A PRO-FORMA APPROACH TO CAR-CARRIER DESIGN

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Abstract

In this work a pro-forma approach is developed for assessing truck and centre-axle tag-trailer or 50/50 car-carrier designs in terms of their compliance with the South African Performance-Based Standards (PBS) pilot project requirements. First, the low-speed performance standards were considered using a low-speed pro-forma design developed by deriving equations for frontal swing, tail swing and low speed swept path. Thereafter, the remaining performance standards were considered, incorporating additional checks to be performed when evaluating a potential vehicle. It was found necessary to specify a minimum drive axle load in order to meet the startability, gradeability and acceleration capability standards. The required drive axle load was determined as 19.3% of the GCM. It was confirmed that the static rollover threshold performance can accurately be predicted by means of the applicable New Zealand Land Transport Rule method. This simplified approach can significantly benefit the PBS pilot project by offering a cost effective method to investigate the PBS conformance of proposed car-carriers.

Keywords: Performance-Based Standards, Pro-Forma, Blueprint, Heavy Vehicles, Car-Carrier

1. Introduction

As a result of successful initiatives in Australia, New Zealand and Canada, a performance-based standards (PBS) scheme has been operated as a demonstration project in South Africa since 2004 (Nordengen, 2014). This pilot project has successfully been running in parallel with the prescriptive legislative framework specified by the National Road Traffic Act (Department of Transport, 1996), or NRTA. Since the commissioning of the first two South African PBS vehicles in 2007, the pilot project has shown a fourfold benefit, offering more economic payload transportation, improved vehicle safety, reduced road infrastructure wear per tonne of payload transported, and reduced emissions. South African heavy vehicle operators that wish to participate in the PBS or Smart Truck pilot project are required to have their vehicle designs assessed in terms of the Australian National Transport Commission's (NTC) PBS standards, which have been slightly modified for the South African context. In South Africa, the safety PBS assessments were initially conducted by Australian NTC-accredited PBS assessors but more recently are generally conducted by the Council for Scientific and Industrial Research (CSIR) or the University of the Witwatersrand using commercially available vehicle dynamics simulation software packages such as TruckSim®. Infrastructure performance standards are assessed using South African pavement and bridge design methodologies.

One significant drawback of the PBS approach in South Africa is the time and expertise required for conducting PBS assessments, generally consisting of gathering input data, modelling and post-processing of output data. The back-and-forth exchanging of design modifications between trailer manufacturers and PBS assessors in trying to arrive at a PBS-compliant design, can also be time-consuming. This is troublesome in South Africa, where there are only four qualified PBS assessors, while the industry is starting to show substantial interest in the PBS project. In addition to this, on 10 March 2014, the final version of the South African Roadmap for Car-Carriers (RCC) was accepted by the Abnormal Load Technical Committee (Abnormal Load Technical Committee, 2014). The RCC specifies that all car-carriers registered after 1 April 2013 will only be granted overall length and height exemptions if the design is shown to meet Level 1 PBS performance requirements. This exemption allows car-carriers to operate up to an overall length of 23 m (including payload projection) and an overall height of 4.6 m, slightly less strict than the NRTA's limits of 22 m and 4.3 m respectively. The new requirement to qualify for these relaxed limitations (which were previously granted regardless of PBS compliance and offer significant benefits to the car-carrier industry in terms of productivity) has resulted in an increased demand for car-carrier PBS assessments. One of the main challenges with these assessments is that each car-carrier design (superstructure and trailer) needs to be assessed with each hauling unit that the operators plan to use, as any change in suspension or other design characteristics of the combination could potentially compromise its PBS compliance. Currently, three commercial car-carrier manufacturers (Unipower Natal, Lohr Transport Solutions ZA, and Rolfo South Africa) are pursuing 23 m designs in South Africa and have developed ten PBS car-carrier design concepts. If each trailer design is assessed with three hauling units, this would require 30 assessments with significant associated assessment costs. Apart from the financial burden, the formal PBS assessment process may cause delays in getting the vehicles on the road and is thus not a sustainable solution. Sparked by the pro-forma approach as implemented in Canada and New Zealand as well as the "Blue-print" approach in Australia, this paper describes the development of a simplified assessment tool to assess truck and centre-axle tag-trailer car-

carrier designs or 50/50 type car-carriers in South Africa. The 50/50 car-carriers get their name from the fact that the proportional lengths of the truck and trailer are respectively approximately 50% and 50% of the total length of the vehicle. The 50/50 car-carriers transport two vehicle units behind the cab on the truck, and are differentiated from short-long car-carriers, which have a significantly shorter wheel-base and transport one vehicle unit behind the cab on the truck.

