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Estimating levels of service (LOS) for freight on rural roads

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Abstract

This paper presents: (i) the analysis and outcomes of a large interview survey for three groups of transport stakeholders (road freight drivers, operators and road infrastructure managers); and (ii) analysis and outcomes of a rural arterial road driver test based circuit survey using both drivers of heavy vehicles and cars to rate variations in three major factors impacting on LOS in order to define the comparative requirements for rural freight. The top three major factors, or road attributes, impacting on LOS for heavy vehicle drivers and freight operators subsequently ranked in descending order of importance by the interview survey were: (i) ride comfort (road roughness); (ii) road shoulder width and condition; and (iii) road and bridge geometry and general access. The follow-up driver test survey investigated the responses of truck and car drivers to variations to the above identified three key road inventory attributes. Analysis of sample rating data indicated that LOS ratings provided by car and truck drivers closely followed changes in LOS for roughness, shoulder width and lane width, but truck drivers on average rated LOS below that rated by car drivers. Results also indicated that the use of road surface measures linked to truck ride characteristics, as opposed to currently used roughness measures such as IRI which heavily reflect car ride response, would improve the capability of asset managers to deliver LOS better tailored to the needs of freight vehicles.

1. Introduction

In order to ensure that the full range of road users are appropriately serviced, road asset managers need to improve their understanding of the requirements of the freight and logistics industry. This can be addressed in part by asking the customers what they want. 'What customers want' can then be translated into quantifiable measures, such as technical levels of service (LOS) relevant to asset management. However, it might be expected that different components of the freight industry may have markedly different needs leading to conflicts both within the industry and with other road users.

In Australia the importance of roads for transporting freight, as assessed by the road freight task (tonne-km per head of population), is high relative to other OECD countries ranking third behind the USA and Finland (Martin et al 2016). Similarly, in terms of the road freight task per unit of gross domestic product (GDP), Australia has the highest value of this statistic relative to all the other OECD countries, indicating the major importance of road freight to the Australian economy.

The above statistics show how important it is for Australia to meet road freight transport needs on a largely rural road network. There are nearly 2.5 million licensed heavy vehicle (HV) drivers (10% of Australia's population) available to drive 560 000 registered heavy vehicles (ABS 2012). These numbers also show the significance of the Australian road freight industry in terms of employment.

2. Surveys Undertaken

2.1. Survey of 2013-14

2.1.1 Approach

The interview survey of 2013-14 was directed at the three road freight stakeholder groups comprising freight industry drivers, logistics industry operators and road infrastructure managers. The survey questionnaire recognised that long haul, short haul, cattle haulage and interstate haulage are all likely to have different LOS needs. Different groups of drivers and logistic managers were consulted to determine what aspects of the road infrastructure mattered to them.

Particular sections of the survey addressed issues associated with each of the above three groups. As shown in Table 1, there were 43 questions, two common questions and the remaining 41 divided across the three stakeholder groups. As both the heavy vehicle drivers and logistics operators are rural road users and the key focus LOS determination, it was appropriate that they should comprise the majority (94.2%) of the completed surveys as shown in Table 1. Although stakeholders from all state/territory jurisdictions were represented, the majority of completed responses were from Victoria (50.7%), followed by New South Wales (19.2%) and Queensland (15.1%).

Freight industry drivers (235), logistics operators (40) and road infrastructure managers (17) completed the 2013-14 survey using a LOS framework developed by Austroads (2006). Some 442 survey questionnaires were distributed to the three stakeholder groups and 292 surveys were fully completed, a response rate of 66.1%. Table 1 summarises the survey participants, their fleet size, the jurisdiction of their operation and the type of survey used.

Table 1: Questionnaire summary

Questions	Category	No.	Heavy vehicle drivers			HV fleet size			Jurisdiction		Survey type	
			Heavy freight vehicles		Buses	≤ 5 (%)	> 5- 20 (%)	≥ 20 (%)	State	Local	Face -to- face	Survey monkey
			Self-employed	Company								
1–2	All	442							All		144	298
3–21	HV drivers	235	89	141	5				All		141	94
22–31	Operators/logistics	40				35	42.5	22.5	All		3	37
32–43	Asset managers	17							12	5	0	17

Table 1 shows that 141 (48%) of the total sample of completed responses (292) were from drivers for a transport company, while 89 (30%) of the total sample of completed responses were from drivers who worked as owner drivers.

A higher proportion of completed heavy vehicle driver responses (59.8%) was achieved by means of a face-to-face interviews compared with the remaining 40.2% that were conducted electronically using survey monkey software. The face-to-face interview was considered to produce sounder and more reliable results than the on-line survey monkey approach. This is because the face-to-face interview provided the opportunity to clarify the questions in the survey. In addition, the face-to-face interview typically carried out at driver assembly and refuelling locations often provided the best access because this group was not readily contactable by email, and/or have internet access for most of their working hours.

2.1.2 Outcomes

The 2013-14 survey found that the three most important factors, or road attributes, impacted on the LOS for both the heavy vehicle drivers and logistic operators in descending order of importance were:

- ride comfort (road roughness) and road surface conditions
- road shoulder width and condition
- road and bridge geometry and general access.

Survey returns also showed the low incidence (11.9%) use by road agencies of the heavy vehicle truck ride index (HATI) measure (Hassan et al 2006), which is especially concerning considering the importance of ride quality and surface conditions to heavy vehicle drivers. While road shoulder width and condition rated highly, related features such as rumble strips and guidepost replacement did not rate as highly, despite the fact that most heavy vehicle drivers experience some night driving.

