A Methodology for the Selection of Lower Impact Vehicles for Timber Haulage

Introduction

There has been increasing demand from roads managers for guidance on the impact of different wheel and tyre configurations with regard to road damage. This concern relates to two different types of road:

- Weak public roads, managed by local authorities. These will generally be categorised as Consultation or lower on Agreed Routes maps
- Weak forest roads, managed by FCS and the private sector

This Draft Report relates primarily to the former and concentrates on public roads with thin bound pavements of about 100mm or less.

Background

There is a wealth of international research on this subject based on both physical tests and theoretical analysis. In reviewing this material it is quite possible to become overwhelmed with the depth and detail of conclusions and lose sight of the aim of this Report: to provide a readily understood guide to frontline practitioners.

The interaction between vehicle and the road is highly complex with a large number of variables. Much research expenditure has been applied to heavily trafficked roads whereas the problem with timber is more generally focussed on minor rural roads which are lightly trafficked until subject to regular use by 44 tonne timber lorries. The challenge has been to identify research that is relevant and useful.

The ROADEX international exchange project has carried out a great deal of research on weak roads subject to timber traffic but unfortunately a gap has remained. Whilst it is well established and intuitively apparent that narrow tyres are much more damaging than wide when carrying the same load it has proved difficult to quantify the damaging power of different timber truck configurations. A typical timber truck has a mix of single, dual and wide base single tyres and a transparent method of grading the different tyre configurations is badly needed. Timber transport is a highly competitive industry and operators have already shown they are willing to invest in more “road friendly” arrangements provided there is a clear commercial opportunity and benefit.

In 2001 the European Commission published a report as part of European Co-operation in the Field of Scientific and Technical Research (COST). This report, titled “COST 334: Effects of Wide Single Tyres and Dual Tyres” investigated in great detail the likely impact of standardising the use of Wide single tyres compared to the more traditional dual wheel arrangement on heavy trucks.

A review of the COST report shows that, although it was chiefly aimed at roads with Thick (300mm) and Medium (200mm) pavements it also drew on research on Thin pavements of 100mm and less bound material. Of particular relevance to this paper, it included both data and findings applicable to two common modes of failure in thin pavements:

- Fatigue, where the pavement fails as a result of cracking induced by multiple repeated loading.
- Secondary rutting, where the failure is largely caused by overloading and compression of the subgrade underlying the pavement.

Tyre Sizes and Dimensions

It may be helpful at this stage to clarify the standard form of tyre sizing, which takes the form:

- 385/55R22.5

In this case 385 is the section width in mm; 55 is the profile of the tire, the sidewall height as a percentage of the section width; R identifies radial ply construction and 22.5 is the rim diameter in inches. Some tyres still use an older system: eg 11R22.5, where 11 is the section width code.

The COST report details dimensions of common HGV tyres then in use (1999). It defines a wide base tyre as:

> "A tyre which is not intended to be mounted in dual assembly, and with
> a load bearing capacity of the same order of magnitude as a dual tyre assembly"

Tread width is a key dimension considered in this report as, except in cases of underloading or excess pressure, it defines the lateral boundaries of the contact area between the tyre and the road surface. Perhaps surprisingly, tread width is not immediately visible in manufacturers data sheets. This is a pity as tread width does vary for the same section size between manufacturers, and so it must be sought out, or measured in situ, if required.

The COST report uses an average tread width and tyre diameter for each size as supplied by the European Tyre and Rim Technical Organisation (ETRTO). Tread widths for the wide base singles considered in the COST report varied between 285mm and 427mm.

Analysis

Tyre Configuration Factors

The COST report draws on a wide body of international research to develop its methodology and conclusions. It develops formulae to calculate the pavement wear characteristics of a large number of tyre options, in dual or single configuration. These formulae then had to be adapted to "real world" conditions, taking into account variables like:

- Load imbalance in dual tyres caused by inflation pressure differences, axle bending or differences in tyre diameter
- The differences in dynamic behaviour.