2. Development of Simplified Assessment Tool

As a starting point, a suitable 50/50-type South African car-carrier was selected and assessed in accordance with the PBS framework. This combination was found to meet the Level 1 PBS requirements. To explore potential pro-forma limits for this design, the low-speed standards were first investigated.

2.1 Low-Speed PBS

A sensitivity analysis was performed using a simplified mathematical model previously developed by CSIR and the University of the Witwatersrand in 2012 (De Saxe, 2012). This model only requires 16 basic geometric properties (illustrated in Figure 1) of the proposed vehicle design and evaluates low speed swept path (LSSP), frontal swing (FS) and tail swing (TS) with an error of less than 5% when compared with fully parameterised simulations in TruckSim®.

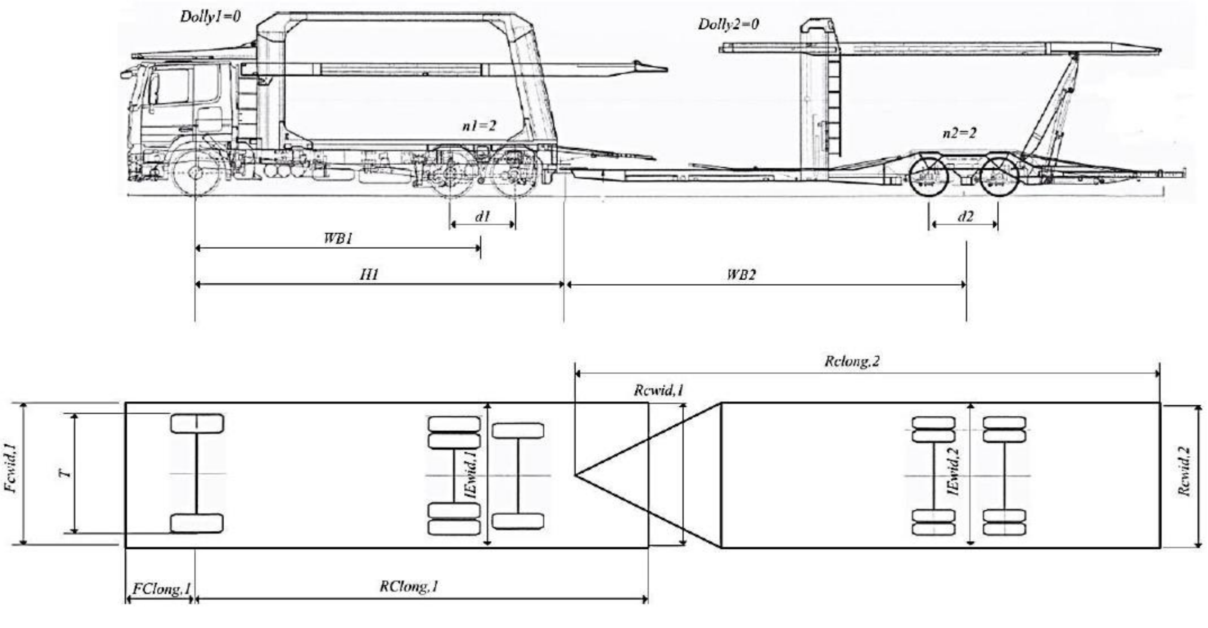

Figure 1 Basic Geometric Inputs Required by Mathematical Model (Benade, Kienhöfer, Berman and Nordengen, 2015)

In the light of the sensitivity analysis results, the parameter boundaries were explored up to borderline Level 1 low-speed PBS compliance. Practical upper and lower limits were observed and assigned to the 16 parameters, similar to the pro-forma approach of New Zealand (De Pont, 2010). Subsequently, 10 000 hypothetical vehicle designs were generated by assigning a random value to each parameter, sampled for a uniform distribution, while complying with the respective upper and lower limits. These designs were evaluated with the mathematical model. It was found that 100% of the designs complied with Level 1 low-speed PBS as shown in Figure 2. The parameter limits were thus sufficient to ensure low-speed PBS compliance. Details or five commercial 50/50-type car-carrier designs were obtained from industry and were evaluated using the proposed pro-forma limits. These designs were found not to comply with the strict upper and lower parameter limits, even though the designs were Level 1 PBS compliant as shown through formal PBS assessments. Further exploration yielded that no fixed-limit pro-forma was able to accommodate the parameter extremities required by the five existing car-carriers. A more flexible approach was needed.