2.2. Survey of 2014-15

A follow-up survey in 2014-15 was undertaken aimed at physically quantifying the above three major factors. The survey took place on a rural arterial road circuit in south-western Victoria, centred on the township of Birregurra, where the drivers of trucks and cars were asked to rate the road attributes on designated road segments as they drove the circuit.

2.2.1 Survey details

Table 2 shows that the circuit was comprised of three sections: Section 1 was a VicRoads class A arterial while Sections 2 and 3 were class C arterial roads. Although the circuit did not include a class B arterial road, it was considered more useful to have two arterial road classes that had a relatively large difference between their likely perceived LOS levels to allow better discrimination between the driver ratings on these roads. The circuit was 65 km in length with 23 identified road segments in it. The segment lengths varied between 300 and 400 m, which was sufficient length for drivers to make a rating, but short enough to ensure that there was limited variation in the road conditions and its attributes. Test vehicles included both cars and trucks.

Most heavy vehicle and cars drivers, regardless of their vehicle type, were able to maintain an average speed of 90 to 100 km/h along each defined road segment. All vehicles were surveyed travelling the circuit in an anti-clockwise direction.

A common questionnaire was used for both truck and car drivers. Each driver was identified on the questionnaire for tracking purposes throughout the survey as often the same driver was used for both the heavy vehicles types (rigid truck and B-double) and a passenger car (Subaru station wagon). Tracking allowed a check on the consistency of the drivers' responses across the different vehicle types.

Five ratings on a simple linear scale from 1 (very poor) to 5 (excellent) were used by drivers to rate the ride comfort for each road segment on the questionnaire. The same scale of ratings (1–5) was also used to separately rate the shoulder width and condition and rate the lane width and overall geometry/access along each of the three road sections.

2.2.2 Measurements

The longitudinal profile on the road segments was measured by a two laser profilometer to derive the following three measures of ride comfort: (i) the International Roughness Index (IRI); (ii) the HATI; and, (iii) the Heavy Vehicle Roughness Band Index (HVRBI).

In addition to collecting data on ride comfort and lane and shoulder widths (see Table 2), additional data on within-cab vibrations was collected for the surveys. Vibrations were measured by a uniaxial 4 g triaxial accelerometer oriented vertically in a seat pad placed on the driver's seat to measure the vibrations entering the driver's body in accordance with Standards Australia (2001). The vibrations were measured on the driver's seat for the passenger car, rigid truck and B-double using the same driver for uniformity of comparison purposes.

Table 2: Summary of road circuit features

Section	Shoulder width (m)[2]	Shoulder condition	Lane width (m)[2]	Mean IRI (m/km)	Terrain/grade
1 Princes Hwy West (class A – 6 segments)	2.5	Sealed[1] (1.5 m width)	3.5	2.42	Flat
2 Birregurra – Deans Marsh (class C – 9 segments)	2.0	Unsealed (low quality gravel)	3.1	3.76	Flat/undulating
3 Deans Marsh - Winchelsea (class C – 8 segments)	2.0	Unsealed (low quality gravel)	3.1	3.65	Hilly/undulating

1 Rumble strip also on lane edge.
2 Shoulder and lane widths are nominal mean dimensions. Variability of dimensions was not measured.

Source: VicRoads (2012).

2.2.3 Heavy vehicle details

Table 3 provides the axle group configuration and loads for the two heavy vehicle types used in the survey. All the heavy vehicles were loaded within their allowable general mass limits (GML) axle limits. Table 3 also shows the approximate ages of both heavy vehicles (6 to 12 years) which is representative of the on road fleet age.

Table 3: Heavy freight vehicle types used in survey

<table>
<tr><th rowspan="2">HV type</th><th colspan="4">Axle configuration and load (tonne)</th><th rowspan="2">GVM[5] (tonne)</th><th rowspan="2">Vehicle age (years)[7]</th></tr>
<tr><th colspan="2">SAST[1]</th><th colspan="2">SADT[2]</th></tr>
<tr><td>Rigid truck</td><td colspan="2">5.36
(6.0)[6]</td><td colspan="2">8.38
(9.0)[6]</td><td>13.74
(15.0)[6]</td><td>6</td></tr>
<tr><td rowspan="2">B-double</td><th>SAST</th><th>TADT[3]</th><th>TRDT[4]</th><th>TRDT</th><th></th><th></th></tr>
<tr><td>6.0
(6.0)</td><td>16.5
(16.5)</td><td>17.25
(20.0)</td><td>17.25
(20.0)</td><td>57.0
(62.5)</td><td>12</td></tr>
</table>

1. SAST = Single axle single tyre.
2. SADT = Single axle dual tyre.
3. TADT = Tandem axle dual tyre.
4. TRDT = Triaxle dual tyre.
5. GVM = Gross vehicle mass.
6. Figures in brackets are maximum allowable axle loads under GML.
7. Estimate based on registration identification.

Table 4 summarises the numbers of drivers used in the survey for the conditions of ride comfort, road shoulder width and condition, lane width and geometry/access. Car drivers were included in the survey for comparative purposes. The car driver survey outcomes were used to develop a LOS estimation procedure for non-freight road users. All survey participants resided within a one-to-two hour travel time from the road circuit. Table 4 also shows that some participants drove two vehicle types and most of these were drivers of the rigid trucks and B-doubles. Over 85% of the car drivers only drove the test car.

