A FRAMEWORK FOR HEAVY VEHICLE TYRE CORNERING PERFORMANCE ASSESSMENT AND CLASSIFICATION WITHIN THE PERFORMANCE BASED STANDARDS SCHEME

M. COLEMAN
Has a B. Eng. Mechatronics and B. Sc. Cs from The University of Melbourne in 2002. MBA from Melbourne Business School in 2010. Currently the managing director of Tiger Spider and a PBS Assessor with over 18 years of engineering consultancy experience in the heavy vehicle industry.

Abstract
Performance Based Standards (PBS) is a regulatory scheme that provides exemptions to prescriptive mass and dimensions limits and has led to increased productivity and safety in the Australian haulage industry. Most PBS designs rely on numerical modelling techniques to confirm if a High Productivity Freight Vehicle (HPFV) meets the various performance criteria defined in the Standards and Vehicle Assessment Rules. This numerical modelling relies on component input data collected from various sources such as component suppliers and accredited testers. However, obtaining reliable input data for tyres is challenging. To numerically model vehicle dynamics, tyre cornering performance characteristics, rolling resistance and vertical stiffness are necessary inputs to determine whether a vehicle passes PBS requirements. It has become necessary to simulate vehicle models with specific tyre data at various positions and compare combinations of steer, drive and trailer tyres for use on a vehicle to meet the performance requirements. However, this is a time-consuming process and can lead to a shortage of suitable tyres available for a vehicle approved with the PBS scheme. Simplification of the current system is essential to increase the availability of tyres and ensure that the PBS scheme continues to grow. This paper presents the Tiger Spider™ PBS Tyre Classification System (TS-TCS), a systematic method of categorizing the assessed tyres for use in the PBS scheme.

Keywords: Force and Moment Tyre Data, Performance Based Standards, High Productivity Vehicles, Tiger Spider™, PBS Tyre Category System.

1. Introduction

In the past there was very limited tyre cornering data available, consequently, the PBS Scheme was based on the tyre data measured from the Michelin XZA in 1986 by Ervin and Guy. However, after a more widespread implementation of the PBS Scheme, the implications of this assumed technical data input have been realised. The Tiger Spider ™ PBS Tyre Classification System (TS-TCS) is a conservative method for assessing and grouping tyres that has proved useful for streamlining the vehicle assessment process and maximizing the tyre options for use on an approved PBS vehicle. The need for such a system was identified through industry consultation as part of a review of the standards for PBS Level 3 and 4 vehicles undertaken by the Coleman *et al.* [1]. The TCS is unique to Tiger Spider and was implemented in December 2014 since reaching consensus on an industry wide system for classifying tyres proved to be politically challenging.

The current study highlights the approach of TS-TCS and provides the reader with practical insights about the system, it's advantages and shortcomings. This paper also assists in understanding the PBS technical, commercial and public policy perspectives for those interested in PBS scheme.

2. Background

The PBS Scheme is much more than a set of objective technical performance standards. To function, the Australian Scheme assigns various individuals and entities, roles and responsibilities within the scheme. Key stakeholders include: The National Heavy Vehicle Regulator (NHVR), PBS Review Panel (PRP), The National Transport Commission (NTC), PBS Assessors, PBS Certifiers, PBS approval holders, truck and trailer manufacturers, transport operators, component suppliers and the various federal, state and local government road managers. The TS-TCS considers various aspects which must be understood in the context of the Australian PBS Scheme. Hence, it is essential to understand: How the PBS standards and limits were determined, the regulatory obligations imposed on PBS Assessors, the design approval and certification inspection process, common PBS configurations, critical performance limits, tyre testing standards, test equipment, test conditions and pre-conditioning.

2.1. Setting the PBS Standards and Limits

Firstly, the PBS Standards limits were set based on the work completed by Prem *et al.* in 2002 [2]. This work was reviewed and re-imagined, at least in part, by the author in 2014. The original selection of standards, performance review of the existing fleet, and subsequent development of the PBS Standards and Vehicle Assessment Rules was a significant and largely successful task. An oversimplified explanation of the process is shown in Figure 1. It is noteworthy to mention some performance limits, like the 0.35 g limit for Static Rollover Threshold (SRT) were based on demonstrated links to rollover crash rates. Other measures, like High Speed Transient Off tracking (HSTO), were largely based on the performance results of what were deemed acceptable vehicles in the existing fleet [1].