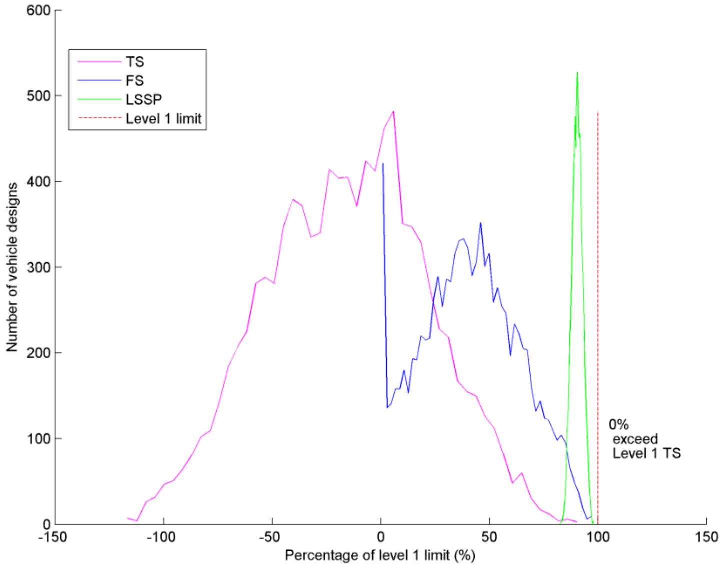

Figure 2 Low-Speed PBS Performance of 10 000 Hypothetical Designs

Customisable Pro-Forma Design

More in line with the Australian Blue Print concept, a customisable pro-forma design was developed. Incorporating the parameter extremities of the five existing car-carriers in conjunction with consulting a number of car-carrier manufacturers, practical minimum and maximum parameter values were obtained as shown in Table 1. Using multivariate polynomial regression, a model was constructed to predict the low-speed PBS performance using only the most critical parameters as identified by the sensitivity analysis. These parameters are shown as “var” in Table 1. Worst-case values were assumed for the other, less critical parameters of FS, LSSP and TS respectively. Parameters of no influence on the particular standard are shaded grey and were assigned the values used in the original car-carrier PBS assessment. 2 000 hypothetical vehicle designs were generated and assessed using the mathematical model. A regression model was trained using 50% of this data set, with the remaining hypothetical vehicle designs being used to test the accuracy of the model. It was found that the maximum error of the regression model was less than 3% for all low-speed performance standards predicted.

Table 1 Customisable Pro-Forma Limits

Proposed limits			Bounds for LSMM			
			Standard			
Parameter	Min	Max	FS	LSSP	TS (Truck)	TS (Trailer)
T	2.1935	2.494	2.494	2.351	2.351	2.351
WB_1	5.75	6.35	var	var	var	var
$FC_{long,1}$	0.5	1.94	var	var	1.352	1.352
$FC_{wid,1}$	1	2.5	var	var	0.2596	2.596
$RC_{long,1}$	8.35	11.93	10.025	10.025	var	6.45
$RC_{wid,1}$	1	2.5	2.3	2.3	var	0.23
n_1	2	2	2	2	2	2
d_1	1.3	1.5	1.5	1.5	1.3	1.3
$IE_{wid,1}$	2.5	2.6	var	2.6	var	2.58
H_1	7.5	8.5	7.825	var	7.825	var
WB_2	7.5	9.2	8.5	var	8.5	var
$FC_{long,2}$			0	0	0	0
$FC_{wid,2}$			0	0	0	0
$RC_{long,2}$	11.2	14.7	12.735	12.735	8.6	var
$RC_{wid,2}$	1	2.5	2.58	2.58	0.258	var
n_2	2	2	2	2	2	2
d_2	1.3	1.8	1.5	1.8	1.5	1.3
$IE_{wid,2}$	2.5	2.6	2.58	2.6	2.58	var
H_2			0	0	0	0

Using this model, an application was developed to evaluate the low-speed PBS compliance of a proposed design. Figure 3 shows the application input screen accepting the five "var" parameters.

