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The Impact of Land Use on Pavement Wear

Prepared for:

The RCA Forum and

New Zealand Forest Owners Association

April 2017

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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
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TERNZ Ltd

642 Great South Rd| Ellerslie | Auckland

PO Box 11029 | Ellerslie | Auckland 1542

Phone +64 9 579 2328

info@ternz.co.nz

www.ternz.co.nz

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INTRODUCTION

In 2016 the RCA Forum commissioned a study to quantify the impacts of land use patterns on pavement wear. This report uses the findings of two draft papers that were prepared as part of that study to develop a methodology for calculating the pavement wear implications of different land uses at the district level.

The main body of the report outlines the methodology and some recommended data sources that can be used to apply it. The Appendix which follows provides specific examples of how the methodology can be applied and gives more detailed information on the data that is available and how it can be used.

LAND USE AND TRANSPORT DEMAND

Basic Methodology for Traffic Generation from Land Use

The following steps outline the process for identifying the Heavy Commercial Vehicle (HCV) traffic generated by a particular land use:

1. Identify the land use or activity to be considered
   i.e. forestry, quarrying, dairying, dry-stock beef farming, stock finishing, sheep, etc.
2. Determine the comparison period to be used to compare the HCV traffic generated by differing land uses.
   Recommend calculating on the basis of a complete production cycle and then determining the equivalent annual average traffic.
3. Determine the <u>average</u> output values in tonnes or tonnes per hectare for that land use utilising:.
   Regional or local stocking rates
   Local milk production statistics
   Local beef, sheep, wool production statistics
   Local forest harvest statistics or quarry statistics
4. Determine the <u>average</u> input values for the land use in tonnes or tonnes per hectare utilising:
   Regional or local fertiliser or lime application rates
   Regional or local statistics for restocking rates
   Regional or local statistics for feed supplement use
   Regional or local statistics for fuel, fencing, etc.
5. Determine the HCV traffic generated by the established land uses.
   For each transport task, identify the typical vehicle configuration(s) that will be used and their payload capacity
   Determine the ESA per payload tonne associated with each input and output quantity
   Determine the ESA per hectare for the land use or activity being considered

Identify Land Use for Assessment

For land based activities such as farming and forestry, the scale of the inputs and outputs is based on the area of land involved. These production rates and input rates may vary substantially around the country but within a district for a class of farm they are likely to be consistent and thus it is reasonable to use average values.

For activities such as quarrying, the output volumes are much less directly dependent on the land area and may be proportionately much higher than for farming or forestry activities. Typically, the number of quarries within a district is relatively small and thus it is appropriate and not too difficult to assess the traffic generated by them on an individual basis. A quarry will have a resource consent which specifies the permitted level of production and in some cases the maximum allowable number of truck movements per day.

This approach of considering individual quarries can also be applied to other significant generators or attractors of heavy vehicle traffic such as dairy factories, meat processing facilities, wood processing facilities and export ports. As with quarries, the input and output volumes of these land uses is not directly linked to their land area but will usually be able to be obtained relatively easily.

It is important to recognise that each truck movement has both an origin and a destination. Attributing the pavement wear associated with that truck trip to either the origin or the destination alone can be problematic, particularly when the origin and destination are not within the same RCA district.

In identifying a land use activity for analysis we need to classify it as either being proportional to land area in which case it is a category of activity can be assessed for the whole district, or as not being proportional to land area in which case each individual operation needs to be assessed separately. This latter type of land use activity assessment would only need to be undertaken for activities that generate substantial amounts of traffic.

Examples of land use activities that are proportional to the land area involved are:

- Forestry
- Dairy farming
- Sheep farming
- Beef breeding
- Beef finishing

Examples of land use activities that are not proportional to land area but might generate substantial traffic are:

- Quarrying
- Dairy processing
- Meat processing
- Export port
- Wood processing

Analysis Period

Different land uses have different cycle times. For example, dairy farming mostly operates on annual cycle, some beef finishing operations operate on a two-year cycle while radiata pine forestry typically has a 26-30 year cycle. One possible approach is to use the land use with the longest cycle time to determine the analysis period and then to calculate the traffic generated by other land uses over that same period. A difficulty with this approach is that the longest cycle time of the land uses that we are considering is that of forestry but this period is not fixed. Trees may be harvested at anywhere between 25 and 35 years of age depending on market conditions and the business imperatives of the owners. The volume of wood extracted depends on the age of the trees.

For this reason we propose using a one year cycle. For each land use activity we recommend determining average annual input and output levels and determining the traffic generated by these. This will enable us to compare the impacts of different land use activities on a common basis.

The main limitation of using the average traffic demand over an analysis period as the measure of pavement wear is that it does not consider the timing issues associated with land uses that have long cycle times.

Determine Average Output and Input Volumes

Land-Area Based Activities

For these we need to determine the annual average output rates in tonnes or kg per ha for the particular district or region under consideration. For pastoral agriculture, there is a widely used measure for quantifying the stock-carrying capacity of pastoral farmland in New Zealand called the live-stock unit (LSU) or more simply a stock unit (SU). In New Zealand the live-stock unit is the ewe equivalent system. It expresses the annual feed requirements required for one ewe rearing a single lamb. The base assumption is that a ewe weighing 55 kg at mating and raising a single lamb to weaning at 25 kg will require approximately 520 kg of good quality pasture dry matter per year. This is 1.0 LSU. Other types of stock are then defined in LSU equivalents. The stock- carrying capacity of pastoral farm land called the stocking rate is defined in term of LSU per ha and is based on the amount of stock carried at June 30 each year. This stocking rate varies substantially around the country and for different farm types. For example, South Island high country farms have average stocking rates of about 1.3 LSU/ha while South Island intensive finishing farms have stocking rates of over 11 LSU/ha[1]. Using the national average figure for all farm types of 6.5 LSU/ha can result in large inaccuracies at the local level.

It is also important to understand exactly what is meant by land area. The stocking rate value is based on the effective land area rather than the total land area. The effective land area is only the area of land that is used for the productive farming or forestry activity. Examples of areas of land that are not part of the effective land are blocks of mature native bush and blocks of native scrub and regenerating native bush. At a national level the effective land area of farms is about 90% of the total land area but there are significant differences between districts and regions[2].

A further complication is that some farms undertake more than one type of farming activity. In estimating the traffic associated with land use we need to consider each of the activity types on the farm but it is reasonable to consider them independently.

Sheep and Beef Farming

Beef+Lamb New Zealand[3] define eight classes of sheep and beef farm. They undertake extensive annual surveys of the industry to characterise the performance of each class of farm in each of five regions. Note that there are five classes of farming that are exclusive to the South Island and three classes that are exclusive to the North Island. Thus for any district that is being analysed there will be at most five farm classes present and usually fewer. The survey data allows farmers to benchmark their farm's performance by comparing it with industry averages for their class of farm in their region.

The stocking rates for these farm classes vary from less than 2 LSU/ha to 15 LSU/ha. The production output of these farms is closely linked to their stocking rates and so to determine the traffic impacts for farms in a district, it is important to know what the local stocking rates are. The class of farm also influences the type of farming activity that is undertaken and the productivity that is achieved.

The survey data can be used to determine the average levels of input and output per hectare for a particular farm class in a particular region. From this information an estimate of the traffic impact can be determined. The Appendix presents an example of these calculations for the three North Island farm classes in the northern region (Northland, Waikato, Bay of Plenty) using the data for the 2014-15 year. Some summary results are shown below.

Table 1 shows the average characteristics of the three farm classes in the northern region. As the land conditions become easier, the farms become smaller and stocking rates increase. The more difficult land also has a higher proportion of sheep while the easier land has more beef. These figures are averages for all the farms surveyed and the average contains a mix of sheep and beef. However, individual farms within the survey may be sheep only or beef only or a mix of sheep and beef. The average values do provide a sound basis for determining the average traffic generated by these types of farms for this region.

We can summarise the average inputs and outputs per ha of northern region sheep and beef farms as shown in Table 2. It is interesting to note that the total input and output rates are quite similar in magnitude and, in fact, for hill country and intensive finishing farms, the inputs are higher than the outputs. It is also important to recognise that the different classes of farm have substantially different output and input rates with the intensive finishing farms have

[1] Beef + Lamb New Zealand (2017) Benchmarking Tool Analysis. http://portal.beeflambnz.com/tools/benchmarking-tool accessed 2/2/17.
[2] Statistics New Zealand (2012) Agricultural areas in hectares. http://www.stats.govt.nz/browse_for_stats/industry_sectors/agriculture-horticulture-forestry/2012-agricultural-census-tables/land-use.aspx accessed 7/2/2017.
[3] Beef + Lamb New Zealand (2017) Farm Classes. http://www.beeflambnz.com/information/on-farm-data-and-industry-production/farm-classes/ accessed 7/2/2017.

nearly four times the input quantities per ha to produce nearly three times the output quantities per ha of the hard hill country farms.

Table 1. Average characteristics of Northern Region sheep and beef farms.

Measure	Units	Hard Hill Country	Hill Country	Intensive Finishing
Effective area	ha	599	334	236
Stocking rate	SU/ha	7.9	9.3	11
Sheep:Cattle SU Ratio	%	56.7	42.4	22.7

Table 2. Average input/output factors for northern region sheep and beef farms.

Outputs/Inputs	Measure	Units	Hard Hill Country	Hill Country	Intensive Finishing
Outputs	Wool	kg/ha	24.73	20.64	11.15
	Store Stock	kg/ha	45.99	70.40	32.76
	Prime Stock	kg/ha	217.29	329.78	764.29
	Total Outputs	**kg/ha**	**289.01**	**420.82**	**808.20**
Inputs	Fertiliser	kg/ha	238.4	446.8	860.2
	Fuel	kg/ha	10.6	18.1	24.7
	Feed	kg/ha	26	101	163
	Total Inputs	**kg/ha**	**275.0**	**565.9**	**1047.9**

Dairy Farming

As with sheep and beef farming, dairying has an industry body, DairyNZ that collects industry data and provides benchmarking information and advice for farmers to help them improve their performance. DairyNZ defines five farm production systems primarily on the basis of when imported feed is fed to dry or lactating cows during the season and secondly by the amount of imported feed and/or off farm dry cow grazing. The definitions do not include grazing or feed for young stock.

System 1 – All grass self-contained, all stock on the dairy platform
No feed is imported. No supplement fed to the herd except supplement harvested off the effective milking area and dry cows are not grazed off the effective milking area.

System 2 – Feed imported, either supplement or grazing-off, for dry cows
Approx 4-14% of total feed is imported. Large variation in % as in high rainfall areas and cold climates such as Southland, most of the cows are wintered off.

System 3 – Feed imported to extend lactation (typically autumn feed) and for dry cows
Approx 10-20% of total feed is imported. Feed to extend lactation may be imported in spring rather than autumn.

System 4 – Feed imported and used at both ends of lactation and for dry cows
Approx 20-30% of total feed is imported onto the farm.

System 5 – Imported feed used all year, throughout lactation and for dry cows
Approx 25-40% (but can be up to 55%) of total feed is imported.

The systems are defined in order of increasing intensity of land use. Clearly the intensity of land use affects the amount of heavy vehicle traffic that is generated. DairyNZ publishes extensive statistics on dairying farming operations. A selection of these data showing the variation between districts for the 2014-15 season are shown in the appendix Note that, although the variations between districts are not insignificant (the highest producing district, North Canterbury, has about double the output per hectare of the lowest producing district, West Coast), it is less than the variations for sheep and beef farming. The districts with the highest production per hectare also tend to have the highest stocking rates and the highest production per cow. This may indicate that more intensive production systems are used in these high producing districts but we cannot assume this. It could also be that these districts have better quality land and a more favourable climate leading to more pasture growth and a longer milking season.

Apart from milk each cow produces a calf. Although about 25%[1] of these calves are retained as replacements, most dairy farmers send their replacement stock away from the milking platform to be grazed elsewhere. Thus, in most cases, all calves are transported off the farm. The calves that are not being kept as replacements will usually be sold at about 4 days of age. Some of these are sold as bobby calves for immediate slaughter while others are sold to calf-rearing operators to be grown into beef cattle.

