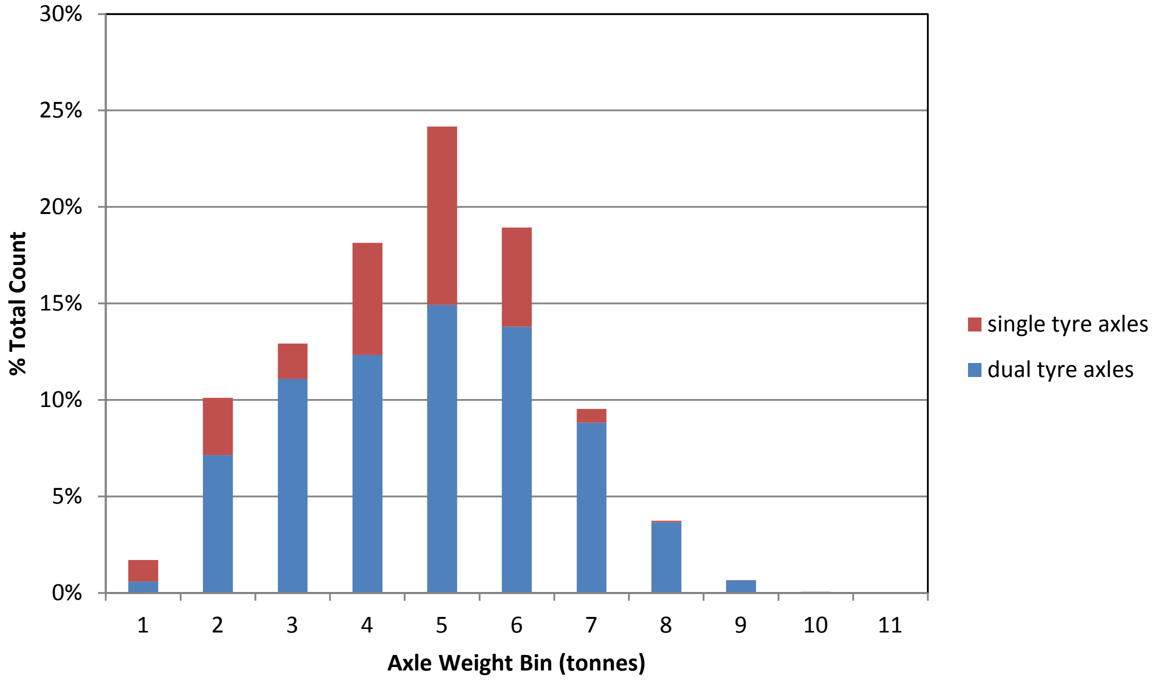


Figure HA.5.13 Histogram of axle weights, Waipara Jan–Feb 2007, northbound

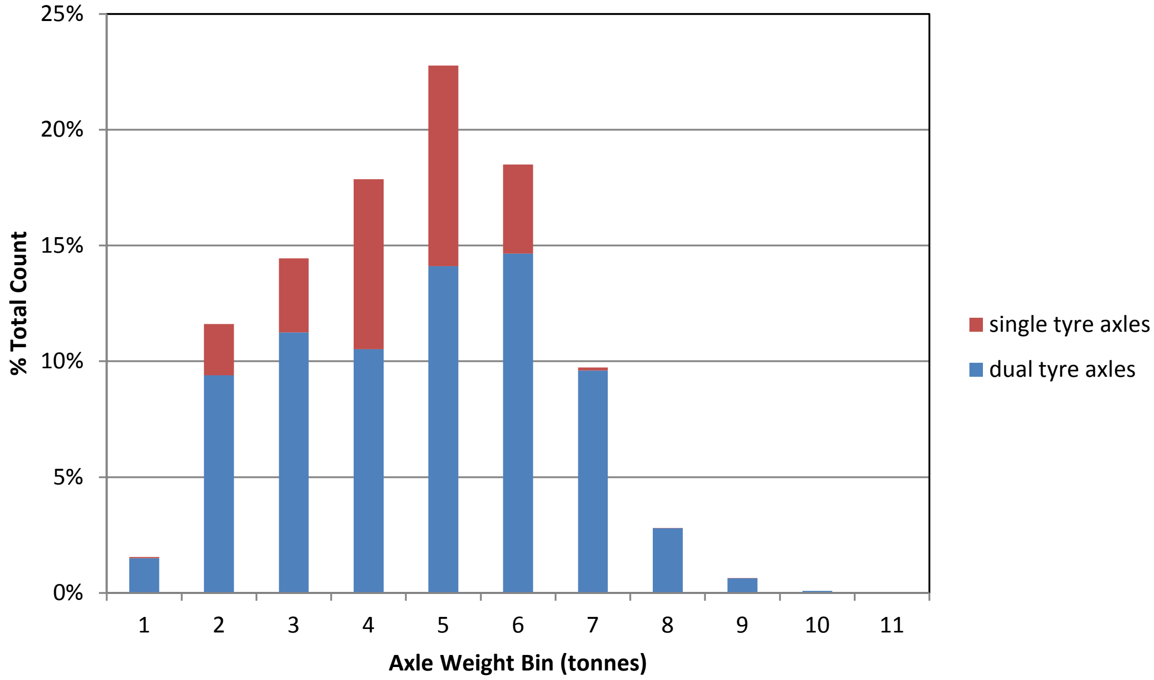


Figure HA.5.14 Histogram of axle weights, Waipara Nov 2010–May 2011, southbound

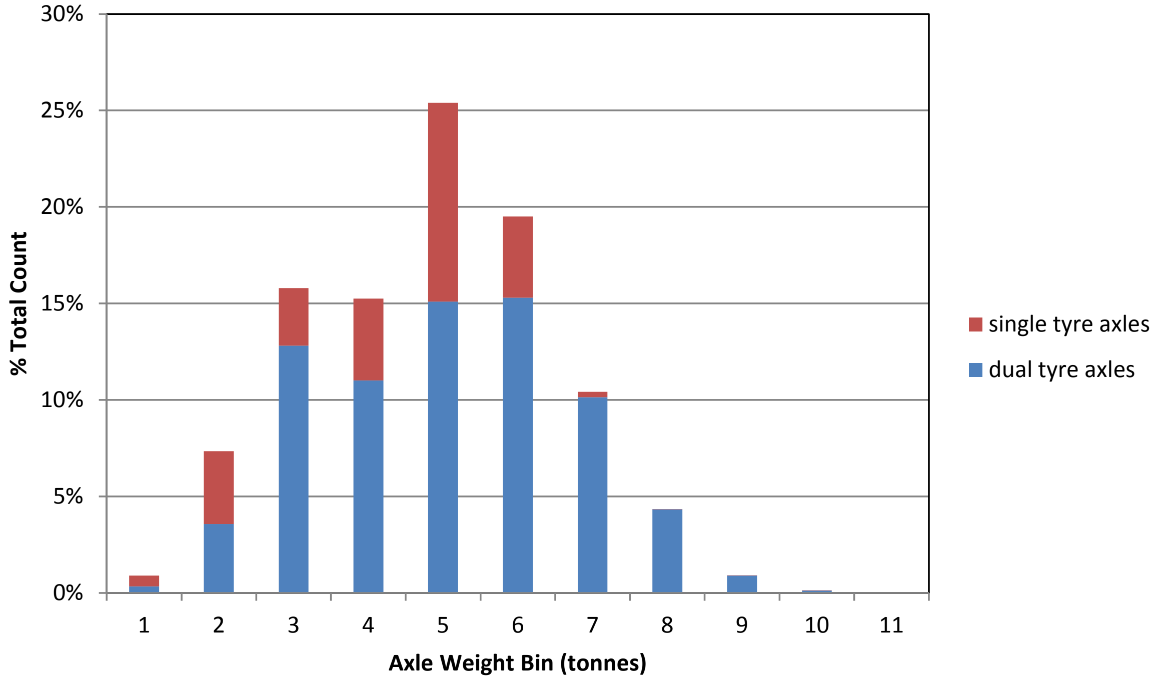
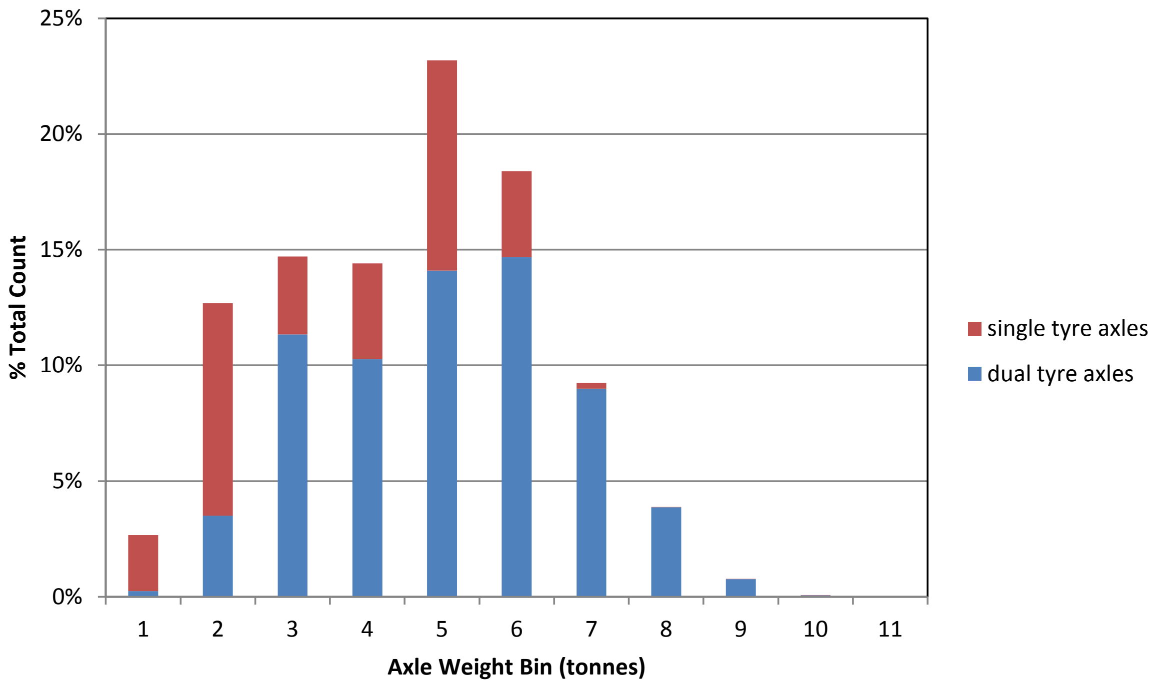