The resulting Tyre Configuration Factors (TCF) give a numerical means of comparing the damage likely to be caused to the selected road pavement, with that caused by the reference tyre assembly. The choice of reference tyre is fairly arbitrary as the factors relate to the relative rather than absolute measure of damage.

The formulae developed in the COST report for the TCF are as follows:
TCF for Secondary Rutting of Thin Pavements=

$$(\text{Total Tread Width}/570)^{-2.57} \text{ X } (\text{Pressure Ratio})^{1.58}$$

TCF for Fatigue of Thin Pavements =

$$(\text{Total Tread Width}/570)^{-2.44} \text{ X } (\text{Tyre Outside Diameter}/1059)^{-2.47}$$

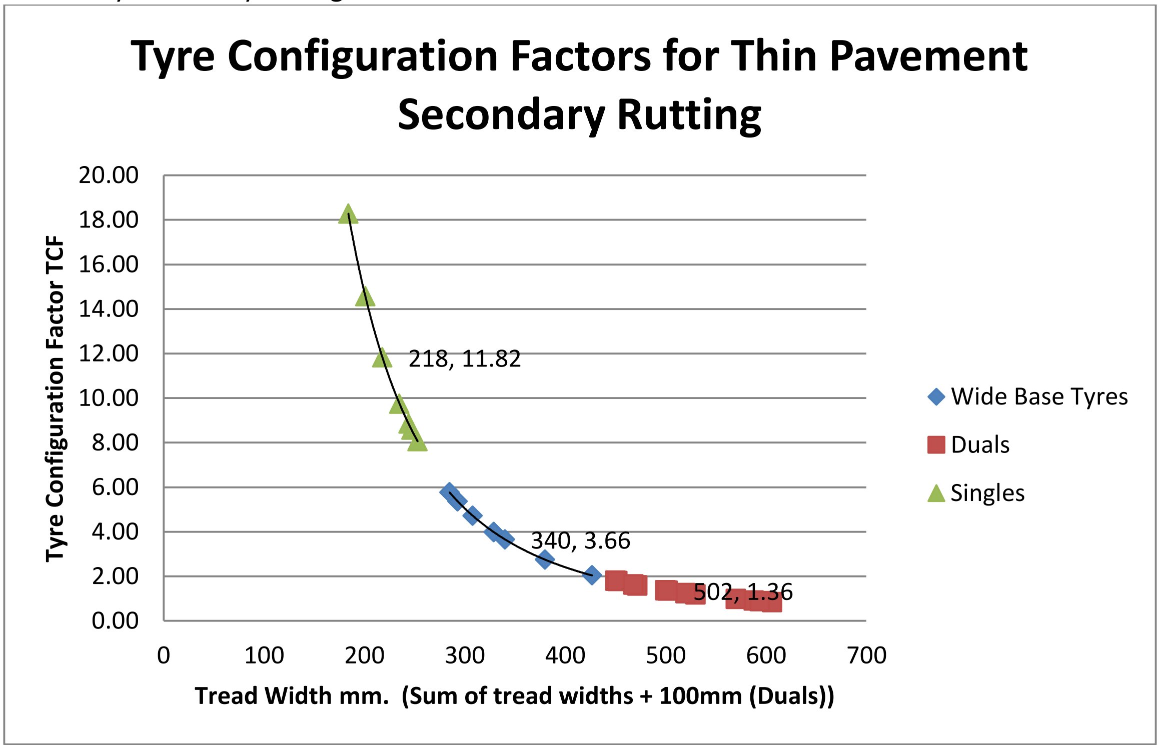
Inspection of these formulae show that the key variables for defining damage to a thin pavement are:

- For distress by fatigue: Total tread width and tyre outside diameter
- For distress by secondary rutting: Total tread width and inflation pressure ratio.

