TERNZ
TRANSPORT RESEARCH

Lower Bound HPMVs – Vehicle Configurations

Prepared for:

NZTA

November 2012

Transport Engineering Research New Zealand Limited (TERNZ) is a research organisation providing high quality independent research services to the transport industry. TERNZ has expertise across a broad range of transport-related areas including vehicle safety, vehicle dynamics, vehicle-infrastructure interaction, fuel efficiency, driver behaviour, driver performance, impacts on communities and other social issues. Our customers also span the range of industry stakeholders and include government agencies, vehicle manufacturers and suppliers, industry associations, individual transport operators and community groups.

TERNZ prides itself on the quality, timeliness and independence of its work.

Authorship: This document was written by John de Pont. For further information, please contact John at j.depont@ternz.co.nz or by phone on 09 579 2328.

TERNZ TRANSPORT RESEARCH

TERNZ Ltd

642 Great South Rd | Ellerslie | Auckland 1051

PO Box 11029 | Ellerslie | Auckland 1542

Phone +64 9 579 2328

info@ternz.co.nz

www.ternz.co.nz

CONTENTS

Introduction **4**

Methodology **5**

Results **7**

RUC Data 7

Registration Data 10

WIM Data 12

Combining the data 18

INTRODUCTION

The 2010 amendment to the Vehicle Dimensions and Mass Rule provided for heavy vehicles to operate under permit at sizes and weights above the standard legal maxima on routes where the infrastructure was capable of coping with them. The provision for the larger vehicles was aimed at increasing productivity and these vehicles were designated as High Productivity Motor Vehicles (HPMVs).

To facilitate the uptake of these provisions the New Zealand Transport Agency (NZTA) promoted the development of pro-forma HPMV designs. These pro-forma designs are dimensional envelopes for different configurations that have been designed so that the vehicles can achieve the same low speed turning performance (or better) than the worst case standard legal vehicle. Thus the road space requirements of the pro-forma designs are no greater than those of existing standard dimension vehicles. At standard legal weights, vehicles meeting these designs can be permitted for general access. At higher weights a route assessment is needed to ensure that the infrastructure can cope.

The pro-forma design concept has been reasonably successful in that about 1000 HPMVs have now been permitted and the vast majority of these are based on pro-forma designs. However, most of these operate at standard legal weights. The uptake of higher weights for HPMVs has been quite limited, primarily because of infrastructure factors. There are two main issues. One is the capacity of the bridges to handle the higher loads. The other is concern by some local road controlling authorities over the additional pavement wear that higher weight vehicles will generate.

To facilitate increased use of the higher weights, NZTA, in consultation with industry, has proposed the development of lower bound pro-forma HPMV designs. The key features of these designs are that:

- they must comply with a revised bridge formula which is an extrapolation of the existing class 1 bridge formula to weights above 44 tonnes and,
- they must not generate any more pavement wear than the existing standard size and weight vehicles that they will replace.

The lower bound pro-forma vehicles are intended to have general access and thus must meet the same low speed turning requirements as the existing pro-forma designs. Our interpretation of the pavement wear requirement is that axle group weights should not current class 1 limits. Individual vehicle trips may incur higher road wear but because the vehicles are more productive there will be fewer trips. The total road wear is wear per trip x number of trips and this should not increase.

There are only two vehicle configuration types in New Zealand that are capable of gross combination weights above 44 tonnes without exceeding axle group weight limits. These are the B-train and the truck and full trailer. For both these configurations pro-forma designs exist which provide an envelope of geometric dimensions that achieves the required low speed turning performance. To convert these designs to lower bound designs all we need to do is determine the additional criteria that need to be applied to ensure that the no increase in pavement wear aim is also achieved.

METHODOLOGY

To be able to compare the pavement wear generated by the lower bound pro-forma designs with that generated by existing standard heavy vehicles we propose to use the following measures:

- Payload tonnes/ESA. This is a productivity measure which shows how much payload is moved for each unit of pavement wear. ESA is an acronym for Equivalent Standard Axle and is measure of pavement wear based on the widely-used fourth power relationship[1] between axle weight and pavement wear.
- ESA/Payload tonne. This is the inverse of the previous measure and characterises pavement life consumption.

The first measure is an efficiency measure while the second is a consumption measure. It is not necessary to have both measures but they give a different perspective.

The first step in the analysis is to quantify the performance of the existing standard size and weight heavy vehicles that might be replaced by lower bound HPMVs. There are three sets of data that are potentially useful for this task. Each of them contains some useful information but none of them on their own provides a complete picture. They are:

1. **Road User Charges (RUC) data**. All heavy vehicles pay RUCs and almost all them pay by weight and distance. Thus from the RUC database, for each RUC vehicle type we can determine the number of vehicles, the distance travelled by these vehicles and the maximum laden weights at which they operate. However, RUCs are paid for individual vehicle units rather than combinations and thus we cannot determine which trailers are connected to which trucks or tractors. Hence we cannot deduce what the mix of configurations is for each combination type. Furthermore, some RUC vehicle type categories include more than one physically distinct vehicle type. For example, RUC vehicle type 43 includes both 4-axle full trailers and 4-axle semi-trailers. On the positive side, all vehicles are included in this database. There are no sampling issues.
2. **Vehicle Registration data**. The vehicle registration database contains information on vehicle type, number of axles, and tare weight. Certain vehicle components are required to be certified by approved engineers and these certification records are also entered in the registration database. This information can fill some of the gaps in the RUC database. For example, the RUC database does not distinguish between semi-trailers that are used on their own and semi-trailers that are used in B-train combinations. However, the first trailer of a B-train has a fifth wheel for coupling to the second trailer and this has to be certified. Similarly drawbars have to be certified and thus we can distinguish between full trailers and semi-trailers. The registration data provides only vehicle numbers not distance travelled or laden weight but when used in conjunction with the RUC data it adds to the picture. As with the RUC data it encompasses all vehicles and there are no sampling issues.
3. **Weigh-in-Motion data**. The NZTA operates six Weigh-in-Motion (WIM) sites on major state highways around the country. These sites record vehicle speed, axle spacing and axle weight. From these measurements, the vehicle configurations and actual operating weights can be derived. The main weakness of this data is that the sites are not fully representative of the whole network being relatively high traffic volume state highways. This means that the mix of vehicle configurations is not necessarily the same as it is for the whole network.

By combining the information that we can extract form the three data sources we will obtain estimates of the mix of truck-trailer and B-train configurations that are currently being used. Based on gross weight data and tare weight estimates we will determine the payload tonnes/ESA performance of these vehicles. This measure will include the contribution of empty or lightly laden running on return trips.

[1] The fourth power rule relating pavement wear to axle loads was originally derived from the AASHO road test experiment in the USA in the early 1960s. There is considerable debate over its validity across different pavement types and wear mechanisms. Nevertheless it is still forms the basis of pavement design practice and Road User Charges in New Zealand.

We will assume that the basic choice of vehicle configuration is primarily driven by operational considerations and hence will not change when choosing a lower bound HPMV substitute. Thus we will assume that the lower bound pro-forma HPMV truck-trailer will replace standard truck-trailers and the lower bound HPMV B-trains will replace standard B-trains.

Designs for both truck-trailers and B-trains that produce the same payload tonnes/ESA as the average for the vehicles they replace will be developed. Inevitably to run at higher gross weight will require an increase in the number of axles. This is because the number of ESA increases in proportion to the fourth power of weight while payload tonnes increase more slowly.

RESULTS

RUC Data

The focus of this analysis is combination vehicles and thus we begin the analysis by considering the trailers. Every trailer must be part of a combination vehicle. The RUC unpowered vehicle types and their definition are shown in Table 1.

Table 1. RUC unpowered vehicle types.

No. of axles	Types of axles	Example vehicles	Vehicle type no.
1	Any configuration		24
2	2 spaced axles, both single tyred		27
	1 group of 2 close axles, both twin tyred		29
	2 spaced axles, both twin tyred		30
	Any other configuration		28
3	1 group of 3 close axles, all twin tyred		33
	Any other configuration		37
4 or more	Any configuration		43

As noted previously, the only vehicle configurations that have the potential to be used as lower bound HPMVs are the truck-trailer and the B-train. Thus the only RUC vehicle types that are potentially relevant are 28, 29, 33, 37 and 43. Table 2 shows the vehicle numbers and on-highway distance travelled for these vehicle types extracted from the 2010 RUC data. The distance travelled is net after refunds and thus represent on-highway distance. Vehicle types 28, 29, 33, 37 and 43 represent over 93% of the trailer fleet and more than 98% of the distance travelled by the trailer fleet.

Table 2. Vehicle numbers and distance travelled from 2010 RUC data.

Vehicle Type No	Number of Vehicles	Total Annual kms (000)	Annual kms/vehicle
28	306	4,235	13,839
29	4,024	161,044	40,021
33	5,428	260,565	48,004
37	3,418	89,315	26,131
43	9,467	624,410	65,956
All other heavy trailers	1,588	18,474	11,634
Total	24,231	1,158,042	47,792

Vehicle type 28 potentially includes a number of different vehicle configurations. For this analysis the only relevant vehicle is the 2-axle semi-trailer with wide single tyres which could potentially be used as part of a B-train. Type 37 is even more complicated because it includes 3-axle full trailers as well as 3-axle semi-trailers with wide single tyres.

The distribution of RUC distance purchased by licence weight for these vehicle types are shown in Figure 1 - Figure 5. We could have considered percentage by vehicle numbers rather than by distance but because we are primarily interested in infrastructure impacts, distance is more relevant.

The distribution of weights in these figures illustrates the mix of vehicle configurations contained within each RUC vehicle type. There are relatively few type 28 vehicles in total but this category includes all two-axle trailers that are not fitted with twin (dual) tyres. This includes a wide range of vehicles as indicated by the range of RUC weights purchased. RUC vehicle type 29 includes semitrailers and simple trailers fitted with a dual-tyred tandem axle set. The legal weight capacity of this axle group configuration is 15 tonnes and there is a small spike at that level. However, most of these vehicles buy RUCs at about 10 tonnes. RUC vehicle type 33 is similar to type 29 but with three axles instead of two. The legal weight capacity of this axle group configuration is 18 tonnes and most RUCs are purchased at about this level. When used in a 44-tonne B-train combination, the axle group would normally only be loaded to about 14-15 tonnes and there is some indication that there are a number of these. RUC vehicle type 37 includes two quite different vehicle configurations in that 3-axle semi- simple trailer without dual tyres are in this category as well as 3-axle full trailers. The tridem axle group (as would occur on semi- and simple trailers) has a legal load limit of 18 tonnes but the 3-axle full trailer has a maximum legal weight limit of 23.2 tonnes. The distribution shown in Figure 4 suggests a significant presence of both vehicle categories. RUC type 43 includes all trailers with four or more axles including the quad-axle semi-trailer and the 4-axle full trailer. The quad-axle semi-trailer is limited to 20 tonnes while, although the 4-axle full trailer could potentially operate at 30 tonnes, it is not practical to do so within a 44-tonne combination weight limit. Typically laden 4-axle full trailers operate at 21-24 tonnes.

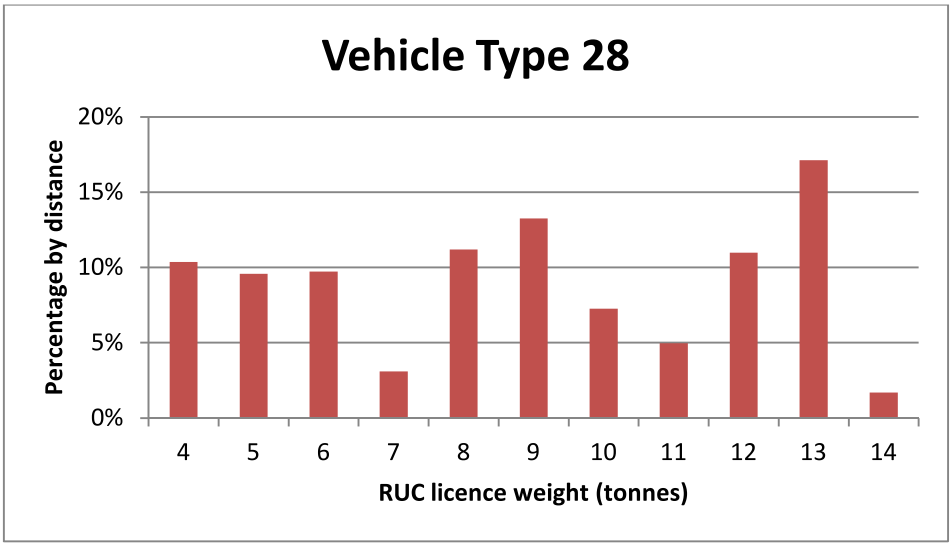


Figure 1. Percentage of RUC distance purchased by licence weight for type 28 vehicles.