Figure HA.5.15 Histogram of axle weights, Waipara Sep-Dec 2011, southbound



Annex H.6 Histogram of axle set weights, individual datasets

Figure HA.6.1 Histogram of axle set weights, Drury Jan-Dec 2011, Lane 1 southbound

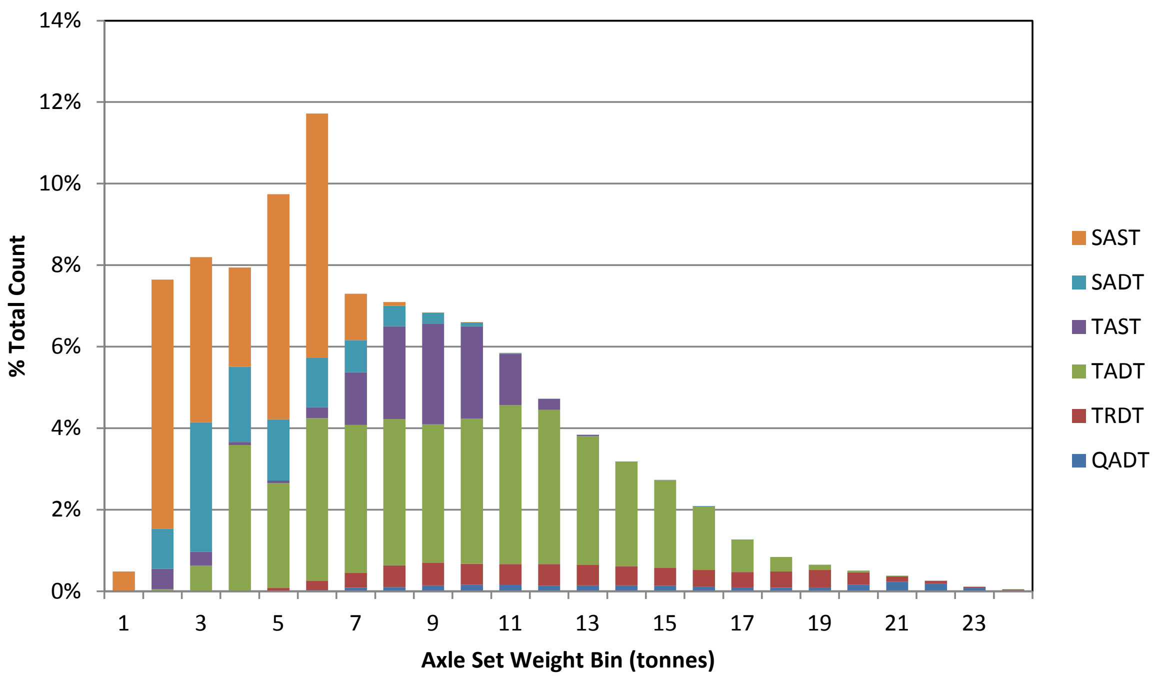


Figure HA.6.2 Histogram of axle set weights, Drury Jan–Sep 2005, Lane 1 northbound