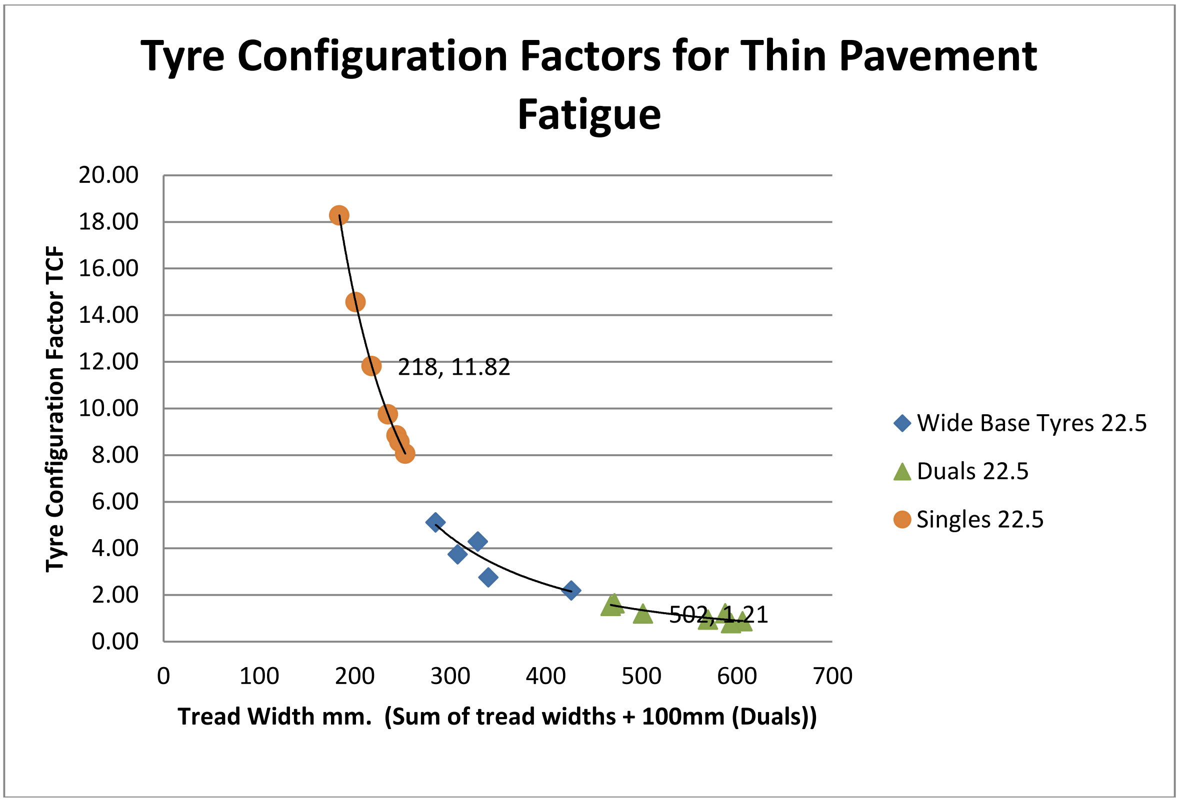
The tread width is taken as the width of the actual tread on the road; not the tyre section width. In the case of dual tyres the total tread width is the sum of the tread widths of the two tyres plus 100mm standard allowance for the gap between the treads. This wider load spread pattern confers a significant advantage to dual tyres.

The inflation pressure ratio is the ratio of the actual pressure to the recommended pressure for the specified load.

The following graph shows a plot of Tyre Configuration Factors against tread width for pavement distress by secondary rutting:



The flowing graph shows the relationship between TCF and tyre width for distress under fatigue. For clarity this shows only tyres of 22.5 rim diameter, as this is the commonest size. Other things being equal, smaller diameter tyres have reduced contact area, greater TCF's and cause more damage than the equivalent larger diameter tyre:



These graphs show very clearly the benefits of a wide tread in reducing road damage in both distress modes.

It is important to point out that the TCF is a relative measure, for comparison with the Reference Tyre, which in the case of the COST analysis was selected as a dual 295/80R22.5. For example the narrowest tyre tested (11R22.5) was only 184mm wide, and the graph shows that it is 18 times more damaging than the reference tyre ***at the same load*** as the reference tyre (10t axle). In fact the 11R22.5 is unlikely to be run at that loading, as it is beyond its rated capacity. This leads to the need to develop another factor to take into account the actual load on the tyre by defining an Axle Wear Factor (AWF). The AWF is defined as follows:

> "The AWF expresses the damage contribution of a single passage of a given tyre with a given axle load, referred to the damage contribution of a single passage of the reference tyre with an axle load of 10t."