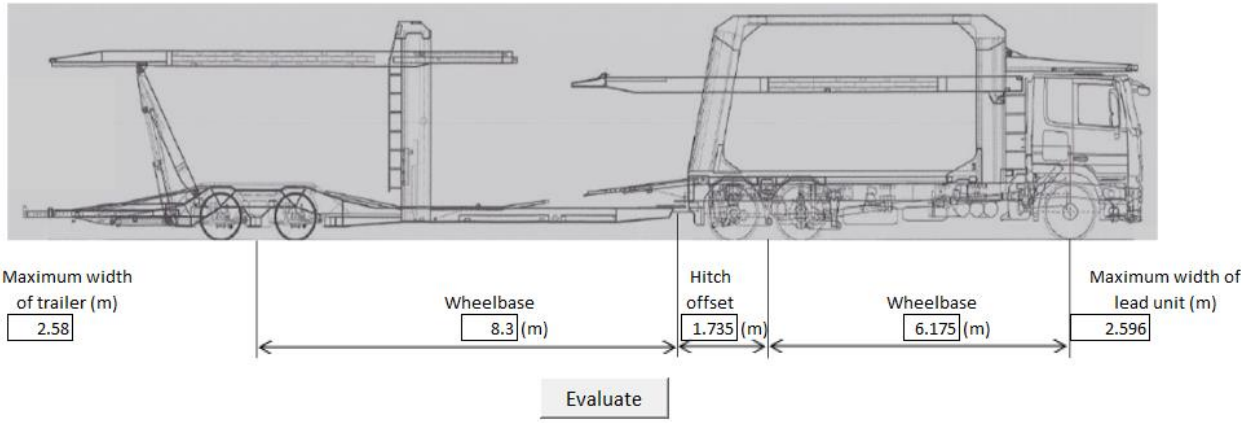
Maximum width of trailer (m) 2.58
Wheelbase 8.3 (m)
Hitch offset 1.735 (m)
Wheelbase 6.175 (m)
Maximum width of lead unit (m) 2.596

Figure 3 Input Parameters of Car-Carrier Low-Speed PBS Assessment Tool

Figure 4 shows the associated output. Based the parameters entered, critical projection limits are calculated and superimposed on the top-view drawing of the combination. If all corners of the vehicle combination and payload projections fall within the boundaries indicated in red, the vehicle is deemed to comply with Level 1 FS and TS requirements. LSSP is also predicted, notifying the user when Level 1 LSSP compliance is not achieved. The five commercial combinations were assessed using this tool and all were found to pass; this is in line with the results of their respective formal PBS assessments.

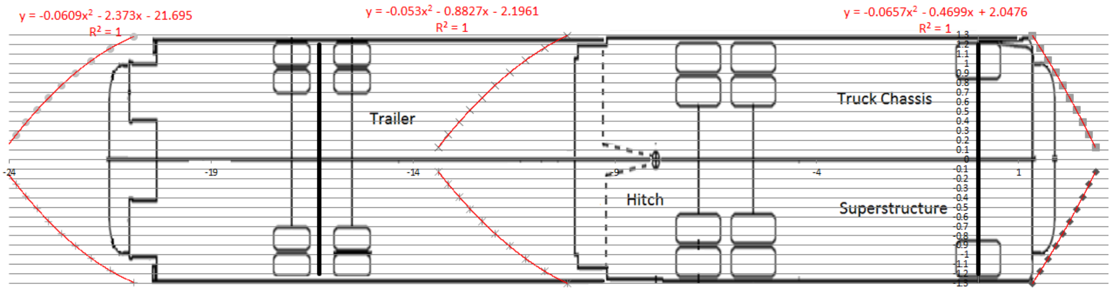

Figure 4 Output Parameters of Car-Carrier Low-Speed PBS Assessment Tool

Steer Tyre Friction Demand

Maximum of difference (MoD) and difference of maxima (DoM) are not applicable to the 50/50 car-carrier type as the trailers have no front overhang. The only remaining low-speed PBS standard to consider was steer tyre friction demand (STFD). The commercial car-carrier PBS assessment showed a STFD performance of only 27%. This is well below the maximum allowed limit of 80%. According to the Australian PBS rules (National Transport Commission, 2008), STFD is typically only a concern for multi-combination vehicles with tri-axle drive combinations that have a widely spread drive axle layout. It is further specified that STFD is generally not an issue for prime movers with single-axle or tandem-axle drive axle configurations. Following Table 1 the customisable pro-forma design only allows for tandem-axle drive systems ($n_1 = 2$) and as such, vehicles complying with the pro-forma requirements will inherently comply with STFD requirements.

