VEHICLE SAFETY PERFORMANCE IMPROVEMENTS USING A PERFORMANCE-BASED STANDARDS APPROACH: FOUR CASE STUDIES

  

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Abstract

As part of a performance-based standards (PBS) research programme for heavy vehicles in South Africa, a need was identified to design, manufacture and operate a number of PBS or Smart Truck demonstration vehicles. The purpose of the demonstration programme is to gain practical experience in the PBS approach and to quantify and evaluate the potential infrastructure preservation, safety and productivity benefits for road freight transport. The Smart Truck demonstration vehicles have been designed and manufactured to comply with the safety standards of the Australian PBS scheme. These include directional and non-directional manoeuvres such as low-speed swept path, tail swing, acceleration capability, static rollover threshold and rearward amplification. Four comparisons between baseline and PBS vehicle assessment results are presented in this paper to highlight some of the safety performance improvements that have resulted through the implementation of the PBS demonstration project. The demonstration vehicles include a timber truck and drawbar trailer, a mining side-tipper road train, a truck and tag-trailer car-carrier and a bi-articulated bus train.

Keywords: Performance-based standards for heavy vehicles, Smart Trucks, Road Transport Management System (RTMS), heavy vehicle productivity, heavy vehicle safety

1 Introduction

Successful initiatives in Australia, New Zealand and Canada illustrated the benefits of a performance-based standards (PBS) approach in the design of heavy vehicles to improve productivity, safety and the protection of road infrastructure. As a result, the introduction of a performance-based standards (PBS) approach in South Africa (SA) was identified by the CSIR as a research area warranting funding. The PBS approach involves setting standards to specify the performance required from the operation of a vehicle on a network rather than prescribing how the specified level of performance is to be achieved. The PBS approach promotes an optimal match between vehicles and the road infrastructure.

A need was identified to design, manufacture and operate a number of PBS demonstration vehicles in South Africa to gain practical experience in the PBS approach and to quantify and evaluate the potential benefits in a South African context. Operators of so-called "Smart Trucks" are required to be certified through the Road Transport Management System (RTMS) self-regulation accreditation scheme (Nordengen and Oberholzer, 2006; Standards South Africa, 2007). The RTMS originated from recommendations of the SA National Overload Control Strategy (Steyn *et al*., 2004), which sought to address the problem of heavy vehicle overloading and constraints regarding overload control enforcement. The report proposed the introduction of self-regulation as part of a comprehensive long-term solution: a scheme whereby initiatives are implemented by industry to establish sound vehicle management practices. Positive outcomes in terms of vehicle load control would complement existing overload control enforcement.

Initially, two PBS demonstration projects were implemented in the forestry industry in which demonstration vehicles were designed and manufactured to comply with Level 2 safety standards of the Australian PBS scheme (Nordengen *et al*., 2008). The positive performance of the demonstration project (Nordengen, 2010) has resulted in the approval to date of more than 100 additional permits for PBS demonstration vehicles. Guidelines for participation in the Smart Truck demonstration project have been developed by the national Department of Transport's Smart Truck Review Panel (CSIR, 2013).

2 Research Method

For the purpose of the PBS demonstration project in South Africa, it was decided to make use of international heavy vehicle PBS research, development and implementation. After reviewing the PBS initiatives in Australia, Canada and New Zealand, the Australian PBS scheme (NTC, 2008) was selected as the basis for the SA PBS project. It was recognised that if this scheme was adopted by the SA Department of Transport in the long term, it would need to be adapted to accommodate South African-specific conditions (*e.g.* maximum vehicle width is 2.5 m in Australia and is 2.6 m in South Africa). After consideration of both the safety and infrastructure performance standards contained in the Australian PBS scheme, it was decided that only the safety performance standards would be used; infrastructure performance standards have been developed based on existing approaches in South Africa for pavement and bridge design and assessment. The safety performance standards include low-speed swept path (LSSP), tail swing (TS), static rollover threshold (SRT), rearward amplification (RA), yaw damping co-efficient (YDC), high-speed transient offtracking (HSTO) and tracking ability on a straight path (TASP).

As part of the demonstration project, PBS assessments of a baseline vehicle and the proposed PBS design are required. The assessment of the baseline vehicle highlights any safety shortcomings of a legal vehicle (that meets all the heavy vehicle prescriptive requirements). The assessment of the proposed PBS vehicle may be iterative, with design modifications eventually resulting in a final design that meets all the PBS requirements. This paper presents four case studies comparing baseline and PBS vehicle assessments, highlighting vehicle safety performance improvements that have resulted using the PBS approach. These include a timber truck and drawbar trailer combination, a mining side-tipper road train, a truck and tag-trailer car-carrier combination and a bi-articulated bus train.