The DairyNZ statistics for 2014-15 show that the national dairy herd is 34.7% Holstein-Friesian, 45.6% Holstein-Friesian/Jersey cross, 10.4% Jersey and 9.2% other breeds and crossbreeds. These breeds are different sizes which affects the weight of the calves and the animal's feed requirements. Using this mix of breeds we can calculate the weight of stock movements in the form of calves, cull cows and replacements. Full details are shown in the appendix.

The other major freight inflows into dairy farms are fertiliser and supplementary feed. The national average rate of fertiliser application for dairy farming land can be derived from Statistics New Zealand data. The supplementary feed freight volumes are more difficult to determine. A method for estimating the supplementary feed volumes for the different farming intensities is described in the appendix.

Applying these figures we can determine the input and output freight factors for any region. The example shown in Table 3 below uses the stocking rate for Northland, which is 2.28 cows per ha to convert per cow data to per ha data. This is to provide a direct comparison with the sheep and beef example presented in the previous section. Similar calculations can be done for any region using the stocking rate and production figures published by DairyNZ and shown in the appendix. These factors are likely to be contentious if they are applied to individual farms. Farmers who operate using a low intensity production system would certainly consider that these factors substantially over-estimate their traffic impacts. Nevertheless the largest single component is milk transport and this is the one with the greatest degree of certainty.

Table 3. Average input/output factors for Northland dairy farms.

Outputs/Inputs	Measure	Units	Average dairy farm
Outputs	Milk (density 1.033kg/l)	kg/ha	8527
	Bobby and beef calves	kg/ha	58.5
	Replacement wiener calves	kg/ha	51.3
	Replaced cows – cull etc.	kg/ha	206.6
	Total Outputs	**kg/ha**	**8843.4**
Inputs	Fertiliser	kg/ha	741
	Feed (assuming PKE)	kg/ha	1621
	Replacement heifers	kg/ha	177.8
	Fuel	kg/ha	66.7
	Total Inputs	**kg/ha**	**2606.5**

[1] Herd replacement rates are reported at about 20% in various DairyNZ reports. However, in-calf rates are typically 90% and some allowance has to be made for calf and heifer mortality so the number of replacement calves needs to be higher than 20%.

Forestry

Log harvest data is often reported in terms of volume (m^3) rather than weight (kg or tonnes). However, the traffic impacts depend primarily on the weight of logs that have to be moved and so we need to know the density of the log to convert volumes to weights. Measurements of radiata pine logs undertaken at Tokoroa in the late 1950s[1] found a density of almost exactly 1 tonne per cubic metre for both saw logs and pulp logs.

The Ministry for Primary Industries (MPI) publishes an annual assessment of the exotic forestry resource in New Zealand called the National Exotic Forest Description (NEFD). The NEFD gives annual figures for the area harvested, the volume of logs extracted and the average age of the trees at harvesting. From these numbers we can easily calculate the yield of forestry in cubic metres per hectare per annum. Each edition of the NEFD contains harvest data for the current year and the previous year. Table 4 shows data from the 2009 and 2015 editions of the NEFD. This data suggests that the yield per hectare has been gradually increasing.

Table 4. Harvest yield data for radiata pine from NEFD.

Year	Area clear-felled (ha)	Volume clear-felled (000 m^3)	Average age (years)	Average yield (m^3/ha/year)
2008	38500	17753	27.9	16.53
2009	37700	18095	28.3	16.96
2014	42896	22331	28.9	18.01
2015	46045	25036	28.4	19.15

The most recent level is 19.15 m^3 per hectare per annum which is 19.15t/ha per annum. There is some variation between regions. The MPI website publishes yield tables[2] for each region. The data for 30 year old radiata pine plantations is shown in Table 5. Although these figures are based on standing trees rather than the harvest they are consistent with the national harvest yield. The variation between regions is large enough to be significant and so we would suggest using the regional yield figures to determine the log transport traffic impact.

Table 5. Yield data by region for 30 year old radiata pine plantations from MPI.

Region	Total Recoverable Volume (m^3/ha)	Average yield (m^3/ha/year)
Northland	543	18.10
Auckland	617	20.57
Central North Island	612	20.40
East Coast	595	19.83
Hawke's Bay	625	20.83
Southern North Island East Coast	562	18.73
Southern North Island West Coast	509	16.97
Marlborough	537	17.90
Nelson	499	16.63
Canterbury	429	14.30
Otago	482	16.07
Southland	502	16.73

[1] F.A. Coulter (1959) Density of Pinus Radiata Logs, New Zealand Journal of Forestry, V8 No 1 pp143-147.

[2] https://www.mpi.govt.nz/news-and-resources/open-data-and-forecasting/forestry/new-zealands-forests/

As well as the log trucks transporting the logs away from the harvest site, there are also some heavy truck movements associated with transporting the machinery associated with log harvesting to and from the harvest site. Some of this machinery is quite large and requires heavy transporters on overweight permits to move it. Information provided by the New Zealand Forest Owners Association from one of their members suggests that for a large forest with a four-year harvest time there would be about five transport movements of road construction machinery and another five movements for harvesting machinery. This give a total of ten transport movements but, of course, there will be a further ten movements to retrieve the machinery although these may also be transporting it to a new harvest site. As we have seen above, the average yield is 19.15t/ha per annum. If the forest is harvested at 28 years of age, then approximately 19 log truck movements per ha will be generated. Thus the number of heavy machinery truck trips is approximately equal to the number of log truck trips for one hectare of forest. The heavy machinery transporters are heavier than log trucks and will have a greater impact on pavement wear per trip as discussed in the appendix but the number of trips is a very small proportion of the total traffic generated by forestry. For small forestry blocks these movements might potentially be more significant but much less heavy machinery is required so there will be fewer movements. The traffic impact effects of these machinery movements are discussed in the next section.

Apart from during harvesting, forestry generates very little heavy vehicle traffic and this can be a major issue for the local road controlling authorities. In established forestry areas where planting has occurred over an extended period and there have already been several harvest cycles, the resulting traffic flows are reasonably consistent from year to year. However, in areas where forestry has not been a traditional land use and where large scale plantings have occurred over a relatively short timeframe in the 1990s in response to government incentives, there will be sudden changes in heavy vehicle traffic volumes as these forests all reach harvesting age at approximately the same time. The annual average traffic figure will not be a good predictor of the actual traffic in any given year.

Land Uses that are not Area Based

As outlined earlier there are land use activities that are substantial generators and/or attractors of heavy vehicle traffic where the volume of traffic is not directly related to the land area being used for the activity. Obvious examples include quarries, dairy factories, saw mills and pulp mills, meat processors, fertiliser plants and ports. Many of these are associated with the one of more of the farming activities discussed in the previous sections.

For single large scale activities, the associated major input and output traffic volumes are often published. Quarries are usually subject to a resource consent which will usually specify how much material can be extracted per annum. In some cases the resource consent will also specify the maximum allowable levels of truck traffic. Similarly large processing facilities will often publish their production volumes in annual reports and other publicity material.

Some examples are described in the appendix.

Heavy vehicle traffic impacts for different transport tasks

Although we can easily convert the input and output volumes for the different land uses into an equivalent number of truck trips, different truck configurations apply different levels of loading to the pavement and this should be taken into account.

Before considering the traffic load impacts of the trucks used for the various freight tasks we should explain some of the basic principles of the approach. The first point to note is that pavements are designed with a finite life and are expected to wear out and need rehabilitation. Thus, in the context of legally loaded trucks using the roads, it is not appropriate to talk about pavement damage. The appropriate term is pavement wear. If the volume of traffic increases to levels above what the pavement was designed for, it will wear out faster than was anticipated. This is accelerated wear. Pavement damage can occur if the pavement is subjected to loads that are higher than it was designed to withstand. This occurs if the vehicles are substantially overloaded. It is not what occurs if there are simply more vehicles at legal weights.

Generally the pavement strength design requirements are determined by the amount of heavy vehicle traffic that it will experience over its design life. The heavy vehicle traffic stream, however, consists of a whole range of vehicles with different axle configurations and axle loadings. The design traffic is calculated by converting all the loading from all the axle groups of heavy vehicles into a number of passes of an Equivalent Standard Axle (ESA). The ESA normalises the pavement wear effect of the spectrum of axle loads and configurations expected on a pavement to the equivalent number of passes of a dual-tyred single axle loaded to 8.2 tonnes (80kN). In general the ESA value for an axle group is determined using a fourth power relationship as follows:

$$ESA = \left(\frac{axle\ load}{reference\ load}\right)^4$$

There are some misconceptions about the appropriate value for this exponent even among pavement engineers. The exponent value characterises the sensitivity of the pavement to changes in load magnitude. It is not a reflection of the pavement's strength as such. Some of the highest values for the exponent reported in the research literature are for very strong pavements (for example, cracking of Portland cement concrete pavements). A commonly expressed view is that a higher exponent is appropriate for weaker pavements such as those on low volume roads. Currently, there is not adequate evidence to support this. Generally the relationship between increased traffic volumes and pavement life is linear. If you double the amount of traffic on a road you will wear it out twice as fast.

A final consideration is the perception that large trucks are worse for the pavement than smaller trucks. This is not necessarily the case. Depending on axle loads and configuration, one large truck will usually generate more pavement wear than one small truck. But, if the large truck has a payload capacity of 25 tonnes and the small truck has a payload capacity of 5 tonnes, then we should be comparing one large truck with five small trucks. Often the large truck will cause less pavement than the equivalent number of small trucks.

For this analysis we will be considering the ESA per payload tonne generated by various vehicle configurations used for the freight tasks identified in the previous sections. For some freight tasks, such as stock transport, we will consider both the large truck and trailer option and the single truck option. This will show the difference between using large and small trucks. Some of the stock movement tasks identified clearly involve smaller quantities of stock which are likely to be undertaken with single trucks rather than large truck and trailer combinations

The discussion in the previous sections considered three main area-based land use activities, sheep and beef farming dairy farming and forestry as well as some other large-scale heavy vehicle traffic generators and attractors. For the area-based activities there are three main truck types involved; milk tankers, stock trucks and logging trucks. In addition to this, there are other trucks for transporting fertiliser, wool, supplementary feed, fuel etc. In recent years, the most popular truck configuration used for milk tankers, stock trucks and logging trucks has been the 4-axle truck towing a 4-axle full trailer with a gross combination weight limit of 44-tonnes. This 8-axle configuration has been more popular than the 7-axle alternatives (either a 3-axle truck and 4-axle trailer or a 4-axle truck and 3-axle trailer) because it incurred sufficiently lower Road User Charges (RUCs) to offset the loss of productivity from a higher tare weight. Interestingly, tipper trucks used for transporting bulk goods such as aggregates from quarries are more typically 7-axle combinations with a 3-axle truck and a 4-axle trailer. The reason for this is that these vehicles usually have much shorter delivery distances and so the impact of RUCs on total operating costs is not as significant as the benefit of extra payload capacity.

The new RUC system introduced in 2012 changed the relativities between the RUCs for 7 and 8 combinations making the 7-axle combinations more attractive. However, this effect was confounded to some extent by the 2010 amendment to the Vehicle Dimensions and Mass (VDAM) Rule which introduced high productivity motor vehicles (HPMVs). The 8-axle combinations are better suited to higher weight operations and so are more attractive as HPMVs. Developments in HPMVs have now led to a 9-axle combination (4-axle truck and 5-axle trailer) known as the 50MAX vehicle which has a gross combination weight limit of 50 tonnes. Complicating things further has been the weighing tolerance which has meant that the operator of a 44-tonne combination could be prosecuted for being overweight unless the total weight exceeded 45.5 tonnes (there are lower tolerances on axle group weight limits but these are not usually exceeded). In some sectors this weighing tolerance has been used as a de facto weight limit with 44-tonne vehicles routinely be operated at 45-46 tonnes.