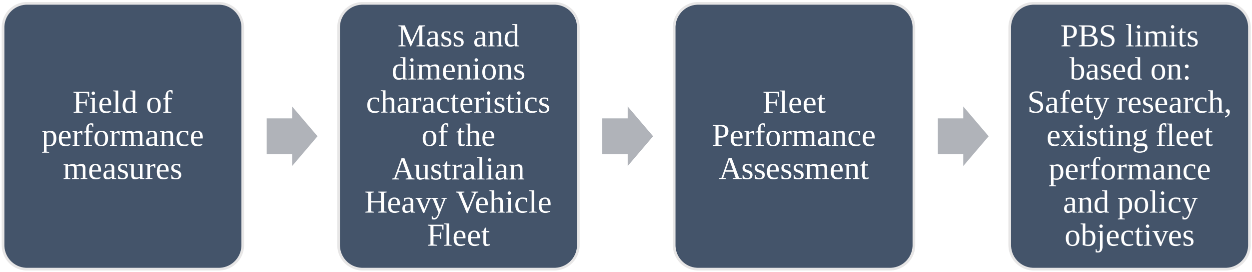


Figure 1. Simplified version of the process involved in setting the PBS standard limits.

2.2. Obligations on PBS Assessors

PBS Assessors enter a contract with the NHVR and are authorised to submit PBS Design Approval applications on behalf of approval holders. The general duties of PBS assessors include: validation of the vehicle designs or vehicles against the set standards by following prescribed test procedures which can be achieved through numerical modelling or physical testing, record the vehicle physical characteristics, perform sensitivity analysis by considering risk sensitive parameters, recommend operating conditions if required, specify the exemptions that are required for the design or a vehicle as per prescriptive requirements. Finally, they may provide formal advice to the NHVR whether a design passes PBS under which performance level. Moreover, they are responsible for the validation of input data and assumptions used in their assessments, where component data is not available from the suppliers, worst-case assumptions must be used [3]. In addition, they are required to have at least $20 M of professional indemnity during the accredited period and also maintain it for 6 years after the cessation of accreditation and $20M of public liability insurance during the accredited period.

2.3. The design approval and certification inspection process

PBS Assessors are predominantly engaged with transport companies (operators) and trailer manufacturers to complete Design Approval (DA). Nevertheless, there is no limit to who can hold a PBS DA. However, in the end, the transport operator holds the PBS Vehicle Approval (VA) and PBS access permit (Permit). Whilst the PBS Assessor must eventually confirm the approved specification, the scope of the DA is ultimately controlled by the approval holder. The DA provides a vehicle specification - vehicle configuration, (mass and dimensions) along with all approved components, for instance engine, transmission, axles, suspensions and tyres. The PBS Certification process requires an accredited certifier who is under contract with the NHVR at the time of certification, inspects each vehicle in the application and confirms that the physical characteristics and technical specifications of the vehicle comply with the approved PBS design [4]. Once the NHVR is satisfied the certified vehicle complies with the DA specification a VA is issued, and the transport operator may apply for a Permit to access the road network.

2.4. Common PBS configurations

Currently, PBS vehicles make up 17% of the heavy vehicle market [5]. On the surface, the PBS market is dominated by Truck and Dog configurations, followed by prime movers and semi-trailers, B-doubles, and A-doubles, (refer Figure 2). However, PBS networks divide the configurations down to a variety of sub-vehicle variations. Component selection becomes key to ensure safe operation for all different heavy vehicle configurations. Most PBS vehicles are restricted access and may have different loading conditions on different PBS networks in addition to access under prescriptive regulations. This has implications for vehicle and tyre selection. For example, the common PBS trucks and quad dog may operate under a prescriptive notice in addition to the PBS Gazette notice for PBS Level 1 & PBS Level 2 truck and dog combinations [6]. The prescriptive PBS truck and quad dog is allowed general network access at 19 m and 50.5 tonnes. PBS Level 1 truck and dogs are allowed up to 20 m and 50.5 tonnes on the PBS Level 1 Network, whereas the very same vehicle, if it passes the approval process, could obtain up to 57.5 tonnes on the PBS Level 2 network. The operating scheme(s) chosen by the operator will determine the range of tyre options available to them.

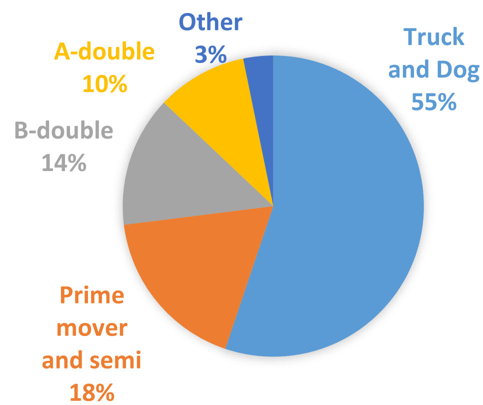


Figure 2. PBS Sale statistics [5].