3 Results and Observations

3.1 Truck/trailer combination for timber transport

The PBS demonstration project in South Africa was initiated in the forestry industry in 2004, primarily because the forestry industry piloted the RTMS accreditation scheme. Combinations consisting of a rigid truck and 4-axle drawbar trailer are commonly used for transporting logs in the forestry industry (Figure 1). Such combinations are limited to an overall length of 22 m and a combination mass of 56 t in terms of the prescriptive regulations. One of the first PBS demonstration vehicles had an overall length of 27.0 m and a maximum combination mass of 67.5 t (Figure 2). The results of the PBS assessments of the baseline and PBS combinations showed that whereas the PBS vehicle met the Level 2 requirements (NTC, 2008), the baseline vehicle did not meet the requirements for the SRT and RA performance standards and only met the Level 3 requirements for HSTO. These results are given in Table 1.

Figure 1 Baseline vehicle comprising a rigid truck towing a 4-axle drawbar trailer

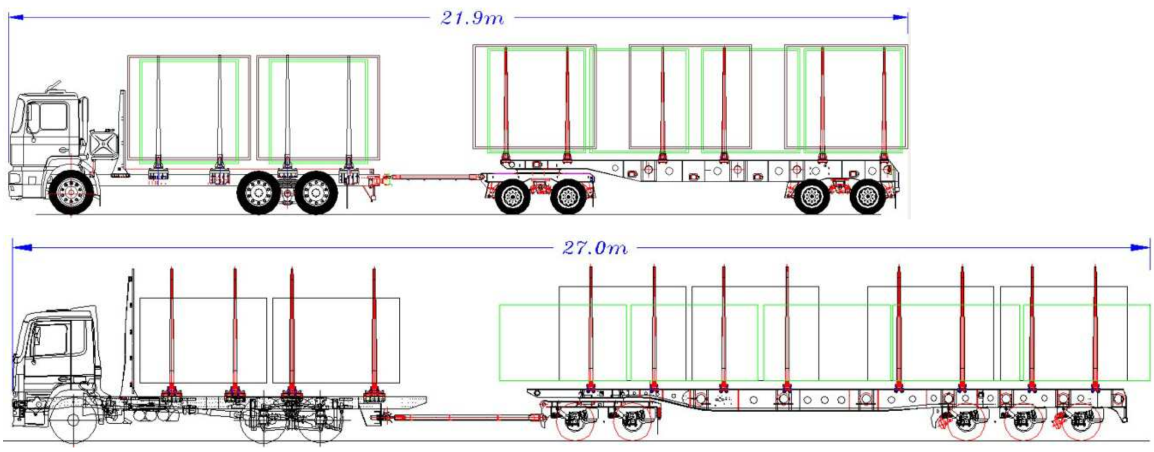

Figure 2 Baseline (top) and PBS (bottom) vehicles at 56 t and 67.5 t maximum combination mass respectively

Table 1 – Summary of assessment results, timber truck and trailer combination

Performance standard	Performance value (Access level)			Performance requirement			
	Concept vehicle		Baseline	L1	L2	L3	L4
	(4-bundle)	(5-bundle)					
	(67.5t, 26.4m)	(67.5t, 27.0m)	(56t, 21.9m)				
Tracking ability on a straight path	2.89 (L1)	2.90m (L1)	2.89m (L1)	≤2.9m	≤3.0m	≤3.1m	≤3.3m
Low-speed swept path	8.20m (L2)	8.20m (L2)	6.62m (L1)	≤7.4m	≤8.7m	≤10.1m	≤13.7m
Steer tyre friction demand	21% (L1)	21% (L1)	18% (L1)	≤80%			
Static rollover threshold	0.354g (L1)	0.354g (L1)	0.305g (-)	≥0.35g (≥0.40g road tankers/buses)			
Rearward amplification*	1.767 (L1)	1.812 (L1)	1.990 (-)	≤5.7SRT_{rrcu} (2.205, 2.428, 1.738)			
High-speed transient offtracking	0.67m (L2)	0.68m (L2)	0.81m (L3)	≤0.6m	≤0.8m	≤1.0m	≤1.2m
Yaw damping coefficient	0.23 (L1)	0.27 (L1)	0.26 (L1)	≥0.15			

* SRT_{rrcu} denotes *SRT* of the rearmost roll-coupled unit which may be different from the vehicle's *SRT* value.