The VDAM Rule has now been updated and the new Rule came into effect on February 1st 2017. The gross combination weight limit for 7-axle combinations will increase to 45 tonnes and 8-axle combinations will increase to

46 tonnes but this change does not come into effect until December 1st 2017. These increases have been made in conjunction with a reduction of the weighing tolerance to 500kg. These changes are likely to make the 8-axle option more attractive although operators may well prefer the 50MAX 9-axle alternative.

There is some uncertainty as to the truck configurations and weights that will be used going forward, but they are likely to be the same for the different area-based land uses. It is therefore reasonable to start by comparing the traffic loading generated by each land use based on the current most common configuration which is the 44-tonne 8-axle truck and trailer. However, this does not mean that log trucks, milk tankers and stock trucks are identical in their effect. The tare weights are different and so the payload capacity of the vehicles is different. Also log trucks "piggy-back" their trailers when empty and so the loading generated by an empty log truck is different from that of an empty milk tanker or stock truck.

To determine the ESA per tonne of payload for the different truck configurations we need to know the tare weight of the vehicles. This applies not only to the three main large truck types; stock trucks, milk tankers and logging trucks but also to inbound truck traffic for such things as fuel, feed and fertiliser. For some land uses the weight of this inbound traffic can be greater than the weight of the outbound traffic. Considering these inbound flows can be problematic because some of these items are carried on smaller trucks and smaller trucks often generate significantly more pavement wear per unit of freight moved than large trucks. Details of this analysis appear in the appendix.

The next step is to determine the ESA values associated with the various truck configurations in the both the loaded and unladen state. Detail of this analysis are shown in the appendix. Using these ESA values we can now determine the ESA / tonne of payload values for the main transport tasks. These values are shown in Table 6 below. Some key points to note are:

- Small scale transport tasks where only a truck is required rather than a truck and trailer generate substantially higher levels of pavement wear per tonne of payload than large scale transport of the same commodity using the same type of vehicles.
- The average ESA values shown are based on the vehicle being empty in one direction of travel and full in the other direction. For most tasks this is a reasonable assumption. This is discussed further in the appendix.
- If a number of farms contribute to a full load (as in the case of milk tankers) then the ESA /tonne approach means that each of them will have the ESA attributed to them in proportion to the amount of the payload that they contribute.
- This approach to assigning an average ESA implicitly assumes that the heavy vehicle traffic impacts are the same in both directions of travel on the road. RUCs are also based on this assumption. In many cases this is not unreasonable because input and output volumes are similar and/or the travel directions of the loaded vehicles are not all the same. However, in some cases, the heavy vehicle traffic will be heavily biased in one of the travel directions. In this situation, the pavement wear in heavily trafficked direction will be much higher on this lane than on the opposite lane. This issue is discussed further in the appendix.
- The low loader vehicles are used for transporting machinery associated with log harvesting. The average ESA for these vehicles is approximately double that of a log transport vehicle. Interestingly the 60t and 90t vehicles generate approximately the same ESA. The reason for this is that the trailer axle loads on the 90t are lower than those on the 60t vehicle. The fourth power exponent amplifies this difference in the ESA value.

Table 6. ESA per tonne of payload for key transport tasks.

Transport Task	Vehicle Configuration	Payload weight	ESA (Average)	ESA / tonne
Milk collection	4-axle truck + 4-axle trailer	25826	1.485	0.058
Stock and augur feed -large scale	4-axle truck + 4-axle trailer	21000	1.514	0.072
Stock and augur feed-small scale	4-axle truck	12000	1.900	0.158
Log transport	4-axle truck + 4-axle trailer	27715	1.509	0.054
Wool - large scale	4-axle truck + 4-axle trailer	27000	1.482	0.055
Wool - small scale	4-axle truck	15000	1.877	0.125
Bulk materials - aggregate, feed, bulk fertiliser - large scale 4-axle truck	4-axle truck + 4-axle trailer	26673	1.483	0.056
Bulk materials - aggregate, feed, bulk fertiliser - small scale	4-axle truck	14673	1.878	0.128
Bulk materials- aggregate, feed, bulk fertiliser - large scale 3-axle truck	3-axle truck + 4-axle trailer	28293	2.305	0.081
Fertiliser spreader – small scale	2-axle truck	5000	1.936	0.387
Fertiliser spreader – medium scale	3-axle truck	7000	1.610	0.230
Fertiliser spreader large scale	3-axle truck + 3-axle trailer	17000	1.900	0.112
Fuel tanker 3-axle	3-axle truck	9000	1.842	0.205
60t low loader	3-axle tractor + 3x8 axle trailer	35000	3.041	0.087
90t low loader	3-axle tractor + 2x8 axle dolly + 3x8 axle trailer	59700	3.187	0.053

An Example Calculation for Northland

We can now apply these factors to various land uses in a region. For sheep and beef farming we illustrated the input and output data extraction process using data for the Northern region and so we will use this region to compare the traffic impacts of various common land use activities.

We can combine the input/output quantities, which are in kg/ha with the ESA/tonne traffic impact factors to calculate traffic impact factors in ESA per 1000ha[1]. For sheep and beef farming, assuming that wool and store stock are transported using the small scale approach while prime stock transport is large scale and feed and fertiliser uses large scale bulk transport we get the traffic impacts shown in Table 7.

Table 7. Heavy vehicle traffic impacts in ESA/1000ha for northern region sheep and beef farms.

Outputs/Inputs	Type	Hard Hill Country	Hill Country	Intensive Finishing
Outputs	Wool	3.09	2.58	1.40
	Store Stock	7.28	11.14	5.19
	Prime Stock	15.67	23.78	55.12
	Total Outputs	**26.04**	**37.51**	**61.70**
Inputs	Fertiliser	13.26	24.85	47.84
	Fuel	2.17	3.70	5.06
	Feed	1.45	5.62	9.06
	Total inputs	**16.87**	**34.17**	**61.96**
Grand Total		**42.92**	**71.68**	**123.65**

[1] ESA/1000ha is used rather than ESA/ha for ease of presentation.

Similarly we can the same approach to the data for Northland dairy farms. In this case we assume that the stock movements are undertaken using small scale trucks, the feed is delivered using small scale bulk materials and the fertiliser is applied using large scale spreader vehicles. The resulting heavy traffic impacts are shown in Table 8.

Table 8. Heavy vehicle traffic impacts in ESA/1000ha for Northland dairy farms.

Outputs/Inputs	Type	Average dairy farm
Outputs	Milk	490.33
	Bobby and beef calves	9.26
	Replacement wiener calves	8.12
	Replaced cows – cull etc.	32.70
	Total	**540.42**
Inputs	Fertiliser	82.81
	Feed (assuming PKE)	207.43
	Replacement heifers	28.15
	Fuel	13.65
	Total	**332.04**
Grand Total		**872.46**

For logging the average yield for Northland is 18.1m^3/ha per annum. Assuming a density of 1000kg/m^3 the traffic impact of this logging activity is **985.4 ESA/1000ha** per annum. In addition to this there are some heavy haulage movements of machinery associated with log harvesting. For large forestry blocks these increase the traffic impact by about 0.2% to **987.4 ESA/1000ha** per annum. For smaller forestry blocks the impact is a little larger but should always be less than 1%. Details are given in the appendix.

As noted in the section on land use activities that are not land area dependent, some of these can generate very significant traffic impacts while occupying only relatively modest land areas. Two quarries in the Auckland district were used as examples. If we consider the Hunua quarry which occupies a land area of 240ha and produces 2M tonnes of aggregate per annum, we can see that this is an output of 8,333,333kg/ha. Assuming this is transported using 3-axle truck and 4-axle trailer combinations, the traffic impact is **675,000 ESA/1000ha** per annum.

Table 9 shows a comparison of the traffic impacts for these different land uses based on the data for Northland and the Northern region.

Table 9. Summary of comparative traffic impacts for different land uses based on Northern region data.

Land Use	Traffic Impact (ESA / 1000ha)
Hard hill country – sheep and beef farming	42.9
Hill country – sheep and beef farming	71.7
Intensive finishing – sheep and beef farming	123.7
Dairy farming – average for a mix of dairying systems	872.5
Forestry	987.4
Quarrying – single example in the Northern region	675,000.0

These traffic impact values highlight a number of key issues:

- Even within a region there is a significant difference in the traffic impact per ha between different categories of sheep and beef farms. For the northern region, intensive finishing farms have about three times the traffic impact/ha of hard hill country farms. At a national level these differences will be much larger still.
- Based on these figures, dairy farms in Northland have about 7 times the traffic impact per ha of intensive finishing sheep and beef farms. The figures for fertiliser and supplementary feed in these calculations are based on estimates of national averages rather the regionally specific data. Northland dairy farms have a relatively low milk output per ha compared to other regions. It may well be that their supplementary feed input is lower as well which would reduce their traffic impact a little.
- Dairy farms in other regions have higher rate of milk output per ha with the highest region being nearly double that of Northland. Clearly dairy farms in these regions will produce a higher traffic impact per ha than Northland although not necessarily proportionately so. The stocking rate in the highest producing region is only just over 50% higher than Northland and so clearly there is more output per cow as well as per hectare.
- In Northland logging has about 13% more traffic impact than dairying. However, the regional variation in forestry output is much less than it is for other land use activities. The highest output region is 15% higher than Northland and the lowest is 21% lower. For logging the traffic impact is directly proportional to the output volumes. Thus in other regions we would expect the traffic impact per ha from logging to be lower than dairying.
- There are specific land use activities such as quarrying that can generate traffic impacts that are hundreds if not thousands of times higher per ha than farming or forestry.

CONCLUSIONS

This report has described a method for estimating the traffic impacts of different land use activities and presented the main data sources needed to apply the methods. It has presented an example of how the method can be applied to a ranges of land use activities in a specific region.

The measure of traffic impact that was used in the method is ESA which describes the traffic loading effects. However, the amount of pavement wear that will result is determined by the loading effect multiplied by the length of road over which it is applied. Transport operators pay for this impact through RUCs which are based on the pavement wear impact of the vehicle and the distance travelled. This analysis has not addressed the distance aspect of the pavement wear impacts.

Furthermore every transport trip has an origin and a destination and both are beneficiaries of the trip occurring. The analysis method developed here has tended focus on one party to each of the trips. However, the method can equally be applied to the other parties. For example, the dairying analysis has considered only dairy farms as generators of milk tanker trips. But dairy factories are attractors of milk tankers and the method can be applied equally to them. Trips would then be counted twice but this can be addressed by attributing part of the distance to the generator and part to the attractor. For local RCAs this approach may be very useful when the generators and the attractors are not in the same RCA.

APPENDIX

Calculation of Traffic Demand Factors

Identify Land Use for Assessment

The previous work in this study considered only land-based activities for comparison and thus determined inputs and outputs on a per hectare basis. However, subsequent discussions did suggest considering other land use activities such as quarrying. This adds an additional level of complexity to the analysis. For land based activities such as farming and forestry, the scale of the inputs and outputs is based on the area of land involved. These production rates and input rates may vary substantially around the country but within a district for a class of farm they are likely to be consistent and thus it is reasonable to use average values.

For activities such as quarrying, the output volumes are much less directly dependent on the land area and may be proportionately much higher than for farming or forestry activities. For example, the Hunua quarry covers 240 ha and produces about 2M tonnes of product per annum[1] while the neighbouring Brookby quarry has a land area of just under 70 ha and has recently had its consent changed to allow an annual production of between 3.9M and 4.6M tonnes[2]. Compared to farming and forestry land use activities, these annual production volumes per ha are enormous and they are also very different between the two sites (8333 tonnes/ha for Hunua and 57,000-67,000 tonnes/ha for Brookby). By comparison dairy farms produce, on average, about 12 tonnes/ha of milk. Typically, the number of quarries within a district is relatively small and thus it is appropriate and not too difficult to assess the traffic generated by them on an individual basis. A quarry will have a resource consent which specifies the permitted level of production.

This approach of considering individual quarries can also be applied to other significant generators or attractors of heavy vehicle traffic such as dairy factories, meat processing facilities, wood processing facilities and export ports. As with quarries, the input and output volumes of these land uses is not directly linked to their land area but will usually be able to be obtained relatively easily.