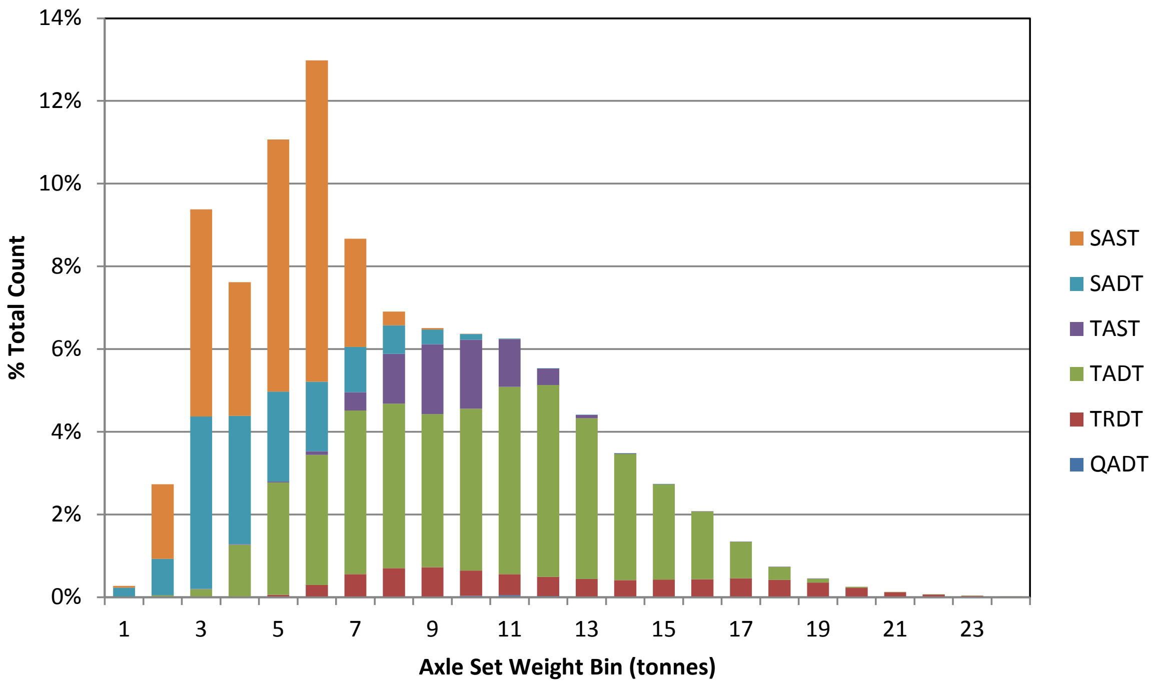


Figure HA.6.3 Histogram of axle set weights, Drury May 2010–Mar 2011, Lane 1 northbound

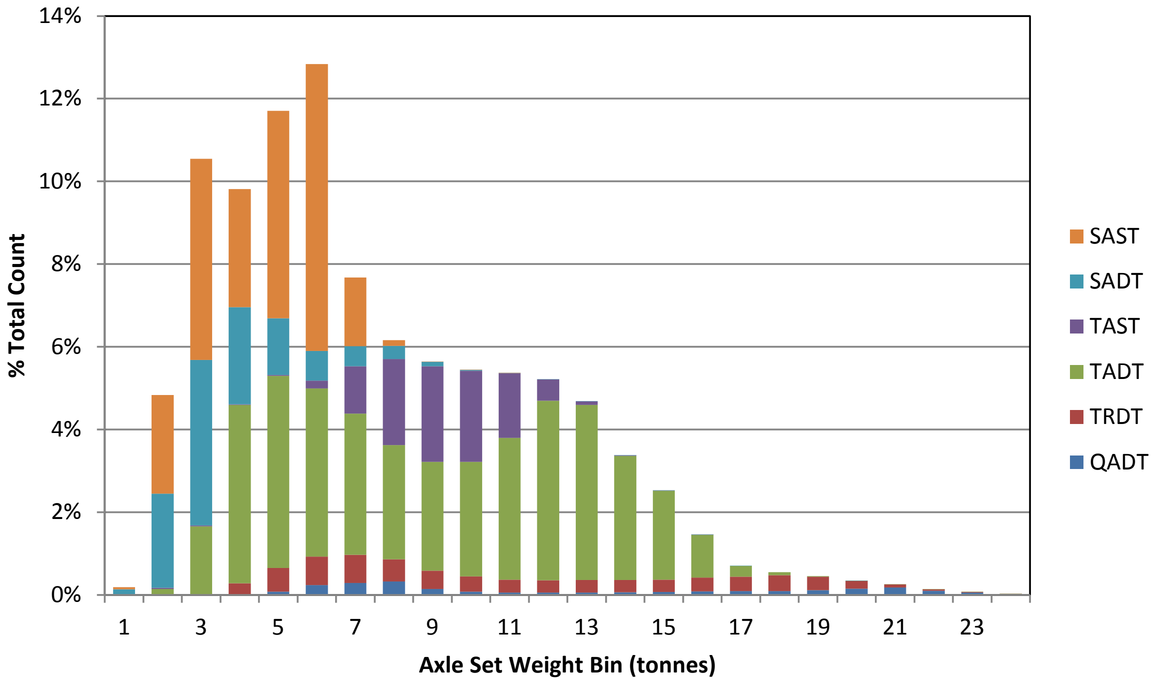


Figure HA.6.4 Histogram of axle set weights, Eskdale Oct 2010–Feb 2011, eastbound

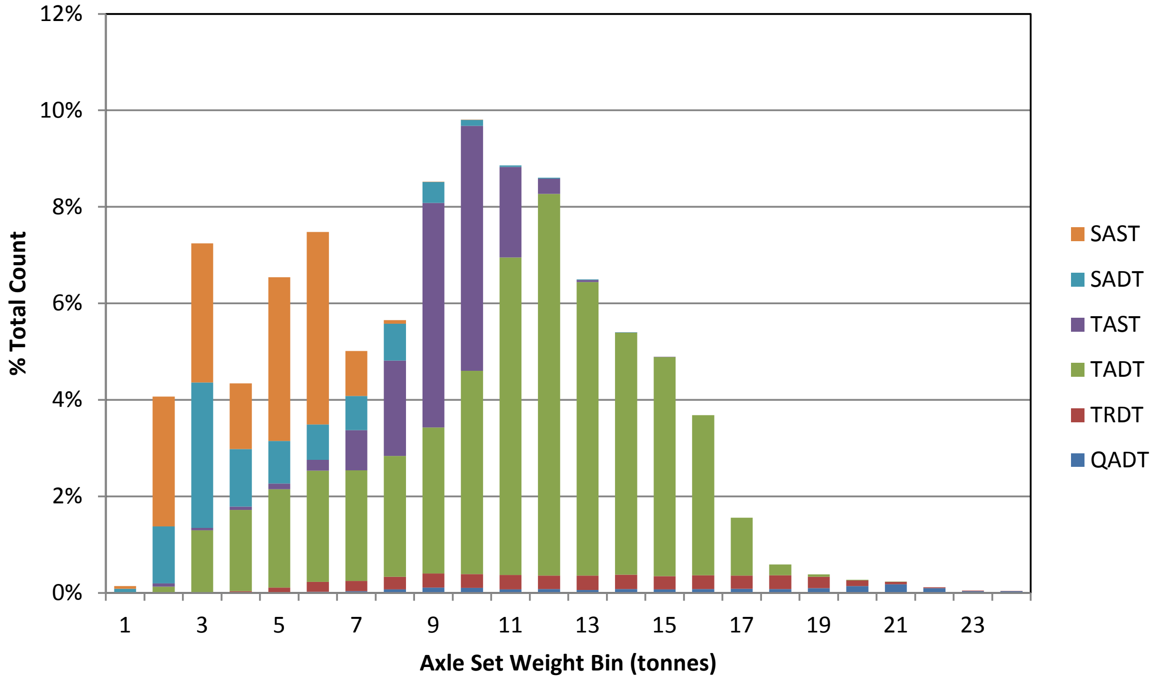


Figure HA.6.5 Histogram of axle set weights, Eskdale Oct 2010–Feb 2011, westbound