3.2 Mining BAB-quad road train

In the province of KwaZulu-Natal (KZN), an A-triple side-tipper road train was being used to transport heavy metal concentrate at the Richards Bay Minerals (RBM) mine. After 10 years of operation, the operator submitted an application to the provincial road authority to increase the payload capacity of the vehicle combination by introducing a fourth trailer. The KZN Department of Transport approved the application on condition that the new design was approved as a PBS demonstration vehicle. The University of Witwatersrand carried out the initial assessment, which was subsequently validated by ARRB Group in Australia (Dessein and Kienhöfer, 2011; Germanchev and Chong, 2011). The baseline A-triple road train had an overall length of 34.95 m and a maximum combination mass of 145.1 t (105 t payload). The PBS BAB-quad combination has an overall length of 41.77 m and a maximum combination mass of 173.8 t (122 t payload). See Figure 3. The results of the PBS assessment of the A-triple baseline combination indicated that this combination failed three of the performance standards (SRT, YDC and RA) as shown in Table 2. In the case of RA, the baseline result exceeded the performance standard limit by 56%.

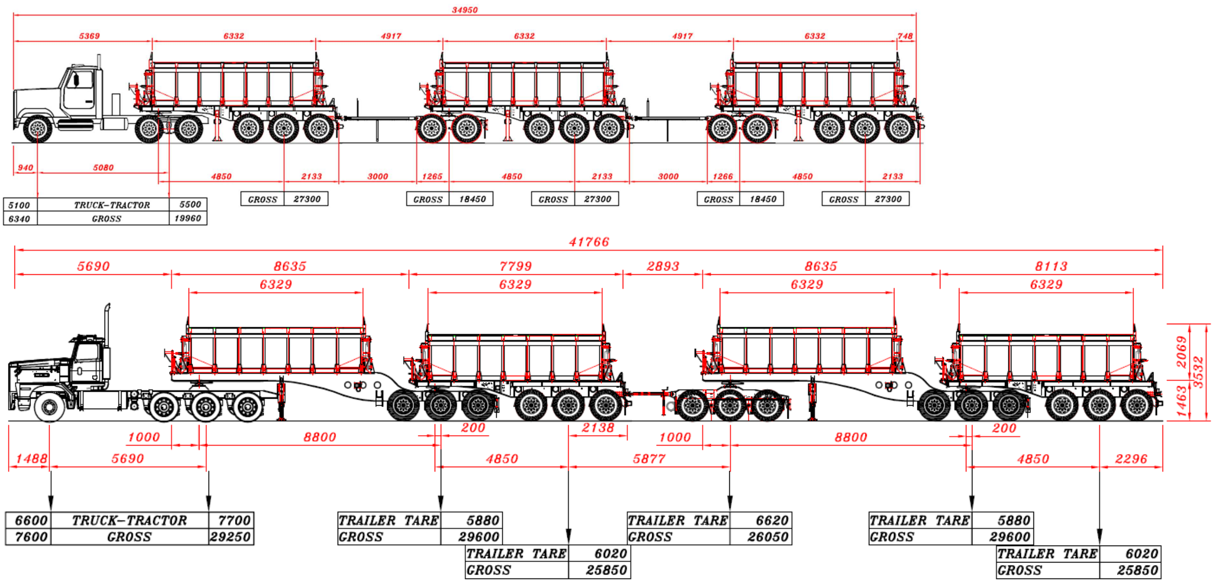

Figure 3 Baseline (top) and PBS (bottom) vehicles at 145.1 t and 173.8 t maximum combination mass respectively

Table 2 – Summary of performance assessment results, mining road train

Performance standard	Existing A-triple	PBS vehicle		Level achieved	Performance requirement	
		Wits	ARRB		L3	L4
Static rollover threshold (g)	0.30	0.36	0.37	All	≥ 0.35	≥ 0.35
Yaw damping coefficient	0.1	0.27	0.27	All	≥ 0.15	≥ 0.15
Rearward amplification	3.36[+]	1.93	1.97	All	≤ 2.15†	≤ 2.15[†]
High-speed transient offtracking (m)	0.8	0.8	0.9	L3	≤ 1.0	≤ 1.2
Tracking ability on a straight path (m)	3.2	3.1	3.13	L3*	≤ 3.1	≤ 3.3
Low-speed swept path (m)	7.6	10.5	10.6	L3	≤ 10.6	≤ 13.7
Tail swing (m)	0.08	0.10	0.09	All	≤ 0.35	≤ 0.50
Frontal swing (m)	0.4	0.60	0.60	All	≤ 0.7	≤ 0.7
Maximum of difference (m)	0.05	0.10	0.13	All	≤ 0.4	≤ 0.4
Difference of maxima (m)	0	0.01	0.00	All	≤ 0.2	≤ 0.2
Steer-tyre friction demand	47%	69%	70%	All	≤ 80%	≤ 80%

[+]Evaluated at 75 km/h because the vehicle could not complete the manoeuvre at the prescribed 88 km/h

[†]The RA limits are calculated $5.7SRT_{rrcu}$ for all levels

*Using the Wits result

3.3 Truck and tag-trailer car-carrier

In 2009 the Abnormal Load Technical Committee (ALTC) of the SA Department of Transport indicated its intention to phase out the practice of issuing abnormal (indivisible) load permits to car-carrier operators. This had, for the past 30 years or so, allowed car-carriers an additional 300 mm in height and 500 mm in length (rear projection). Discussions were subsequently initiated to allow these dimensional increases to continue on condition that the vehicle combinations comply with the PBS demonstration project requirements. A proposal for regulating the use of car-carriers in South Africa using a PBS approach (De Saxe and Nordengen, 2013a) was used as the basis for a roadmap for the operation of car-carriers, which was developed in consultation with the SA Car Transporters Association (SACTA) and was approved by the ALTC in March 2014.