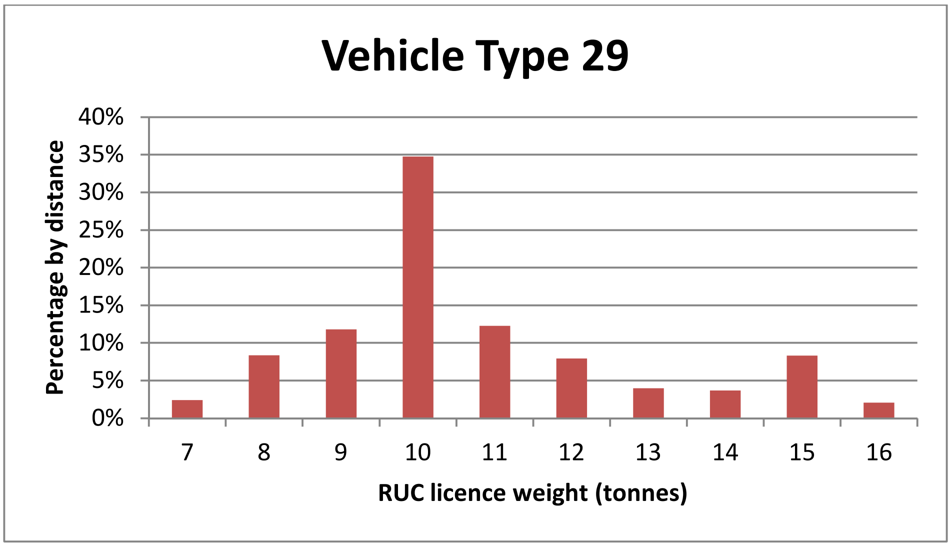


Figure 2. Percentage of RUC distance purchased by licence weight for type 29 vehicles.

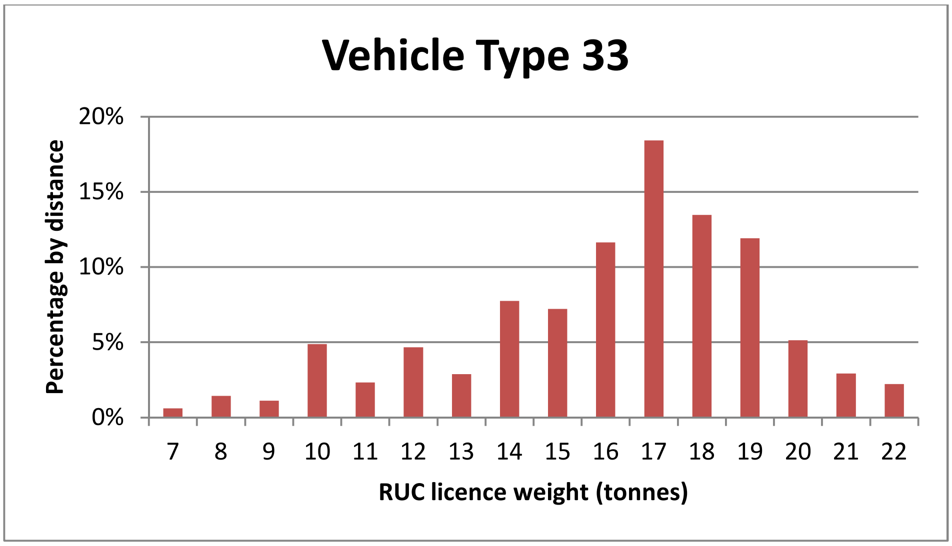


Figure 3. Percentage of RUC distance purchased by licence weight for type 33 vehicles.

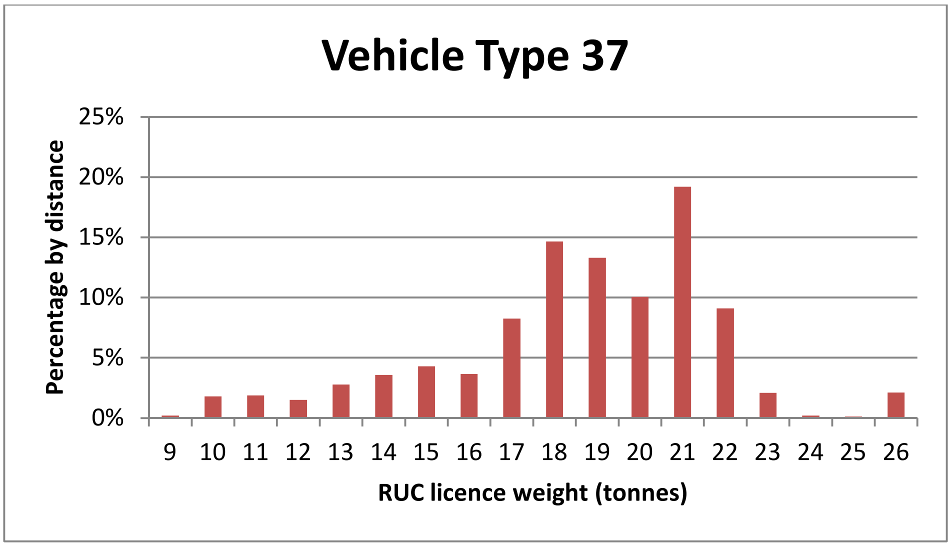


Figure 4. Percentage of RUC distance purchased by licence weight for type 37 vehicles.

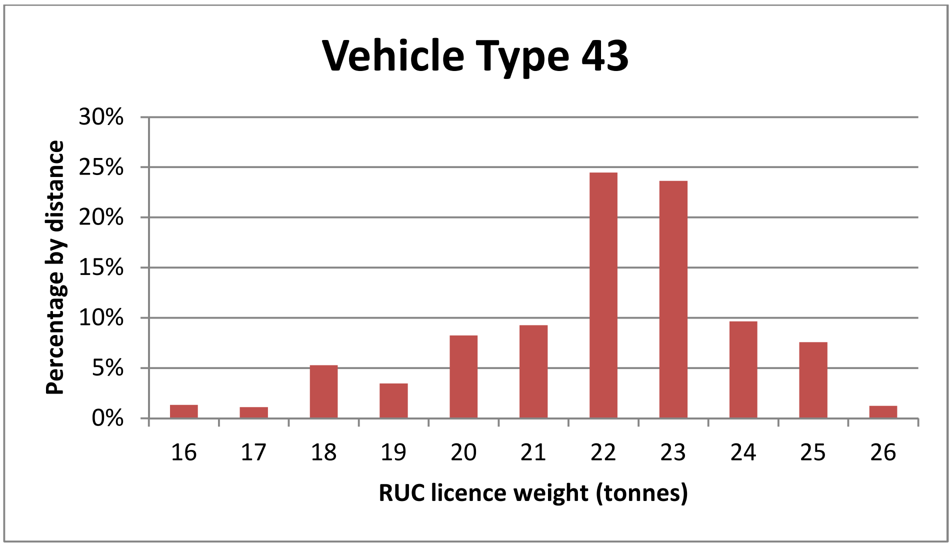


Figure 5. Percentage of RUC distance purchased by licence weight for type 43 vehicles.

Registration Data

Like the RUC database, the registration database gives a picture of the whole fleet not just a sample. It contains quite detailed vehicle description data and so it is possible by deduction to determine the number of vehicles by configuration to a level of detail that is not possible from the RUC data.

Two data sets were extracted from the registration data:

- The first dataset was of all vehicles that were certified for compliance with NZS5446 HV Towing Connections, Drawbars and Drawbeams. All trailers in this set are full trailers or simple trailers because semi-trailers do not have a drawbar.
- The second dataset was of all vehicles that were certified for compliance with both NZ5450 (kingpins) and NZS5451 (fifth wheels). The only vehicle type that would normally be expected to have both a kingpin and a fifth wheel is the front trailer of a B-train.

Note that while the RUC data that was presented in the previous section was for 2010, the registration data was extracted on 26th June 2012 and was current at that date.

Table 3 shows the full trailer numbers derived from the registration data with average tare weights. We have separated the vehicles with dual tyres from those with other tyre configurations so that we can match the numbers up with the RUC data.

Table 4 shows the same information for simple trailers. Simple trailers were selected from the database as those with only a front or a rear axle set (i.e. not both).

Table 3. Full trailer numbers from registration data.

No of Axles	Full Trailers with dual tyres		Full Trailers without dual tyres	
	Number of	Average tare (kgs)	Number of	Average tare (kgs)
2	2655	3864	510	2705
3	4047	5313	59	4678
4	9552	5984	420	5783
5	93	7061	2	6960
6	7	23046	-	-

Table 4. Simple trailer numbers from registration data.

No of Axles	Simple Trailers with dual tyres		Simple Trailers without dual tyres	
	Number of	Average tare (kgs)	Number of	Average tare (kgs)
1	310	2421	163	1814
2	541	4115	181	3048
3	152	6016	60	2981
4	16	8412	5	7982

The first dataset also included information on all trucks that are fitted with a certified towing connection. This provides useful information on tare weights. Selecting only class NC vehicles, the information shown in Table 5 can be extracted. Not surprisingly the truck numbers are higher than the trailer numbers because not all trucks fitted with a tow coupling are used for towing. The average tare weight of the 5-axle vehicles is somewhat higher than might be expected from the other vehicles but this category includes some specialist vehicles fitted with heavy equipment. Because the total number of 5-axles is small these specialist vehicles have a significant impact on the average tare weight.

Table 5. Truck numbers and weights from registration data.

No of Axles	Class NC trucks fitted with a certified tow coupling	
	Number of	Average tare (kgs)
2	3657	6803
3	11435	9732
4	10766	11447
5	40	18482

From the second dataset we can determine the B-train first trailer numbers. These are shown in Table 6 and again we have separated them by tyre configuration for the purpose of matching with the RUC data.

There are some inconsistencies and obvious errors in the registration data but these appear to be relatively minor and should not affect the analysis. An example of the inconsistencies is that for simple trailers and semi-trailers the axle configuration data is sometimes entered as front axles, sometimes as rear axles and sometimes as a mixture of the two. These inconsistencies just complicate the data processing but are not a major problem. Examples of errors are: in the first dataset there are 12 vehicles listed as having 0 axles although none of these are heavy trailers; one trailer had a tare weight of 777,777kgs and another had a tare weight of 111,111kgs. Where the errors are obvious, adjustments can be made but there may well be some errors that we have not detected. However, it would appear that these would be limited to a very small number of data entries and so the overall picture provided by the data is reliable.

Table 6. B-train first trailer numbers from registration data.

No of Axles	B-train first trailers with dual tyres		B-train first trailers without dual tyres	
	Number of	Average tare (kgs)	Number of	Average tare (kgs)
2	613	5167	12	4667
3	1754	5813	58	6281
4	12	7363	1	7320

WIM Data

The NZTA operates six WIM sites. These are located on:

- State Highway 1 at Drury near Auckland
- State Highway 2 at Te Puke in the Bay of Plenty
- State Highway 1 at Tokoroa in South Waikato
- State Highway 35 near Gisborne
- State Highway 5 at Eskdale in the Hawke Bay
- State Highway 1 at Waipara in Canterbury

All of these are on major State Highways with relatively high traffic volumes. The mix of heavy vehicle traffic at these sites is not necessarily representative of heavy vehicle fleet traffic on the network as a whole. For example, most of the sites are rural and thus we would expect smaller rigid trucks, which are extensively used for urban delivery work, to be under-represented. Thus, although the WIM data is a sample of the fleet, it is not a random sample and this needs to be taken into account when interpreting the data.

On the positive side, the WIM data records that actual loads carried by heavy vehicles in service and the distribution of those loads across the axle groups within the vehicle as well as speeds and axle spacing. For this study WIM data for a one whole month period from each of the six sites was used. The months used varied a little from site to site but were all from early 2012 ranging from January to April.

As noted earlier in this analysis, the only vehicle configurations with sufficient weight capacity to be considered as lower bound HPMVs are truck and full trailer combinations and B-trains. Thus the analysis of the WIM data focussed on these vehicles.

The data from all six sites was combined. There are differences in the mix of configurations from site-to-site because of differences in the types of economic activity that predominate at the various localities and hence difference in the vehicles used to support that activity. Combining the data reduces these local effects.

The processing of the WIM data uses the number and spacing of the axles to classify each vehicle with a PAT class. The classification scheme used by NZTA is described in their “Annual Weigh-in-Motion (WiM) report, 2010” and the classification table from that report is reproduced below.

Table 7. Heavy vehicle classification scheme used by NZTA for WiM data.