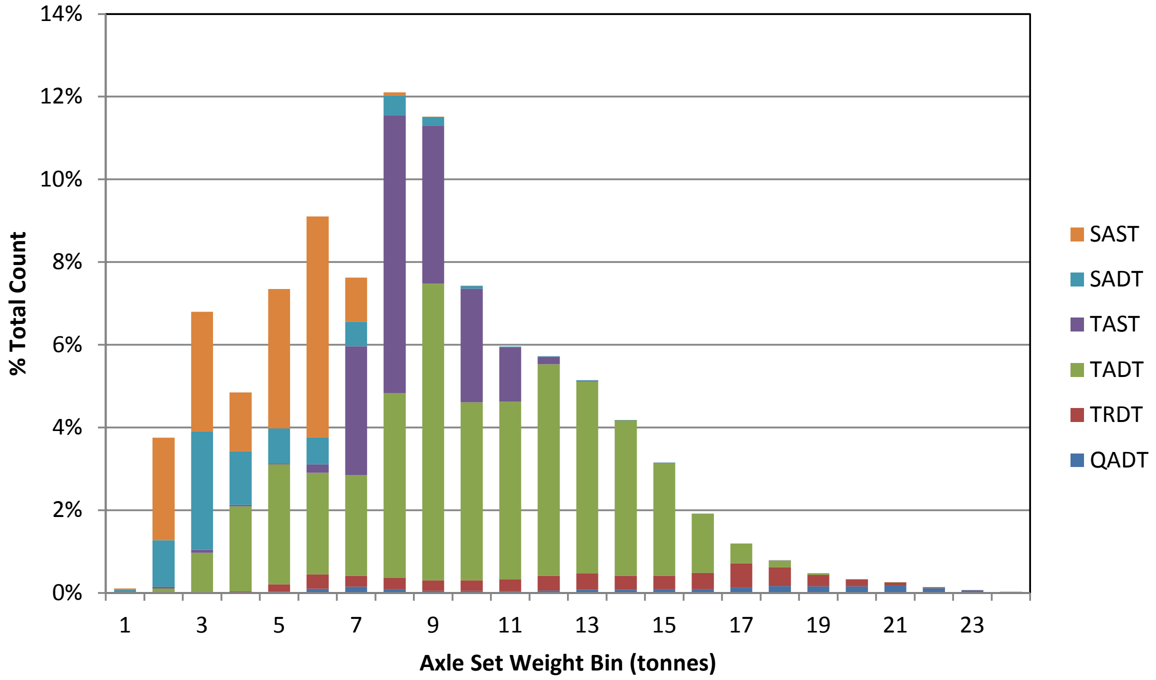


Figure HA.6.6 Histogram of axle set weights, Te Puke Jan–Jun 2005, westbound

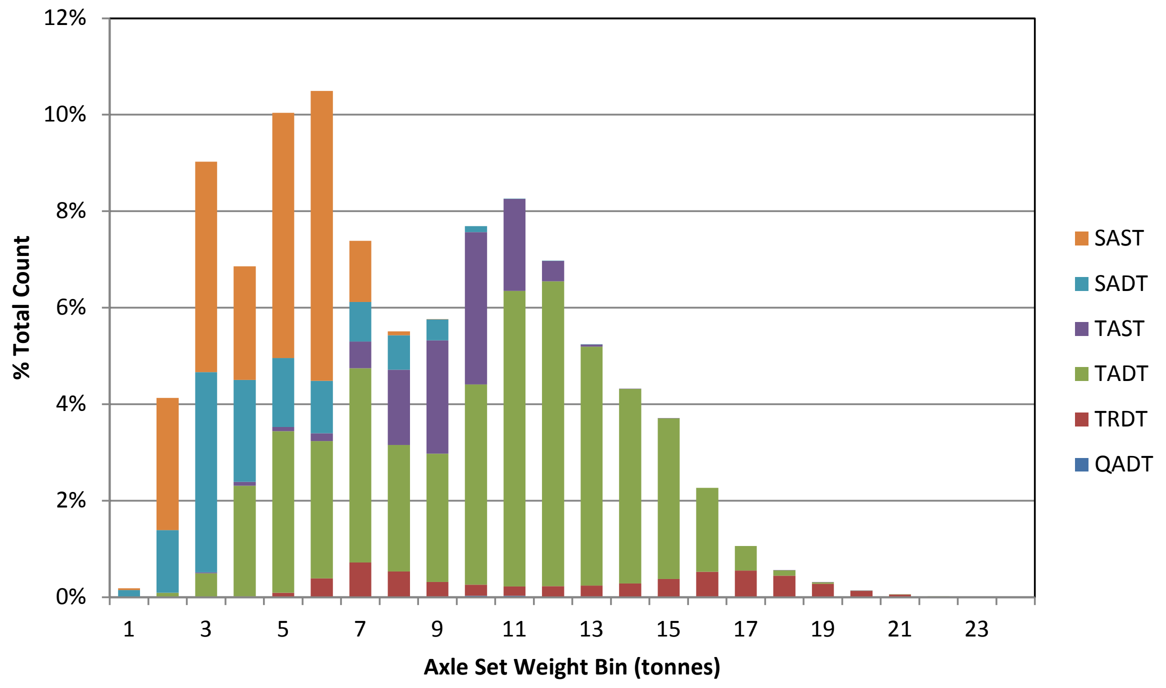


Figure HA.6.7 Histogram of axle set weights, Te Puke Nov–Dec 2007, westbound

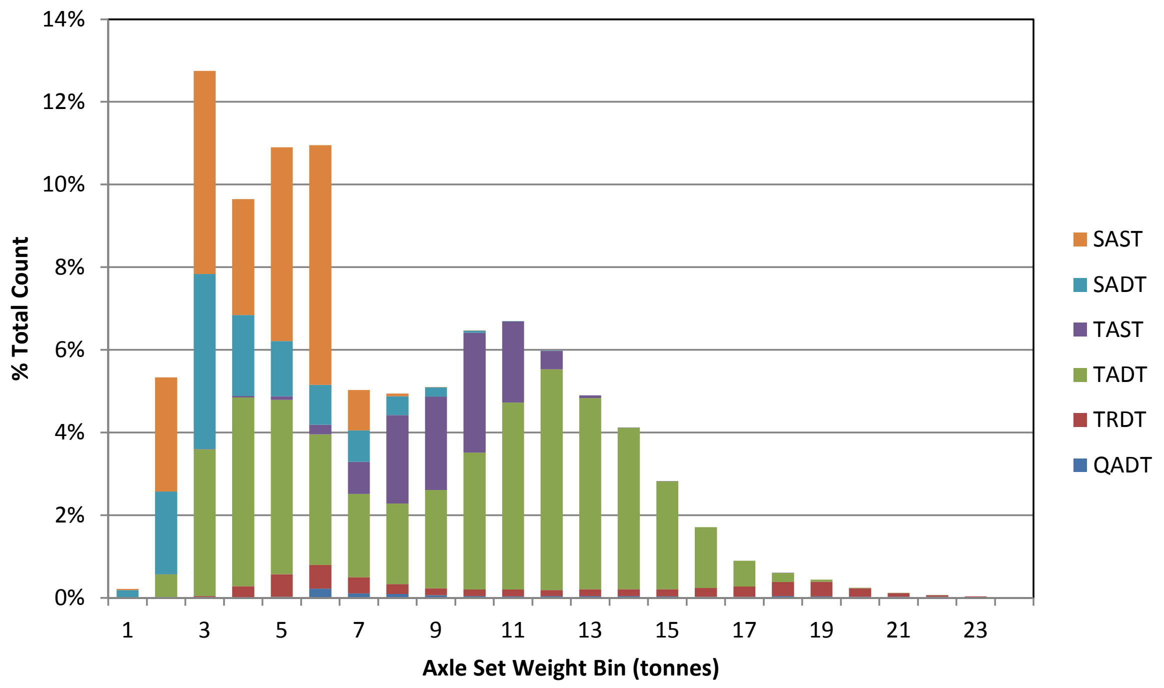