This does raise an interesting question on how to attribute traffic impacts which are effectively generated by two land uses. For example, should the transport of milk from dairy farms to a dairy factory be attributed to the farms or to the factory or to both? A simple solution is to attribute only the output volumes to each land use activity as the input volumes represent the outputs of some other land use activity. Using this approach each transport movement is allocated to only one land use activity.

However, this does not necessarily result in a fair attribution of the heavy vehicle traffic impacts to the land use. For example, the yield of whole milk powder from whole milk is typically about 13%. Thus, a dairy factory producing milk powder would only have 11.5% of its total truck traffic attributed to it. The other 88.5% would be attributed to the farms supplying the factory. For a local RCA, this can be particularly problematic because, in some instances, the farms and the factory will not be in the same RCA's territory. An extreme example is Fonterra's Te Rapa dairy factory, which lies within Hamilton City's boundary while there are few if any dairy farms within the city boundary. Note that in this discussion, dairying is simply being used as an example. The same situation arises with forestry and wood processing or log export facilities and with sheep and beef farming and meat and wool processing facilities. It can also occur for farm inputs such as fertiliser production.

An alternative approach can be derived as follows. The proposed methodology estimates the traffic impact in terms of ESA which is a measure of the traffic loading. The pavement wear impact can be estimated by ESA-km, which is the traffic loading impact multiplied by the length of road affected. Thus the combined effect of, for example, dairy farms and dairy factories can be accounted for by attributing some road distance values to each land use and counting both inputs and outputs. In this way a processing plant which gets most of its inputs from outside the district will still show up as having a significant traffic impact. The main difficulty with this approach is determining what the appropriate distance factor to use for each land use.

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[1] Winstone Aggregates Hunua Quarry (2017) www.hunuaquarry.co.nz accessed 1/2/17.
[2] Brookby Quarries Ltd (2017). www.brookbyquarry.co.nz/NEWS.html accessed 1/2/17.

Determine Average Output and Input Volumes

Sheep and Beef Farming

Beef + Lamb New Zealand[1] define eight classes of sheep and beef farm as shown in Table A1. They undertake extensive annual surveys of the industry to characterise the performance of each class of farm in each of five regions. This survey data allows farmers to benchmark their farm's performance by comparing it with industry averages for their class of farm in their region.

The stocking rates for these farm classes vary from less than 2 LSU/ha to 15 LSU/ha. The production output of these farms is closely linked to their stocking rates and so to determine the traffic impacts for farms in a district, it is important to know what the local stocking rates are. The class of farm also influences the type of farming activity that is undertaken and the productivity. Beef + Lamb New Zealand undertake annual surveys of sheep and beef farm performance and present the results by region and by farm class in quintiles based on EBITR per ha[2]. From this data we can extract the average productivity of sheep and beef farms in a region by farm class. Note that every region does not include every farm class. Obviously there are no South Island high country farms in the North Island.

Table A1. Beef + Lamb NZ Survey - Farm Classes

Sheep and beef farm survey 2014-15 farm class			Estimated farms
1	South Island	High country	215
2	South Island	Hill country	810
3	North Island	Hard hill country	1,065
4	North Island	Hill country	3,640
5	North Island	Intensive finishing	1,275
6	South Island	Finishing breeding	2,505
7	South Island	Intensive finishing	1,290
8	South Island	Mixed finishing	495
Total all classes			**11,295**

To illustrate how this data can be used let us consider survey results for the Northern North Island region which consists of Northland, Waikato and Bay of Plenty. There are three farm classes in this region, hard hill country, hill country and intensive finishing which are number 3, 4 and 5 in the table above. The latest time period for which finalised data is available is 2014-15. There is provisional data for 2015-16 and forecast data for 2016-17.

The survey data is geared towards farm economics but it does provide information on farm production although this does need some processing to convert it into freight demand in kg/ha. The outputs of these farms are meat, wool and stock. The survey data shows the average wool production in kg/ha so this figure can be used as is. For meat it shows the average number of animals produced by type and age class. For these it also gives the price received in $/head and $/kg but the weight here refers to carcass weight while for transport calculations we need to know the live weight. Some animals are sold as "store" which means that they are sold to other farmers for finishing. For these animals the survey data shows the numbers sold and the price in $/head but it does not show the weights. However, Beef + Lamb NZ also produce a tool for calculating production volumes on sheep and beef farms[3] and this tool includes standard default values for the "dressing out" percentage of different stock types

[1] Beef + Lamb New Zealand (2017) Farm Classes. http://www.beeflambnz.com/information/on-farm-data-and-industry-production/farm-classes/ accessed 7/2/2017.
[2] Beef + Lamb New Zealand (2017) Benchmark your farm. http://beeflambnz.com/information/on-farm-data-and-industry-production/benchmarking-data accessed 7/2/17.
[3] Beef + Lamb New Zealand (2017). Meat and Wool Production Calculator http://portal.beeflambnz.com/tools/MeatWoolCalc accessed 9/02/2017.

and for the live weight of "store" animals of different types and age classes. Using these factors we can calculate the live weight per ha of prime stock sold for meat and store stock sold for finishing elsewhere.

For prime animals: average live weight = $/head / $/kg (CW) *100/ Dressing out percentage.

Output (kg/ha) = average live weight * number of animals / number of ha

For store animals: Output (kg/ha) = average live weight * number of animals / number of ha

Applying these factors to the Northern Region survey data gives the average outputs for the different farm classes shown in Table A2. From a transport perspective, most of the demand is generated from prime livestock. It is also noteworthy that there are substantial differences in the average output per ha for the three classes of farm.

Table A2. Average outputs in kg/ha for sheep and beef farms in the Northern Region 2014-15.

Measure	Units	Hard Hill Country	Hill Country	Intensive Finishing
Wool Shorn	**kg/ha**	**24.73**	**20.64**	**11.15**
Store Lambs LW/ha	kg/ha	15.10	11.36	5.23
Calf/Wnr Str Store LW/ha	kg/ha	2.20	4.61	0.93
Calf/Wnr Hfr Store LW/ha	kg/ha	2.76	3.10	0.00
Calf/Wnr Bull Store LW/ha	kg/ha	0.90	2.68	0.76
1-1.5 Steer Store LW/ha	kg/ha	11.41	13.24	8.52
1-1.5 Heifer Store LW/ha	kg/ha	4.41	5.93	13.98
1Yr+ Bulls Store LW/ha	kg/ha	9.21	29.49	3.34
Total Store Stock	**kg/ha**	**45.99**	**70.40**	**32.76**
Prime Lambs LW/ha	kg/ha	80.92	102.21	65.49
Prime Hogget LW/ha	kg/ha	6.73	14.27	45.52
Prime Ewes LW/ha	kg/ha	22.84	29.56	19.54
1-1.5 Strs Prime LW/ha	kg/ha	2.10	2.95	0.00
1-1.5 Hfrs Prime LW/ha	kg/ha	7.98	10.86	12.69
2Yr+ Hfrs Prime LW /ha	kg/ha	15.41	20.92	44.17
2Yr+ Strs Prime LW /ha	kg/ha	32.95	32.87	258.91
Prime Cows LW/ha	kg/ha	17.70	15.15	13.00
Prime Bulls LW/ha	kg/ha	30.67	100.99	304.96
Total Prime Stock	**kg/ha**	**217.29**	**329.78**	**764.29**

The main farm inputs that are shown in the benchmarking data spreadsheets are fertiliser and lime. The amounts applied in 2014-15 in the northern region are shown in Table A3. Again it is clear that the more intensive farm classes which have higher stocking rates and higher levels of production also have higher levels of inputs.

Table A3. Average fertiliser and lime applied to Northern Region sheep and beef farms 2014-15.

Measure	Units	Hard Hill Country	Hill Country	Intensive Finishing
Total Fertiliser	kg/ha	190	258	407
Lime	kg/ha	48.4	188.8	453.2
Combined Total	**kg/ha**	**238.4**	**446.8**	**860.2**

One other significant input that we would have expected to see for some farm classes is store stock but it does not appear in the benchmarking spreadsheets. All of the farm classes have revenue from the sale of "store" stock and the spreadsheets show the average number of animals of each type and age category sold but there is no expenditure item for the purchase of "store" stock for any of the farm classes. As expected the average hard hill country farm has a higher proportion of "store" animals relative to "prime" than the average hill country farm which, in turn, is higher than the average intensive finished farm but there is no indication of a net inflow of store animals for any farm class in any region. We have checked the spreadsheets for all regions. This does not appear to make sense. We have e-mailed the economics section of Beef+Lamb NZ to see if they can explain it but as yet we have had no response. Logically all "store" stock outputs should be matched by "store" stock inputs elsewhere. Clearly we would expect store stock from hill country farms to be moved to intensive finishing farms but we don't know whether these will be in the same region or not.

Most of the other expenditure items on the benchmarking spreadsheets do not require significant levels of transport. There are two items that will generate a small amount of freight which are "Vehicles & Fuel" and "Feed & Grazing". Both of these are shown by expenditure in $/ha and not in quantities relating to transport requirements. However, because the volumes involved are relatively small we can make some reasonable assumptions for converting the expenditure to weight and not distort the resulting overall traffic loadings.

The Beef+Lamb NZ sheep and beef farm survey outputs have a whole farm analysis[1] which separates vehicle expenses from fuel expenses. For all farms surveyed in New Zealand fuel was 47% of "Vehicles & Fuel" costs although this percentage does vary from region to region. This variation may be a reflection of higher fuel costs in some regions but we have not investigated this. Most of the fuel involved is likely to be diesel. The average pump price for 2014-15 was $1.27 per litre[2]. Excluding GST this is $1.10 per litre. The density of diesel is 0.832 kg/l. Thus we can calculate a conversion factor to convert the expenditure/ha on "vehicles and fuel" to a weight of fuel in kg/ha. This is:

Weight of fuel used (kg/ha) = Expenditure ("Vehicles & Fuel") x 0.47 / 1.10 x 0.832

= 0.36 x Expenditure ("Vehicles & Fuel")

For petrol, the average pump price was $1.966 per litre but this includes 67.284c per litre of fuel excise tax which farmers can get rebated for off-road use. Without the excise tax and GST, the price of petrol was $1.12 per litre. The density of petrol is about 0.74 kg/l. Thus if the fuel was petrol

Weight of fuel used (kg/ha) = Expenditure ("Vehicles & Fuel") x 0.47 / 1.12 x 0.74

= 0.31 x Expenditure ("Vehicles & Fuel")

Thus the difference between the two conversion factors is very small and so it appropriate to use a mid-point value of 0.335.

The situation with "Feed and Grazing" expenditure is complicated by the fact that we don't know the split between the two components. If we assume that the expenditure is entirely on feed then we just need to know the average price of feed in $/kg. Palm Kernel Expeller (PKE) is a feed supplement widely used in dairying which in 2015 cost about $0.3 /kg for bulk volumes. Other bulk feeds such as maize, barley or oats are more expensive at $0.4-$0.5 /kg. Pelletised feeds are more expensive still ranging from about $0.5 to over $1 /kg. For supplementary feed if we set a range of prices from $0.3 /kg to $1.0/kg we can estimate a range of weights for the amount of feed transported to the farm per ha. For grazing, it is possible to get estimates of the cost per week per animal or per SU. However, we can't determine from this, how many animals were grazed off the farm for how long and so we can't estimate the associated traffic impacts. For example, if we assume that the expenditure is all for grazing and calculate that it is equivalent to, say, 1000 weeks of grazing for a heifer. Then we

[1] Beef+Lamb NZ (2017). Whole farm analysis: New Zealand, http://www.beeflambnz.com/information/on-farm-data-and-industry-production/sheep-beef-farm-survey/nz/ accessed 14/02/17

[2] Ministry of Transport (2017). Transport-Related Price Indices: Prices, http://www.transport.govt.nz/ourwork/tmif/transportpriceindices/ti006/ accessed 14/02/17.

can't tell whether this represents 25 heifers grazed for 40 weeks, 50 heifers grazed for 20 weeks or 100 heifers grazed for 10 weeks. Furthermore we can't tell whether the grazing is on a neighbouring farm that the animals could walk to or whether it involves hundreds of kms of truck travel. We will begin by assuming that "Feed and Grazing" expenditure was all for feed and then assess whether spending the money on grazing would significantly change the transport demand. The average fuel and feed inputs for the three classes of northern region sheep and beef farms are shown in Table A4.