In deriving the AWF from the TCF the COST Report only considers distress from primary rutting on primary roads as that is the most likely failure mode for such roads, and the report was aimed at the damage to key networks. However there is no logical reason why the same process should not be followed for roads with thinner pavements and different failure modes, provided always that the analysis does not stray outside the range of the original experimental data.

In developing the TCF into the AWF the COST report uses the accepted power law between axle load and aggressiveness:

Aggressiveness=K(Axle Load/Reference Load)^{n}, where K is a constant.

The value of the power “n” has traditionally been taken as 4, resulting in it being called the Fourth Power Law. This law is a key consideration in pavement design and an important reason to avoid excess loading. Doubling the load on an axle does not just double the damage; it increases it by a factor of 16.

COST analyses previous research on this subject and concludes that whilst “n” is taken as 2 for Primary Rutting, values of 4 and 5 appropriate for fatigue and secondary rutting respectively. This report will use the value of 4.

Applying this to the TCF to allow for actual loading and to derive the Axle Wear Factor, and using the fourth power relationship:

$$AWF = TCF \times (\text{Axle Load}/\text{Reference Load})^4$$

where the reference load is 10t.

Using this on the narrow 11R22.5 tyre discussed above and assuming it is carrying a 6.3t axle (its maximum rating):

$$AWF = 18 \times (6.3/10)^4 = 2.8$$

This means that the damage caused by the passage of a 6.3t axle on 11R22.5 single tyres is 2.8 times the damage caused by the reference axle carrying 10t. The 2.8 factor applies to the case of a thin pavement suffering either fatigue or secondary rutting distress, as the graphs for both modes are broadly similar.

Developing Truck Wear Factors

It seems entirely reasonable and logical to take this procedure forward to determine a Truck Wear Factor, defining the relative damage caused by the single passage of a multi axle truck by simply computing and summing the individual Axle Wear Factors.

To develop this concept, axle loading data has been selected for three “real world” timber trucks tested under the ROADEX project. These are described in two published reports assessing the impact of tyre pressure control systems. The individual axle weights were measured and are shown in the following table. The Gross vehicle weights of Trucks 1-3 were respectively 42.9, 44.1 and 45.8 tonne and the three trucks were artics with six axles. One had double drive and the other two were single drive with lifting tag axle. All drive arrangements were twin wheels and the variety of other wheel and tyre arrangements are detailed in the table.

Using standard tyre dimension data from the COST report the Tyre Configuration Factor for each tyre arrangement was calculated for the thin pavement condition under distress from Fatigue; this was then repeated for the same pavement under distress from Secondary Rutting.

The Axle Wear Factor was then calculated from the Tyre Configuration factor using the fourth power relationship described above. In the first instance this calculation used the actual axle weights for each truck, and the six AWF’s were then summed to give a vehicle total. The vehicle AWF totals were 3.55, 4.91 and 7.79 respectively. It is immediately clear that Truck one, with four dual wheeled axles is the most “road friendly” of the trio.

It is important to recall that this analysis is founded on relative damaging factors rather than absolute values which could be used to predict when a pavement might fail. The latter is well beyond the brief of this document. What we can do however is use the summed AWF's for Truck 1 as a quotient to determine the comparative Truck Wear Factor for each configuration.

The outcome of this shows that, if we take Truck 1 as our reference standard, and all trucks as actually loaded, Trucks 2 and 3 will respectively cause 1.38 and 2.2 times as much fatigue damage to the road pavement as Truck 1. The comparable figures for Secondary Rutting are 1.44 and 2.3

Interesting as it is for the specifics of a single journey, the above analysis is slightly unfair for wider application. Truck 1 is lightly loaded, whereas Truck 3 happens to be overloaded. Because of this a second analysis was carried out by adjusting each measured axle load on a pro rata basis to give a theoretical total of 44t, the legal limit.