Figure HA.6.8 Histogram of axle set weights, Te Puke Jan-May 2010, westbound

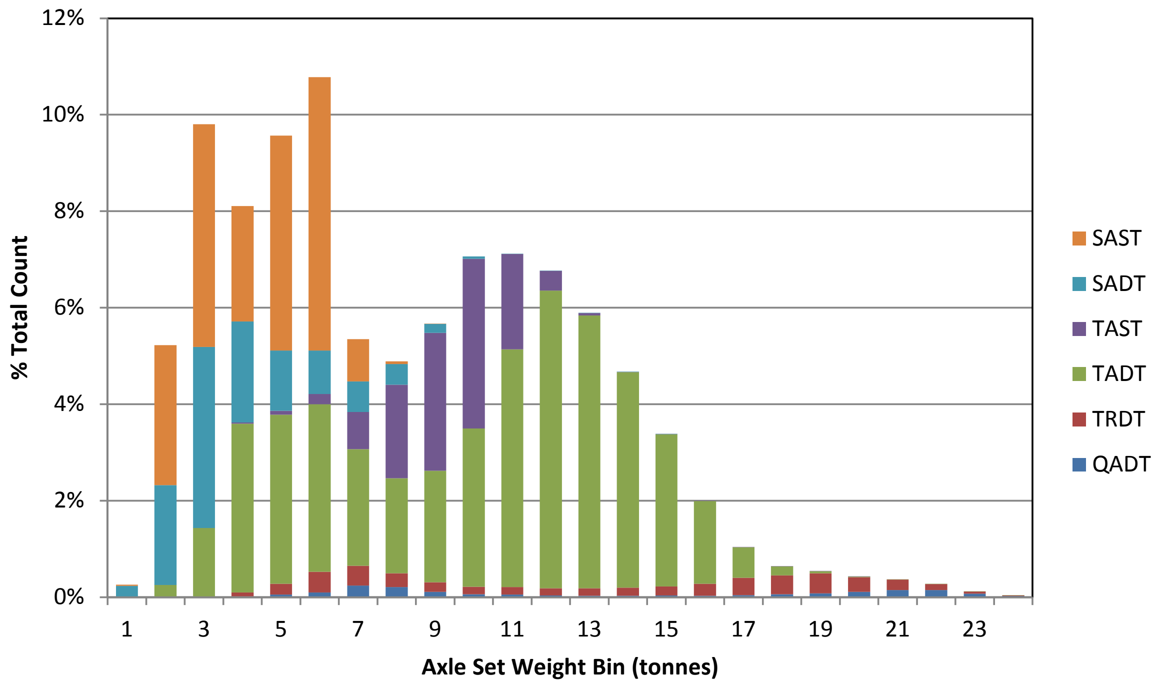


Figure HA.6.9 Histogram of axle set weights, Tokoroa Nov-Dec 2005, northbound

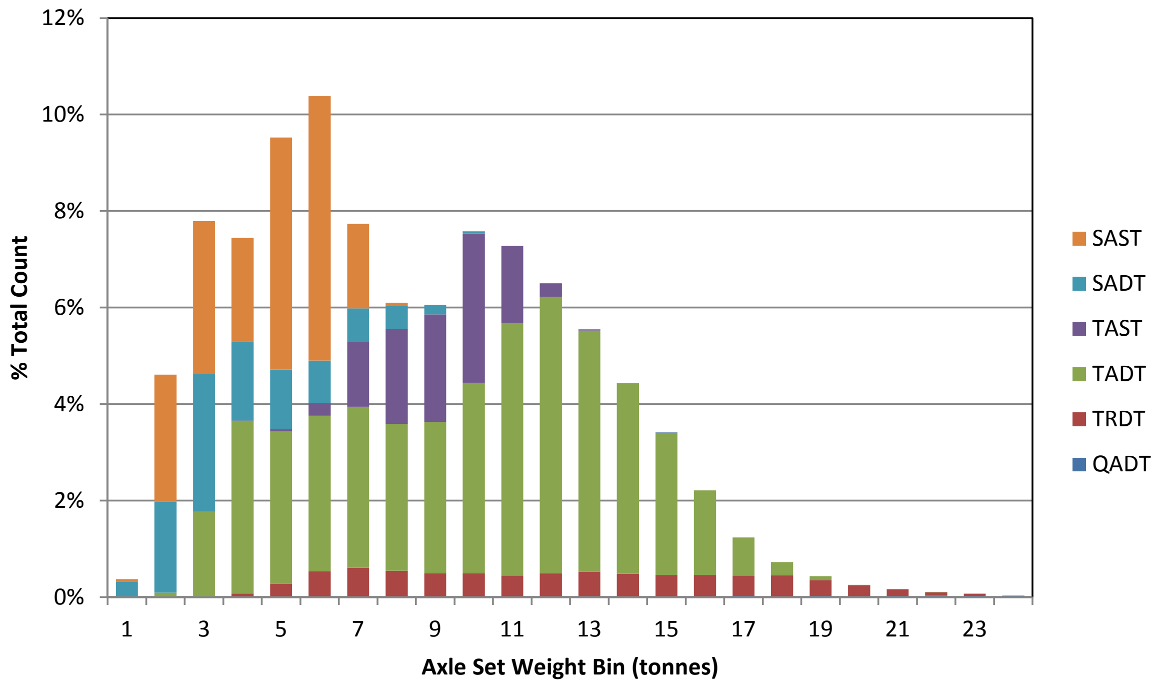


Figure HA.6.10 Histogram of axle set weights, Tokoroa Jan–Jul 2010, northbound