Table 4: Rural arterial road survey participants

Vehicle type	No. of participants	Car drivers	Rigid truck drivers	B-double drivers
Car (Subaru Wagon)	34	29	5	-
Rigid truck	10	-	4	6
B-double	17	-	6	11
Total	61			

3. Survey Results for 2014-15

3.1. Ride Comfort – Seat Vibration Assessment

The triaxial acceleration data of the seat pad vibrations was collected and compared with the results by vehicle and by road segment. The data from the test apparatus was output in gravity terms, g (= 9.81 $m.s^{-1}$). The accelerations, α, for each data set were converted to root mean square (RMS) values by taking the square root of the average of the squared accelerations in each dimension *x*, *y* and *z* as shown in Equation 1.

$$a_x = \sqrt{\frac{1}{N}\sum_{n=1}^{N} a_n^2} \qquad (1)$$

The RMS accelerations in *x*, *y* and *z* for each data set were combined according to the requirements for seat vibrations in Australian Standard 2670.1 2001 (Standards Australia 2001) to produce a combined measure of the vibrations, g_{rms}, for each data set as shown in Equation 2.

$$g_{rms} = \sqrt{\left(ia_x^2 + ja_y^2 + ka_z^2\right)} \qquad (2)$$

The coefficients *i*, *j* and *k* were set to unity for the seat vibrations.

Although the vehicles were travelling at different average speeds with variations in speed over the length of each section, this would have had a small effect on the vibrations experienced. The results summarised in Table 5 give a good indication of the relative seat vibrational performance of the vehicles on these roads. Results are reported for four test segments, section 2 of the test network was split into A and B sub sections, centred on the township of Birregurra.

Table 5 clearly show the differences in the RMS of seat vibrations between the car, rigid truck and B-double along the three road sections. Not unexpectedly, the vibrations experienced by the rigid truck were always much greater than those experienced by the B-double and the car. Table 5 shows that relative to the car, the rigid truck experienced seat vibrations ranging from 4.65 to 6.12 times those of the car, while the B-double experienced seat vibrations ranging from 3.37 to 4.46 times those of the car.

This simple experiment shows that the IRI measure of roughness is based on a car ride response to the longitudinal road profile which is a substantially dampened ride experience relative to the ride comfort (roughness) experienced in a rigid truck and B-double. Consequently, the IRI is probably a non-optimal measure of a heavy vehicle ride response to the longitudinal road profile.

Table 5: Comparative RMS acceleration values for each dataset

Vehicle type	Road section	g_{rms} all dimensions	Vibration relative to car
Rigid truck	1 (class A)	0.0530	4.77
	2 A[(1)] (class C)	0.0551	4.92
	2 B[(2)] (class C)	0.0704	6.12
	3 (class C)	0.0674	4.65
B-double	1 (class A)	0.0420	3.78
	2 A[(1)] (class C)	0.0377	3.37
	2 B[(2)] (class C)	0.0513	4.46
	3 (class C)	0.0533	3.68
Car	1 (class A)	0.0111	1
	2 A[(1)] (class C)	0.0112	1
	2 B[(2)] (class C)	0.0115	1
	3 (class C)	0.0145	1

1. Road Section 2A comprises that part of Section 2 from Princes Hwy West to Birregurra.
2. Road Section 2B comprises that part of Section 2 from Birregurra to Deans Marsh.

3.2. LOS-Ride Comfort Ratings

The results of the LOS-ride comfort survey are summarised in Table 6 which shows the means and standard deviations of the ride comfort ratings for each of the 23 segments broken down by vehicle type and each of the three road sections in the circuit. For each of the three component road sections, sub-total mean and standard deviation estimates are also reported.

3.2.1 Statistical analysis of ride comfort ratings

By comparing section sub-means, the consistency and direction of changes in driver ratings in moving from class A to class C road segments can be determined, as well as testing whether levels and changes are statistically significant. Table 6 shows that the mean ride comfort rating for cars on the class A section was 3.75 which reduced to a mean of 3.14 on the class C sections, a mean decrease of 0.61. For rigid trucks their mean ride comfort rating on the class A section was 3.40 which reduced to 2.83 on the class C sections, a mean decrease of 0.57. In the case of the B-doubles, their mean rating on the class A section was 3.19 which reduced to a mean of 2.75 on the class C sections, a mean decrease of 0.44. The mean ride comfort ratings for each of the vehicle types reduced when changing from the class A to the class C sections, reflecting the change in LOS ride comfort, although the standard deviations around the mean ratings varied from 0.86 (cars) to 1.05 (rigid truck). The ‘t’ test procedure (Moore & McCabe 1989), quantifying the significance of the difference of the mean ride comfort ratings of trucks and B-doubles changing from class A to class C sections, found these differences to be significant ($p < 0.05$). This supports the view that the rigid and B-double heavy vehicle drivers were more sensitive to the change in LOS for ride comfort compared with car drivers.

The general trend of the mean of the ride comfort ratings was that the ratings also reduced with vehicle size. On the class A section, the mean ride comfort rating of cars was 3.75, while that for rigid trucks and B-doubles was 3.40 and 3.19, respectively. The 't' test procedure quantifying the significance of the difference of the mean ride comfort ratings from cars to rigid trucks and cars to B-doubles on the class A and class C sections found the differences to be significant ($p < 0.05$). However, the differences in mean ride comfort ratings between rigid trucks and B-doubles on the class A and class C sections found the differences to be insignificant ($p > 0.05$).