Table A4. Fuel and feed inputs to Northern Region sheep and beef farms 2014-15.

Measure	Units	Hard Hill Country	Hill Country	Intensive Finishing
Expenditure "Vehicles & Fuel"	$/ha	31.56	53.91	73.80
Weight fuel used	kg/ha	10.6	18.1	24.7
Expenditure "Feed & Grazing"	$/ha	11.88	46.51	75.35
Weight feed	kg/ha	11.9 - 39.6	46.5 - 155	75.4 – 251.2

Although there is some uncertainty regarding these input figures, they are much lower than the fertiliser input figures and so the effect of the uncertainty on the overall traffic impacts is quite small.

It should be noted that the fuel expenses are not limited to those associated with off-highway vehicles. They are likely to also include fuel for the road vehicles associated with the farm and this fuel may well be purchased at the pump rather than delivered to the farm.

From the definition of LSU given previously we can see that weight of dry matter annual feed requirements for an animal is 6-7 times the weight of the animal itself. Thus if the grazing period is more than 2 months, the transport volume associated with off-farm grazing will be less than the transport volume associated with bringing in an equivalent amount of supplementary feed.

Assuming a mid-range value for supplementary feed inputs we can summarise the average inputs and outputs per ha of northern region sheep and beef farms as shown in Table A5. It is interesting to note that the total input and output rates are quite similar in magnitude and, in fact, for hill country and intensive finishing farms, the inputs are higher than the outputs. It is also important to recognise that the different classes of farm have substantially different output and input rates with the intensive finishing farms have nearly four times the input quantities per ha to produce nearly three times the output quantities per ha.

Table A5. Average input/output factors for northern region sheep and beef farms.

Outputs/Inputs	Measure	Units	Hard Hill Country	Hill Country	Intensive Finishing
Outputs	Wool	kg/ha	24.73	20.64	11.15
	Store Stock	kg/ha	45.99	70.40	32.76
	Prime Stock	kg/ha	217.29	329.78	764.29
	Total Outputs	**kg/ha**	**289.01**	**420.82**	**808.20**
Inputs	Fertiliser	kg/ha	238.4	446.8	860.2
	Fuel	kg/ha	10.6	18.1	24.7
	Feed	kg/ha	26	101	163
	Store stock	kg/ha	unknown	unknown	unknown
	Total Inputs	**kg/ha**	**275.0**	**565.9**	**1047.9**

Dairy Farming

Dairy farming has traditionally been undertaken on relatively good quality pasture land in areas with relatively high rainfall and with relatively high stocking rates. The reasons for this are reasonably obvious. The cows are brought in for milking twice a day and so they need to be able to be grazed within reasonable walking distance of the milking shed. Thus higher stocking rates are desirable. The higher rainfall is desirable to promote pasture growth and because milking cows need a lot of water. In recent years the relatively high returns from dairying farming have encouraged the conversion of farms to dairying in non-traditional areas as well as larger herds and more intensive farming. These changes have been achieved through the use of irrigation and a greater use of supplementary feeding.

As with sheep and beef farming, dairying has an industry body, DairyNZ that collects industry data and provides benchmarking information and advice for farmers to help them improve their performance. DairyNZ defines five farm production systems primarily on the basis of when imported feed is fed to dry or lactating cows during the season and secondly by the amount of imported feed and/or off farm dry cow grazing. The definitions do not include grazing or feed for young stock.

System 1 – All grass self-contained, all stock on the dairy platform

No feed is imported. No supplement fed to the herd except supplement harvested off the effective milking area and dry cows are not grazed off the effective milking area.

System 2 – Feed imported, either supplement or grazing-off, for dry cows

Approx 4-14% of total feed is imported. Large variation in % as in high rainfall areas and cold climates such as Southland, most of the cows are wintered off.

System 3 – Feed imported to extend lactation (typically autumn feed) and for dry cows

Approx 10-20% of total feed is imported. Feed to extend lactation may be imported in spring rather than autumn.

System 4 – Feed imported and used at both ends of lactation and for dry cows

Approx 20-30% of total feed is imported onto the farm.

System 5 – Imported feed used all year, throughout lactation and for dry cows

Approx 25-40% (but can be up to 55%) of total feed is imported.

As can be seen the systems are defined in order of increasing intensity of land use. DairyNZ publishes extensive statistics on dairying farming operations. A selection of these data showing the variation between districts for the 2014-15 season are shown in Table A4. Note that, although the variations between districts are not insignificant (the highest producing district, North Canterbury, has about double the output per hectare of the lowest producing district, West Coast), it is less than the variations for sheep and beef farming. The districts with the highest production per hectare also tend to have the highest stocking rates and the highest production per cow. This may indicate that more intensive production systems are used in these high producing districts but we cannot assume this. It could also be that these districts have better quality land and a more favourable climate leading to more pasture growth and a longer milking season.

Mounsey[1] has undertaken an economic analysis of the different production systems. For his analysis he groups the systems such that system1 and 2 are categorised as low intensity, system 3 as medium intensity and systems 4 and 5 as high intensity. Over the years the dairy industry has moved from being primarily low intensity to having an almost uniform distribution of intensities. The latest figures given by Mounsey are for the 2013-14 season and this shows 30% of farms at low intensity, 41% at medium intensity and 29% at high intensity. The economic benefits of supplementary feeding depend on the milk price and the cost of feed. With a low milk price it may be more profitable to change to a less intensive farming production system. This is not inherently difficult to do but it is difficult to forecast what the final milk price will be and farmers can often get supplementary feed at a better

[1] Mounsey, Z. (2015). Analysis of Production Systems in the New Zealand Dairy Industry. Kellogg Rural Leadership Programme. Research Report. DairyNZ.

price if they contract in advance to buy a guaranteed quantity. These two factors mitigate against rapid changes in intensity.

Table A6. Dairy farming statistics by district from DairyNZ 2014-15.

Farming Region	Average effective area per farm (ha)	Average number (cows per herd)	Average production (litres / cow)	Average number (cows per ha)	Average production (litres per ha)
Northland	136	311	3621	2.28	8255
Auckland	112	273	3900	2.42	9439
Waikato	113	335	4177	2.97	12405
Bay of Plenty	119	337	4154	2.84	11796
Central Plateau	199	541	4254	2.73	11614
Western Uplands	204	515	3426	2.52	8635
East Coast	217	588	3444	2.7	9298
Hawkes Bay	231	652	4128	2.82	11641
Taranaki	102	291	4311	2.85	12286
Manawatu	144	396	4543	2.75	12492
Wairarapa	132	366	4013	2.77	11115
North Island	**123**	**342**	**4148**	**2.78**	**11530**
Nelson/Marlborough	130	370	4006	2.84	11377
West Coast	188	414	3742	2.2	8233
North Canterbury	231	808	4708	3.5	16479
South Canterbury	235	803	4435	3.41	15125
Otago	202	612	4226	3.03	12805
Southland	213	591	4253	2.77	11780
South Island	**209**	**633**	**4371**	**3.03**	**13243**
New Zealand	**146**	**419**	**4239**	**2.87**	**12167**

Apart from milk each cow produces a calf. Although about 25%[1] of these calves are retained as replacements, most dairy farmers send their replacement stock away from the milking platform to be grazed elsewhere. Thus, in most cases, all calves are transported off the farm. The calves that are not being kept as replacements will usually be sold at about 4 days of age. Some of these are sold as bobby calves for immediate slaughter while others are sold to calf-rearing operators to be grown into beef cattle. The average weight of bobby calves is 34.2kg[2]. As we are assuming that 75% of calves fall into this category, this is 25.7kg of calf per cow.

Replacement calves are reared on the farm until weaning. At this time they should achieve about 20% of their mature weight. This is about 76kg for a Jersey cow, about 98kg for a Holstein-Friesian and 88kg for a Jersey-Friesian cross. The DairyNZ statistics for 2014-15 show that the national dairy herd is 34.7% Holstein-Friesian, 45.6% Holstein-Friesian/Jersey cross, 10.4% Jersey and 9.2% other breeds and crossbreeds. Using these breed mix proportions we can estimate the weight of an average weaner replacement calf at 90kg. With 25% of calves in this category we have a replacement calf output of 22.5kg per cow.

[1] Herd replacement rates are reported at about 20% in various DairyNZ reports. However, in-calf rates are typically 90% and some allowance has to be made for calf and heifer mortality so the number of replacement calves needs to be higher than 20%.

[2] New Zealand Animal Evaluation Limited (2013). Live weight. Analysis prepared for DairyNZ. https://www.dairynz.co.nz/media/928750/Liveweight-Economic-Model.pdf accessed 17/02/17

There are some regional variations in the mix of breeds but using these will only have a minor impact on the estimate of the average weaner calf weight. For each region the number of cows/ha is shown in Table A6 and we can calculate estimates of the weight of replacement calves per ha and the weight of bobby/beef calves per ha transported from the average farm.

As noted above the average cow replacement rate is about 20%[1]. Thus there is also an outflow of mature cows which is equivalent to 20% of the herd. Of the 20% about 2% of these are deaths and the other 18% are sold or culled. Using the same breed proportions as for calves and the same mature weight values, we can estimate the average weight of a mature cow as 453kg. The output rate of cows being replaced is 90.6kg per cow in the herd. This assumes that dead cows are also disposed of off the farm.

For each of the mature cows removed from the herd there is an inflow of pregnant heifers as replacement stock. These arrive back at about 21 months of age and at 86% of mature weight (390kg). Because we are replacing 20% of the herd, this is equivalent to 78kg per cow in the herd.

The other major freight inflows into dairy farms are fertiliser and supplementary feed. The national average rate of fertiliser application for dairy farming land can be derived from Statistics New Zealand data. For the 2012 year (the latest for which data is published) the average application rate was 0.741 t/ha (741kg/ha). This calculation is based on effective land area as it only includes land used for pasture or for growing feed crops. It is likely that there are some regional variations in the fertiliser application rates but we have not found any data for these.

The supplementary feed freight volumes are also difficult to determine. The LSU for dairy cows ranges from 6.5 for a Jersey cow to 8.5 for a Holstein-Friesian cow with the cross breed about midway between. Based on the breed proportions given previously this gives an average for the dairy herd of 7.77 LSU. As an LSU is based a dry matter (DM) feed requirement of 520kg p.a., this means that the average dairy cow requires 4040kg of DM feed p.a. The feed requirements per ha can be calculated for each region using the stocking rates shown in Table A6. As outlined above, Mounsey reduced the five production systems to three intensity levels and determined the proportion of farms in each level. If we assume that the mid-point of the range of supplementary feeding proportions represents the average, then we see that low intensity farming buys in 4.5% of its feed requirements, medium intensity buys in 15% and high intensity buys in 28.75%. Using the proportions of farms in each level we can estimate an industry average of 15.85%. This equates to 640kg of DM per cow. The DM content of various feed types varies. PKE is about 90% DM, hay is 85% whereas silage is between 30% and 50%. Thus the weight of feed to be transported depends on the type feed. At 15.85% supplementary feeding, for PKE about 711 kg per cow is required, for hay about 753kg per cow while for silage, 1208- 2133kg per cow. The earlier paper identified the practice of wintering off the milking herd. This is done mainly in Southland and other cold climate areas with minimal winter pasture growth and to some extent in wetter North Island areas where keeping the cows on the waterlogged pasture causes damage to the pasture which affects its productivity in the spring. As noted in the definitions above this approach is actually a form of production system 2. The difference is that instead of bringing the supplementary feed to the cows, the cows are taken to the supplementary feed. As shown above the average weight of a mature cow is approximately 453kg. In the wintering-off situation it is likely to be a little below desirable weight when taken to the grazing and should be a little above it when returning just prior to calving. The weight transported is therefore around 900kg per cow with the two trips. This is more than the weight of feed when using dry feeds like PKE or hay but less than when using silage feeds.