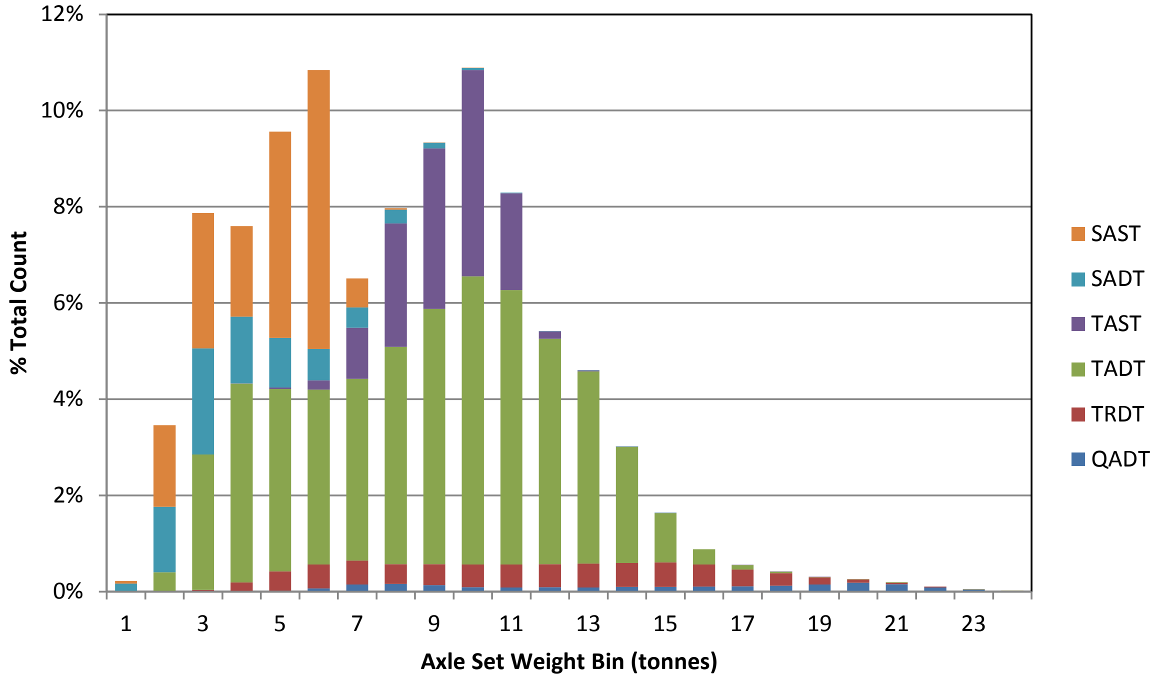


Figure HA.6.11 Histogram of axle set weights, Tokoroa Jan–Jun 2011, northbound

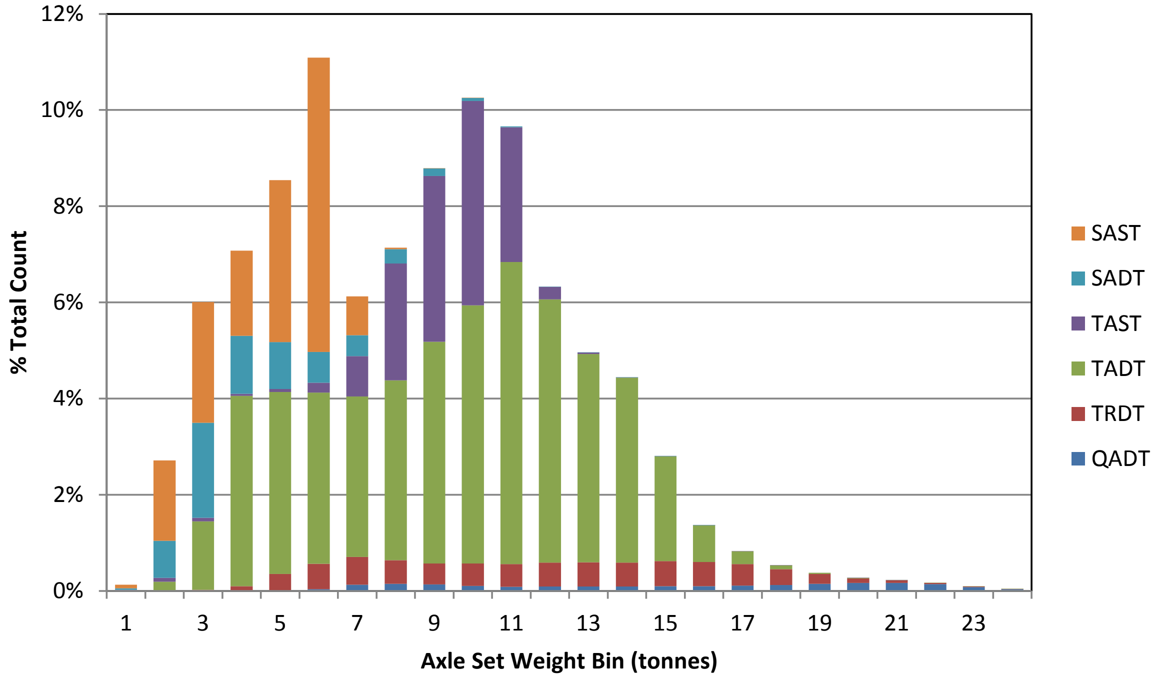


Figure HA.6.12 Histogram of axle set weights, Tokoroa Aug–Dec 2011, southbound

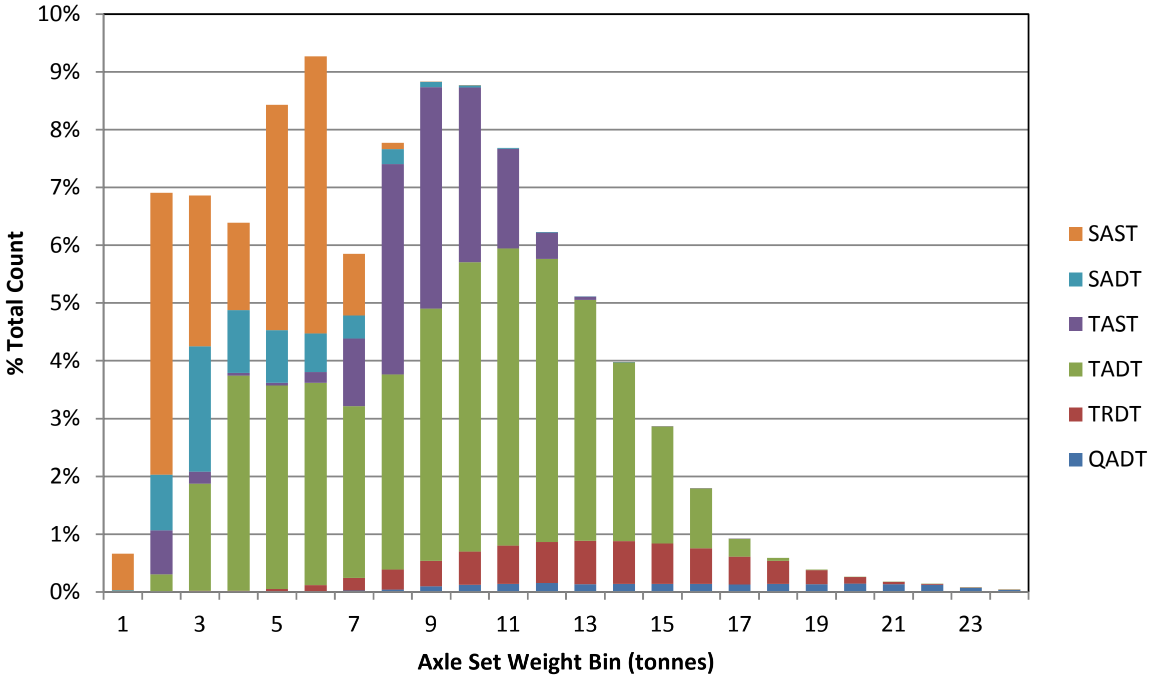