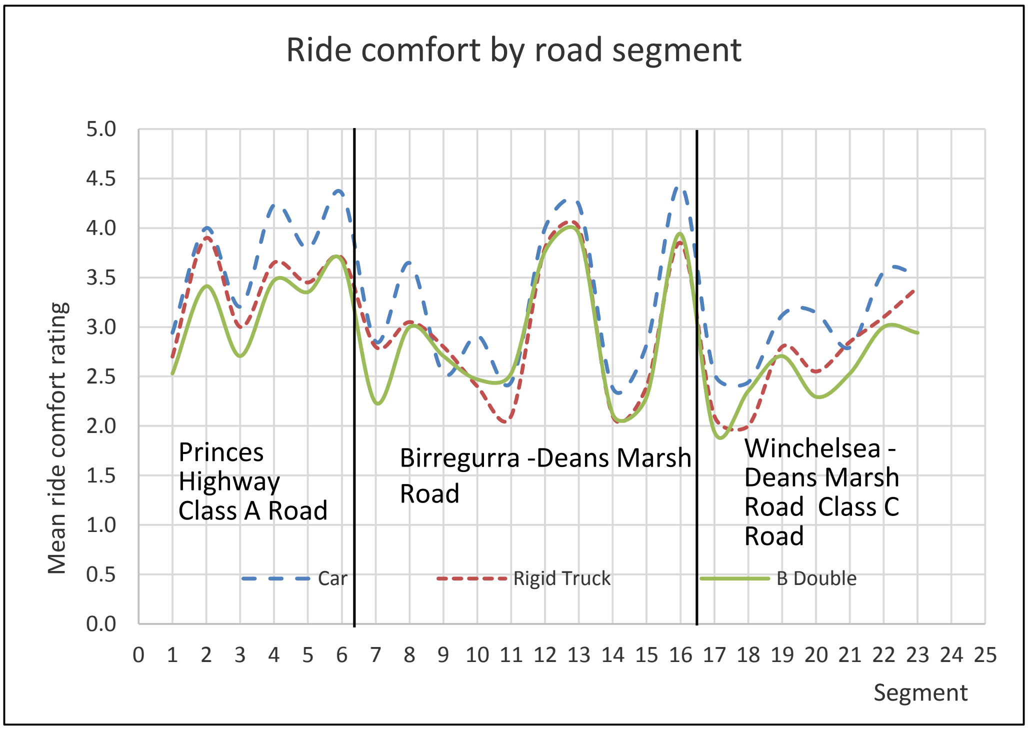
These observations indicate that heavy vehicle drivers tend to rate ride comfort lower for common road sections compared to the ride comfort ratings of car drivers. For the test sections, the lower mean ride comfort ratings by heavy vehicle drivers is likely to reflect in part the relatively higher level of vibrations they experience at any given level of road roughness (Table 5). Despite the fact that rigid trucks experienced higher vibrations than the B-doubles, the differences in their mean ride comfort ratings were not statistically significant.

Table 6: Summary of ride comfort ratings on each segment

Road section	Segment no.	Car ride comfort rating		Rigid truck ride comfort rating		B-double ride comfort rating	
		Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
Section 1 Princes Highway (class A)	1	2.94	0.78	2.70	0.82	2.53	1.07
	2	4.00	0.60	3.90	0.74	3.41	1.00
	3	3.21	0.77	3.00	0.94	2.71	0.99
	4	4.24	0.61	3.65	1.00	3.47	0.94
	5	3.79	0.73	3.45	1.07	3.35	0.86
	6	4.35	0.65	3.70	1.06	3.67	0.92
	Total	**3.75**	**0.86**	**3.40**	**1.00**	**3.19**	**1.03**
Section 2 Birregurra-Deans Marsh Road (class C)	7	2.85	0.89	2.80	0.92	2.24	0.83
	8	3.65	0.69	3.05	0.96	3.00	0.87
	9	2.53	0.61	2.80	0.92	2.71	0.77
	10	2.91	0.93	2.40	0.97	2.47	0.72
	11	2.44	0.75	2.10	0.57	2.53	0.72
	12	4.00	0.65	3.80	1.14	3.76	0.66
	13	4.24	0.55	4.00	0.82	3.94	0.66
	14	2.38	0.74	2.10	0.57	2.12	0.78
	15	2.82	0.72	2.40	0.70	2.29	0.99
	Total	**3.09**	**0.98**	**2.83**	**1.05**	**2.78**	**0.99**
Section 3 Winchelsea -Deans Marsh Road (class C)	16	4.44	0.61	3.85	.82	3.94	0.75
	17	2.53	0.83	2.10	.57	1.94	0.97
	18	2.44	0.75	2.00	.82	2.35	1.00
	19	3.12	0.69	2.80	.79	2.71	0.85
	20	3.15	0.86	2.55	.69	2.29	0.99
	21	2.79	0.81	2.85	.82	2.53	0.94
	22	3.56	0.79	3.10	1.10	3.00	0.94
	23	3.53	0.79	3.40	0.97	2.94	0.90
	Total	**3.19**	**0.97**	**2.83**	**0.99**	**2.71**	**0.92**

When the individual segment means set out in Table 6 were plotted out as in Figure 1, it can be seen that the survey drivers were responding to commonly perceived variations in surface condition, in addition to responding differentially to the type of vehicle driven. This applies at a segment as well as the section mean level previously considered. In almost all instances, the car drivers rated ride comfort higher than the heavy vehicle drivers.

Figure 1: Mean ride comfort rating vs. segment number



3.2.2 Ride comfort ratings relationship to roughness measures

The relationship between ride comfort ratings and the technical measures of ride comfort (roughness) used by road agencies was also investigated. There were three candidate measures of surface condition for this exercise: IRI, HATI, and HVRBI. A simple linear regression model, based on past work shown in Equation 3 was selected (Martin 2005).

$$\text{Ride comfort rating} = \alpha - \beta \times \text{ride comfort measure} \qquad 3$$

where

α = constant from linear regression

ride comfort measure (roughness) = IRI, HATI and HVRBI

It should be noted that as ride comfort ratings increase ride comfort measures decrease.

On this basis a set of simple linear regression models was estimated which sought to estimate variations in mean ride comfort from variations in the measures road roughness, using segment-level data presented in Table 6. Separate models were developed for car, rigid truck, and B-double drivers. Three alternative measures of road roughness were evaluated. The results are summarised in Table 7.