2.5. Critical performance limits

Tyre characteristics will affect vehicle performance across all PBS measures; however, the sensitivity of vehicle performance to tyre characteristics varies for each. A summary of critical tyre properties and the affect PBS metrics are shown below in Table 1. This paper is focused on tyre cornering properties and their impact on High- Speed Transient Off-tracking (HSTO) in particular. This is because HSTO is often the critical measure for popular PBS vehicles, e.g. truck and dogs and a-coupled road trains. When HSTO is the critical performance measure a vehicle will not pass with all available tyres. Continuing the above example, a 50.5 tonne truck and quad dog will generally require a tyre with good cornering characteristics to meet the Level 1 0.6 m HSTO limit compared to the exact same vehicle operating at 57.5 tonnes on the Level 2 network with 0.8 m HSTO limit. If operating under prescriptive regulations, essentially any tyre may be used.

It is important to note that the focus on HSTO has emerged from the relative important of the various standards for popular vehicles and the limits set for other performance measures. If, for example, a vehicle is marginal in Tracking Ability in a Straight Path (TASP), Low Speed Swept Path (LSSP) or Tail Swing (TS) tyre cornering performance can also become critical. Indeed, if a truly performance-based measure for the Pavement Horizontal Loading Standard (PHLS) such as the one proposed by Donald *et al.* [7] be introduced, a tyre with higher cornering power would provide a clear benefit for e.g. HSTO and TASP but would reduce PHLS performance. These features of PBS make any tyre classification scheme difficult to implement and should the structure of the PBS change over time, any means of classifying tyres may also need to change.

Table 1. Critical tyre properties and affected PBS performance

Performance category	**Performance standard**	**Critical tyre characteristics**
Longitudinal driveline	Startability Gradeability Acceleration capability	Longitudinal stiffness Rolling resistance [8]
Low speed manoeuvring	Low Speed Swept Path (LSSP) Frontal Swing (FS) Tail Swing (TS) Steer Tyre Friction Demand (STFD)	Lateral/Longitudinal (cornering) stiffness [9]
Yaw Dynamics	Tracking Ability on a Straight Path (TASP) Rearwards Amplification (RA) High Speed Transient Off-tracking (HSTO) Yaw Damping Coefficient (YDC)	Lateral/Longitudinal (cornering) stiffness Rolling resistance [10]
Rollover	Static Rollover Threshold (SRT)	Vertical stiffness [1]
Infrastructure	Pavement Vertical Loading Pavement Horizontal Loading Bridge Loading Tyre Contact Pressure Distribution	Lateral/Longitudinal [9] (cornering) stiffness Vertical stiffness Contact pressure distribution Rolling resistance

2.6. Test facilities, Tyre testing standards and conditions

Tyres tested for lateral force and moment characteristics for the purposes of PBS scheme are based on the requirements of SAE J2429 Free Rolling Cornering standards [11]. According to SAEJ2429 test facilities must measure: aligning moment (Mz), ambient temperature (TA), inflation pressure (p), lateral force (Fy), loaded radius (R1), longitudinal force (Fx), normal force (Fz), test speed (S), slip angle (α), spin angular velocity about the wheel spindle (ω), and spindle torque (TS) [11]. Yet, issues arise in assuring a consistent method is used in testing's tyres. Test surface curvature, friction value, test speed, temperature and inflation pressure can all vary the measured tyre cornering properties. Tyre conditions are relevant in influencing tyre testing results - for comparable results, ideally all test tyres should be of approximately the same age, have been stored under essentially identical conditions, have experienced approximately the same exercise history, and have been sampled from production lots with similar statistical characteristics [12]. However, for the purposes of PBS this is of course impossible.

Tyre cornering performance data has been obtained from various test facilities. These include drum and some flat surface machines sourced directly from manufacturers. However, the bulk has been sourced from independent test facilities, including: Smithers Rapra and Calspan in North America, Australian Road Research Board (ARRB) and IPW Automotive in Germany. There is some concern about the comparability between different facilities and whether there is a need to have a benchmarking process or reference test data. The authors have attempted to remedy; however, due to resource constraints this has been done only in a limited way. Nevertheless, it is inevitable that there will be differences between different test facilities for a range of reasons, i.e. test engineer, test conditions, tyre pre-conditioning and the repeatability of test machine. For example, Calspan an indoor machine has data which shows a repeatability of less than 2%; whereas ARRB a relatively newer outdoor test facility with far less data has reported repeatability of less than 5% The author notes that there were informal claims and did not critically investigate the data or analysis underpinning either claim. Nevertheless, it is clearly something that needs to be considered when using data from various sources. It is critical that tyre results are comparable between different test facilities to not only ensure tyre safety standards are meet under PBS, but also to ensure a fair market outcome for tyre OEMS and PBS approval holders.