Table 5.0 | Heavy vehicle classification scheme

PEM Class	NZTA 2011	TNZ Class	PAT Class	Vehicle Type	Axles	Length Range (WiM data)	RUC Class	Group	Axle Group (Pave. Des.)
MCV	4	3	20	o-o (wb2.0-3.2m, gw>=3.5t)	2	4m-11m	2	RIGID	
			21	o--o (wb2.0-3.2m, gw>=3.5t)				RIGID	1s-1d
HCV1	5	4	31	o--oo	3	7m-12m	6	RIGID	1s-2
			34	oo--o			5	RIGID	1s-1s-1d
		5	30	o-o--o	3	6m-15m	2,24	T&T	1s-1d-1d
	6	6	45	oo--oo	4 (truck)	8m-11m	14	RIGID	1s-1s-2
			47	o--ooo			14	RIGID	1s-3
	3/7*	7	40	o--o-o--o	4 (T&T)	11m-19m	2,30	T&T	1s-1d-1d-1d
	5		44	oo-o--o			5,24	T&T	1s-1s-1d-1d
	7		41	o-o--oo			2,29	T&T	1s-1d-2
			42	o-oo--o			6,24	T&T	1s-2-1d
HCV2	8	8	52	o--oo-o--o	5	11m-19m	6,30	T&T	1s-2-1d-1d
			53	o-oo--oo			6,29	ARTIC	1s-2-2
	9	9	69	o-oo--ooo	6	15m-18m	6,33	ARTIC	1s-2-3
			68	oo-oo--oo			14,29	T&T	1s-1s-2-2
	10	10	63	o--oo-o--oo	6 (T&T) (A-Train)	16m-20m	6,37	T&T	1s-2-1d-2
			66	oo--oo-o--o			14,30	T&T	1s-1s-2-1d-1d
			65	oo--o-o--oo			5,37	T&T	1s-1s-1d-1d-2
			61	o-o--o-o--oo			6,29,30	T&T	1s-2-1d-1d-1d
			621	o-oo--o-o--o			?	A TRAIN	
	11	11	751	o-oo--oo--oo	7	18m-21m	6,29	T&T	1s-2-2-2
			74	o-oo--oo-o--o			6,29,30	A TRAIN	1s-2-2-1d-1d
	na		78	o--ooo-o--oo			?	A TRAIN	
			731	o-oo--o-o--oo			?	T&T	
	9		747	o--ooo---ooo			14,33	ARTIC	1s-3-3
			791	o-oo-oooo			6,43	ARTIC	1s-2-4
	12	12	713	oo-oo--ooo	7-11	15m-21m	?	ARTIC	
			77	oo--oo-o--oo			14,37	T&T	1s-1s-2-1d-2
			891	oo--oo-oo--oo			14,43	T&T	1s-1s-2-2-2
			914	oo-oo--ooo-oo			14	T&T	1s-1s-2-2-3
	9		826	oo-oo--oooo			14,43	ARTIC	1s-1s-2-4
	12		915	oo-oo--oo-ooo			14,33,29	T&T	1s-1s-2-3-2
			1020	oo-oo-ooo-ooo			14,33,33	B TRAIN	1s-1s-2-3-3
			1133	oo-oo-ooo-oooo			14,33,43	B TRAIN	1s-1s-3-4
	13	13	851	o-oo--ooo--oo	8-10	19m-21m	6,33,29	B TRAIN	1s-2-3-2
	12		951	o-oo-ooo-ooo			6,33,33	B TRAIN	1s-2-3-3
	13		1032	o-oo-ooo-oooo			?	B TRAIN	1s-2-3-4
			85	o-oo--oo-o--oo			?	A TRAIN	
			89	o-oo--ooo-o--o			?	A TRAIN	
	9		847	o--ooo---oooo			14,43	ARTIC	1s-3-4
	14	14		Not Classified					

Symbol: na not applicable
* TNZ 1999 PAT class 40 was split into two categories in the new NZTA 2011 classifications. The car towing car (o-o--o-o) gone to vehicle type class 3 while the truck tow heavy trailer (o--o--o--o) classified as vehicle type class 7.

There are a few inconsistencies in this table. For PAT classes 914 and 915, the Vehicle Type descriptions are not consistent with the Axle Group descriptions. When we look at the raw data, it appears that the Vehicle Type description is correct while the Axle Group descriptions should be swapped. Furthermore the Group description identifies both 914 and 915 as T&T (truck and trailer) where 914 is almost certainly a B-train. The mapping between the Vehicle Type, the RUC class and the Group is not always consistent. For PAT Class 915 is assumed to be a truck and trailer (T&T), but the RUC classes associated with it consist of a truck or tractor and two semi/simple trailers.

These issues are easily addressed but one that is slightly more complicated relates to PAT class 751. This is identified as a T&T although the RUC classes associated with it do not support this identification. In fact, this configuration could be either a truck and trailer (R12T22) or a B-train (B1222) and there is no perfect method for distinguishing the two. Following discussions with a truck supplier we have applied a criterion that if the truck/tractor wheelbase is greater than or equal to 4.25m, the vehicle is a truck and trailer while if the truck/tractor wheelbase is less than 4.25m it is a B-train. The reason for this is that to achieve a 44t gross combination weight limit the truck wheelbase must be 4.25m or more and thus it is unlikely that shorter wheelbase trucks would be used. However, there is no legal impediment to using longer wheelbase tractors for B-trains except the overall length limit for the combination. Longer tractors result in shorter trailers.

As noted previously, the only viable candidate vehicles for the lower bound HPMVs are truck and full trailers and B-trains. Thus we have focussed our analysis of the WIM data on these vehicle combinations.

Table 8 and Table 9 show the distribution of truck-trailer and B-train combinations recorded at the WIM stations and their average gross combination weight. Thus there were over three times as many truck-trailers as B-trains.

Table 8. Truck-trailer combinations recorded at WIM sites.

PAT Class	Configuration	Number of Vehicles	Average gross weight (kgs)	Average ESA
63	o--oo-o--oo	1323	27497	2.09
751	o--oo-oo--oo	15284	33800	2.46
77	oo--oo-o--oo	2828	34347	2.37
891	oo--oo-oo--oo	64414	35237	1.89
915	oo--oo-oo--ooo	1099	37216	1.75
1020	oo--ooo-oo--ooo	293	37273	1.04
Total		85241	34862	2.01

Table 9. B-train combinations recorded at WIM sites.

PAT Class	Configuration	Number of Vehicles	Average gross weight (kgs)	Average ESA
751	o--oo--oo--oo	3231	33227	2.39
811	o--oo--oo--ooo	222	40630	2.65
851	o--oo--ooo--oo	16434	34818	1.69
914	oo--oo--ooo--oo	259	39436	1.54
951	o--oo--ooo--ooo	5824	36243	1.68
Total		25970	35035	1.78

The average gross weight includes fully laden, partly laden and empty vehicles. This is illustrated quite clearly when we look at the weight distributions. Figure 6 - Figure 10 show the weight distributions for the five most common vehicle configurations. For the two truck-trailer combinations, the laden and unladen situations are quite obvious, although it does appear that the R22T22 vehicles are achieving more partial loads (presumably as back-loads). The B1222 combination is similar to the truck-trailers but the other two B-trains appear to be achieving quite a lot of partial load running with the empty running situation being far less obvious.

It is also notable that there appears to be a significant degree of overloading. The standard legal maximum allowable gross combination weight is 44 tonnes and for each vehicle configuration there seems to be a significant number of vehicles that exceed this weight. Some may be operating under HPMV permits but the number of these they have been issued covers only a small proportion of the fleet while it appears that 20-25% of vehicles are above 44 tonnes.

The lower bound HPMVs will be able to carry more weight for the fully laden situation but it is not clear that they would carry any more weight in the partly laden situation. In this situation the existing vehicles could carry more weight if the freight was available to be carried. The complication factor in that analysis is that if the lower bound HPMVs could carry, say, 10% more payload they would undertake 10% fewer trips. This would mean that there were 10% fewer vehicle-trips available for the back-loads and hence the weight of the back-loads might increase accordingly. However, this is largely conjecture.

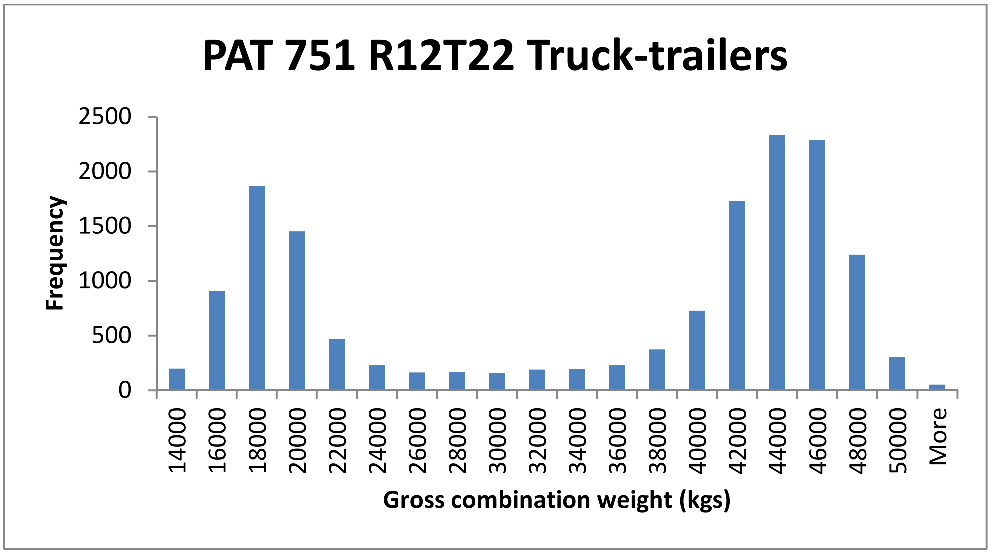


Figure 6. Gross combination weight distribution for R12T22 truck-trailers.

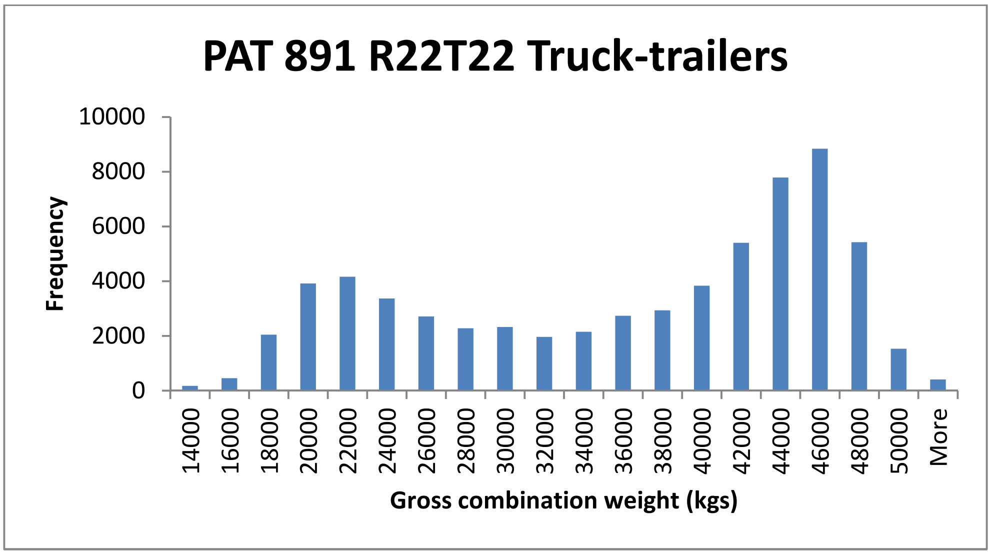


Figure 7. Gross combination weight distribution for R22T22 truck-trailers.

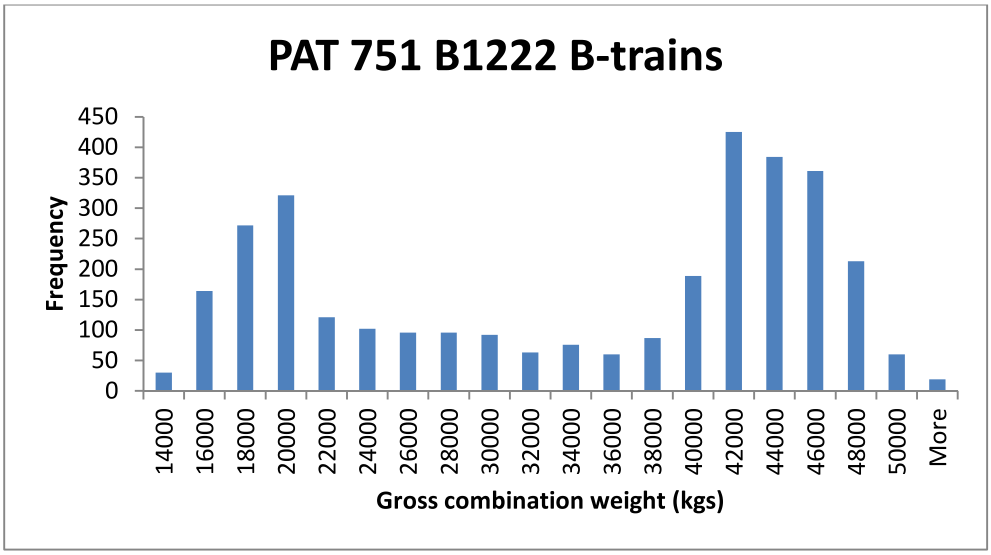


Figure 8. Gross combination weight distribution for B1222 B-trains.