In this case the comparable Truck Wear Factors for Trucks 2 and 3 are 1.24 and 1.69 in respect of Fatigue; the figures are 1.29 and 1.76 in respect of Secondary Rutting. Broadly speaking Truck 2 will cause about 30% more damage to the road compared to Truck 1; Truck 3 about 80% more.

There remained a significant difference in the axle weights between the three trucks, even after the adjustment to 44t. This could be explained by the vehicles having different tare weights, particularly Truck 3 with the double drive; uneven loading of the timber is another reason. Despite this, it was felt useful to consider applying the same "Standard" load applied to each configuration, amounting in total to 44t. Further work is required to determine what the correct Standard Load should be, but the advantage of this approach is that it would be possible to calculate the comparable Truck Wear Factor for any common configuration, knowing only the wheel and tyre arrangement.

This was carried out for the case of Truck 4, an unladen vehicle selected at random in the street. Feeding in only the observed tyre sizes and configuration it can be seen to have a Truck Wear Factor of 2.06 (Fatigue) and 2.19 (Secondary Rutting) i.e. it can be expected to cause more than double the damage of the dual wheeled Truck 1.

A further exercise was carried out to see how the most "road friendly" truck might be configured. Truck 1, with dual wheels on four axles was the best so far. However if its single tag wheel were replaced by a double, all but the steering axle would be duals.

Running the calculations for such a vehicle (Truck 5), and rebasing the Truck Wear Factor to that vehicle, results in the following:

	Table of Comparative Truck Wear Factors for thin pavements (Truck 5 as reference)		
Truck Ref	Description	TWF for Fatigue	TWF for Secondary Rutting
Truck 1	4 dual axles, single tag and steering	1.15	1.16
Truck 2	3 extra- wide base singles trailer, 1 dual drive, single tag and steering	1.53	1.43
Truck 3	2 dual drives, 3 wide base singles on trailer and single steering	2.18	2.30
Truck 4	3 wide base singles on trailer, dual drive, single tag and steering	2.38	2.55
Truck 5	5 dual axles, single steering	1.00	1.00

Simplifying this table further for the use of practitioners, the Truck Wear Factor is reduced to a single rounded value, the maximum of that for fatigue or Secondary Rutting. Details of the tyre sizes are also included:

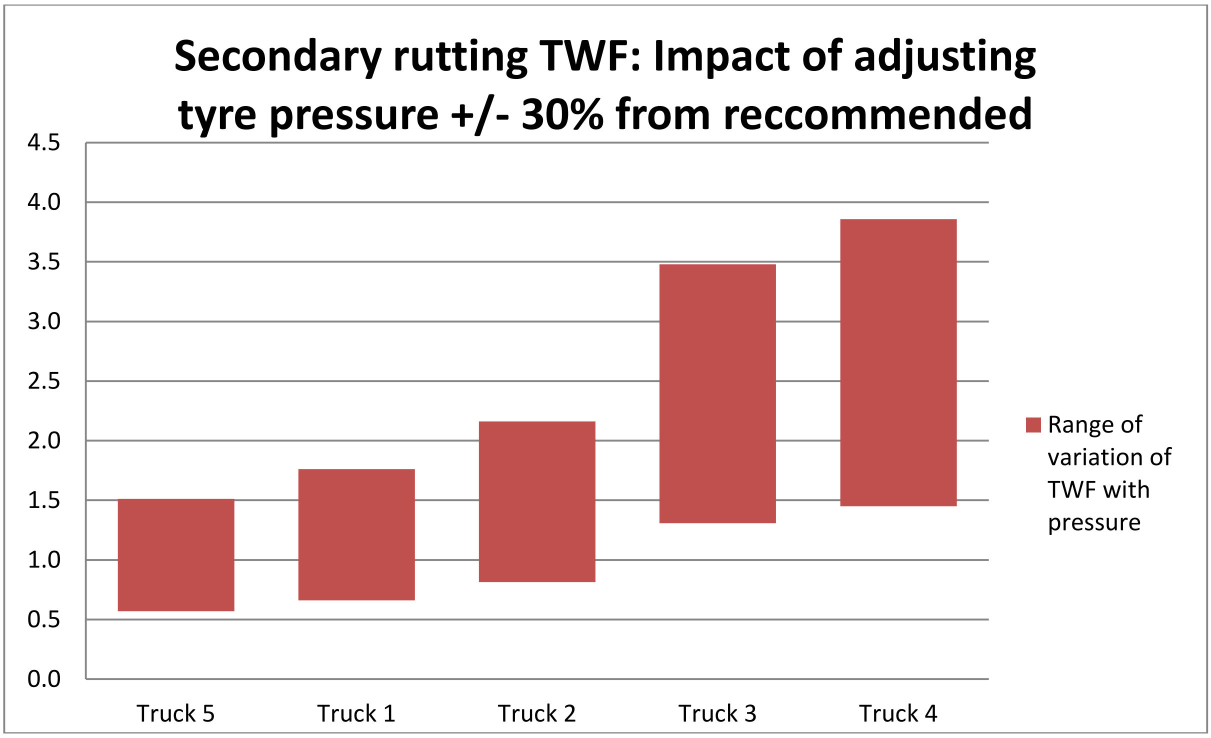
	Axle	Tyre size	Configuration	Truck Wear Factor
Truck 1	Steer	295/80R22.5	single	**1.2**
	Drive	295/80R22.5	dual	
	Tag	385/65R22.5	wide base	
	Trailer	11R22.5	dual	
	Trailer	11R22.5	dual	
	Trailer	11R22.5	dual	
Truck 2	Steer	315/80R22.5	single	**1.5**
	Drive	315/80R22.5	dual	
	Tag	315/80R22.5	single	
	Trailer	455/45R22.5	wide base	
	Trailer	455/45R22.5	wide base	
	Trailer	455/45R22.5	wide base	
Truck 3	Steer	315/80R22.5	single	**2.3**
	Drive	295/80R22.5	dual	
	Drive	295/80R22.5	dual	
	Trailer	385/65R22.5	wide base	
	Trailer	385/65R22.5	wide base	
	Trailer	385/65R22.5	wide base	
Truck 4	Steer	315/80R22.5	single	**2.6**
	Drive	315/80R22.5	dual	
	Tag	315/80R22.5	single	
	Trailer	385/65R22.5	wide base	
	Trailer	385/65R22.5	wide base	
	Trailer	385/65R22.5	wide base	
Truck 5	Steer	295/80R22.5	single	**1.0**
	Drive	295/80R22.5	dual	
	Drive	295/80R22.5	dual	
	Trailer	11R22.5	dual	
	Trailer	11R22.5	dual	
	Trailer	11R22.5	dual	

Impact of Tyre Pressure

The calculations were repeated for the Secondary Rutting distress mode with the Pressure Ratio varied between 0.7 and 1.3, reflecting a pressure variation of +/- 30% from the recommended pressure. Interestingly, the COST formulae only recognise tyre pressure as a key variable in the case of distress by Primary and Secondary rutting, and not Fatigue.

The following graph indicates how the Truck Wear Factor for each vehicle varied in these conditions. Some limited conclusions can be drawn, although this may be going beyond the comfortable limits of the data:

- The aggressiveness of Trucks 3 and 4 can be reduced by reducing Tyre pressure but, even then, they do not match the road friendliness of Trucks 1 and 2 when the latter are at recommended pressures
- If the aim is to reduce road damage, choosing a configuration that increases the amount of "tread on the road" would seem to be the prime objective, followed by reducing tyre pressure.



Summary:

The analytic method described in this document has been developed from the methodology and research described in the 2001 EC COST334 Report. Whilst that report concentrated on Primary Routes with thick pavements this document has focussed on the sort of weak, thin pavement, minor routes that typically link forests to the Primary Network.