The vehicles and fuel cost figures for dairy farms in 2014-15[2] was $199/ha. If we assume that, like sheep and beef farms, 47% of this cost is fuel. Then using the same cost and density factors we obtain the factor that the weight of fuel used is 0.335 x expenditure on vehicles and fuel. Thus the estimated fuel use is 66.7 kg/ha. As with sheep and beef farms, some of this fuel will be purchased at the pump for road vehicles and not all of it is necessarily delivered to the farm.

Applying these figures we can determine the freight factors for any region. For the example shown in Table A7 below we have used the stocking rate for Northland, which is 2.28 cows per ha to convert the per cow data to per

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[1] Xu Z. and Burton L. (2003). Reproductive performance of dairy cows in New Zealand. Livestock Improvement Corporation, Hamilton
http://www.lic.co.nz/user/file/Monitoring%20fertility%20report%20for%20distribution.pdf accessed 17/02/17

[2] DairyNZ (2015). DairyNZ Economic Survey 2014-15. https://www.dairynz.co.nz/media/4291790/dairynz-economic-survey-2014-15.pdf accessed 17/02/17

ha data. Similar calculations can be done for any region using the stocking rate and production figures shown in Table A6**Error! Reference source not found.**.

Table A7. Average input/output factors for Northland dairy farms.

Outputs/Inputs	Measure	Units	Average dairy farm
Outputs	Milk (density 1.033kg/l)	kg/ha	8527
	Bobby and beef calves	kg/ha	58.5
	Replacement wiener calves	kg/ha	51.3
	Replaced cows – cull etc.	kg/ha	206.6
Inputs	Fertiliser	kg/ha	741
	Feed (assuming PKE)	kg/ha	1621
	Replacement heifers	kg/ha	177.8
	Fuel	kg/ha	66.7

These factors are likely to be contentious if they are applied to individual farms. Farmers who operate using a low intensity production system would certainly consider that these factors substantially over-estimate their traffic impacts. Nevertheless the largest single component is milk transport and this is the one with the greatest degree of certainty.

Forestry

In most data sources the log harvest is reported in terms of volume (m^3) rather than weight (kg or tonnes). However, the traffic impacts depend primarily on the weight of logs that have to be moved and so we need to know the density of the log to convert volumes to weights. Measurements of radiata pine logs undertaken at Tokoroa in the late 1950s[1] found a density of almost exactly 1 tonne per cubic metre for both saw logs and pulp logs. This value is entirely consistent with expectations. It implies that logs placed in water will have neutral buoyancy. They will neither float nor sink. Also we know that dried timber has a density considerably less than 1 tonne per cubic metre and that all that the drying process does is remove water which has a density of exactly 1 tonne per cubic metre.

The Ministry for Primary Industries (MPI) publishes an annual assessment of the exotic forestry resource in New Zealand called the National Exotic Forest Description (NEFD). The NEFD gives annual figures for the area harvested, the volume of logs extracted and the average age of the trees at harvesting. From these numbers we can easily calculate the yield of forestry in cubic metres per hectare per annum. Each edition of the NEFD contains harvest data for the current year and the previous year. Table A8 shows data from the 2009 and 2015 editions of the NEFD. This data suggests that the yield per hectare has been gradually increasing. This is almost certainly correct and probably reflects improvements in the performance of the trees through breeding as well as improvements in siviculture.

Table A8. Harvest yield data for radiata pine from NEFD.

Year	Area clear-felled (ha)	Volume clear-felled (000 m^3)	Average age (years)	Average yield (m^3/ha/year)
2008	38500	17753	27.9	16.53
2009	37700	18095	28.3	16.96
2014	42896	22331	28.9	18.01
2015	46045	25036	28.4	19.15

[1] F.A. Coulter (1959) Density of Pinus Radiata Logs, New Zealand Journal of Forestry, V8 No 1 pp143-147.

The most recent level is 19.15 m^3 per hectare per annum which is 19.15t/ha per annum. There is some variation between regions. The MPI website publishes yield tables[1] for each region. The data for 30 year old radiata pine plantations is shown in Table 5. Although these figures are based on standing trees rather than the harvest they are consistent with the national harvest yield. The variation between regions is large enough to be significant and so we would suggest using the regional yield figures to determine the log transport traffic impact.

Table 10. Yield data by region for 30 year old radiata pine plantations from MPI.

Region	Total Recoverable Volume (m^3/ha)	Average yield (m^3/ha/year)
Northland	543	18.10
Auckland	617	20.57
Central North Island	612	20.40
East Coast	595	19.83
Hawke's Bay	625	20.83
Southern North Island East Coast	562	18.73
Southern North Island West Coast	509	16.97
Marlborough	537	17.90
Nelson	499	16.63
Canterbury	429	14.30
Otago	482	16.07
Southland	502	16.73

As well as the log trucks transporting the logs away from the harvest site, there are also some heavy truck movements associated with transporting the machinery associated with log harvesting to and from the harvest site. Some of this machinery is quite large and requires heavy transporters on overweight permits to move it. Information provided by the New Zealand Forest Owners Association from one of their members suggests that for a large forest with a four-year harvest time there would be about five transport movements of road construction machinery and another five movements for harvesting machinery. This give a total of ten transport movements but, of course, there will be a further ten movements to retrieve the machinery although these may also be transporting it to a new harvest site. As we have seen above, the average yield is 19.15t/ha per annum. If the forest is harvested at 28 years of age, then approximately 19 log truck movements per ha will be generated. Thus the number of heavy machinery truck trips is approximately equal to the number of log truck trips for one hectare of forest. The heavy machinery transporters are heavier than log trucks and will have a greater impact on pavement wear per trip as discussed in the appendix but the number of trips is a very small proportion of the total traffic generated by forestry. For small forestry blocks these movements might potentially be more significant but much less heavy machinery is required so there will be fewer movements.

The heavy haulage vehicles that are used for transporting machinery for log harvesting typically use an axle configuration known as "rows-of-eight". An illustration of this axle configuration is shown in Figure A1. Typically the machinery is moved using a semitrailer fitter with three "rows of eight" axles as shown in Figure A2. For heavier machinery more axles are used. There are trailers with four, five or more rows of axles and adding a dolly between the tractor and the semitrailer adds a further two axles.

[1] https://www.mpi.govt.nz/news-and-resources/open-data-and-forecasting/forestry/new-zealands-forests/

Figure A1. Widening dolly fitted with "rows of eight" axles shown in the widened position.

Figure A2. Log hauler being transported on a semi-trailer with three "rows of eight" axles.

Apart from harvesting, forestry generates very little heavy vehicle traffic and this can be a major issue for the local road controlling authorities. In established forestry areas where planting has occurred over an extended period and there have already been several harvest cycles, the resulting traffic flows are reasonably consistent from year to year. However, in areas where forestry has not been a traditional land use and where large scale plantings have occurred over a relatively short timeframe in the 1990s in response to government incentives, there will be sudden changes in heavy vehicle traffic volumes as these forests all reach harvesting age at approximately the same time. The annual average traffic figure will not be a good predictor of the actual traffic in any given year.

Land Uses that are not Area Based

As outlined earlier there are land use activities that are substantial generators and/or attractors of heavy vehicle traffic where the volume of traffic is not directly related to the land area being used for the activity. Obvious examples include quarries, dairy factories, saw mills and pulp mills, meat processors, fertiliser plants and ports. Many of these are associated with the one of more of the farming activities discussed in the previous sections.

For single large scale activities, the associated major input and output traffic volumes are often published. For example, the Brookby Quarry website[1] states that it has been given resource consent to increase its production to between 3.9M and 4.6M tonnes p.a. and that the consent allows for 902 truck movements per day for six days a week. Almost all of the quarry traffic will be associated with quarry outputs. There will be some inbound traffic associated with fuel deliveries for the quarry machinery but this will be relatively small. Note that intensive finishing sheep and beef farms in the northern region generate about 1856 kg/ha p.a. of freight (inbound and outbound), so, in terms of freight volumes, this quarry is equivalent to more than 2 million ha of intensive finishing sheep and beef farming or about 7 million ha of hard hill country.

Similarly, Fonterra's web-site describes the processing characteristics of their plants. For example, the Te Rapa plant[2] produces 325,000 tonnes of product annually (250,000 tonnes of milk powder and 75,000 tonnes of cream products) and has peak milk processing capability of 8 million litres per day. The milk powder consists of some whole milk powder and some skim milk powder and the cream products are made using the cream extracted to make the skim milk. If we assume that the yield of cream products is 0.2kg/l, then 375Ml of milk are required for the cream products. The yield of skim milk powder is 0.09 kg/l of whole milk so the milk used for cream products will produce 33,750 tonnes of skim milk powder. Thus we have 216,250 tonnes of whole milk powder produced. The yield of whole milk powder is 0.13kg/l so this implies that 1663Ml of whole milk was used for whole milk powder production. Thus this factory has inflows of over 2,000Ml or 2 million tonnes of raw milk p.a. and produces 325,000 tonnes of product p.a. The average dairy farm produces 12 tonnes/ha of milk p.a. so this input volume is equivalent to the output of 167,000 ha of dairy farm or 1142 average sized farms.

Heavy vehicle traffic impacts for different transport tasks

Earlier work converted the freight demand for different land uses as outlined in the previous section into equivalent number of truck trips. This approach has some limitations in terms of how it reflects the pavement wear implications. Different truck configurations apply different levels of loading to the pavement and this should be taken into account.

Generally the pavement strength design requirements are determined by the amount of heavy vehicle traffic that it will experience over its design life. The heavy vehicle traffic stream, however, consists of a whole range of vehicles with different axle configurations and axle loadings. The design traffic is calculated by converting all the loading from all the axle groups of heavy vehicles into a number of passes of an Equivalent Standard Axle (ESA). The ESA normalises the pavement wear effect of the spectrum of axle loads and configurations expected on a pavement to the equivalent number of passes of a dual-tyred single axle loaded to 8.2 tonnes (80kN). In general the ESA value for an axle group is determined using a fourth power relationship as follows:

$$ESA = \left(\frac{axle\ load}{reference\ load}\right)^4$$

The reference loads for various axle groups that cause the same pavement wear as a single standard axle are reproduced from Austroads Pavement Design Guide in Table A9. The "rows of eight" axles used for heavy haulage vehicles do not have reference weights in the Austroads Pavement Design Guide. Essentially each one can be regarded as consisting of two axles operating side by side. The reference loads shown in Table A9 imply that there is an interaction effect when axles are closely spaced. Separate reference loads are given for multi-axle groups. However, if we calculate the ESA that would accrue if we were to treat the multi-axle groups as a series of single axles we find that there is surprising little difference. For example, a 135kN tandem axle group generates 1 ESA, while two 67.5kN single axles generate 1.01 ESA. A 181kN tridem group generates 1 ESA, while three 60.33kN single axles 0.97 ESA. A 221kN quad-axle group generates I ESA while four 55.25kN single axles generate 0.91 ESA. This suggests that we could reasonably use a reference load of 135kN for a "row of eight" axle.

The fourth power exponent is what is used in New Zealand and Australia for sprayed seal unbound granular pavements. Other values for the exponent are used in the Austroads Guide for different types of pavement construction and failure mechanisms.

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[1] Brookby Quarries Ltd (2017). News, http://www.brookbyquarry.co.nz/NEWS.html accessed 17/2/2017
[2] Fonterra (2017). Te Rapa, https://www.fonterra.com/nz/en/about/our+locations/newzealand/te+rapa/te+rapa accessed 17/02/2017

Table A9. Reference loads for various axle configurations.

Axle group type	Load (kN)
Single axle with single tyres	53
Single axle with dual tyres	80
Tandem axle with single tyres	90
Tandem axle with dual tyres	135
Tri-axle with dual tyres	181
Quad-axle with dual tyres	221

There are some misconceptions about the appropriate value for this exponent even among pavement engineers. The exponent value characterises the sensitivity of the pavement to changes in load magnitude. It is not a reflection of the pavement's strength as such. Some of the highest values for the exponent reported in the research literature are for very strong pavements (for example, cracking of Portland cement concrete pavements). A commonly expressed view is that a higher exponent is appropriate for weaker pavements such as those on low volume roads. There is little evidence to support this. Generally the relationship between increased traffic volumes and pavement life is linear. If you double the amount of traffic on a road you will wear it out twice as fast.