The models shown in Table 7 indicate that all models are satisfactory in terms of statistical significance, goodness of fit (r^2), and mathematical signs associated with parameter values. However, important variations can be observed for models developed for different vehicles, and equivalent models using different roughness measures.

For models using IRI as the explanatory variable, the best results in terms of goodness of fit were achieved for cars (r^2 = 0.85), and the worst results for B-doubles (r^2 = 0.71). In Table 7 the constant value 'α' in the models reduced as the vehicles became larger which is consistent with a lower LOS reported for larger vehicles. Furthermore, as shown by a comparison of slope coefficients 'β', the car regression model showed a greater reduction in predicted ride comfort rating to a unit increase in IRI than was the case for rigid trucks and B-doubles. Predicted changes in user ride comfort ratings for a given change in IRI would therefore be larger for cars, than for rigid trucks, which in turn would be larger than for B-doubles. In an asset management context, if these results were applicable to all roads, they would indicate that for a given IRI value ride comfort ratings would be less for freight vehicles than for cars, and changes in roughness measured by IRI would have less effect on freight vehicle ride quality than cars for the roughness ranges considered.

Table 7: Relationship between mean ride comfort ratings and roughness measures

Explanatory variable	Vehicle	Regression parameters		r^2	Statistical significance	
		Constant	Co-efficient		F	*p*
IRI	Car	4.78	–0.44	0.85	127.60	<0.005
	‘t’	33.65	–11.30			
	Rigid truck	4.36	–0.41	0.83	109.15	<0.005
	‘t’	30.43	–10.45			
	B-double	4.08	–0.36	0.71	55.38	<0.005
	‘t’	23.14	–7.44			
HVRBI	Rigid truck	4.10	–0.39	0.81	95.64	<0.005
	‘t’	31.93	–9.78			
	B-double	3.87	–0.35	0.73	60.47	<0.005
	‘t’	26.75	–7.78			
HATI	Rigid truck	4.34	–0.75	0.83	106.09	<0.005
	‘t’	30.22	–10.30			
	B-double	4.18	–0.72	0.83	107.48	<0.005
	‘t’	30.55	–10.37			

Different outcomes are shown for the models using HVRBI and HATI, although these measures are not directly comparable with using IRI. Results were reported for rigid trucks and B-doubles. For the HVRBI models, the goodness of fit is marginally below that for the equivalent IRI model for rigid trucks (r^2 = 0.81), but slightly better for B-doubles (r^2 = 0.73). The HATI models show an equivalent goodness of fit to IRI models for rigid trucks (r^2 = 0.83), but an appreciably better fit for B-doubles (r^2 = 0.83). As was the case for IRI models, for a given level of HVRBI or HATI, lower predicted ride comfort ratings are predicted for B-doubles compared with rigid trucks, while a given change in either index is likely to result in a smaller change in predicted ride comfort rating for B-doubles compared with rigid trucks. With respect to these two indexes it would appear that the HVRBI needs further refinement to improve its ability to estimate ride comfort LOS, while the results for HATI indicate a positive case for its use by road agencies for estimating levels and changes in heavy vehicle ride comfort LOS.

3.3. Assessment of Shoulder, Lane and Geometrical Attributes

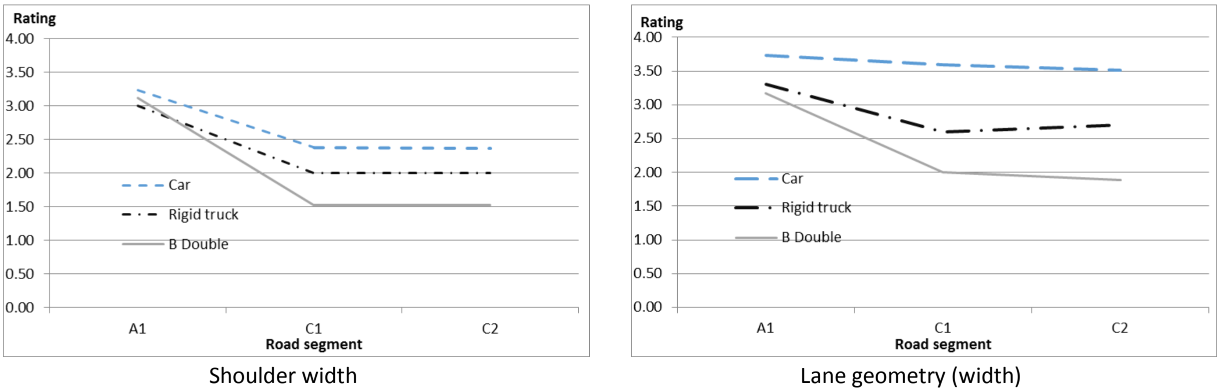
3.3.1 Initial analysis of driver rankings of road shoulder and lane attributes

Survey respondents were requested to rate the LOS associated with shoulder condition and lane width using the same rating scale as that used for ride comfort (1–5). Table 2 shows the different shoulder and lane mean LOS driver ratings associated with class A and class C road sections. Compared with the ride comfort analysis, variation in shoulder and lane width was limited, comprising one set of values for the class A road with a single lane width and alignment and a single shoulder width consistent across the whole section. A reduced set of values for shoulder and lane width were constant across the two class C road sections.

While these limited comparisons restricted the possibility of developing LOS functions equivalent to those developed for ride comfort, it did permit some testing of the sensitivity of driver LOS rating in response to changing shoulder widths and lane geometry.

It was expected that lower shoulder and lane LOS ratings would be occur on the class C road sections compared with the class A road section, and that LOS ratings would be similar between the two class C road sections. It was also expected that different LOS scores would be recorded between vehicle types for the same shoulder and lane widths. From the plots of mean ratings for recorded shoulder and lane width set out in Figure 2, it appears as if both expected variations occurred.