The suggested Truck Wear Factors are straightforward to calculate and offer, possibly for the first time, a convenient tool for forest and public road managers to assess the best vehicle configuration for a weak road. This is not an exact science and judgement and experience have a place, but it does give a much needed measure of quantitative comparison. The fact that the damaging power of the trucks considered above vary by as much as 150% gives some confidence that it is a valid and meaningful selection tool. It also confirms the intuitive and well established view that wide base singles are very significantly more damaging than twins on thin pavement public roads.

Further work is needed to develop some of the concepts discussed above, including:

- Ascertaining the most commonly used tyre sizes in the trade

- Ascertaining the key considerations hauliers use when selecting truck and tyre configurations
- Ascertaining the Standard loading that could be used in the case of six axle vehicles, to quickly work out the Truck Wear Factor
- Ascertaining the grounds for treating extra-wide base singles, say those with tread width greater than 400mm, as a separate group, less damaging than narrower wide base singles and closer to twins
- Understanding the balance of reasoning when choosing twin drive over drive and tag and quantifying the increase in weight
- Understanding the operational balance of reasoning for choosing truck and drag versus artic.

Second DRAFT

DERIVATION OF TYPICAL TRUCK WEAR FACTORS FOR THIN PAVEMENTS																	
	Tyre details					Configuration Factors		Axle loads			AWF for Fatigue			AWF for Secondary Rutting			
	Axle	Tyre size	Configuration	Tread Width mm	Diameter mm	Fatigue TCF	Secondary Rutting TCF	Actual	Adjusted	Standard	Actual	Adjusted	Standard	Actual	Adjusted	Standard	Mean for 44t
	Steer	295/80R22.5	single	235	1059	8.69	9.75	5.80	5.95	6.00	0.98	1.09	1.13	1.10	1.22	1.26	
	Drive	295/80R22.5	dual	470	1059	0.94	0.98	9.10	9.33	8.00	0.64	0.71	0.39	0.67	0.74	0.40	
	Tag	385/65R22.5	wide base	285	1071	5.12	5.76	5.10	5.23	6.00	0.35	0.38	0.66	0.39	0.43	0.75	
Truck 1	Trailer	11R22.5	dual	368	1054	1.54	1.63	7.90	8.10	8.00	0.60	0.66	0.63	0.63	0.70	0.67	
	Trailer	11R22.5	dual	368	1054	1.54	1.63	7.50	7.69	8.00	0.49	0.54	0.63	0.51	0.57	0.67	
	Trailer	11R22.5	dual	368	1054	1.54	1.63	7.50	7.69	8.00	0.49	0.54	0.63	0.51	0.57	0.67	
							Total	42.90	44.00	44.00	3.55	3.93	4.07	3.83	4.24	4.41	
									Truck Wear Factor		**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**
	Steer	315/80R22.5	single	247	1085	6.83	8.58	6.54	6.52	6.00	1.25	1.24	0.88	1.57	1.55	1.11	
	Drive	315/80R22.5	dual	494	1085	0.80	0.88	8.08	8.06	8.00	0.34	0.34	0.33	0.38	0.37	0.36	
	Tag	315/80R22.5	single	247	1085	6.83	8.58	5.00	4.99	6.00	0.43	0.42	0.88	0.54	0.53	1.11	
Truck 2	Trailer	455/45R22.5	wide base	408	980	2.67	2.31	8.02	8.00	8.00	1.11	1.09	1.09	0.95	0.94	0.94	
	Trailer	455/45R22.5	wide base	408	980	2.67	2.31	8.16	8.14	8.00	1.18	1.17	1.09	1.02	1.01	0.94	
	Trailer	455/45R22.5	wide base	408	980	2.67	2.31	8.32	8.30	8.00	1.28	1.27	1.09	1.10	1.09	0.94	
							Total	44.12	44.00	44.00	5.59	5.53	5.38	5.56	5.50	5.42	
									Truck Wear Factor		**1.58**	**1.41**	**1.32**	**1.45**	**1.30**	**1.23**	**1.31**
	Steer	315/80R22.5	single	247	1085	6.83	8.58	5.62	5.39	6.00	0.68	0.58	0.88	0.86	0.73	1.11	
	Drive	295/80R22.5	dual	470	1059	0.94	0.98	8.52	8.18	8.00	0.50	0.42	0.39	0.52	0.44	0.40	
	Drive	295/80R22.5	dual	470	1059	0.94	0.98	7.72	7.41	6.00	0.33	0.28	0.12	0.35	0.30	0.13	
Truck 3	Trailer	385/65R22.5	wide base	285	1071	5.12	5.76	7.82	7.51	8.00	1.91	1.63	2.10	2.15	1.83	2.36	
	Trailer	385/65R22.5	wide base	285	1071	5.12	5.76	7.98	7.66	8.00	2.08	1.76	2.10	2.34	1.98	2.36	
	Trailer	385/65R22.5	wide base	285	1071	5.12	5.76	8.18	7.85	8.00	2.29	1.95	2.10	2.58	2.19	2.36	
							Total	45.84	44.00	44.00	7.79	6.61	7.68	8.79	7.46	8.72	
									Truck Wear Factor		**2.20**	**1.69**	**1.89**	**2.30**	**1.76**	**1.98**	**1.83**
	Steer	315/80R22.5	single	247	1085	6.83	8.58			6.00			0.88			1.11	
	Drive	315/80R22.5	dual	494	1085	0.80	0.88			8.00			0.33			0.36	
	Tag	315/80R22.5	single	247	1085	6.83	8.58			6.00			0.88			1.11	
Truck 4	Trailer	385/65R22.5	wide base	285	1071	5.12	5.76			8.00			2.10			2.36	
	Trailer	385/65R22.5	wide base	285	1071	5.12	5.76			8.00			2.10			2.36	
	Trailer	385/65R22.5	wide base	285	1071	5.12	5.76			8.00			2.10			2.36	
							Total			44.00			8.39			9.66	
									Truck Wear Factor				**2.06**			**2.19**	**2.13**