A final consideration is the perception that large trucks are worse for the pavement than smaller trucks. This is not necessarily the case. Depending on axle loads and configuration, one large truck will usually generate more pavement wear than one small truck. But, if the large truck has a payload capacity of 25 tonnes and the small truck has a payload capacity of 5 tonnes, then we should be comparing one large truck with five small trucks. Often the large truck will cause less pavement than the equivalent number of small trucks.

For this analysis we will be considering the ESA per payload tonne generated by various vehicle configurations used for the freight tasks identified in the previous sections. For some freight tasks, such as stock transport, we will consider both the large truck and trailer option and the single truck option. This will show the difference between using large and small trucks. Some of the stock movement tasks identified do clearly involve smaller quantities of stock which are likely to be undertaken with single trucks rather than large truck and trailer combinations

The discussion in the previous sections considered three main area-based land use activities, dairy farming, sheep and beef farming and forestry as well as some other large scale heavy vehicle traffic generators and attractors. For the area-based activities there are three main truck types involved; milk tankers, stock trucks and logging trucks. In addition to this there are other trucks for transporting fertiliser, wool, supplementary feed, fuel etc. In recent years, the most popular truck configuration used for milk tankers, stock trucks and logging trucks has been the 4-axle truck towing a 4-axle full trailer with a gross combination weight limit of 44-tonnes. This 8-axle configuration has been more popular than the 7-axle alternatives (either a 3-axle truck and 4-axle trailer or a 4-axle truck and 3-axle trailer) because it incurred lower Road User Charges (RUCs) which offset the loss of productivity from a higher tare weight. Interestingly, tipper trucks used for transporting bulk goods such as aggregates from quarries are more typically 7-axle combinations with a 3-axle truck and a 4-axle trailer. The reason for this is that these vehicles usually have much shorter delivery distances and so the impact of RUCs on total operating costs is not as significant as the benefit of extra payload capacity.

The new RUC system introduced in 2012 changed the relativities between the RUCs for 7 and 8 combinations making the 7-axle combinations more attractive. However, this effect was confounded to some extent by the 2010 amendment to the Vehicle Dimensions and Mass (VDAM) Rule which introduced high productivity motor vehicles (HPMVs). The 8-axle combinations are better suited to higher weight operations and so are more attractive as HPMVs. Developments in HPMVs have now led to a 9-axle combination (4-axle truck and 5-axle trailer) known as the 50MAX vehicle which has a gross combination weight limit of 50 tonnes. Complicating things further has been the weighing tolerance which means that the operator of a 44-tonne combination cannot be prosecuted for being overweight unless its weight exceeds 45.5 tonnes (there are lower tolerances on axle group weight limits but these are not usually exceeded). In some sectors this weighing tolerance has been used as a de facto weight limit with 44-tonne vehicles routinely be operated at 45-46 tonnes.

The VDAM Rule has now been updated and the new Rule came into effect on February 1st 2017. The gross combination weight limit for 7-axle combinations will increase to 45 tonnes and 8-axle combinations will increase to 46 tonnes but this does not come into effect until December 1st 2017. These increases have been made in conjunction with a reduction of the weighing tolerance to 500kg. These changes are likely to make the 8-axle option more attractive although operators may well prefer the 50MAX 9-axle alternative.

There is some uncertainty as to the truck configurations and weights that will be used going forward, but they are likely to be the same for the different area-based land uses. It is therefore reasonable to start by comparing the traffic loading generated by each land use based on the current most common configuration which is the 44-tonne 8-axle truck and trailer. However, this does not mean that log trucks, milk tankers and stock trucks are identical in their effect. The tare weights are different and so the payload capacity of the vehicles is different. Also log trucks "piggy-back" their trailers when empty and so the loading generated by an empty log truck is different from that of an empty milk tanker, for example.

The first step is to determine the payload capacity of the different truck configurations. We have some load capacity values published by Fonterra for milk tankers. For stock crates, Fairfax Industries advertises a low tare weight 8-axle stock truck combination on their web-site[1] which has a tare weight of 22,580kg. This implies a payload capacity of 21,420kg. Typical values for tare weights were obtained from a New Zealand trailer manufacturer[2] who produces all three vehicle types. They quoted a typical tare weight for an 8-axle logging combination at 16.9 tonnes, an 8-axle stock truck combination at 23-23.5 tonnes and a milk tanker at 19-19.5 tonnes. These values imply payload capacities of 27,100kg for logs, 20,500 – 21,000kg for stock and 24,500 - 25,00kg for milk. Fonterra's publicity material[3] states that their tankers can carry 25,500 litres of milk. The density of milk is 1.033 kg/l so this volume corresponds to a payload capacity of 26.34 tonnes. These values are more consistent but are still a bit uncertain.

From the NZTA database of RUC purchases in part of 2012-13 we have extracted the officially recorded tare weights. These are provided by the supplier when the vehicle is first registered but there is no real checking to ensure that they are correct. By using the data fields "Road_Transport_Code" and "Industry_Class" we can identify the transport application that the vehicle is used for. The "RUC_Vehicle_Type" field identifies vehicle type (truck or trailer) and axle configuration. Applying these filters we get the data shown in Table A10. The milk tanker, log truck and tipper truck values are all consistent with the earlier data. The stock truck tare weights, however, are low. The reason for this appears to be that stock crates are generally removable and thus, in most cases, the tare weight recorded is that of the vehicle without the stock crate fitted. The manufacturer-supplied data is a better estimate.

We also need to consider inbound truck traffic for such things as fuel, feed and fertiliser. For some land uses the weight of this inbound traffic can be greater than the weight of the outbound traffic. Considering these inbound flows can be problematic because some of these items are carried on smaller trucks and smaller trucks often generate significantly more pavement wear per unit of freight moved than large trucks. Consider a 44-tonne 8-axle truck and trailer combination with 8 tonnes on the twin-steer axles and 12 tonnes on each of the three tandem axle sets. Fully loaded this vehicle generates 2.31 ESA. As a livestock truck with 21000kg of payload, this vehicle transports 9.09 tonnes of payload per ESA or conversely applies 0.11ESA per tonne of payload. Now consider a 3-axle rigid truck operating as a fuel tanker for farm deliveries. Fully loaded this vehicle can weigh 21 tonnes with 6 tonnes on the steer axle and 15 tonnes on the drive axles. In this configuration it generates 2.93 ESA. Typically it would have a payload capacity of about 9 tonnes. Thus it transports only 3.07 tonnes per ESA or conversely generates 0.326 ESA per tonne of payload. That is, it generates nearly three times as much pavement wear per unit of payload as the stock truck. Some of the inward traffic such as livestock will be similar in character to the outward traffic but other traffic will not.

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[1] http://www.fairfaxindustries.co.nz/stocktake

[2] Paul Goodman, TMC trailers, Personal communication by telephone, 4th November 2016.

[3] https://www.fonterra.com/wps/wcm/connect/5f8c1eed-d06e-4bc2-9412-0ceaec3eb1fe/Clandeboye+Fact+Sheet+2015.pdf?MOD=AJPERES&CACHEID=5f8c1eed-d06e-4bc2-9412-0ceaec3eb1fe

Table A10. Tare weights and payload capacity derived from 2012-13 RUC data.

Vehicle Configuration	Truck tare (kg)	Trailer tare (kg)	Payload capacity (kg)
Milk tanker 4-axle truck 4-axle trailer	11490	6684	25826
Stock truck 4-axle truck 4-axle trailer	11136	5900	26964
Stock truck 4-axle truck 4-axle trailer from manufacturer estimates	14000	9000	21000
Log truck 4-axle truck 4-axle trailer	10931	5354	27715
Tipper truck 4-axle truck 4-axle trailer	11327	6000	26673
Tipper truck 3-axle truck 4-axle trailer	9707	6000	28293
Flat deck 4-axle truck and 4-axle trailer	11000	6000	27000

For average sheep and beef farms the largest component of the inward traffic is fertiliser. For dairy farms it is second to supplementary feed. The number of trucks and the pavement wear implications of fertiliser traffic are highly dependent on the scale of the batches of fertilizer being applied. If we look at the web-site of one the ground-spreading companies[1] we see that 5-tonne batches can be delivered and applied by a 2-axle truck, 7-tonne batches can be delivered and applied by a 3-axle truck, additional 10-tonne batches can be delivered and applied by adding a trailer to the spreader truck while larger quantities can be delivered to a farm-based stockpile using 44-tonne truck and trailer combinations. On difficult hill country farms the fertiliser will often be spread using topdressing aircraft. However, even in this case, the fertiliser will be delivered to the airfield by truck. Determining what size of truck will be used for fertiliser delivery is not simple. After the fertiliser is applied to a paddock, stock must be kept off it until the fertiliser has been absorbed into the ground. This absorption is facilitated by rainfall but this is unpredictable and generally stock are kept off for a period of two weeks or so after fertiliser application. What this means for a dairy farm, for example, is that the fertiliser is usually applied to one or two paddocks at a time. The cows are rotated around the farm for grazing and the fertiliser application follows them around. Thus, although the total amount of fertiliser applied may be quite large, each individual application is not necessarily so. Estimates of the typical tare weights and payload capacities of the fertiliser trucks are shown in Table A11.

Table A11. Estimated tare weights and payload capacity of fertiliser trucks.

Vehicle Configuration	Truck tare (kg)	Trailer tare (kg)	Payload capacity (kg)
2-axle spreader truck	10000	n/a	5000
3-axle spreader truck	13000	n/a	7000
3-axle spreader truck 3-axle trailer	13000	6000	17000
Tipper truck 3-axle truck 4-axle trailer	9707	6000	28293

Supplementary feed is also delivered to the farm in batches. This can be in smaller batches in bags or in bulk quantities of either a truckload or a truck and trailer load. On some farms the feed is stored in silos and thus the delivery vehicle is an augur truck which can raise the feed from the truck body to a sufficient height for filling the silo. On other farms there are storage bunkers for feed and the feed can be delivered by bin trucks similar to the tipper trucks shown in Table A10. The augur trucks have a higher tare weight and thus will deliver less payload for the same gross weight. We do not have good data on the tare weight of augur trucks but the supplementary feed supplier web-sites indicate that a typical truckload of feed weighs about 11 tonnes. This suggests that the tare weight of augur trucks is similar to that of stock trucks.

[1] http://www.wealleans.co.nz/gs/groundspreading/

For heavy haulage vehicles moving forestry machinery, typical gross weights are around 60 tonnes although weights of up to 90 tonnes are possible. At these weights the vehicles require overweight permits and so the local RCAs can control the maximum axle loads and spacing. By limiting the axle loads the pavement wear effects of these heavier vehicles can be managed and the main issue is usually protecting structures such as bridges and culverts from overloading. From a heavy haulage trailer manufacturer website[1] we can obtain tare weights for these types of trailers. Table A12 shows estimated tare weights and payload capacities for the two vehicle configurations described above.

Table A12. Estimated tare weights and payload capacity of low loaders on-highway.

Vehicle Configuration	Truck tare (kg)	Trailer tare (kg)	Payload capacity (kg)
3-axle tractor + 3x8 low loader trailer (60t)	9000	16000	35000
3=axle tractor + 2x8 dolly + 3x8 low loader (90t)	9000	5300+16000	59700

The next step is to determine the ESA per payload tonne for each type of truck and each transport task. For almost all the tasks, the truck travels empty in one direction and loaded in the other. Thus we need to consider the ESA rating for the vehicles in both the loaded and unladen states. The Cost Allocation Model which is used to determine the Road User Charges assumes that the vehicle is fully loaded in one direction and empty or nearly empty in the other. For the loaded case it assumes that the load distribution across the axle groups is optimised to a give the minimum ESA value possible for the total gross weight. For the "empty" state it assumes that the ESA is 10% of the loaded ESA and so the average ESA is 0.55 x the loaded ESA. Using the optimal ESA for the loaded vehicle does not result in completely unrealistic axle group weight distributions but it does give lower ESA values. For example, for a 44 tonne 8-axle truck and trailer, the minimum ESA distribution implies 8 tonnes on the twin-steer axles and 12 tonnes on each of the tandem axle groups to give a total of 2.31 ESA. We might argue that a more realistic weight distribution is 9 tonnes on the twin-steer 13 tonnes on the truck drive axles and 11 tonnes on each of the trailer axle groups as this puts equal weight on each of the truck and the trailer. This weight distribution gives an ESA value of 3.00 for the loaded vehicle which is 30% higher than the minimum. Both load distributions are entirely legal and could occur in practice.