Figure 2: Variations in mean shoulder width and lane geometry LOS ratings (values cross-tabulated by vehicle type driven and road segment)



3.3.2 Analysis of driver rankings of road shoulder attributes

Examination of the mean rating values for shoulder width shown in Table 8 indicated that subjects did not rate the class A section particularly highly with the mean rate for cars amounting to 65.4% of the maximum possible rating, with equivalent estimates being 60% for rigid trucks and 62.4% for B-doubles. However, absolute mean values were quite similar across vehicle types for the class A section. Shoulder LOS ratings were consistently lower for class C sections, indicating reduced shoulder widths did result in lower ratings. Mean LOS ratings for the class C sections were very similar, supporting the case that driver rating decisions were consistent and rational. Reductions in shoulder LOS as measured by mean rating also displayed a positive association with vehicle size, varying between 28% and 27% for cars, 33% for rigid trucks, and 51% for B-doubles.

All of the differences between mean shoulder ratings between class A and C road sections were regarded as statistically significant as shown by the paired ‘t’ test outcomes in Table 9 irrespective of vehicle type driven. Differences in mean values between the two class C sections were not statistically significant, meaning mean ratings can be regarded as equivalent. Consequently, in the shoulder-width dimension, all changes in LOS as previously described were regarded as statistically significant ($p < 0.05$) and not due to chance. However, this was not uniformly the case when mean rating values were compared in the between-vehicle types as in Table 10.

Analysis of Figure 2 and Table 8 shows that the class A mean shoulder width ratings were equal to 3 or greater, which is considered to be an acceptable LOS indicating the shoulder widths were, on average, acceptable to all vehicle types. However, the class C mean shoulder width ratings were between 1.53 and 2.39, indicating the shoulder widths were, on average, unacceptable to all vehicles types, especially for the heavy vehicles which had the lowest ratings.

Table 8: Ratings of shoulder width by road class and vehicle type (mean values, standard deviations, and sample sizes)

Vehicle category	Road section		
	Section 1 - class A	Section 2 - class C	Section 3 - class C
Car			
Mean	3.27	2.35	2.39
Standard deviation	0.90	1.18	1.10
No. of observations	34	34	34
Rigid truck			
Mean	3.00	2.00	2.00
Standard deviation	1.15	1.05	1.05
No. of observations	10	10	10
B-double			
Mean	3.12	1.53	1.53
Standard deviation	1.17	0.80	0.80
No. of observations	17	17	17
All vehicle categories			
Mean	3.19	2.08	2.10
Standard deviation	1.01	1.12	1.07
No. of observations	61	61	61

Table 9: Changes in mean rating of shoulder widths by road class and vehicle type (paired 't' test results)

Vehicle category	*Road section*		
	Section 1 to 2 (class A to class C)	*Section 1 to 3 (class A to class C)*	Section 2 to 3 (class C)
Car			
Mean reduced rating	*0.85*	*0.85*	–0.03
Standard deviation	*1.16*	*1.09*	0.81
't' value	*4.29*	*4.46*	–0.22
Degrees of freedom (df)	*33*	*32*	32
p	*0.00*	*0.00*	0.83
Rigid truck			
Mean reduced rating	1.00	1.00	0.00
Standard deviation	1.15	1.25	0.82
't' value	2.74	2.54	0.00
Degrees of freedom (df)	9	9	9
p	0.02	0.03	1.00
B-double			
Mean reduced rating	1.59	1.59	0.00
Standard deviation	1.00	1.06	0.50
't' value	6.52	6.15	0.00
Degrees of freedom (df)	16	16	16
p	0.00	0.00	1.00
All vehicle categories			
Mean	0.52	0.58	0.05
Standard deviation	0.89	1.03	0.75
't' test	4.62	4.39	0.52
Degrees of freedom (df)	60	59	59
p	0.00	0.00	0.61

Examination of the results of tests for statistical significance of differences between mean ratings (Table 10) for shoulder LOS between vehicle types for the class A section indicated a lack of statistical significance between all possible pairs of vehicles. Consequently, it cannot be concluded that on average drivers of the three vehicle types rate shoulder LOS differently. For the two class C sections the lower mean ratings for B-doubles compared with cars were significant, indicating that for this class of road B-double drivers observe a lower LOS than car drivers.

Table 10: Comparison of differences between mean ratings for shoulder widths between vehicle types−results of independent group 't' tests

Attribute	Section	Comparison	't' test of difference between means		
			't'	df	*p*
Shoulder	1 (class A)	Car with rigid truck	0.67	42	0.5070
		Car with B-double	0.39	49	0.6964
Shoulder		Rigid truck with B-double	0.25	25	0.8016
	2 (class C)	Car with rigid truck	0.94	42	0.3541
		Car with B-double	2.73	49	0.0088
		Rigid truck with B-double	1.31	25	0.2013
	3 (class C)	Car with rigid truck	0.92	42	0.3636
		Car with B-double	2.75	49	0.0083
		Rigid truck with B-double	1.31	25	0.2013
	All sections	Car with rigid truck	1.40	130	0.1652
		Car with B-double	3.06	151	0.0026
		Rigid truck with B-double	1.01	79	0.3140

For the rigid truck drivers, even though mean shoulder ratings fell between cars and B-doubles, a lack of statistical significance of comparisons between this group and cars and B-doubles indicated an indeterminate result. The contention that these differences between mean values reflected random variation in ratings between subjects cannot be dismissed. Consequently it cannot be argued that mean values are comparable with either those reported for cars or B-doubles. This outcome appeared to be associated with two factors, a small sub-sample size for rigid trucks (n = 10) and a relatively high degree of variability in ratings as measured by standard deviations (Section 2 and 3 standard deviation = 1.05, Table 8) compared with mean values (Section 2 and 3 mean = 2, Table 8).