2.2 Remaining performance standards

Before attempting to develop a pro-forma for each of the remaining standards, we considered the PBS performance of the five 50/50-type car-carriers as described earlier, to identify the critical remaining standards for this vehicle configuration. These combinations included five different truck models from three manufacturers and four different trailer models from two manufacturers and offer a reasonable representation of what can be expected from the South African 50/50-type car-carrier fleet. The low-speed performance standards are included in Table 2 for reference (shaded grey), however these standards have been accounted for. The top half of this table indicates the PBS performance while the bottom half shows the performance achieved as a ratio of the relevant Level 1 limit. Naturally, for standards where the performance is required to be less than a certain value, such as acceleration capability, the fraction was calculated as the performance divided by the required performance. For the standards where the performance is required to be greater than a certain value, such as SRT, the inverse ratio was calculated, that is, the limit (0.35g in this case) divided by the relevant performance. Using the latter approach slightly skews the results as the benchmark/denominator is not consistent, but gives a useful indication of what the critical standards are for 50/50-type car-carriers. Cases where the performance is close to the limit (~=100 %) are shaded red and those far from the limits (<<100 %) are shaded blue.

Table 2 PBS Performance of Five Commercial 50/50 Car-Carriers

	Combination Performance					
	1	**2**	**3**	**4**	**5**	**Required Performance (Level 1)**
Startability (%)	13	13	15	13	24	≥ 12%
Gradeability A (Maintain motion) (%)	18	15	16	16	25	≥ 15%
Gradeability B (Maintain speed) (km/h)	88	95	89	89	89	≥ 70 km/h
Acceleration Capability (s)	16.5	16.0	18.1	16.6	18.9	≤ 20.0 s
Tracking Ability on a Straight Path (m)	2.8	2.8	2.7	2.8	2.7	≤ 2.9 m
Low Speed Swept Path (m)	7.0	7.1	6.7	6.7	6.7	≤ 7.4 m
Frontal Swing (m)	0.7	0.7	0.7	0.7	0.7	≤ 0.7 m
Tail Swing (m)	0.25	0.24	0.26	0.26	0.18	≤ 0.30 m
Steer-Tyre Friction Demand (%)	24	35	29	23	34	≤ 80%
Static Rollover Threshold (g)	0.37	0.38	0.45	0.38	0.37	≥ 0.35·g
Rearward Amplification	1.30	1.83	1.68	1.10	1.94	≤ 5.7·SRT_rrcu*
High-Speed Transient Offtracking (m)	0.4	0.5	0.5	0.5	0.5	≤ 0.6 m
Yaw Damping Coefficient @ 80 km/h	0.28	0.30	0.36	0.29	0.19	≥ 0.15
* 5.7·SRT_rrcu (g)	2.11	2.17	2.57	2.51	2.68	
	Relative to Level 1 limit (%)					
Startability (%)	92	92	80	92	50	≥ 12%
Gradeability A (Maintain motion) (%)	83	97	97	94	60	≥ 15%
Gradeability B (Maintain speed) (km/h)	80	74	79	79	79	≥ 70 km/h
Acceleration Capability (s)	83	80	91	83	95	≤ 20.0 s
Tracking Ability on a Straight Path (m)	96	97	93	97	93	≤ 2.9 m
Low Speed Swept Path (m)	95	96	91	91	91	≤ 7.4 m
Frontal Swing (m)	100	100	100	100	100	≤ 0.7 m
Tail Swing (m)	83	80	87	87	60	≤ 0.30 m
Steer-Tyre Friction Demand (%)	30	44	36	29	43	≤ 80%
Static Rollover Threshold (g)	95	92	78	92	95	≥ 0.35·g
Rearward Amplification	62	84	65	44	72	≤ 5.7·SRT_rrcu*
High-Speed Transient Offtracking (m)	67	83	85	83	82	≤ 0.6 m
Yaw Damping Coefficient @ 80 km/h	54	50	42	52	79	≥ 0.15