Figure HA.6.13 Histogram of Axle Set Weights, Waipara Jan–Feb 2007, northbound

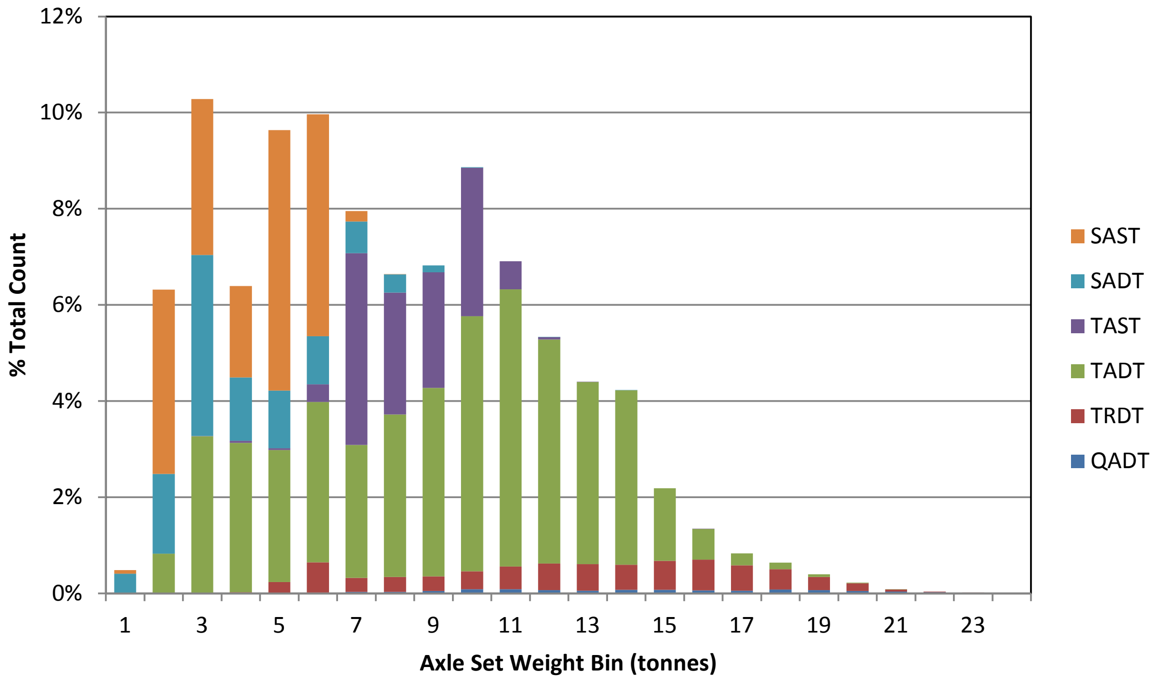


Figure HA.6.14 Histogram of axle set weights, Waipara Nov 2010–May 2011, southbound

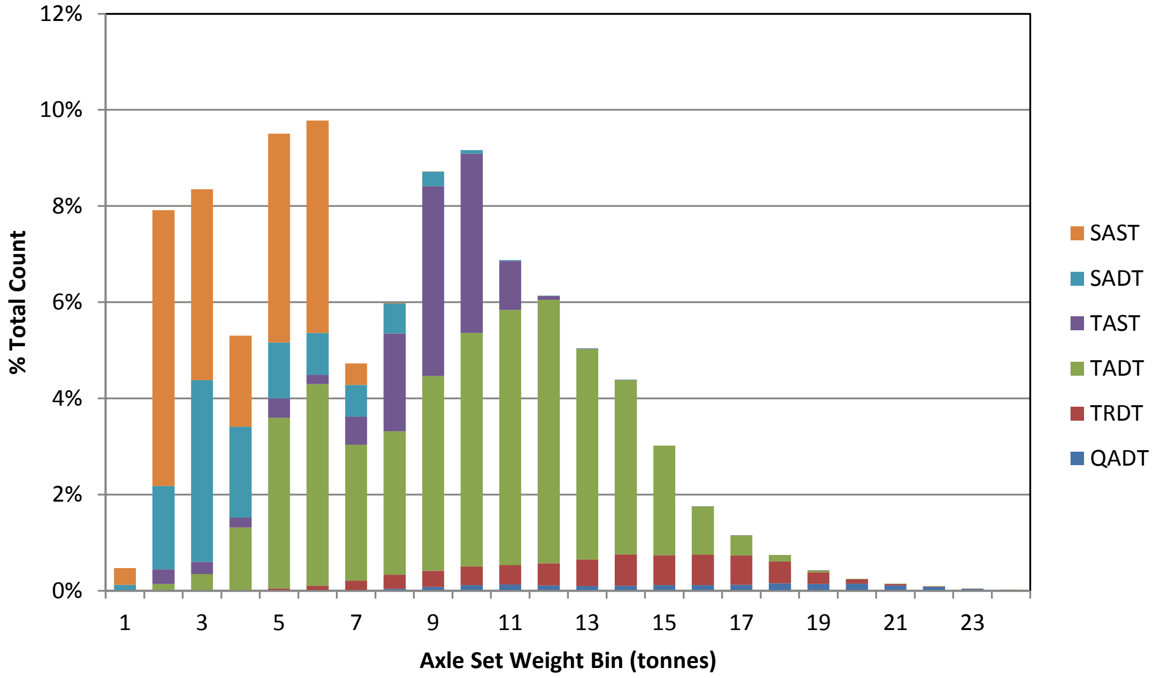
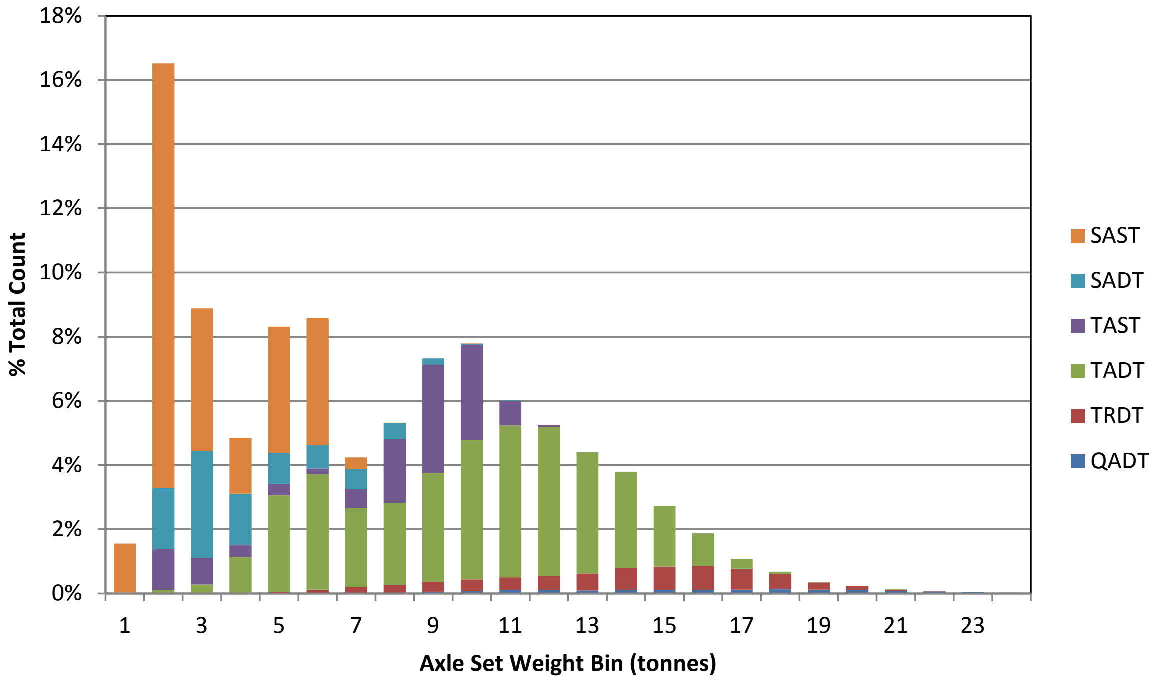