3. The Tiger Spider Tyre Classification System

The Tiger Spider Tyre Category System TS-TCS conservatively groups tyres to streamline the PBS assessment process. The system can be used across multiple dimension of tyre performance, e.g. cornering performance, vertical stiffness and rolling resistance. Different standards will be sensitive to different aspects of tyre performance. For, example, HSTO and TASP are sensitive to tyre cornering performance, SRT is sensitive to tyre vertical stiffness and Gradeability can be sensitive to tyre rolling resistance. However, since HSTO is so often a critical performance measure for popular PBS vehicles for this paper we will focus on the TS-TCS as it relates to tyre cornering characteristics and HSTO.

The TS-TCS has 6 categories: TS001, TS002, TS003, TS004, TS005 and TS006 (non-specific). Each of these categories is represented by a ‘virtual’ reference tyre. The essential characteristic is lateral force versus slip angle for various vertical loads. Whilst the shape of the lateral force versus slip angle curves are based on real tyre data curves, the magnitude of the curves has been scaled to allow a spread of tyre performance between categories. When the virtual tyres were originally defined, when limited tyre data was available – at the time, in 2014 we have perhaps 30 test tyres, mainly 11R22.5 from various suppliers predominantly tested at Smithers. Whilst drum data from manufactures was available, this was not used when setting the categories because drum data generally shows lower cornering force for a tyre that if the same tyre were tested on a flat surface.

The choice of performance level (lateral force magnitude) for each virtual category tyre was largely based on attempts to get as many tyres options as possible on PBS Level 1 truck and dogs. Consequently, the better performing tyre categories TS001 and TS002 are closer in performance than the lower performing categories. The TS006 category represents the worst-case tyre. In principle all possible tyres available in the market should be worse than the TS006 virtual tyre. Therefore, ideally, a PBS vehicle would be assessed with TS006 category tyres and provided it passed the HSTO requirements with this tyre then we will specify non-specific tyres on the PBS design approval.

In contrast the TS001 tyre has very good cornering characteristics, roughly 10% of tyres in our database are able to meet or exceed the cornering performance of the TS001 tyre. This is significant because the TS001 tyre essentially matches the performance of the reference tyre used when setting the PBS limits. Some PBS vehicles, especially PBS Level 1 truck and dogs require TS001 tyres fitted to all positions to pass Level 1 HSTO requirements. This means, that they will have very limited tyre options. The intermediate tyre categories are become progressively less-well performing such that TS001 performance better than TS002, TS002 better than T003 and so on until finally TS006 is the worst performing tyre.

The TS-TSC attempts to remove the need to assess a vehicle with a specific make and model of tyre. Instead, when assessing a vehicle for PBS using numerical modelling one of the six TS reference tyres is used. In a separate process force and moment data representing a 'real' tyre with associated size, make and model is compared to the virtual reference tyres. The 'real' tyre is then categorised based upon the 'virtual' tyres for which it generates higher cornering performance.

The process of doing this classification is not straight forward. Tyres cornering forces are non-linear so there is no simple way to determine that one tyre will perform better than another. Indeed, there are cases where one tyre may perform better on say a truck and dog, and worse on a b-double compared to a reference tyre. Therefore, to have certainly that a 'real' tyre will always perform better than a 'virtual' tyre some conservatism or safety factor is required in the classification process. In practice, that means that there will be times when a vehicle assessed to required say TS002 tyres in all positions, may be able to also pass the PBS requirements with some tyres that are only deemed TS003 category tyres. Conservatism in any TCS could be reduced by adding more categories. However, adding more categories adds complexity and the benefits of the TCS are diminished.

A key feature of the TS-TSC is that it, in principle, shifts the costs of assessing tyres many times from the VA holder to the tyre supplier. It also makes the PBS Scheme more manageable to both VA holders and tyre suppliers who are generally not PBS experts and therefore become frustrated the rigidity and complexity of the PBS Scheme. However, despite these aims, the reality is that the fundamental complexity of vehicle and tyre interactions, the classification system will never address all cases and re-assessment of vehicles and tyres is required to increase tyre options in the field. That is not to say that a TSC doesn't have a place, rather that it can only go so far, and it cannot substitute a full numerical modelling assessment of a vehicle with a specific size, make and model of tyre.