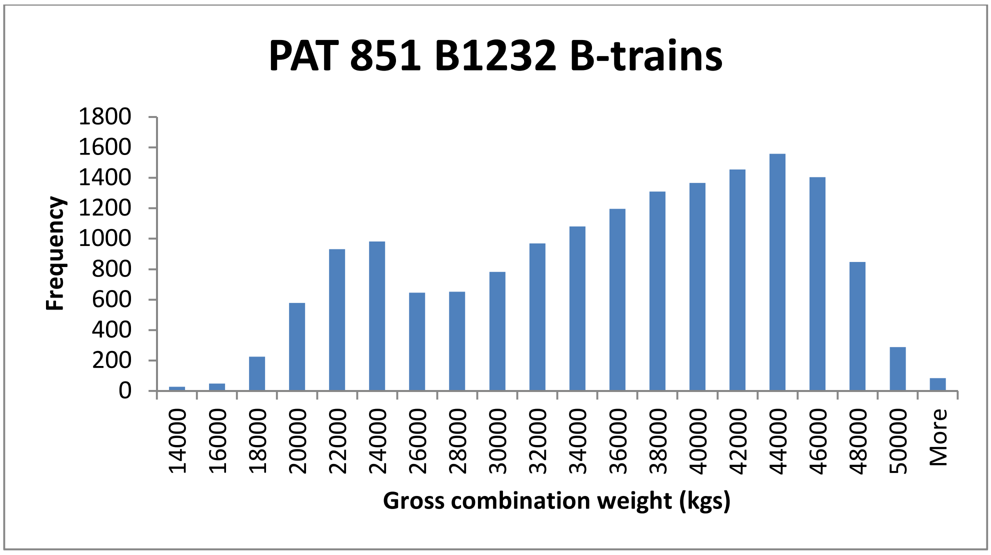


Figure 9. Gross combination weight distribution for B1232 B-trains.

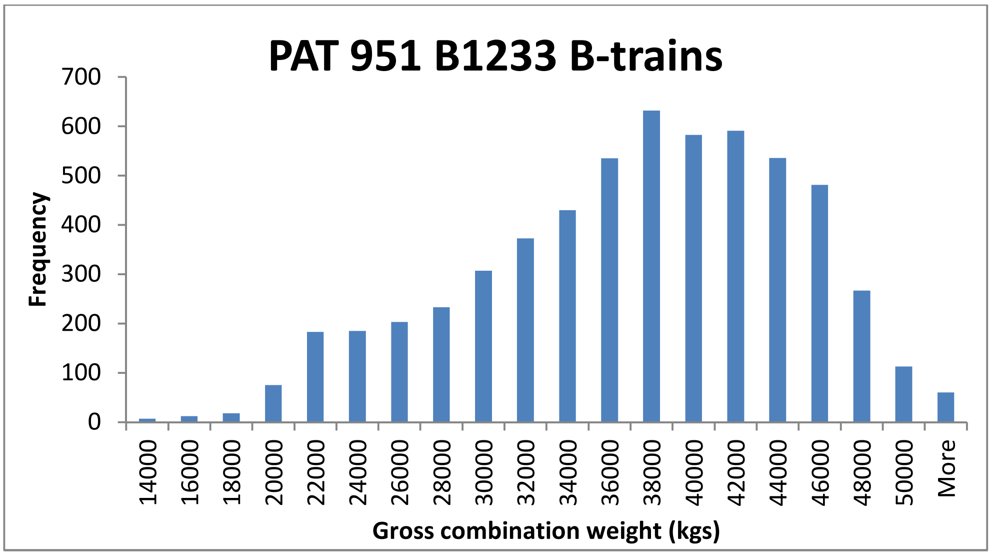


Figure 10. Gross combination weight distribution for B1233 B-trains.

For the purposes of this study the average weights and average ESA are not particularly useful because they include a mix of fully laden, partly laden and empty running. Because of the fourth power relationship between weight and pavement wear we cannot simply apply weight increases to the average weights to estimate the pavement wear impact.

Thus we have considered the "laden" running and "empty" running separately. The average weights and lengths of truck-trailers under these two conditions are shown in Table 10 and Table 11. The criteria used to define "laden" and "empty" are also shown. The WIM sites measure traffic in both travel directions and so if the "laden" and "empty" vehicles are samples from the same national fleet but just at different stages of their journey, then we would expect the length measures to be the same in both datasets. These measures are similar but not identical even when the number of vehicles sampled is quite large.

The two most common truck-trailer combinations are PAT classes 751 and 891. These are the R12T22 and R22T22 configurations. If we take the difference between the average "laden" and "empty" GCWs for these two we see that the R12T22 has an average payload of 27.5 tonnes while the R22T22 has an average payload of about 24 tonnes. We would have expected the difference between these two payload figures to be about one tonnes not 3.5 tonnes. The reason for this is the difference in "empty" weight. This may be because of differences in the types of trucks in the two categories or it may be that the "empty" criteria for the R22T22s is set too high and includes too many partly loaded vehicles.

Table 10. Average weights and lengths of "laden" truck-trailers.

PAT Class	Selection criteria	Number	Average Weight (tonnes)			ESA	Average Length (m)		
			GCW	truck	Trailer		truck WB	trailer WB	First to last axle
63	36t to 46t	325	39.88	19.75	20.13	4.04	4.47	3.96	15.12
751	42t to 48t	5870	44.58	20.12	24.46	3.88	4.87	4.63	16.80
77	42t to 48t	913	44.55	24.15	20.40	4.07	5.03	5.05	17.10
891	42t to 48t	22079	44.76	22.88	21.88	2.98	4.94	5.59	17.62
915	42t to 48t	332	44.89	21.59	23.31	2.44	4.95	6.51	18.96
1020	44t plus	130	47.44	21.16	26.28	1.78	5.09	6.60	19.88

Table 11. Average weights and lengths of "empty" truck-trailers.

PAT Class	Selection criteria	Number	Average Weight (tonnes)			ESA	Average Length (m)		
			GCW	truck	Trailer		truck WB	trailer WB	First to last axle
63	20t or less	427	17.10	10.76	6.34	0.65	4.68	4.40	15.56
751	20t or less	4423	17.05	10.22	6.83	0.52	4.76	4.49	16.63
77	26t or less	819	20.93	13.95	6.97	0.58	4.87	4.73	16.68
891	26t or less	16815	20.87	13.05	7.81	0.50	4.76	5.43	17.21
915	26t or less	158	21.49	12.62	8.88	0.50	4.95	6.71	18.97
1020	33t or less	147	28.07	15.41	12.66	0.37	5.14	6.69	20.08

For B-trains there are three component vehicles. The average weights and lengths for "laden" and "empty" vehicles "empty" vehicles are shown in

Table 12 to Table 15 below. However, some care is needed in interpreting these figures. The weights are the weights recorded for the axle groups fitted to the vehicle. With semi-trailers part of the weight of the semi-trailer is supported by the vehicle towing it. Thus the trailer weights shown are not the actual trailer weights. Furthermore the trailer wheelbase values shown are the distances from the rear axis of the semi-trailer to the rear axis of the vehicle towing it. Effectively this assumes that the hitch offsets are zero. In general this will not be the case but we cannot determine the hitch offset from the WIM data.

Table 12. Average weights of "laden" B-trains.

PAT Class	Selection criteria	Number	Average Weight (tonnes)				ESA
			GCW	tractor	first trailer	second trailer	
751	42t to 48t	960	44.58	20.04	11.74	12.80	4.01
811	42t to 48t	139	44.62	19.75	10.06	14.81	3.20
851	42t to 48t	3819	44.59	17.66	16.94	9.99	2.70
914	42t to 48t	96	44.72	19.54	16.04	9.19	2.06
951	42t to 48t	1289	44.53	17.04	15.70	11.79	2.42

Table 13. Average lengths of "laden" B-trains

PAT Class	Selection criteria	Number	Average Length (m)			
			tractor WB	first trailer WB	second trailer WB	First to last axle
751	42t to 48t	960	4.14	6.74	4.49	15.98
811	42t to 48t	139	4.67	6.13	5.07	17.12
851	42t to 48t	3819	4.40	6.21	6.47	17.70
914	42t to 48t	96	4.19	5.75	6.58	18.06
951	42t to 48t	1289	4.29	5.89	6.77	18.18

Table 14. Average weights of "empty" B-trains

PAT Class	Selection criteria	Number	Average Weight (tonnes)				ESA
			GCW	tractor	first trailer	second trailer	
751	22t or less	908	17.73	10.59	3.84	3.30	0.69
811	24t or less	11	18.84	10.49	3.85	4.50	0.77
851	26t or less	3437	21.62	10.93	6.81	3.87	0.70
914	24t or less	11	20.96	11.10	6.22	3.64	0.26
951	26t or less	683	22.27	10.87	6.67	4.73	0.76

Table 15. Average lengths of "empty" B-trains

PAT Class	Selection criteria	Number	Average Length (m)			
			tractor WB	first trailer WB	second trailer WB	First to last axle
751	22t or less	908	4.13	6.62	4.55	15.91
811	24t or less	11	4.77	6.29	4.65	16.94
851	26t or less	3437	4.40	6.20	6.27	17.49
914	24t or less	11	4.25	6.11	6.30	18.20
951	26t or less	683	4.20	5.91	6.58	17.90

Combining the data

These datasets are not totally consistent. For example, the registration database shows that there are 4106 3-axle full trailers (see Table 3). However, all 3-axle full trailers are included in RUC vehicle type 37 but the RUC data (Table 2) shows only 3418 type 37 vehicles and this vehicle type also includes 3-axle simple trailer and semi-trailers that do not have dual tyres. There is a difference in the timing of the data because the RUC data is for the 2010 calendar year while the registration data is current (2012) but it is extremely unlikely that vehicle numbers in this category have increased by 20% in just over a year particularly in the current economic environment.

For the purposes of this study we are primarily concerned with truck and trailer combinations and B-trains operating at or near the maximum allowable gross combination weight. Operators who are not using the maximum weight capacity available at present are unlikely to have a requirement to use the higher weight capacities proposed for the lower bound HPMVs.

Truck and Trailers

If we consider the WIM data (Table 8) we see that 93.5% of the large truck and traffic is provided by two vehicle configurations. Of these two vehicle configurations, 80% are R22T22 and 20% are R12T22. Both of these configurations use a 4-axle full trailer. The registration data (Table 3) shows that there are 9972 of these trailers while the RUC data (Table 2) shows 9467 type 43 vehicles. RUC vehicle type 43 also includes quad axle semi-trailers but there are only a few hundred of these. Potentially RUC vehicle type 43 also includes five and six axle trailers but these vehicles only exist in very small numbers (Table 3) and they can apply for a special RUC rate, which, anecdotally, it appears that most of them do.

The RUC data (Table 2) shows that type 43 vehicles purchased RUC for an annual distance of 624.4M kms in 2010. From Figure 5 we see that 67% of that is purchased for RUC weights of 22 tonnes or more, 76% at 21 tonnes or more and 84% at 20 tonnes or more. The WIM data for "laden" truck-trailers (Table 10) show an average trailer weight of 24.5 tonnes when connected to a 3-axle truck and 21.9 tonnes when connected to a 4-axle truck. These weights correspond to average combination weights of 44.6 tonnes and 44.8 tonnes respectively. Thus it reasonable to assume than 76% or 474.5M kms of the RUC distance purchased for type 43 vehicles is for combination vehicles operating at about the maximum allowable weight.