The assumption that the ESA associated with the empty vehicle is 10% of the loaded ESA is significantly less accurate. In the first place the tare weights vary considerably depending on the transport application and vehicle type (trucks have much higher tare weight than trailers). In the second place, the axle loadings do not reduce proportionately on the truck axle groups as the vehicle is unloaded. On an unladen truck, the weight on the steer axles is typically 80-85% of the weight when loaded while the weight on the drive axles is around 30% of the laden weight. The ESA value for empty trailers is typically much less the 10% of the value when fully laden while the ESA value for empty trucks is significantly more than 10% of the value when fully laden.

The approach that we have used is that for 4-axle truck and 4-axle trailer combinations at 44 tonnes we have assumed 22 tonnes on each vehicle. For the 3-axle truck and 4-axle combinations at 44 tonnes we have assumed that 21 tonnes is on the truck and 23 tonnes on the trailer. The distribution of weight between the two axle groups of each vehicle has been done to give the optimum (i.e. lowest) ESA. For empty trailers the tare weight is also distributed across the axle groups to give the optimum ESA. For empty trucks, it is assumed that the tare weight of a twin-steer axle group is 7500kg and the tare weight of a single steer axle group is 5000kg with the remaining tare weight being on the rear axle group. These steer axle weights are realistic but they have been selected rather arbitrarily. However, they only affect the ESA value of the empty truck which is relatively small compared to the ESA of the laden truck. Furthermore changing these values by, say, 500kg has only a minor effect on the overall ESA for the vehicle. Applying these assumptions we can calculate the ESA for the various vehicle configurations identified previously. These are shown in Table A13. Note that for some vehicle types such as the 4-axle stock truck, there are two entries with different laden weights. The lower weight (22,000kg) is for when the vehicle is operating in a truck and trailer combination while the higher weight (26000kg) is for when the vehicle is operating as a single unit truck. The other vehicles that are slightly different are the log vehicles. When a log truck is empty the trailer is lifted onto the truck and the vehicle operates as a single unit truck. However, it is not truly "empty" because the truck has the trailer as its load. Thus in Table A13 the trailer does not have an

[1] Tidd Ross Todd Ltd (2017). www.trt.co.nz/home web page accessed 10/4/2017.

unladen ESA value and the unladen ESA value for the truck takes into account the trailer load. The ESA average shown for the truck is, in fact, the average for the combination.

Table A13. ESA values for laden and empty vehicles.

Vehicle Configuration	Tare (kg)	Laden weight (kg)	ESA (laden)	ESA (unladen)	ESA (average)
Milk tanker 4-axle truck	11490	22000	1.693	0.454	1.073
Milk tanker 4-axle trailer	6684	22000	0.816	0.007	0.412
Stock truck 4-axle truck	14000	26000	3.303	0.496	1.900
Stock truck 4-axle truck	14000	22000	1.693	0.496	1.095
Stock truck 4-axle trailer	9000	22000	0.816	0.023	0.420
Log truck 4-axle truck	10931	22000	1.693	0.508	1.509
Log truck 4-axle trailer	5354	22000	0.816	n/a	
Tipper truck 4-axle truck	11327	26000	3.303	0.453	1.878
Tipper truck 4-axle truck	11327	22000	1.693	0.453	1.073
Tipper truck 4-axle trailer	6000	22000	0.816	0.005	0.410
Tipper truck 3-axle truck	9707	21000	2.884	0.747	1.815
Tipper truck 4-axle trailer	6000	23000	0.975	0.005	0.490
Flat deck 4-axle truck	11000	26000	3.303	0.451	1.877
Flat deck 4-axle truck	11000	22000	1.693	0.451	1.072
Flat deck 4-axle trailer	6000	22000	0.816	0.005	0.410
Fertiliser spreader 2-axle	10000	15000	2.997	0.875	1.936
Fertiliser spreader 3-axle	13000	20000	2.372	0.848	1.610
Fertiliser trailer 3-axle	6000	16000	0.568	0.011	0.290
Fuel tanker 3-axle	12000	21000	2.884	0.801	1.842
3-axle tractor	9000	21000	2.884	0.741	1.812
3x8 low loader	16000	39000	2.389	0.068	1.228
5x8 low loader	21300	59000	2.703	0.046	1.374

Using these ESA values we can now determine the ESA / tonne of payload values for the main transport tasks. These values are shown in Table A14. Some key points to note are:

- Small scale transport tasks where only a truck is required rather than a truck and trailer generate substantially higher levels of pavement wear per tonne of payload than large scale transport of the same commodity using the same type of vehicles.
- The average ESA values shown are based on the vehicle being empty in one direction of travel and full in the other direction. For most tasks this is a reasonable assumption. For milk tankers, a full load is achieved by collecting the milk from a number of farms and during this collection phase of the journey the vehicle is only partly loaded. However, Fonterra uses sophisticated software algorithms to schedule their tanker pick-up routes and these algorithms aim to maximise the vehicle load and minimise the vehicle-kms travelled. The effect of this optimisation is that the amount of partially-loaded travel will be minimised. Although milk tankers will not be able to achieve the full 50% loaded running they do get quite close to it.
- If a number of farms contribute to a full load (as in the case of milk tankers) then the ESA /tonne approach means that each of them will have the ESA attributed to them in proportion to the amount of the payload that they contribute.
- This approach to assigning an average ESA implicitly assumes that the heavy vehicle traffic impacts are the same in both directions of travel on the road. RUCs are also based on this assumption. For some land use activities described above, the input and output traffic volumes are quite similar so this balance is likely to be correct. For other land use activities the traffic flows are strongly biased in one direction (usually outputs). If the roads being used are through roads, the total heavy vehicle traffic may still be reasonably well-balanced in both directions because of the mix of transport activities using the road.

However, if the road is a no exit road or if there is a predominance of a particular transport task using the road that is uni-directional it may be necessary to consider using laden ESA values for the critical direction rather than average ESA values for both lanes. Referring to Table A13 we can see that this would increase the impact of the particular transport task by 60-70%.

- The low loader vehicles are used for transporting machinery associated with log harvesting. The average ESA for these vehicles is approximately double that of a log transport vehicle. Interesting the 60t and 90t vehicles generate approximately the same ESA. The reason for this is that the trailer axle loads on the 90t are lower than those on the 60t vehicle. The fourth power exponent amplifies this difference in the ESA value.

Table A14. ESA per tonne of payload for key transport tasks.

Transport Task	Vehicle Configuration	Payload weight	ESA (Average)	ESA / tonne
Milk collection	4-axle truck + 4-axle trailer	25826	1.485	0.058
Stock and augur feed -large scale	4-axle truck + 4-axle trailer	21000	1.514	0.072
Stock and augur feed-small scale	4-axle truck	12000	1.900	0.158
Log transport	4-axle truck + 4-axle trailer	27715	1.509	0.054
Wool - large scale	4-axle truck + 4-axle trailer	27000	1.482	0.055
Wool - small scale	4-axle truck	15000	1.877	0.125
Bulk materials - aggregate, feed, bulk fertiliser - large scale 4-axle truck	4-axle truck + 4-axle trailer	26673	1.483	0.056
Bulk materials - aggregate, feed, bulk fertiliser - small scale	4-axle truck	14673	1.878	0.128
Bulk materials- aggregate, feed, bulk fertiliser - large scale 3-axle truck	3-axle truck + 4-axle trailer	28293	2.305	0.081
Fertiliser spreader – small scale	2-axle truck	5000	1.936	0.387
Fertiliser spreader – medium scale	3-axle truck	7000	1.610	0.230
Fertiliser spreader large scale	3-axle truck + 3-axle trailer	17000	1.900	0.112
Fuel tanker 3-axle	3-axle truck	9000	1.842	0.205
60t low loader	3-axle tractor + 3x8 axle trailer	35000	3.041	0.087
90t low loader	3-axle tractor + 2x8 axle dolly + 3x8 axle trailer	59700	3.187	0.053

An Example Calculation for Northland

We can now apply these factors to various land uses in a region. For sheep and beef farming we illustrated the input and output data extraction process using data for the Northern region and so we will use this region to compare the traffic impacts of various common land use activities.

The sheep and beef farm inputs and outputs per ha for three farms classes were shown in Table A5. By multiplying the input/output quantities, which are in kg/ha by the ESA/tonne traffic impact factors shown in Table A14, we obtain traffic impact factors in ESA per 1000ha[1]. Assuming that wool and store stock are transported using the small scale approach while prime stock transport is large scale and feed and fertiliser use large scale bulk transport we get the factors shown in Table A15.

[1] ESA/1000ha is used rather than ESA/ha for ease of presentation.

Table A15. Heavy vehicle traffic impacts in ESA/1000ha for northern region sheep and beef farms.

Outputs/Inputs	Type	Hard Hill Country	Hill Country	Intensive Finishing
Outputs	Wool	3.09	2.58	1.40
	Store Stock	7.28	11.14	5.19
	Prime Stock	15.67	23.78	55.12
	Total Outputs	**26.04**	**37.51**	**61.70**
Inputs	Fertiliser	13.26	24.85	47.84
	Fuel	2.17	3.70	5.06
	Feed	1.45	5.62	9.06
	Total inputs	**16.87**	**34.17**	**61.96**
Grand Total		**42.92**	**71.68**	**123.65**

Similarly we can take the input and output data for Northland dairy farms shown in Table A5. In this case we assume that the stock movements are undertaken using small scale trucks, the feed is delivered using small scale bulk materials and the fertiliser is applied using large scale spreader vehicles. The resulting heavy vehicle traffic impacts are shown in Table A16.

Table A16. Heavy vehicle traffic impacts in ESA/1000ha for Northland dairy farms.

Outputs/Inputs	Type	Average dairy farm
Outputs	Milk	490.33
	Bobby and beef calves	9.26
	Replacement wiener calves	8.12
	Replaced cows – cull etc.	32.70
	Total	**540.42**
Inputs	Fertiliser	82.81
	Feed (assuming PKE)	207.43
	Replacement heifers	28.15
	Fuel	13.65
	Total	**332.04**
Grand Total		**872.46**

For logging the average yield for Northland is 18.1m^3/ha per annum. Assuming a density of 1000kg/m^3 the log transport traffic impact of this logging activity is **985.4 ESA/1000ha** per annum. The heavy transport associated with moving machinery onto harvest sites and back again consists of about 20 truck trips for large forestry blocks. In terms of ESA each of these trips is equivalent to about two log truck trips. These trips occur once per harvest cycle. For a 30-year harvest, these heavy haulage trips are equivalent to the log transport required for two additional hectares of harvest. If we assume that a large forest is 1000ha, then the traffic impact becomes **987.4 ESA/1000ha.** This increase in traffic impact of 0.2% is negligibly small. For smaller forestry blocks the impact is potentially larger but less machinery and of a smaller scale is required. It would appear that the increase in traffic impact due to heavy haulage machinery movements will be less than 1%.

As noted in the section on land use activities that are not land area dependent, some of these can generate very significant traffic impacts while occupying only relatively modest land areas. Two quarries in the Auckland district were used as examples. If we consider the Hunua quarry which occupies a land area of 240ha and produces 2M tonnes of aggregate per annum, we can see that this is an output of 8,333,333kg/ha. Assuming this is transported using 3-axle truck and 4-axle trailer combinations, the traffic impact is **675,000 ESA/1000ha** per annum.