To illustrate how the TS-TCS works in practice we have provided analysis of some popular PBS vehicles. According to the NHVR statistics truck and dogs make up at least 55% of all PBS vehicles, followed by semitrailers (18%), B-doubles (14%) and A-doubles (10%). For this study we chose a truck and quad dog, prime move and quad-axle semi-trailer and 11-axle A-double based on market demand and PBS performance, (refer Figure 2 & Figure 3).

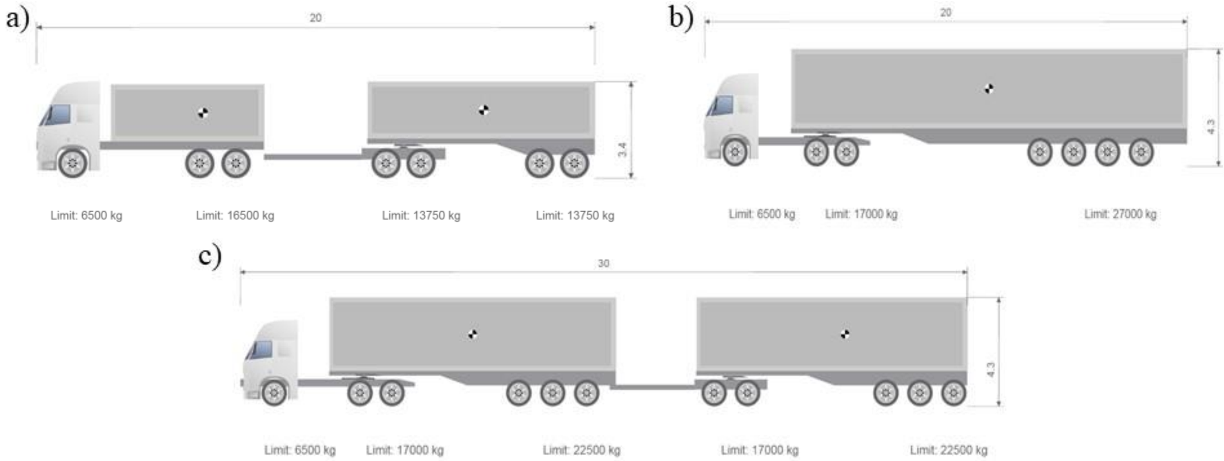


Figure 3. a) 20 m Truck and dog trailer b) 20 m semi-trailer c) 30 m A-double combinations.

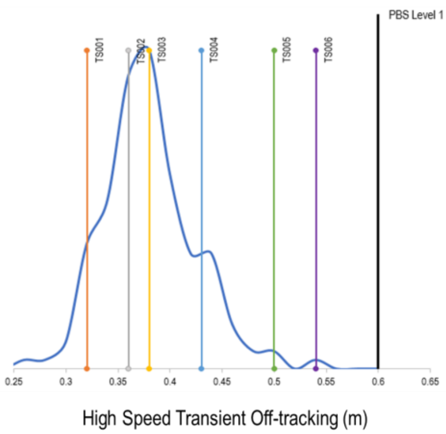
We have assessed HSTO performance for each of the three test vehicles with 165 different make and model of tyres. (see Figure 4(a to c)). The 165 tyres were tested on various flat surface machines. We specifically excluded all tyres data tested on drum machines and those with insufficient supporting information. As such, most data are from independent test facilities; however, in a few cases we've included data sourced directly from manufacturers with in-house flat surface machines.

Figure 4a shows the spread of HSTO performance of the reference prime mover and quad-axle semi-trailer across the 165 test tyres and the 6 'virtual tyres'. Given the inherent performance of the prime mover and quad-axle semi-trailer the vehicle exceed the PBS Level 1 limit of 0.6 m for all tyres. In contrast, Figure 4b shows the spread of HSTO performance of the PBS Level 1 Truck and Dog across the 165 test tyres and 6 'virtual tyres'. The HSTO corresponds to the TS001 category tyre. The data shows that of the 165 'real' tyres tested only 20 or 12% are eligible for this vehicle. Figure 4c shows the spread of performance for the A-double and we can see that the limit corresponds with TS003 category tyres so that 46% of all tyres in the market are available for use.

The limited number of tyre options available because of the PBS Level 1 limit for truck and dogs is at the core of the frustration of tyres and PBS. Were the level 1 Limit set to 0.8 m rather than 0.6 m then TS003 tyres could be specified and more than 50% of available tyres would be available for use on Truck and Dogs. This alone would go a long way to ease the frustration of operators within the PBS scheme.