3.3.3 Analysis of driver rankings of lane width attributes

The mean lane width rating values shown in Table 11 indicate that drivers did not rate the class A section particularly highly with the mean rate for cars amounting to 75.2% of the maximum possible rating, with equivalent estimates being 66% for rigid trucks and 63.6% for B-doubles.

For car drivers, the lane width LOS ratings varied minimally between road classes. Average ratings for class C sections were only slightly below the class A section means. By contrast, the rigid truck categories lane LOS ratings were consistently lower for the class C sections, indicating that for these drivers reduced lane width did result in lower ratings. Mean LOS ratings for the two C class sections were similar. Reductions in lane width LOS as measured by the mean rating also displayed a positive association with vehicle size, varying between 5% and 7% for cars, 18% and 21% for rigid trucks, and 37% and 41% for B-doubles. This pattern is similar to that observed for shoulder width.

Analysis of Table 11 shows that the class A mean lane width ratings were all greater than 3, indicating the lane width was, on average, acceptable across all vehicle types in the sample.

However, the class C mean lane width ratings were between 3.57 (cars), 2.00 (rigid trucks) and 1.88 (B-double), indicating the reduced lane width was, on average, considerably less acceptable across heavy vehicles types. The small size of the sample, combined with a narrow range of lane widths, indicates that further survey work may be required before these findings can applied to the broader road network.

Table 11: Ratings of lane geometry by road category and vehicle type

Vehicle category	Road section		
	Class A1	Class C2	Class C3
Car			
Mean	3.76	3.57	3.50
Standard deviation	0.72	0.60	0.74
No. of observations	34	34	34
Rigid truck			
Mean	3.30	2.60	2.70
Standard deviation	1.06	0.84	0.82
No. of observations	10	10	10
B Double			
Mean	3.18	2.00	1.88
Standard deviation	0.88	0.87	0.86
No. of observations	17	17	17
All vehicle categories			
Mean	3.53	3.00	2.94
Standard deviation	0.85	0.99	1.05
No. of observations	61	61	61

The paired ‘t’ test results reported in Table 12 indicate that differences between mean lane LOS estimates for car drivers reported for class A and C sections were not statistically significant ($p > 0.05$). Consequently, the survey results did not support the hypothesis that lane width LOS for car drivers varied in response to changing lane width.

For rigid truck drivers, mixed results in terms of statistical significance of differences were indicated. Comparisons between the class A section and the class C1 section indicated a significant difference, while a similar comparison between the class A section and the class C2 section was not significant ($p > 0.05$).

Only for the B-double were differences between class A and C sections statistically significant, indicating that reductions in LOS were not a chance occurrence. In terms of comparisons between the two class C road sections, none of the vehicle type lane width LOS ratings differences were found to be statistically significant. This supported the contention that the mean LOS ratings for the two class C sections could be regarded as the same.

In Table 13 differences in mean lane width LOS estimates are tested for statistical significance in the between-vehicles dimension. For the class A section the only between vehicle type difference that can be regarded as statistically significant ($p < 0.05$) is between cars and B-doubles. For the class C section C2 differences in mean values between cars and rigid trucks and cars and B-doubles can be regarded as statistically significant, but those between rigid trucks and B-doubles nominally cannot ($p > 0.05$). However, if the ‘t’ test is converted from the two tailed test to a one tailed test, the difference is statistically significant ($p = 0.046$). This modification is considered to be valid given it was expected that the class A section mean LOS would be greater than its C2 equivalent. Consequently, the observation that mean lane width rating reduces with vehicle size for this road section is supported by statistical evaluation. For the C3 section, independent group ‘t’ test outcomes indicates that all differences between vehicle types are significant, which indicates reductions in mean LOS values are unlikely to be associated with random variations in the survey sample.

Table 12: Changes in ratings of lane width by road category and vehicle type−paired 't' test results

Vehicle category	Road section		
	Class A1 to class C2	Class A1 to class C3	Class C1 to class C3
Car			
Mean reduced rating	0.15	0.21	0.06
Standard deviation	0.78	0.93	0.83
't' value	1.09	1.31	0.42
Degrees of freedom (df)	33	32	32
p	0.28	0.20	0.68
Rigid truck			
Mean reduced rating	0.70	0.60	-0.10
Standard deviation	0.95	1.17	0.57
't' value	2.33	1.62	-0.56
Degrees of freedom (df)	9	9	9
p	0.04	0.14	0.59
B-double			
Mean reduced rating	1.18	1.29	0.12
Standard deviation	0.64	0.77	0.70
't' value	7.63	6.91	0.70
Degrees of freedom	16	16	16
p	0.00	0.00	0.50
All vehicle categories			
Mean	0.52	0.58	0.05
Standard deviation	0.89	1.03	0.75
't' test	4.62	4.39	0.52
Degrees of freedom (df)	60	59	59
p	0.00	0.00	0.61

Table 13: Statistical assessment of differences between lane width mean LOS values by vehicle type-results of independent group 't' tests

Attribute	Section	Comparison	't' test of difference between means		
			't'	df	*p*
Lane	A1	Car with rigid truck	1.46	42	0.1508
		Car with B-double	2.36	49	0.0222
		Rigid truck with B-double	0.33	25	0.7470
	C2	Car with rigid truck	4.12	42	0.0002
		Car with B-double	7.60	49	0.0000
		Rigid truck with B-double	1.75	25	0.0915
	C3	Car with rigid truck	3.07	42	0.0037
		Car with B-double	7.21	49	0.0000
		Rigid truck with B-double	2.43	25	0.0228
	All sections	Car with rigid truck	4.77	130	0.0000
		Car with B-double	8.94	151	0.0000
		Rigid truck with B-double	2.23	79	0.0285