To determine how much payload these vehicles are carrying we need to estimate the tare weights. This can be done from either the registration data (Table 3 and Table 5) or from the WIM data for "empty" running (Table 11). A comparison of these tow estimates is shown in Table 16. For the R12T22 combination the two sets of figures are reasonably consistent. The manufacturer's tare weight for a truck normally includes only a driver and a minimal amount of fuel. The WIM figure is just 490kg higher which can easily be accounted for by fuel, tools and other items of driver's equipment. The WIM data figure for the trailer is 950kg higher than the registration data figure. This difference is greater than might be expected. There will be equipment carried on the trailer that was not included when the registration tare weight value was determined but it seems unlikely that it would weigh as much as 950kg. For the R22T22 configuration, the WIM estimates of average tare weight are significantly higher than those obtained from the registration data. If we compare the histogram of observed weights (Figure 7) compared to that of the R12T22 (Figure 6) we see that the "empty" and "laden" conditions are not as clearly defined for the R22T22. It appears that the R22T22s are carrying more partial loads when "empty".

Table 16. Comparison of tare weights estimated from registration data and WIM data.

Vehicle Configuration	Average tare weight from registration data (tonnes)			Average tare weight from WIM data (tonnes)		
	Truck	Trailer	Combination	Truck	Trailer	Combination
R12T22	9.73	5.98	15.71	10.22	6.83	17.05
R22T22	11.45	5.98	17.43	13.05	7.81	20.87

One other complicating factor is log trucks. There are approximately 1500 of these. They are nearly all truck and trailer combinations and they each travel about 90,000km per year. Because they are specialised vehicles they have limited opportunities for back-loading and so about half the travel distance is laden and half is unladen. When unladen, they piggy-back the trailers. Thus the trailers do not incur RUCs when the vehicle is unladen and "empty" log trucks do not appear in the WIM data as truck and trailer combinations. They appear as partly loaded rigid trucks. The total RUC distance purchased by logging trailers is approximately 67.5M kms which is about 10% of the total RUC distance for type 43 vehicles. The missing "empty" running kms are of the same magnitude. This is a significantly large number of absent "empty" vehicles and it affects the shape of the weight distribution histogram shown in Figure 7.

B-trains

The registration data indicate that there are 2450 B-train first semi-trailers in the fleet (Table 6). 74% of these are 3-axle trailers and 26% are 2-axle trailers. The WIM data (Table 9) shows three main B-train configurations with the B1222 making up 12%, the B1232 making up 63% and the B1233 making up 22%. Thus the WIM data suggests that 85% of B-train first trailers (by distance) should have 3-axles.

There are a number of possible explanations for this discrepancy:

- It is possible that B1222 B-trains travel less annual distance than the other configurations and thus they would appear less frequently in the WIM record than the number of vehicles would predict. The B1222 configuration incurs significantly higher RUCs than the B1232 and thus it is less likely to be used for operations involving substantial travel distances.
- The B1222 is geometrically the same as the R12T22. In our analysis we split the WIM data between the two configurations on the basis of the truck/tractor wheelbase. It is possible that a number of the vehicles that were classified as truck-trailers were, in fact, B-trains and that the number of B1222 vehicles in the WIM is higher than shown.
- The WIM sites are not necessarily representative of the road network as a whole. Thus the mix of vehicles observed at the WIM sites is not necessarily the same as the mix of vehicles in the fleet.

As with the truck-trailers we also have to estimate the tare weights to determine the payload. However, in this case it is more complicated because part of each semi-trailer's weight is supported by its towing vehicle and thus the tare weights shown in the registration database do not relate directly to the weights recorded at the WIM sites.

If we compare the average "empty" weights of the B1233 with those of the B1232 (Table 14) the relativities appear reasonable. The axles of the second trailer of the B1233 are 850kg heavier than those of the B1232 which is a reasonable weight for a trailer axle. The other weights are quite similar. However, if we compare the average "empty" weights of the B1222 with the other two it appears quite light. The tractor weight is similar but the first trailer axles are about 3 tonnes lighter than those of the other two configurations where the only significant difference is one fewer axle. It does appear from the weight distributions shown in Figure 9 and Figure 10 that the B1232 and B1233 combinations are achieving more back-loading and so it is possible that the estimate of "empty" weight includes a proportion of partly laden vehicles. The weight distribution for the B1222 combination in Figure 8 shows a clearer pattern of laden and unladen running.

The average laden weights for the three combinations are very similar.

LOWER BOUND PRO-FORMA HPMV DESIGNS

Introduction

The criteria on which the lower bound HPMV designs are based are:

- They must meet the low speed turning criterion for general access that other pro-forma HPMV designs are required to meet.
- They must not generate any more pavement wear than the existing standard legal vehicles when moving the same quantity of freight.
- They must meet the extrapolated bridge formula, namely GCW = 3L + 10 up to 27 tonnes and GCW = 1.6L + 18 over 27 tonnes.

There are only two vehicle configurations that have the axle group weight capacity to allow additional gross weight. These are the truck and trailer and the B-train. We are assuming that the choice of vehicle configurations is primarily driven by operational requirements and thus lower bound HPMV truck and trailers would replace standard truck and trailer and lower bound HPMV B-trains would replace standard B-trains. Thus we can consider the two configurations independently. We will consider the implications of this assumption being wrong.

The existing pro-forma designs meet the low speed turning criterion and so they represent a viable starting point for the lower bound designs. The pavement wear and bridge formula requirements will impose additional constraints on these designs. In this section we determine what those additional constraints should be.

Truck and Trailers

It is clear that for laden vehicles, the criterion that pavement wear must not increase means that the lower bound HPMVs must have more axles than the existing vehicles. We can demonstrate this by considering the WIM data for the laden R22T22 combinations. The average weight data by axle group and by vehicle are shown in Table 17.

Table 17. Average weight distribution for laden R22T22.

Average Weight (tonnes)							ESA[2]
Axle Gp 1	Axle Gp 2	truck	Axle Gp 3	Axle Gp 4	Trailer	GCW	
9.34	13.54	22.88	10.71	11.16	21.88	44.76	2.81

Consider now adding an additional one tonne of payload to this vehicle. The least pavement wear impact will result if the weight is added to the axle groups that are least loaded in terms of ESA. These are the two trailer axle groups. Adding 0.5 tonnes to each of the two trailer axle groups increases the ESA value for the whole combination to 2.96, i.e. by just over 5%. If the additional one tonne represents more than 5% of the payload, then the payload/ESA would increase and we would see a reduction in pavement wear. Conversely if the additional one tonne represents less than 5% of the payload, then the payload/ESA would reduce and we would see an increase in pavement wear. Thus if the payload 44.76t GCW is more than 20 tonnes, an increase in payload will lead to an increase in pavement wear. It would be very unusual for a fully laden R22T22 vehicle with a GCW in excess of 44 tonnes to be carrying less than 20 tonnes of payload and thus it is necessary to add axles to reduce the ESA.

It is useful to consider the "empty" vehicle situation. As noted previously the weights suggest that some of these are partly laden. The average weights for these are shown in Table 18. If we add one tonne to the trailer as we did for the laden case the ESA for the combination increases to 0.45, i.e. by only just over 2%. Thus unless the payload is greater than 44 tonnes (which is physically impossible), for the "empty" vehicle adding payload reduces the amount of pavement wear per tonne moved.

---

[2] The value shown here is ESA value for the average weights. The value shown previously in Table 10 is the average of the ESA values. Because of the fourth power relationship these two figures are not the same.

Table 18. Average weight distribution for "empty" R22T22.

Average Weight (tonnes)							ESA[3]
Axle Gp 1	Axle Gp 2	truck	Axle Gp 3	Axle Gp 4	Trailer	GCW	
7.28	5.77	13.05	4.05	3.76	7.81	20.87	0.44

This is a useful result. The simplest model of freight movements has the vehicle travelling fully laden in one direction and completely unladen on the return trip. This model is used for determining the RUC rates. Obviously this is less than optimal and operators will try to get back-loads wherever possible. However, in many sectors, the opportunities for back-loading are very limited. For liquid tankers such as milk and fuel it is even difficult to achieve the 50% loading because they have multiple stops for loading or unloading. In other cases, such as log trucks and stock trucks the vehicles are quite specialised and thus there are few other forms of freight that they can carry. The "empty" vehicle results show that when carrying partial loads, adding additional payload reduces the pavement wear per tonne of payload. Thus if the pro-forma lower bound HPMVs carry a little more payload on the back-load trips because they are doing fewer trips this has a beneficial effect on pavement wear.

The two obvious vehicle configurations for lower bound HPMV truck–trailers are the R22T23 and the R23T23. The first step is to determine what GCWs these configurations could operate at without increasing pavement wear.

The existing vehicles that these would replace are the R12T22 and the R22T22 and at present the traffic consist of approximately 20% of the former and 80% of the latter. To estimate the payloads from the gross weights we need to know tare weights. Estimates are shown in Table 16. Because the WIM data for "empty" vehicles appears to include some partial loads we will use the registration data as the basis for this analysis but with 500kg added to the truck weight to allow for fuel, tools and driver belongings. The split between axle groups is based on the WIM data and experience. These are shown in Table 19.

Table 19. Gross and tare weights for two key truck-trailer combinations.

Vehicle Configuration	Load State	Average Weight (tonnes)							ESA[3]
		Axle Gp 1	Axle Gp 2	truck	Axle Gp 3	Axle Gp 4	Trailer	GCW	
R22T22	Laden	9.34	13.54	22.88	10.71	11.16	21.88	44.76	2.81
R22T22	Tare	6.89	5.06	11.95	2.99	2.99	5.98	17.93	0.34
R12T22	Laden	5.67	14.45	20.12	11.73	12.73	24.46	44.58	3.68
R12T22	Tare	4.61	5.62	10.23	2.99	2.99	5.98	16.21	0.56

Based on these figures, the average R22T22 is carrying a payload of 26.83 tonnes and the average R12T22 is carrying a payload of 28.37 tonnes. If we assume that the vehicles travel one direction laden and the other direction empty, then the R22T22 incurs pavement wear at the rate of 0.117 ESA/payload-tonne and the R12T22 incurs pavement wear at a rate of 0.150 ESA/payload-tonne.

If we assume that 20% of the travel is undertaken by R12T22s and 80% by R22T22s, then 21% of the freight is moved by R12T22s and 79% by R22T22s. This difference from the distance proportion occurs because the R12T22s carry more payload. On this basis the average rate of pavement wear for the two primary combinations in the maximum weight truck-trailer fleet is 0.124 ESA/payload-tonne.

Consider first the R22T23 option. If we assume that the truck tare weight is the same as that of the R22T22 and the trailer tare weight is one tonne more with all of that weight on the rear group, then we find that we can increase the payload weight by five tonnes and achieve approximately the same ESA/payload-tonne as the R22T22 provided that only one tonne of the additional payload is carried by the truck and four tonnes are carried by the trailer. This is shown in Table 20.

[3] The value shown here is ESA value for the average weights. The value shown previously in Table 11 is the average of the ESA values. Because of the fourth power relationship these two figures are not the same.

Table 20. Gross and tare weights for R22T23 HPMV option.

Vehicle Configuration	Load State	Average Weight (tonnes)							ESA
		Axle Gp 1	Axle Gp 2	truck	Axle Gp 3	Axle Gp 4	Trailer	GCW	
R22T23	Laden	9.84	14.04	23.88	12.21	14.66	26.88	50.76	3.42
R22T23	Tare	6.89	5.06	11.95	2.99	3.99	6.98	18.93	0.34

If we assume that, as before, the vehicle travels fully laden in one direction and empty in the other the pavement wear is 0.118 ESA/payload-tonnes. This is only marginally worse than the R22T22 at six tonnes less and is better than the average for the two truck-trailer combinations.

If we put more of the additional weight on the truck and less on the trailer the pavement wear increases but it is still less than the fleet average. The effect of assuming half laden travel and half empty travel reduces the difference between the R22T22 and R22T23 vehicles because the ESA incurred during empty travel is much the same for both. If we consider the extreme case of no empty travel (100% back-loading) then the R22T22 at 44.76t GCW incurs 0.105 ESA/payload-tonne while the R22T23 at 50.76t GCW incurs 0.107 ESA/payload-tonne so the R22T23 at 50t is slightly worse than the R22T22 at 44t but significantly better than the R12T22 at 44.58t GCW which incurs 0.130 ESA/payload-tonne. Thus the effect of assuming half laden and half unladen travel does not significantly affect the result.

We have assumed that the pattern of overloading for the lower bound HPMVs will be similar to that for existing vehicles. Thus the 50.76t R22T23 vehicle is assumed to have a nominal gross weight of 50t. To achieve this weight the bridge formula requires that the distance from the first to last axle of the vehicle must be greater than 20m. (50.76t requires 20.475m). The current pro-forma designs for truck-trailers are all based on a maximum overall length of 23m. This length has been accepted by Kiwirail and NZTA as providing adequate clearance at intersections. With a maximum overall length of 23m and a minimum first-to-last axle spacing of 20m the combined front and rear overhangs (measured from the first and last axle respectively) cannot exceed 3m. A European truck fitted with a frontal underrun protection system (FUPS) has a front overhang of about 1.5m. The minimum rear overhang from the rearmost axle centre that is achievable is about 0.8m. Thus the 20m first-to-last axle distance is possible within a 23m overall length.