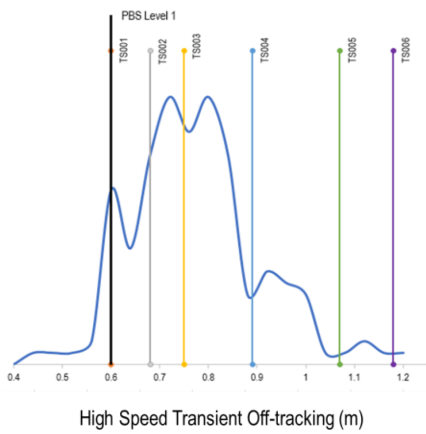
The figures in Figure 4 show that the spread of HSTO tyre performance across tyres follows a normal distribution and that each vehicle combination has a unique signature. Perhaps the most striking features is the spread of HSTO performance across tyres. For each configuration, the HSTO performance with the best tyre is more than 100% better than the worst tyre in the sample.

a) PBS Level 1 20 m quad-axle semi-trailer



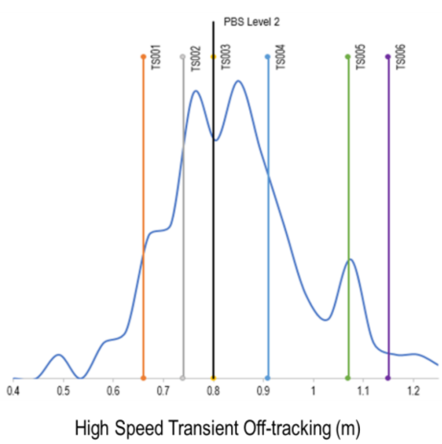
Number of Tyres Simulated	165	
Number of Eligible Tyres	165	100%
Mean	0.38	
Standard Deviation	0.04	
TS001	19	12%
TS002	52	43%
TS003	36	65%
TS004	41	90%
TS005	16	99%
TS006	1	100%

b) PBS Level 1 20 m truck and quad dog



Number of Tyres Simulated	165	
Number of Eligible Tyres	20	12%
Mean	0.76	
Standard Deviation	0.13	
TS001	20	12%
TS002	28	29%
TS003	42	55%
TS004	51	85%
TS005	20	98%
TS006	4	100%

c) PBS Level 2 30 m A-double



Number of Tyres Simulated	165	
Number of Eligible Tyres	78	46%
Mean	0.83	
Standard Deviation	0.14	
TS001	21	13%
TS002	26	28%
TS003	31	47%
TS004	52	79%
TS005	27	95%
TS006	5	98%

Figure 4. HSTO for 165 different tyres: a) Level 1 prime mover quad-axle semi-trailer b) Level 1 20 m truck and quad-dog c) Level 2B 30 m A-double

The results of classification of each tyre category are shown Figures 5 and 6. Figure 5 shows that only 9% of available tyres are included in TS001. However, when separated by tyre position, it is apparent that the situation for drive tyres is worse, with only 2% of available drive tyres able to meet TS001 requirements. This leaves very limited drive tyre options on some PBS Level 1 truck and dogs.

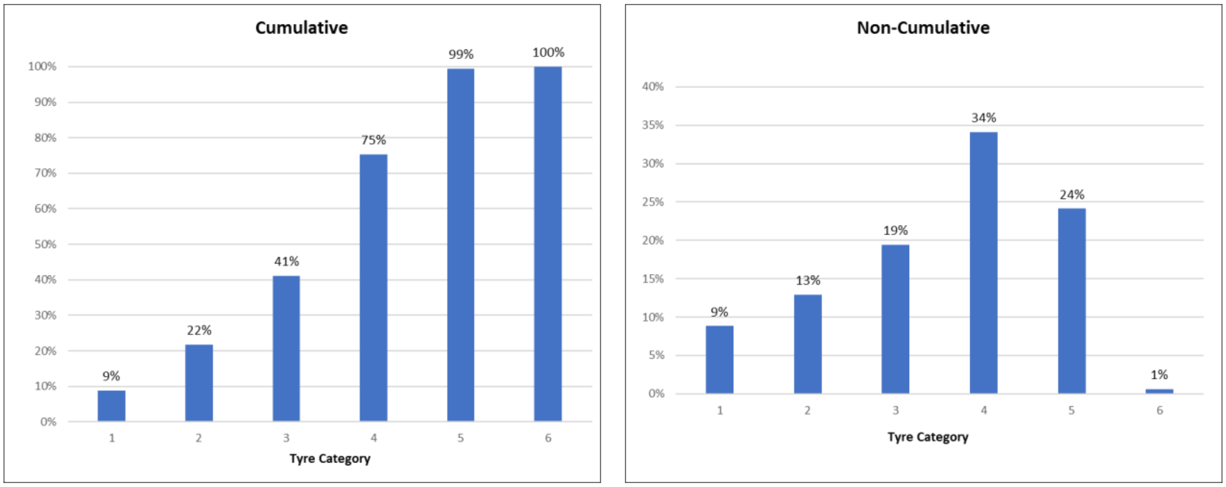


Figure 5. Percentage of tyres in each Category (including virtual tyres)