The performance of the combinations in terms of startability, gradeability A and acceleration capability were borderline for a number of combinations. These standards had to be further investigated to specify a rule or model to ensure compliance for the pro-forma design. Gradeability B was found not to be a concern. The tracking ability on a straight path (TASP) performance was borderline but the South African Smart Truck Review Panel (STRP) had previously relaxed the TASP requirements on a case-by-case basis as lane widths in South Africa are generally wider than those in Australia and can thus accommodate poorer TASP performance. In addition, the maximum width of heavy vehicles in South Africa is 2.6 m compared with 2.5 m in Australia. In coherence with the NTC's arguments, STFD was found to be non-critical for the five combinations. The static rollover threshold (SRT) performance of four of the five combinations were close to the limit. SRT had to be investigated further, especially considering its significant influence on vehicle safety. The rearward amplification (RA) performance of all five car-carriers was well within the relevant limit. This is typical for this vehicle configuration with a low number of articulation points. High-speed transient offtracking (HSTO) and yaw damping (YD) were also far from the respective Level 1 limits.

The standards that were identified as borderline and not regulated by the low-speed pro-forma were investigated further with the aim of finding a simple method to insure compliance.

Startability, Gradeability A and Acceleration Capability

In South Africa, engine power is governed by the NRTA's power-to-weight ratio regulations (Department of Transport, 1996). Subsequently, the general trend in the PBS demonstration project thus far has been that startability, gradeability A, and acceleration capability performance are typically limited by traction, rather than by engine power. This is particularly applicable to 6x2 car-carrier trucks as the load on the drive axle is low. Ensuring an acceptable drive axle load is thus the main priority when attempting to ensure acceptable startability, gradeability A and acceleration capability performance.

A simple, effective method to ensure that sufficient drive axle load is achieved is to specify a minimum drive axle load per ton of total combination mass. To specify such a value for 50/50-type car-carriers, a worst-case hypothetical design was assessed at 100 kg drive axle load increments to find the minimum required drive axle load allowing Level 1 startability, gradeability A, and acceleration capability performance to be achieved. In the light of hypothesising a worst-case design, the GCMs of all five commercial car-carriers were considered. The highest GCM was recorded as 43 300 kg. This was conservatively rounded up to 44 000 kg for the hypothetical worst-case. The driveline data of a popular hauling unit was assumed to be representative. A worst case frontal area was assumed as 4.6 m x 2.6 m, the maximum allowed height and width based on NRTA (Department of Roads and Transport, 1996) and RCC (Abnormal Load Technical Committee, 2014). The minimum required drive axle loads based on startability, gradeability A, and acceleration capability were 7 340 kg, 8 480 kg and 4 200 kg respectively. The critical standard is gradeability A, requiring the highest drive axle load (8 480 kg). As a fraction of GCM (44 000kg), this means that 19.3% (or more) of the total GCM is required to be loaded onto the drive axle to ensure compliance.

Static Rollover Threshold

A number of simplified approaches to predicting SRT have been developed over the years. These approaches are typically less accurate but offer a simplified approach without requiring costly computer software packages. The simplest approximation of predicting SRT as explained by Gillespie (1992) is as follows:

$$SRT = \frac{T}{2H} \tag{1}$$

where:
T = track width (m)
H = CoG height of entire vehicle including payload (m)

This method disregards the effects of deflection in the suspension and tyres. According to Gillespie, this method is a first-order estimate, and although it is a useful tool for comparing vehicle performance, it is not a good predictor of absolute SRT performance.

An improvement to Equation (1) is an approximation developed by Elischer and Prem (1998), incorporating a factor, F, empirically derived to approximate the lateral shift of the sprung mass CoG as the body rolls. Elischer and Prem (1998) confirmed that this model was found to produce SRT results accurate to 7% for vehicles with a variety of load densities and configurations.

$$SRT = \frac{T}{2HF} \qquad (2)$$

where:
T = track width (m)
H =CoG height of entire vehicle including payload (m)
$F = 1 + \frac{W_p\left(H_p - H_e\right)}{H\left(W_e + W_p\right)}$

where:
W_p = payload mass (kg)
W_e = empty vehicle mass (kg)
H_p = height of CoG of payload (m)
H_e = height of CoG of empty vehicle (m)

An even more detailed approximation is required by New Zealand’s Land Transport Rule (NZLTR, 2002), “case 1”, “case 2” and “case 3”. This method calculates the roll of the axle itself due to tyre compliance (φ), as well as the roll of the sprung mass relative to the axle due to suspension compliance (θ) as shown in Figure 5. Various physical suspension properties, including lash are incorporated into the model allowing for more accurate prediction.