Using the R23T23 configuration could potentially allow greater weight but to do this requires an increase in the first-to-last axle distance and this is barely possible within an overall length of 23m.

The current pro-forma design for the 23m truck and trailer is shown in Figure 11. To make this a valid lower bound HPMV requires the following in addition:

- the rear axle group on the trailer must be a tridem group. Other axle groups may be tridem group but this is not a requirement.
- For 50t GCW, the distance from the first-to-last axle must be a minimum of 20m, for 49t it must be a minimum of 19.375m, for 48t a minimum of 18.75m, for 47t a minimum of 18.125m and for 46t a minimum of 17.5m.
- All other axle combinations must be checked for compliance with the bridge formulae given above and axle group weight limits must be specified such that it is not possible to exceed the bridge formula while complying with the axle group limits.

This is illustrated in Figure 12.

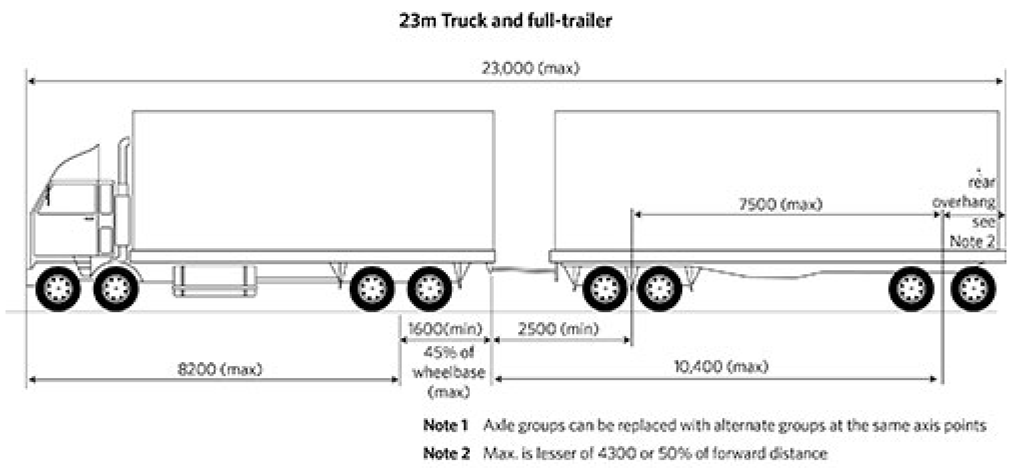
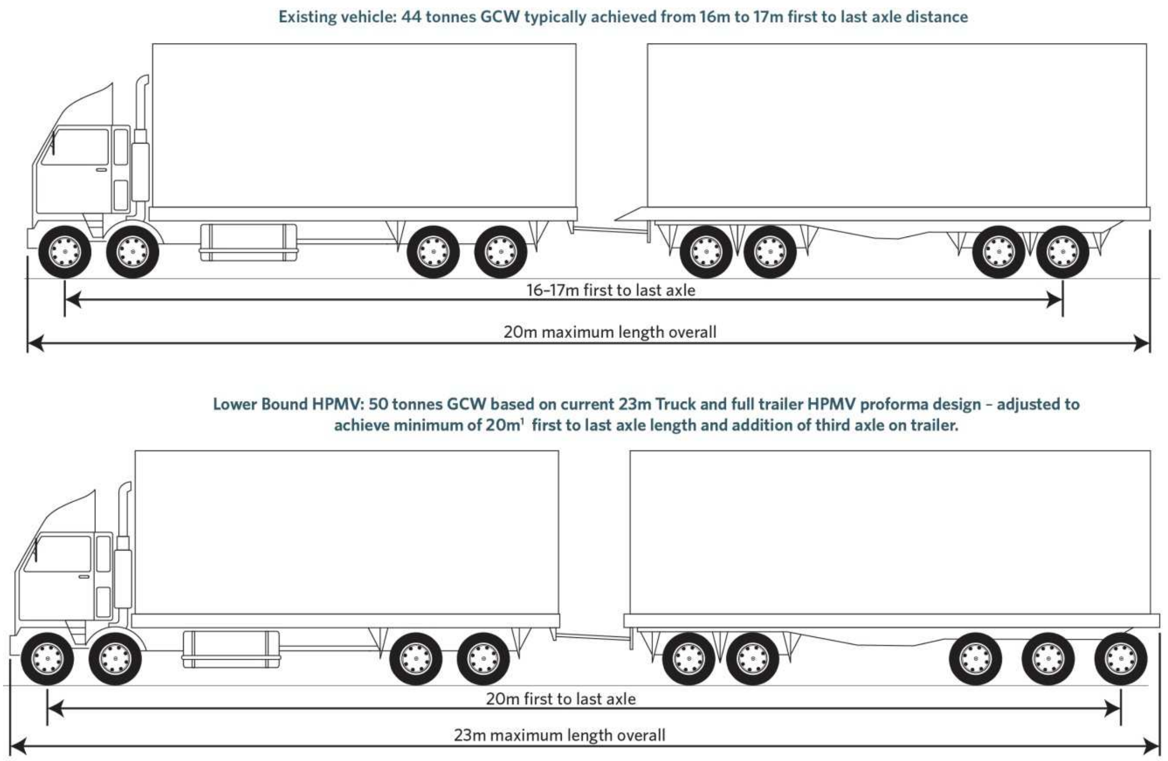


Figure 11. Current 23m pro-forma truck and trailer.



[1] Maximum gross weight is determined by the formula **18 tonnes + (1.6 multiplied by first to last axle length)**. A minimum of 20 metres first to last axle length is therefore required to achieve 50 tonnes GCW. Examples of maximum GCW available from shorter first to last axle lengths are provided in the following table:

First to last axle length	Maximum gross combination weight (GCW)
18.75m ≤ y < 19.375m	48t
19.375m ≤ y < 20m	49t
20m ≤ y	50t

Figure 12. Conditions for lower bound HPMV truck and trailer.

B-trains

There are three B-train configurations in widespread use, the B1222, the B1232 and the B1233. Of these the B1232 is then most common making up 63.3% of the B-train fleet with B1233s making up 22.4% and B1222s making 12.4%. All other B-train configurations combined make up the remaining 1.9%.

The WIM data gives a good estimate of the laden weights of these vehicles but it is more difficult to determine the tare weights and hence the payload. Trailer tare weights are given in the registration database but these are for the standalone vehicle. When connected up as a B-train part of the trailer weight is carried by the towing vehicle and thus the weight recorded for its axles is only part of its weight. For first trailers the axle weight also includes some weight from the second trailer. The weight distributions used in this analysis are shown in Table 21 below. The laden weights are based on WIM data. The tare weight for the B1222 combination also comes from the WIM data because the distribution of GCW in Figure 8 shows clear peaks for laden and empty running. For the other two B-trains the “empty” situation is less distinct and so we have estimated the tare weights by using the B1222 values and adding one tonnes for each additional axle.

Table 21. Gross and tare weights for three B-train combinations.

Vehicle Configuration	Load State	Average Weight (tonnes)					ESA
		Axle Gp 1	Axle Gp 2	Axle Gp 3	Axle Gp 4	GCW	
B1222	Laden	5.82	14.22	11.74	12.80	44.58	3.76
B1222	Tare	4.75	5.85	3.84	3.30	17.74	0.64
B1232	Laden	5.26	12.40	16.94	9.99	44.59	2.54
B1232	Tare	4.75	5.85	4.84	3.30	18.74	0.64
B1233	Laden	5.50	11.54	15.70	11.79	44.53	2.26
B1233	Tare	4.75	5.85	4.84	4.30	19.74	0.64

As before, assuming 50% laden running and 50% empty, the rate of pavement wear generated by the B-trains is 0.164 ESA/payload-tonne for the B1222, 0.123 ESA/payload-tonne for the B1232 and 0.117 ESA/payload-tonne for the B1233.

When we look at the B1233 configuration above we see that some axle groups (mostly notably the fourth) are very lightly loaded compared to their capacity. Axle group 4 is a tridem group with standard legal weight limit of 18 tonnes and even at 18 tonnes it only incurs one ESA of pavement wear. Thus we find that by adding weight to the less heavily loaded axles in the B1233 we can achieve a significant increase in GCW without increasing the rate of pavement wear. This is illustrated in Table 22. The GCW has been increased by six tonnes and the ESA for the laden vehicle has increased from 2.26 to 2.98 but the rate of pavement wear is unchanged at 0.117 ESA/payload-tonne.

Table 22. Gross and tare weights for HPMV B1233 at 50 tonnes GCW.

Vehicle Configuration	Load State	Average Weight (tonnes)					ESA
		Axle Gp 1	Axle Gp 2	Axle Gp 3	Axle Gp 4	GCW	
B1233	Laden	5.51	12.54	16.7	15.79	50.54	2.98
B1233	Tare	4.75	5.85	4.84	4.3	19.74	0.64

In theory we could increase the weight further but as with the truck-trailer a 50t GCW requires a first-to-last axle spread of 20m. The longest current pro-forma B-train designs are 22.3m and so, after allowing for minimal front and rear overhangs, a 20m axle spread is as much as can realistically be achieved.

The assumption of 50% laden running and 50% empty running is clearly wrong but as we have shown, with partial loads, the lower bound HPMVs incur a lower rate of pavement wear than standard vehicles.

There are current three pro-forma B-train designs as shown in Figure 13 - Figure 15.

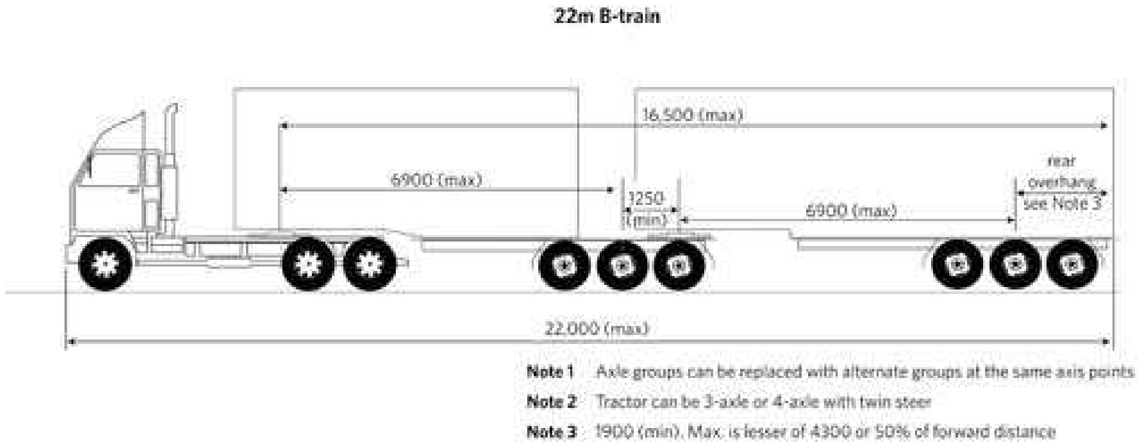


Figure 13. 22m pro-forma B-train.

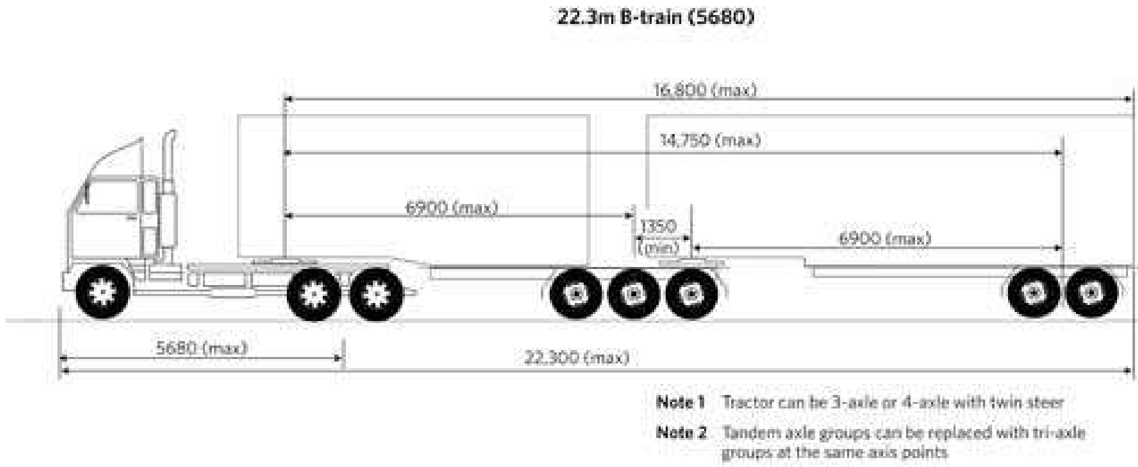


Figure 14. 22.3m pro-forma B-train with 5.68m tractor.