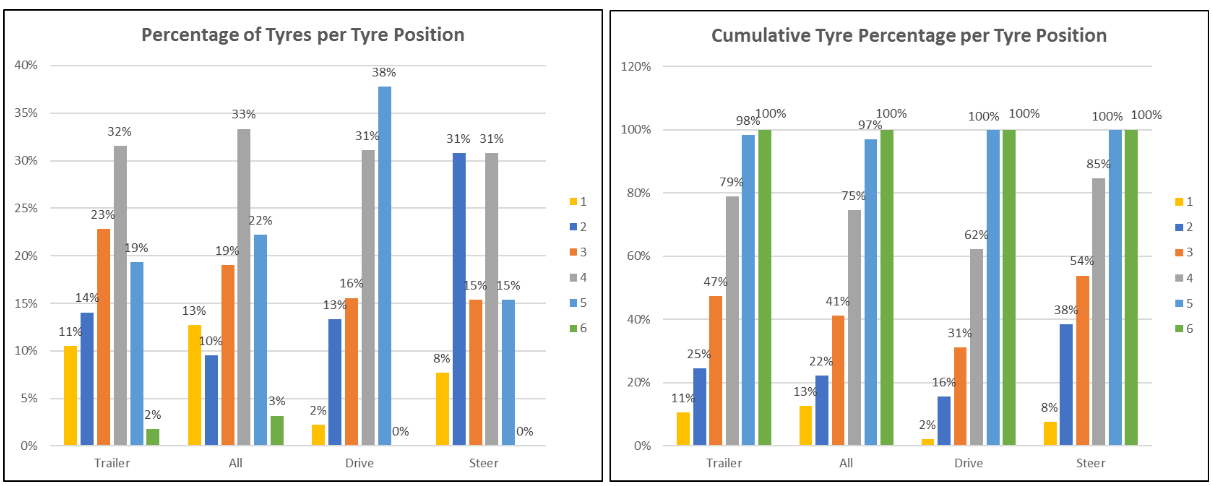


Figure 6. Percentage of tyres in each category per tyre position

To further illustrate the spread of tyre performance between size make and model. We have shared the results from a set of 25 tyres from five different manufacturers – all tested at the same test facility under the same conditions over a course of three days. As expected, smaller tyres with a narrow width and smaller contact patch did not performance as well as larger wider tyres. However, the even the spread of performance on a standard 11R22.5 tyre is large. For the truck and quad dog the Brand E 11R22.5 All position tyre achieves HSTO of 0.83 m compared with the 0.63 m achieved by Brand B All position tyre. This 0.2 m difference corresponds exactly to the difference between PBS Level 1 and PBS Level 2 performance.

Tyre Size	Brand	Tyre Position	High Speed Transient Offtracking (m)			Category
			Quad Semi	Truck and Dog	A Double	
255/70R22.5	Brand-A	Steer	0.42	0.85	0.95	TS005
275/70R22.5	Brand-A	Steer	0.39	0.75	0.83	TS004
275/70R22.5	Brand-A	All	0.41	0.84	0.9	TS004
11R22.5	Brand-A	Drive	0.44	0.95	1.06	TS005
11R22.5	Brand-A	Drive	0.44	0.94	1.05	TS005
295/80R22.5	Brand-A	All	0.39	0.78	0.86	TS004
11R22.5	Brand-B	All	0.32	0.6	0.66	TS001
255/70R22.5	Brand-B	All	0.4	0.79	0.88	TS004
275/70R22.5	Brand-B	All	0.3	0.59	0.63	TS001
11R22.5	Brand-B	Trailer	0.43	0.91	1.04	TS005
215/75R17.5	Brand-B	Trailer	0.43	0.93	1.05	TS005
11R22.5	Brand-B	All	0.31	0.58	0.63	TS001
315/80R22.5	Brand-B	All	0.26	0.41	0.45	TS001
11R22.5	Brand-B	Drive	0.36	0.7	0.76	TS003
11R22.5	Brand-B	Drive	0.42	0.87	0.96	TS005
11R22.5	Brand-C	Drive	0.4	0.82	0.9	TS004
11R22.5	Brand-D	Drive	0.38	0.77	0.86	TS004
275/70R22.5	Brand-D	All	0.37	0.72	0.79	TS003
255/70R22.5	Brand-D	All	0.35	0.72	0.8	TS003
11R22.5	Brand-D	All	0.32	0.62	0.66	TS002
235/75R17.5	Brand-D	Trailer	0.37	0.74	0.8	TS003
11R22.5	Brand-D	Drive	0.42	0.9	1.02	TS005
255/70R22.5	Brand-D	Steer	0.37	0.71	0.76	TS003
11R22.5	Brand-E	All	0.37	0.77	0.83	TS004
11R22.5	Brand-E	Drive	0.4	0.83	0.91	TS004