HIGHLAND TIMBER TRANSPORT GROUP

ACCESS TO FORESTS OVER NARROW AND FRAGILE CONSULTATION ROUTES:

Draft Protocol for use of Tyre Pressure Control System (TPCS) equipped vehicles.

Explanatory notes:

1. The Matrix below is at Draft stage and subject to consultation. Its aim is to provide a useful tool to assist hauliers and Council roads managers to reach agreement on the most suitable configuration for a particular road on a consistent basis.
2. Engineering judgement and experience will normally be used to categorise a road but survey techniques such as Ground Penetrating Radar or Falling Weight Deflectometer may be used where cost can be justified.
3. The Matrix has been drawn on the basis of established pavement behaviour and experience of TPCS in the Highlands. The damaging power of recently developed Wide Super Singles (such as 455/45 R22.5) is considered to lie between that of Super Singles and that of twin wheels but further research is needed to determine the exact relationship *(hence "?" in table below).*
4. For high curvature or narrow single track roads the truck and drag configuration is felt to be preferable to a standard artic in terms of minimising edge overrun.

Road Type ⇩	**Preferred minimum configuration**		
Standard 2 lane (5.5m or more)	Twin wheel; Wide super singles with TPCS?	Twin wheel; Super singles with TPCS	Twin wheel; Super singles
Standard 3.3m single track/ narrow 2 lane	Twin wheel with TPCS	Twin wheel; Wide super singles with TPCS?	Twin wheel; Super singles with TPCS
Narrow single track (<3.3m)	Twin wheel with TPCS	Twin wheel with TPCS	Not applicable
Road pavement strength ⇨	*Very weak (eg thin pavement on soft subgrade or peat)*	*Weak (eg thin pavement on hard subgrade)*	*Strong (eg properly engineered pavement)*

Disclaimer: The Highland Timber Transport Group has prepared this document in pursuit of its policy of facilitating timber transport solutions. Neither the Group nor its Consultant can accept any liability arising from the use of the information contained in it.

11/02/2009 19:46 *Colin JT Mackenzie*