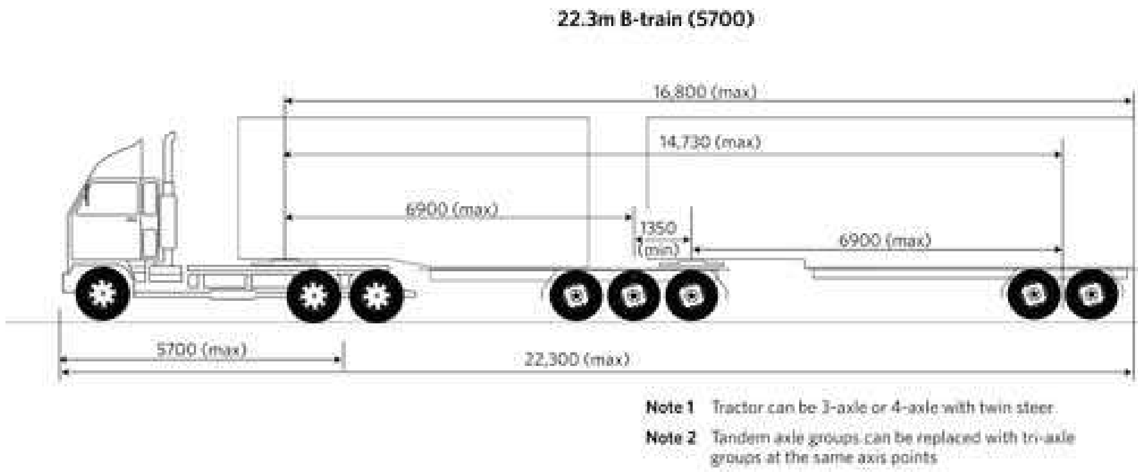


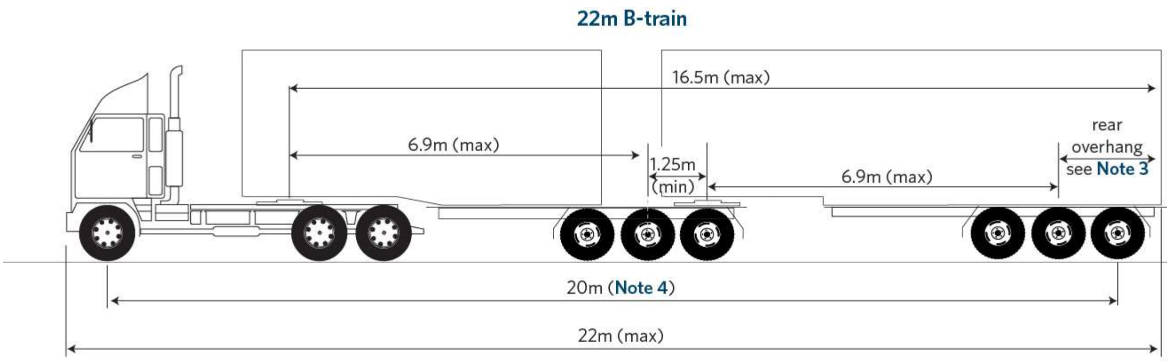
Figure 15. 22.3m pro-forma B-train with 5.70m tractor.

The lower bound pro-forma HPMV could use the dimensional envelopes of any of these three designs with the following additional conditions:

- The trailer axle groups must be tridems

- For 50t GCW, the distance from the first-to-last axle must be a minimum of 20m, for 49t it must be a minimum of 19.375m, for 48t a minimum of 18.75m, for 47t a minimum of 18.125m and for 46t a minimum of 17.5m.
- All other axle combinations must be checked for compliance with the bridge formulae given above and axle group weight limits must be specified such that it is not possible to exceed the bridge formula while complying with the axle group limits.

The resulting lower bound pro-forma designs are shown in Figure 16 - Figure 18.



Note 1 Tractor can be 3-axle or 4-axle with twin steer.

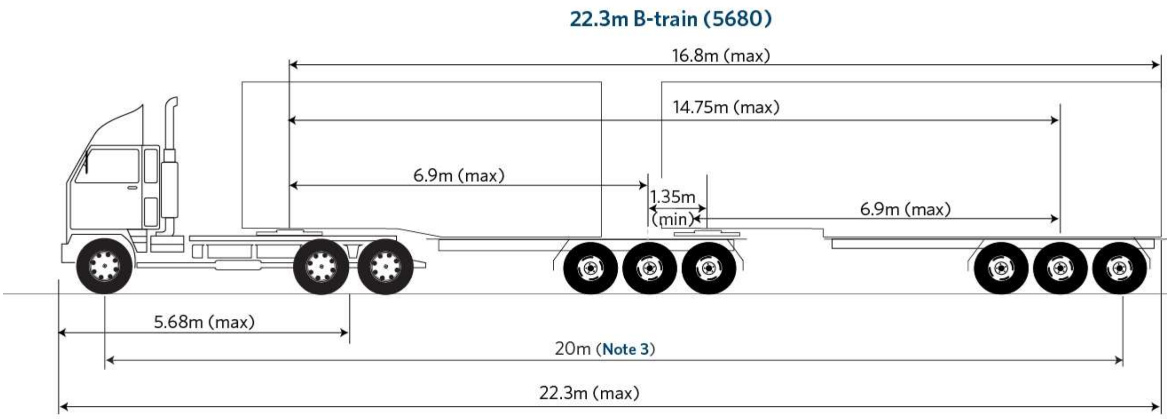
Note 2 Tandem axle groups can be replaced with tri-axle groups at the same axis points.

Note 3 1.9m (min). Max. is lesser of 4.3m or 50% of forward distance

Note 4 Maximum gross weight is determined by the formula **18 tonnes + (1.6 multiplied by first to last axle length)**. A minimum of 20 metres first to last axle length is therefore required to achieve 50 tonnes GCW. Examples of maximum GCW available from shorter first to last axle lengths are provided in the following table:

First to last axle length (y)	Maximum gross combination weight (GCW)
18.75m ≤ y < 19.375m	48t
19.375m ≤ y < 20m	49t
20m ≤ y	50t

Figure 16. Lower bound pro-forma design based on 22m pro-forma B-train.



Note 1 Tractor can be 3-axle or 4-axle with twin steer.

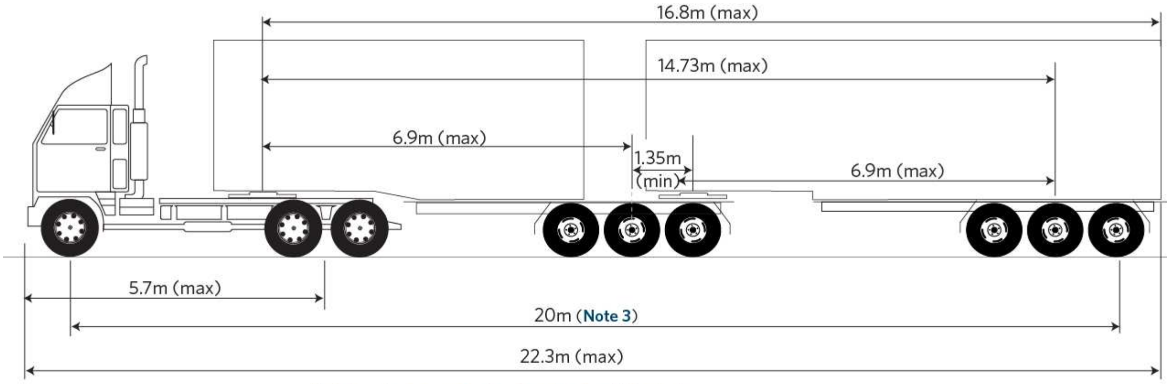
Note 2 Tandem axle groups can be replaced with tri-axle groups at the same axis points.

Note 3 Maximum gross weight is determined by the formula **18 tonnes + (1.6 multiplied by first to last axle length)**. A minimum of 20 metres first to last axle length is therefore required to achieve 50 tonnes GCW. Examples of maximum GCW available from shorter first to last axle lengths are provided in the following table:

First to last axle length (y)	Maximum gross combination weight (GCW)
18.75m ≤ y < 19.375m	48t
19.375m ≤ y < 20m	49t
20m ≤ y	50t

Figure 17. Lower bound pro-forma design based on pro-forma 22.3m B-train (5680).

22.3m B-train (5700)



Note 1 Tractor can be 3-axle or 4-axle with twin steer.

Note 2 Tandem axle groups can be replaced with tri-axle groups at the same axis points.

Note 3 Maximum gross weight is determined by the formula **18 tonnes + (1.6 multiplied by first to last axle length)**. A minimum of 20 metres first to last axle length is therefore required to achieve 50 tonnes GCW. Examples of maximum GCW available from shorter first to last axle lengths are provided in the following table:

First to last axle length (y)	Maximum gross combination weight (GCW)
18.75m $\leq$ y < 19.375m	48t
19.375m $\leq$ y < 20m	49t
20m $\leq$ y	50t

Figure 18. Lower bound pro-forma design based on pro-forma 22.3m B-train (5700).

CONCLUSIONS

The lower bound pro-forma designs developed in the previous section are based on the existing pro-forma designs. For both the truck-trailer and the B-train it is possible to increase the GCW to 50 tonne without increasing pavement wear using the R22T23 and B1233 combinations.

Under the proposed bridge formula, the 50t GCW requires at minimum spacing for the first-to-last axle of 20m. The current pro-forma designs are limited to 23m overall length. Within this length constraint it is not practical to go to higher weights because first-to-last axle spacing required would be difficult to achieve.

The 23m overall length limit has been accepted for general access as it provides adequate clearances at railway crossings and intersections. It is relatively easy to configure a truck-trailer that is longer than 23m and can still achieve the required low speed turning performance and thus if a longer overall length was permissible it would be possible to increase the allowable GCW for the truck-trailer. The B-train is inherently more constrained because its low speed turning performance is poorer. Longer B-trains have been built that can achieve the required low speed turning performance but they achieve this by using steering axles on the trailer which is specifically prohibited in the VDAM Rule and thus requires an exemption.

3rd December 2012

Opportunities for Lower Bound HPMVs

John de Pont, TERNZ Ltd

BACKGROUND

When operators chose a vehicle configuration to undertake a transport task they are essentially trying to solve an optimisation problem. Ideally they want to find the configuration that will deliver maximum profitability. As with all real world optimisation problems, there are constraints that the solution has to comply with. In particular, vehicles must meet the requirements of the dimensions and mass regulations. There may also be other constraints. For example, milk tankers need to be manoeuvrable enough to get in and out of farm gates.

The 2010 amendment to the Vehicle Dimensions and Mass (VDAM) Rule provided for the use of High Productivity Motor Vehicles (HPMVs) which relaxed some of the constraints on vehicle dimensions and mass where the infrastructure can accommodate it. This requirement for the infrastructure to be able to cope with vehicles effectively introduces alternative constraints.

To facilitate the uptake of HPMVs the NZTA introduced the concept of pro-forma designs that would have general access at standard weights. In order to ensure that these vehicles could fit on the existing infrastructure, the NZTA developed a low speed turning performance measure and used the performance of the worst case standard legal vehicle to establish the benchmark level.

A number of pro-forma design envelopes have been developed on this basis. These are "optimal" in that they are the largest vehicles of their configuration type that can operate within the constraints that were imposed upon them. By international standards this approach has been very successful. The uptake of HPMVs in New Zealand has been very high compared to that in other countries where different approaches to increasing transport productivity have been used.

The pro-forma designs have general access at standard legal weights but require route approval to operate at higher weights. Route approval must be obtained from all of the road controlling authorities involved and requires that the infrastructure is assessed to establish that it can cope with the increased weight. This process is time-consuming and costly and as a result there have been many fewer HPMVs approved at higher weights than at standard weights.

To address this issue, the NZTA in conjunction with the industry have proposed the concept of "lower bound" pro-forma HPMV designs. The principle behind these pro-forma designs is that the lower bound HPMVs would be able to operate on a general access basis at higher weights without requiring route approval because they would have no more impact on the infrastructure than existing standard legal vehicles.

Thus for developing the lower bound HPMV designs, as well as the usual vehicle performance constraints such as low speed turning ability, rollover stability etc, two infrastructure impact constraints were applied:

1. The vehicles had to comply with a revised bridge formula which is an extrapolation of the existing class 1 bridge formula to weights above 44 tonnes and,
2. The vehicles could not generate any more pavement wear than the existing standard size and weight vehicles that they will replace.