Figure HA.6.15 Histogram of axle set weights, Waipara Sep–Dec 2011, southbound



Appendix I Glossary of terms

AADT	Annual average daily traffic volume
AASHTO	American Association of State Highway and Transportation Officials
ADTT	Average daily truck traffic (heavy vehicle counts per day)
AHB	Auckland Harbour Bridge
Axxx	Articulated truck and semi-trailer, where x equals the number of axles in each axle set (group)
Bridge formula	Specifies the maximum legal vehicle or axle group mass as a function of wheelbase length
B-Train	Articulated truck with two semi-trailers
Bxxxx	B-Train, where x equals the number of axles in each axle set (group)
CAFL	Constant Amplitude Fatigue Limit – the highest constant stress range (amplitude) at which fatigue cracks in steel components are not expected to propagate. The limit varies with detail category (class) and is prescribed in steel design codes (and may vary amongst codes). Also known as 'constant amplitude non-propagating stress range' (BS 5400.10), 'constant stress range fatigue limit' (AS 5100.6)
Class 1	Heavy vehicle mass limits specified in the Land Transport Rule, Vehicle Dimensions and Mass 2002 (VDAM rule)
Cube-out	Payloads limited by volume restrictions before weight restrictions
EEM	NZ Transport Agency *Economic evaluation manual* (2010)
ESA	Equivalent standard axle (calculated using an exponent of 4)
GCM	Gross combination mass – the gross mass of the vehicle and trailer combination
Gross mass	In relation to any vehicle or combination, means the mass of the vehicle or combination and its load, equipment and accessories
GVM	Gross vehicle mass – same as gross mass or GCM in the context of this report, meaning the mass of the vehicle or combination and its load, equipment and accessories, but may refer to only the rigid vehicle or trailer portion of a combination vehicle in other contexts
HCV	Heavy commercial vehicle, defined in the EEM as 'trucks or articulated vehicles with three or more axles', thus excluding buses. This must not be confused with the heavy vehicle definition given below. The EEM definition includes HCV1 and HCV2 subsets
HCV1	Heavy commercial vehicle 1 – a rigid truck with or without a trailer, or an articulated vehicle, with three or four axles in total
HCV2	Heavy commercial vehicle 2 – a truck and trailer, or articulated vehicle with or without a trailer, with five or more axles in total
HERA	New Zealand Heavy Engineering Research Association
Heavy vehicle	Heavy motor vehicle as defined below
HMV	Motor vehicle with gross mass over 3500kg (defined in the Land Transport Rule, Vehicle Dimensions and Mass 2002) **This definition is important for the specification of fatigue loading described in this report**, as counts for these include buses, MCVs, HCVs and any other type of heavy vehicle that may be omitted from more narrow definitions (particularly 'HCV')

HN	The unfactored design loading representing normal highway bridge loading defined in the NZ Transport Agency Bridge Manual, 2nd ed. (2003) comprising a 10.5kN/m UDL and two 120kN axles at 5m spacing
HPMV	High productivity motor vehicle – higher mass limit vehicles introduced by a 2010 amendment to the Land Transport Rule requiring a permit to operate with masses and/or lengths exceeding those for normal heavy vehicles (maximum 44 tonne gross mass)
LCV	Light commercial vehicle, with gross mass up to 500kg, excluded from counts used for fatigue assessments
M1600	Moving design vehicle specified in AS 5100.2 excluding the UDL component when used in fatigue loading specifications
Mass-out	Payloads limited by gross combination mass restrictions before volume constraints
MCV	Medium commercial vehicle (2-axle truck with gross mass over 3500kg, defined in the NZ Transport Agency EEM, excludes buses). These are sometimes included in 'HCV' counts reported in transportation studies, but this cannot be relied upon. It should be noted that recorded count data for this class of vehicle can unintentionally include long-wheelbase cars, SUVs and utility vehicles (LCV)
MoT	Ministry of Transport
NZTA2011	The designation for the revised 14-class vehicle type classification scheme adopted by the Transport Agency from 2011 (see appendix A for the current list used in this report)
pa	per annum
PAT	Pietzsch AutomatisierungsTechnik GmbH, the German company that originally supplied the bending plate WIM equipment used by the Transport Agency. IRD (International Road Dynamics) of Canada bought PAT and supplied most of the currently installed equipment. An independent New Zealand company PAT (NZ) Ltd is the current agent and maintenance provider
Rxx	Rigid truck, where x equals the number of axles in each axle set (group)
RxxTx	Rigid truck and simple trailer, where x equals the number of axles in each axle set (group)
RxxTxx	Rigid truck and full trailer, where x equals the number of axles in each axle set (group)
SHnn	State highway number nn
SM1600	Bridge design live loading specified in AS 5100.2
SN	S-N curves describe the relationship between the number of cycles (N) and fatigue strength for a constant stress range (S)
T&T	Truck-and-trailer unit
TMS	Traffic Monitoring System (the NZ Transport Agency's database system)
UDL	Uniformly distributed load
VDAM	Vehicle dimensions and mass, as in the Land Transport Rule, Vehicle Dimensions and Mass 2002
WIM	Weigh-in-motion – equipment embedded in the road surface to weigh and record data for moving vehicles
α	Dynamic load allowance factor specified in AS 5100.2, $0.3 \leq \alpha \leq 0.4$, $(1+\alpha)$ is comparable to the 'impact factor' applied to vehicle live loads in other standards (eg NZ Transport Agency Bridge Manual *SP/M/022*, 3rd ed., 2013)