4. Summary of Survey Findings for 2014-15

4.1. General

The 2014–15 survey tested freight vehicle drivers' ability to assess physical variations in LOS, by recording the LOS ratings of a sample of freight vehicle drivers who drove around a calibrated rural road circuit in south-western Victoria. The subjects of the ratings process were three road attributes: ride comfort (roughness), shoulder width and condition, and lane width and geometry/access. These attributes were identified by a large scale interview survey in 2013–14 in which these attributes were found to be the three highest ranking attributes affecting overall LOS delivered to freight vehicles by road infrastructure. Overall, the process was successful with the attribute rating system yielding consistent and robust statistical results as survey ratings in response to variations in the key attributes. The availability of equivalent ratings from a sample of car drivers using the same circuit allowed comparisons to be made between the LOS delivered to cars and trucks.

Generally, drivers of all heavy vehicle types responded consistently to variations in ride comfort and road shoulder attributes associated with changes in LOS moving from class A to class C rural arterials. Reductions in LOS ratings associated with reduced lane width were strongly reported by the B-double drivers, while the rigid truck drivers were not statistically sensitive to reductions in lane width, although the number of rigid truck drivers surveyed was relatively low. When comparisons were drawn with LOS ratings made by car drivers, truck drivers reported lower LOS levels and greater reductions in LOS per equivalent reduction in the three measures of road roughness being considered.

4.2. Assessment of LOS Ride Comfort

The following is a summary of the findings regarding heavy vehicle LOS for ride comfort:

- Measured seat vibrations in three dimensions showed that relative to the car, the rigid truck experienced seat vibrations ranging from 4.65 to 6.12 times those of the car, while the B-double experienced seat vibrations ranging from 3.37 to 4.46 times those of the car.
- The heavy vehicle drivers were sensitive to changes in LOS for ride comfort.
- The heavy vehicle drivers tended to rate ride comfort lower for a given measured roughness level compared to the ride comfort ratings of car drivers.
- Despite the fact that rigid trucks experienced higher vibrations than B-doubles, the differences in their mean ride comfort LOS ratings were not statistically significant.
- The variations in ride comfort ratings over the circuit recorded for cars, rigid trucks, and B-doubles followed the same relative track, with the car ratings lying above the rigid truck ratings, which in turn lay above the B-double ratings. This indicated consistency across groups which reflect the variations in physical measures (IRI, etc.) that are matched by driver ratings. This also indicated that absolute levels and variations in roughness conditions yielded a lower LOS for freight vehicles, which in turn was a greater reduction in LOS for B-doubles compared with rigid trucks.
- The IRI roughness measure produced the best fit for equations seeking to relate ride comfort ratings to a measured roughness relationship for cars compared with alternative roughness measures for freight vehicles.
- The HATI and HVRBI roughness measures produced similar to marginally worse fits to the ride comfort ratings and roughness relationships for heavy vehicles than those found by the IRI measure for cars.

- Where only trucks were considered, the HATI yielded the best and a satisfactory goodness of fit compared with the HVRBI for the ride comfort rating relationship for both rigid trucks and B-doubles.
- The HVRBI for B-doubles performed only marginally better than IRI. However, because the HVRBI was originally derived from measured truck vibrations (Ai 2012) and particular truck configurations, it has the greatest potential as a truck roughness index to estimate truck ride comfort LOS from. This study has shown that further refinement of the HVRBI is required if it is to be used to assess the ride comfort LOS for specific to heavy vehicles.
- Based on estimates of acceptable LOS ratings for ride comfort, all freight vehicles would prefer to have lower roughness levels when travelling on all different road classes.
- The estimated acceptable LOS ratings for ride comfort for B-doubles was lower than that of any other vehicle type.

4.3. Assessment of LOS for Shoulders, Lane and Geometric Attributes

The following is a summary of the findings regarding the heavy vehicle LOS for shoulder width and conditions, lane width and geometrical attributes:

- The heavy vehicle drivers were sensitive to changes in LOS for shoulder width and lane width. Where two road sections shared width and lane attributes, average LOS ratings were similar, with any differences proving to be statistically non-significant. This indicated that on average freight vehicle drivers considered that these sections provided the same LOS for these attributes. This outcome validates the methodology used, and was replicated for car drivers.
- The heavy vehicle drivers were more sensitive to changes in shoulder width as opposed to lane width. However, B-double LOS ratings were significantly sensitive to the lane width reductions associated with a lower LOS.
- As a consequence of the above, heavy vehicle driver sensitivity to shoulder and lane width increased with heavy vehicle size, showing that different heavy vehicle types require different mixes and intensities of LOS provided by specific road attributes.

5. Future Research

Future research should be considered to undertake the following activities:

(1) Confirm the inferred differences between rigid and B-double LOS ratings for ride comfort and road geometry attributes by increasing the number of rigid vehicle drivers surveyed on the road circuit from 10 to 17.

(2) Extend the range of freight vehicles considered to cover the LOS experienced by other mainstream vehicles, such as six-axle articulated trucks, and to test the validity of the HATI and HVRBI measures for other heavy vehicle types.

(3) An increase in the range of variation in shoulder width and lane geometry LOS considered by means of extending the study’s road classes to VicRoads class M (freeway/motorway) and class B (medium class highway).

(4) Determine a process for road agencies to set a separate LOS for: (i) ride comfort; (ii) lane and shoulder width; and (iii) road and bridge geometry for rural roads based on road function (class) and freight vehicle requirements and their configurations.

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