Although we could view these constraints as being restrictive because they do limit what is possible with the lower bound designs they do provide opportunities for the widespread and immediate application of these vehicles to increase productivity.

The revised bridge formula has been developed so that the vast majority of bridges on the New Zealand road network are included. With this approach all routes will be included by default and a small number of routes will be excluded by exception. This is the converse of the current approach where each route has to be assessed to be included in each vehicle's permit. This represents a major step forward in both the simplicity and the cost of getting higher weight HPMVs permitted.

The pavement wear implications of higher weight HPMVs has been a sticking point for a number of local road controlling authorities and they have been reluctant to issue permits for these vehicles to operate on their roads. The main issue is that although transport operators pay for the additional pavement wear that the heavier vehicles generate through increased Road User Charges, the local road controlling authorities are only reimbursed for about half of their pavement maintenance costs from the National Land Transport Fund. The other half of the costs have to be met by ratepayers and thus there is considerable pressure to keep these costs down. By designing the lower bound HPMVs so that there is no increase in pavement wear for the same volume of freight moved we eliminate this issue for the local road controlling authorities. Thus with this approach lower bound HPMVs will be able to get general access at higher weights without requiring route approval.

VEHICLE CONFIGURATIONS AND ALTERNATIVES

Using this approach several lower bound pro-forma HPMV designs for B-trains and truck-trailers have been developed. Broadly they are similar to the existing pro-forma designs except that they are required to have at least 9-axles and their gross weight capacity depends on the spacing between the first and last axles. To achieve 50t gross combination weight (GCW), this spacing is required to be over 20m. At lesser axle spreads lower gross combination weight apply but these weight limits are typically still well in excess of the 44t GCW limit that applies to standard legal vehicles.

Currently the most widely used truck-trailer and B-train configurations have eight axles. Thus a downside for the lower bound HPMVs is that they have one more axle than the most common current vehicles. This additional axle is not needed to achieve the required level of GCW. It is only required because of the need to keep the pavement wear impacts to levels comparable to those of current standard weight vehicles, i.e. to meet constraint 2 above.

From the transport industry perspective the additional axle incurs additional capital costs and reduces the payload capacity for a given GCW. One question from the industry has been: "Why can the lower bound HPMVs not include 8-axle vehicles at up to 48t rather than the proposed 9-axle vehicles at up to 50t?" The focus of the question has been truck-trailer combinations but it also applies to B-trains.

The productivity gains from taking this alternative are less because each additional axle adds approximately one tonne of tare weight and thus a 9-axle combination at 50t would generally carry one tonne more payload than an 8-axle vehicle at 48t. However, there are many more existing 8-axle vehicles than 9-axle vehicles currently operating and thus we might anticipate a more rapid uptake if the 8-axle vehicle at 48t were an option.

Although options of higher weights without increasing the number of axles were considered when developing the lower bound pro-forma designs the results were not presented in the report. Thus we will specifically consider the option of 8-axle vehicles at 48t GCW now.

To achieve 48t GCW under the proposed bridge formula, the first-to-last axle spacing must be greater than 18.75m. From the WIM data only 8% of current 8-axle truck and full trailers achieve this. However, it is possible to increase this dimension by increasing the drawbar length which is a relatively straightforward modification. For 8-axle B-trains a slightly larger proportion (8.8%) achieve this axle spacing but it is more difficult and expensive to modify a B-train to increase this dimension. Thus the vast majority of existing 8-axle truck-trailers and B-trains would not be able to operate at 48t using the proposed bridge formula unless they are modified to increase the spacing from their first-to-last axles.

The main issue to consider is pavement or road wear. The road wear generated by a vehicle is characterised by the number of Equivalent Standard Axles (ESA) that it applies to the road as it travels. A standard axle is a single 8.2t axle fitted with dual tyres. There are formulas for converting other types of axles at different weights to a number of ESA. Thus, for any heavy vehicle, the ESA for each axle group can be calculated based on its weight and tyre configuration, and then the ESA for vehicle is determined by adding the ESA for its axle groups. Of course, it is not the absolute value of ESA that matters but the ESA per tonne of payload moved which takes into account the fact that larger trucks require fewer trips to move the same amount of freight.

The axle weight distributions and associated ESA values for truck and trailer combinations are presented in Table 1 below. The tare weights for the 7-axle and 8-axle vehicles come from the vehicle registration database and the first two laden cases are based on measurements recorded at the Weigh-in-Motion (WIM) sites. This is a snapshot of the current 44-tonne fleet. The weights on the 48t 8-axle vehicle were determined by adding two tonnes to each of the truck and trailer of the 44t combination. The distribution of the additional weight between axle groups was done in the same proportions as the payload on the 44t vehicle. The 9-axle vehicle is the lower bound pro-forma design which is a 4-axle truck towing a 5-axle trailer. The tare weights are based on the 8-axle vehicle with one additional tonne on the rear trailer axles. The additional five tonnes of payload was applied by adding one tonne to the truck and four tonnes to the trailer. The ESA/Payload calculation was done by assuming that for each trip the vehicle travels a distance fully laden and an equal distance unladen for the return journey.

Table 1. Axle weights and ESA for truck and trailer options.

Vehicle Configuration	Load State	Average Weight (tonnes)						ESA	ESA/ payload
		Axle Gp 1	Axle Gp 2	Axle Gp 3	Axle Gp 4	GCW	Payload		
7-axle Reg. data	Tare	4.61	5.62	2.99	2.99	16.21		0.56	
7-axle WIM (44t)	Laden	5.67	14.45	11.73	12.73	44.58	28.37	3.68	0.149
8-axle Reg. data	Tare	6.89	5.06	2.99	2.99	17.93		0.34	
8-axle WIM (44t)	Laden	9.34	13.54	10.71	11.16	44.76	26.83	2.81	0.117
8-axle @ 48t	Laden	9.79	15.09	11.68	12.19	48.76	30.83	3.87	0.137
9-axle	Tare	6.89	5.06	2.99	3.99	18.93		0.34	
9-axle @ 50t	Laden	9.84	14.04	12.21	14.66	50.76	31.83	3.42	0.118

Currently the proportion of 8-axle truck-trailers to 7-axle truck-trailers is about 4:1. Thus the weighted average ESA/Payload for the current fleet is 0.124. From Table 1 we can see that the proposed lower bound pro-forma design is only slightly worse than the current 44t 8-axle vehicles and is better than the current fleet average. The 48t 8-axle vehicle on the other hand is about 10% worse than the current fleet average and 17% worse than the current 44t 8-axle vehicles.

Comparable data for B-trains is shown is Table 2. The first three vehicles are the current fleet at 44t using registration data for the tare weights and WIM data for their laden weights. As with the truck-trailers this shows that the proposed 9-axle 50t lower bound vehicle produces less pavement wear than the current fleet while an alternative 8-axle 48t vehicle would produce more pavement wear.

Thus the vast majority of existing 8-axle truck-trailers and 8-axle B-trains cannot meet the design constraints for the lower bound pro-forma designs if operated at 48t GCW. Many of them could be modified to meet the bridge formula constraint. For some vehicles these modifications would be relatively simple and inexpensive while for others they will be costly. However, the pavement wear constraint which specifies that the vehicles should incur no more pavement wear than the current fleet undertaking the same transport task cannot be met by these vehicles when operating at 48t. In principle this should not matter because, at the higher weights these vehicles would pay additional Road User Charges to offset the additional pavement wear generated. However, without a mechanism to reimburse local road authorities for this additional pavement wear, many road controlling authorities will remain reluctant to issue permits for these vehicles to operate at higher weights on their roads.

Table 2. Axle weights and ESA for B-train options.

Vehicle Configuration	Load State	Average Weight (tonnes)						ESA	ESA/ payload
		Axle Gp 1	Axle Gp 2	Axle Gp 3	Axle Gp 4	GCW	Payload		
7-axle Reg. data	Tare	4.75	5.85	3.84	3.30	17.74		0.64	
7-axle WIM (44t)	Laden	5.82	14.22	11.74	12.80	44.58	26.84	3.76	0.164
8-axle Reg. data	Tare	4.75	5.85	4.84	3.30	18.74		0.64	
8-axle WIM (44t)	Laden	5.26	12.40	16.94	9.99	44.59	25.85	2.54	0.123
9-axle Reg. data	Tare	4.75	5.85	4.84	4.30	19.74		0.64	
9-axle WIM (44t)	Laden	5.50	11.54	15.70	11.79	44.53	24.79	2.26	0.117
8-axle @ 48t	Laden	5.34	13.41	18.81	11.04	48.60	29.86	3.35	0.134
9-axle @ 50t	Laden	5.51	12.54	16.7	15.79	50.54	30.80	2.98	0.118

Although the proposed lower bound pro-forma designs are not the most productive or most cost-effective designs possible in an absolute sense they are the most productive configurations that we have been able to develop which can also meet the imposed infrastructure constraints. Designs that do not meet the infrastructure constraints are limited to operating on approved routes that have been assessed to show that they can cope and where local road controlling authorities are satisfied that the benefits to their stakeholders outweigh the costs. General access is not currently available for these vehicles.

OPPORTUNITIES FOR LOWER BOUND HPMVS

The pro-forma design approach where vehicles fitting within specified design envelopes can obtain an HPMV permit without any need for either a vehicle assessment or a route assessment has very successful. Compliance costs are kept relatively low and the uptake of HPMV permits in New Zealand has been very strong with around 2000 vehicles permitted in less than two years. By contrast, the Australian Performance Based Standards (PBS) approach requires comprehensive vehicle and route assessments which are both costly and time-consuming. Although the PBS approach has the potential for greater productivity gains, compliance costs are high and the uptake has been much slower. The PBS system was introduced in October 2007 and by January 2010, 80 vehicles had been approved[1].

Lower bound pro-forma designs provide an opportunity to extend this very successful pro-forma design approach to achieving high GCWs with general access. The infrastructure constraints used in developing the lower bound designs are based on the current capacity of the infrastructure and thus it is possible to commence implementation immediately because no infrastructure upgrades are needed.

The 9-axle lower bound HPMV designs that have been developed in this study provide some significant opportunities for productivity gains. Although the cost of an additional axle when building these vehicles or modifying existing vehicles is not insignificant, the vehicles will have general access (or close to it) at up to 50t GCW without any need to undertake performance assessments on the vehicle or route assessments for where it can operate. Thus the process of registering and permitting vehicle will be straightforward and inexpensive. A GCW of 50t represents approximately 5t of additional payload compared to an 8-axle vehicle at 44t which in most cases is a 15-20% productivity gain.

[1] NTC (2010). "PBS Maps Portal Frequently Asked Questions". National Transport Commission, Melbourne, Australia (http://www.ntc.gov.au/filemedia/Groups/PBSmapsportalFAQ.pdf).

Furthermore under the HPMV provisions in the 2010 amendment to the Vehicle Dimensions and Mass Rule, these 9-axle vehicles could operate at up to 58t or more on approved routes. Thus there is scope for the same vehicle to operate at 50t on general access and up to 58t where approved.

One obvious benefit is the potential to get better utilisation out of an HPMV vehicle when there is no work available for it on the approved higher weight routes. In this situation, the vehicles would be able to operate anywhere on the network at 50t rather than at 44t as is currently the case.

This mixed operations ability offers further potential opportunities for some particular types of operation. For example, if an operation involves either a series of deliveries where the payload is steadily decreasing during the trip or a series of pick-ups where the payload is steadily increasing, it may be possible to organise the routing so that the vehicle is at its heaviest when it is on an approved HPMV route and that it does not travel on non-approved routes except when its weight is 50t or less. Possible applications of this approach are milk collection and fuel delivery.

SUMMARY

The key points are:

- The lower bound pro-forma HPMVs (9-axle at up to 50t) are not the most cost–effective and productive vehicle configurations that are possible but they are the best that can be done while satisfying the constraints imposed by the current infrastructure.
- Suggested alternatives such as the 8-axle 48t vehicles do not satisfy these infrastructure constraints.
- Meeting the infrastructure constraints means that implementation can proceed forthwith without any significant requirements for infrastructure upgrades or legislative change to road funding mechanisms.
- The pro-forma design allows for a simple and relatively inexpensive approach to permit approvals without needing either vehicle or route assessments. This has been a significant factor in the success of HPMVs to date.
- Although there are additional costs in meeting the lower bound pro-forma design requirements particularly those associated with the additional axle, the productivity gains are substantial being of the order of 15-20%.
- The lower bound pro-forma HPMVs are capable of operating at significantly higher weights on approved routes. This provides opportunities for mixed operations which are substantially more productive than is possible at present where the vehicles are limited to 44t when they are not on their approved routes.