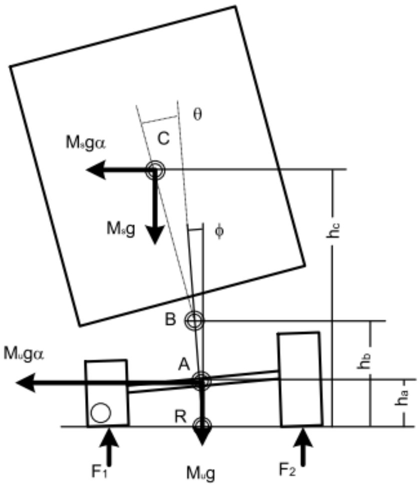

Figure 5 Land Transport Rule Method (New Zealand Government, 2014)

More detail of each approach is summarised in a paper presented at the South African Transport Conference earlier in 2016. (Benade, Berman, Nordengen and Kienhöfer, 2016)

For each of the five car-carriers, the SRT was assessed using all identified SRT approximations and compared the result to that of TruckSim®, with the aim of identifying an acceptable tool to be used in conjunction with the customisable pro-forma design. The results are shown in Table 3.

Table 3 SRT Performance Using Various Predictor Tools

	Combination						
SRT Model	**1**	**2**	**3**	**4**	**5**		
TruckSim (Full Combination)	0.375	0.387	0.446	0.391	0.369		
Truck SRT(g)							
TruckSim	0.375	0.384	0.428	0.393	0.363		
Gillespie (Averaged)	0.528	0.542	0.564	0.552	0.538		
Elischer & Prem (Averaged)	0.397	0.405	0.430	0.427	0.422		
NZLTR “Case 1” (Averaged)	0.418	0.448	0.436	0.443	0.470		
NZLTR “Case 2” (Averaged)	N/A	N/A	0.432	N/A	N/A		
NZLTR “Case 3”	0.397			0.412	0.352		
Trailer SRT (g)							
TruckSim	0.439	0.446	0.484	0.468	0.475		
Gillespie	0.504	0.511	0.585	0.570	0.572		
Elischer & Prem	0.373	0.376	0.440	0.434	0.428		
NZLTR “Case 1”	0.446	0.453	0.482	0.468	0.472		
Percentage Error w.r.t Vehicle Unit's TruckSim SRT Performance						Average Absolute Error	Maximum Absolute Error
Truck							
Gillespie	40.9%	41.2%	31.8%	40.6%	48.1%	40.5%	48.1%
Elischer & Prem	6.0%	5.4%	0.7%	8.6%	16.2%	7.4%	16.2%
NZLTR “Case 1”	11.4%	16.7%	2.0%	12.9%	29.3%	14.5%	29.3%
NZLTR “Case 2”	N/A	N/A	1.1%	N/A	N/A	1.1%	1.1%
NZLTR “Case 3”	6.0%	N/A	N/A	5.0%	-3.0%	4.7%	6.0%
Trailer							
Gillespie	14.8%	14.5%	20.9%	21.7%	20.4%	18.5%	21.7%
Elischer & Prem	-15.1%	-15.8%	-9.0%	-7.3%	-9.9%	11.4%	15.8%
NZLTR “Case 1”	1.7%	1.4%	-0.4%	0.0%	-0.6%	0.8%	1.7%

It is important to note that the NTC rules dictate that SRT be evaluated based on the complete hitched-up vehicle combination, whereas using any of the identified tools, the SRT of only a single vehicle unit can be evaluated at a time. The NTC further defines the point of roll instability as when the vertical load on all of the non-steering tyres on the lightly loaded side of the combination have reduced to zero or when the roll angle of any unit exceeds 30°. The identified tools generally define instability when the load on all tyres on the lightly loaded side of the vehicle unit have reduced to zero. Generally, 50/50-type car-carrier trailers are hauled by pintle hitches with negligible roll-coupling. It was therefore expected that the SRT performance of the worst-performing vehicle unit would correlate well with the overall combination performance.