Figure 7. A sample of 25 tyres tested under the same condition, their HSTO performance on the reference vehicles and TS Classification category.

4. Conclusions

The TS-TSC simplifies the assessment process for PBS Vehicles and provides non-expert PBS stakeholders an understandable model for how tyre performance affects PBS vehicles. However, there are inherent limitations to any TCS and the necessary safety margin ensures that to achieve the best performance outcome, payload and approval conditions, there is no substitute for a complete assessment of each specific vehicle combination based on component data performance that best aligns with the constructed vehicle.

As manufacturers and operators continually push the limits of performance for high productivity vehicles there will inevitably be vehicle configurations for which a more limited set of component options is available. However, this fundamentally drives innovation as truck and trailer manufacturers are forced not only to configure vehicles differently, but components suppliers are incentivised to develop their products to produce enhanced performance.

Since tyres causes a great deal of frustration for many PBS stakeholders, regulators are under constant pressure to address the issue somehow. However, as in all schemes there are winners and losers. Where there is scarcity, those suppliers that can meet the demand do well in the market, whereas as those that cannot complete do poorly and complain when their market share is eroded. The appropriate policy response is difficult to judge but should be done so on the grounds of improved road safety and sound engineering principles.

References

[1].Coleman, M., Kovalev, R., Bluyval, A. and Longhurst, B. (2015), PBS Level 3 and 4 Standards Review, Austroads Research Report AR-R483-15. Accessed online at: https://www.onlinepublications.austroads.com.au/items/AP-R483-15.

[2]. https://www.transportationgroup.nz/papers/2001/O2_Edgar.PDF, Accessed online on 14/09/2018.

[3].https://www.ntc.gov.au/Media/Reports/(098E8420-09E4-AACA-B3DB-9AB1D7B55CF3).pdf , Accessed online on 14/09/2018.

[4]. https://www.nhvr.gov.au/files/201803-0019-pbs-vehicle-certification-rules.pdf. Accessed online on 14/09/2018.

[5]. https://www.nhvr.gov.au/files/201805-0795-nhvr-artsa-pbs-report-may-2018.pdf Accessed online on 14/09/2018.

[6]. https://www.nhvr.gov.au/files/c2016g00589-national-class-2-pbs-level-1-2a-truck-and-dog-notice-2016.pdf. Accessed online on 14/09/2018.

[7]. Donald, G., Coleman, M., Mathias, C., Clarke, M., Jameson, G., Peters, B. and Longhurst, B. (2011), Pavement wear assessment method for PBS vehicles, Austroads Research Report AR-R372-11. Accessed online at: https://www.onlinepublications.austroads.com.au/items/AP-R372-11.

[8]. Chattaraj, P., Bohara, P. and Mukhopadhyay, R. (2001), Tyre Force and Moment Properties for Vehicle Handling, SAE Technical Paper, 2001-26-0030.

[9]. Odhams, A.M.C., Roebuck, R.L., Jujnovich, B.A. and Cebon, D. (2011), Active steering of a tractor–semi-trailer, Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering, 225(7), 847-869.

[10]. Dahlberg, E. (2000), A method determining the dynamic rollover threshold of commercial vehicles, Journal of Commercial Vehicles, 109(2), 789-801.

[11]. SAE standards, J2429_201509, (2015), Free-Rolling Cornering Test for Truck and Bus Tyres, SAE International.

[12]. SAE standards, J2675_201711, (2017), Combined Cornering and Braking Test for Truck and Bus Tyres, SAE International.

[13]. Pottinger, M.G., Pelz, W., Winkler, C. and Tapia, G.A. (1995), A combined cornering and braking test for heavy duty truck tires, Road Transport Technology, University of Michigan, Transportation Research Institute, Ann Arbor, MI. Accessed on 14/09/2018.

[14]. Pottinger, M.G., Pelz, W., Tapia, G.A. and Winkler, C.B. (1996), A free-rolling cornering test for heavy duty truck tyres, Tire Science and Technology, 24(2), 153-180.