For all the combinations, the trucks (as assessed using TruckSim®) were the worst-performing vehicle units and their results correlated well with the results of the respective "full combination", also assessed using TruckSim®. Assessing the trucks using the methods of Gillespie (Gillespie, 1992), Elischer & Prem (Elischer and Prem, 1998), NZLTR "Case1" and NZLTR "Case2" required some assumptions to be made to arrive at an effective suspension i.e. combining the front and rear suspension of the truck. The axle track width, for example, was taken as the average of that of the front and rear suspensions, weighted by the axle group load. Similar assumptions were made for spring track and roll centre heights. Stiffness features were summed as these function in parallel. For NZLTR "Case3", the front and rear suspension characteristics are required to be specified separately, however again the concept of averaging was applied in combining the drive and tag axles where non-identical. As expected, when compared to the TruckSim® vehicle unit results as a baseline, the method of Gillespie (Gillespie, 1992) did not provide accurate results, with an average absolute error of 40.5% for trucks and 18.5% for trailers. The method of Elischer & Prem (Elischer and Prem, 1998) provided more accurate results, especially considering the simplicity of the model with an average absolute error of 7.4% for trucks and 11.4% for trailers. With the truck assessments, NZLTR "Case1" proved to be less accurate than Elischer & Prem's (Elischer and Prem, 1998) method, with an absolute average error of 14.5%. NZLTR "Case2" was only applicable to the third truck, which showed a 1.15% error. The remainder of the trucks experienced wheel lift-off before lash could occur and was thus not assessed using NZLTR "Case2". The reason for this is the high auxiliary roll stiffness of the respective trucks' averaged suspensions. When using NZLTR "Case3", the individual axle groups characteristics were incorporated allowing an improved accuracy or an average absolute error of 4.7%. With the trailer assessments, the NZLTR "Case1" provided excellent accuracy with an average absolute error of 0.8%. Here lash was also not achieved due to the high auxiliary roll stiffness of the trailer axles. The methods of the NZLTR for predicting SRT was found to provide the best correlation with TruckSim® results. This is likely due to the fact that the NZLTR approach incorporates customised suspension characteristics, such as spring stiffness, auxiliary roll stiffness, tyres stiffness and lash, allowing for improved prediction accuracy.

3. Conclusion

A pro-forma approach has been developed for assessing 50/50-type car-carrier designs in terms of compliance with the South African PBS pilot project requirements. All the relevant PBS were considered and simplified means of assessing the critical standards were established. The low-speed performance standards were considered and a customisable low-speed pro-forma design was developed by deriving equations for the frontal swing, tail swing and low speed swept path standards, with a maximum absolute error of 3%. These equations were incorporated into a simplified tool for assessing the low-speed PBS compliance of car-carriers using a top-view drawing of the design. The minimum drive axle load required was determined as 19.3% of the total combination mass to ensure that the vehicle passes startability, gradeability A and acceleration capability. It was determined that the SRT performance can accurately be predicted by means of the NZLTR method, with a maximum absolute error of 6% for the truck and 1.7% for the trailer. The pro-forma approach offers a cost-effective and sustainable alternative to conventional TruckSim® PBS assessments. The study is limited to 50/50-type car-carriers, however the methodology developed will be used to construct assessment frameworks for short-long and tractor-and-semitrailer car-carrier combinations as well as heavy combinations in other industries. The pro-forma approach can have a significantly positive impact on the South African PBS pilot project by allowing for the efficient and sustainable PBS assessment of future 50/50-type car-carrier combinations.

4. Recommendations and Practical Implications Going Forward

The NZLTR method for calculating SRT specifies various default suspension parameters such as typical spring stiffness, suspension track width, composite roll stiffness, axle lash and roll centre height for generic steer, steel and air suspensions. For our validation, the exact values of these properties were sourced from TruckSim® and relevant PBS reports. As this information is time-consuming to gather from OEMs, it is recommended that further investigation is done to assess the impact of using the generic NZLTR suspension characteristics when assessing SRT for 50/50-type car-carriers. If these generic characteristics provide acceptable results, it would streamline the assessment process significantly. It is envisaged that this approach will replace the formal PBS assessment for 50/50-type car-carriers in South Africa. As an interim, these assessments should only be conducted (and reported on) by certified PBS assessors, but with the necessary training can later be delegated to members of the Department of Transport. The default PBS permits and commissioning procedures hold. The potential use of the low-speed PBS tool for the purpose of design optimisation should be investigated.

5. References

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