A review of the tail swing performance of the SA car-carrier fleet (De Saxe *et al.*, 2012) highlighted a shortcoming in the SA legislation in terms of the permissible maximum rear overhang, which results in tail swings of up to 1.25 m compared with the PBS Level 1 limit of 0.30 m. The first PBS assessment of a car-carrier was carried out in 2012 (De Saxe and Kienhöfer, 2012). A baseline and PBS revision of a Unipower truck and tag-trailer combination were assessed. The assessment showed that design modifications (primarily an increase in trailer wheelbase from 9 to 10 m) yielded a design that meets the tail swing requirement and achieves notable improvements in other performance measures. The PBS design is shown in Figure 4. A summary of the PBS assessment results is given in Table 3.

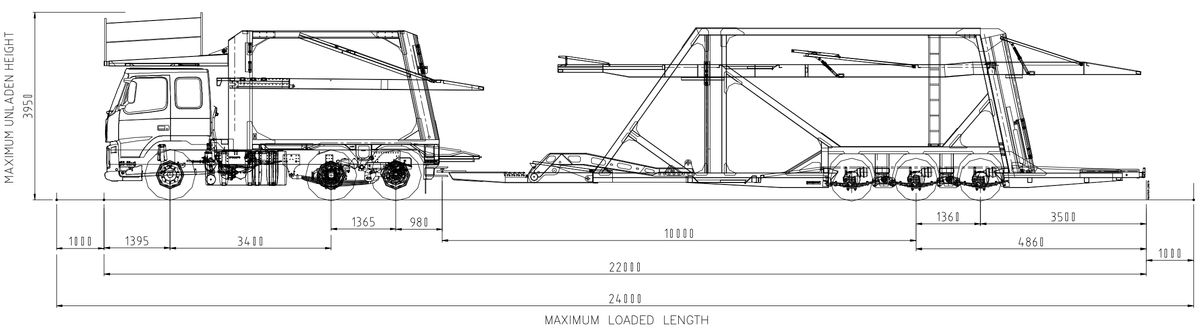

Figure 4 General arrangement drawing of the Unipower PBS car-carrier combination

Table 3 – Summary of performance assessment results, car-carrier combination

Performance standard	Baseline vehicle	Level achieved	PBS vehicle	Level achieved	Performance requirement (L1)
Low-speed swept path (m)	6.7	All	7.2	All	≤ 7.4
Tail swing (m)	0.66	None	0.30	All	≤ 0.3
Frontal swing (m)	0.7	All	0.7	All	≤ 0.7
Steer tyre friction demand (%)	34	All	34	All	≤ 80
Rearward amplification	1.82	All	1.27	All	$\leq 5.7 \cdot SRT_{rrcu}$
High-speed transient offtracking (m)	0.7	L2	0.6	All	≤ 0.6
Tracking ability on a straight path (m)	3.0	L2	2.9	All	≤ 2.9
Static rollover threshold (g)	0.35	All	0.38	All	≥ 0.35
Yaw damping coefficient	0.09	None	0.29	All	≥ 0.15

3.4 Bi-articulated bus

Buscor, a bus company operating approximately 300 buses and transporting 160 000 passengers per day in the province of Mpumalanga, was granted an abnormal load permit in October 2007 to operate a 27.0 m bi-articulated bus. Another nine such buses were added during 2010. By the end of October 2013, these buses had travelled 1.78 million kms and transported 2.7 million passengers. Although the crash rates are considerably lower than those of the single-articulation and rigid buses, the Smart Truck Review Panel recommended that a PBS assessment be carried out to evaluate the safety performance of the bus. MAN Bus and Coach SA (Pty) Ltd were tasked with the redesign and testing of a new bi-articulated bus. The original vehicle or prototype was different from the ten buses operated by Buscor. The original vehicle design was altered to increase the wheelbases of the second and third vehicle units (See Figure 5 and Figure 6) (Kienhöfer *et al*., 2012; Kienhöfer, 2013). The assessment results are shown in Table 4. The original design failed the YDC, HSTO and TS Level 1 performance measures whereas the proposed design passed all the required performance measures. A parametric study of the wheelbases of the second and third vehicle units showed that both wheelbase increases were required for the vehicle to pass the PBS Level 1 safety requirements (Kienhöfer *et al*., 2012).

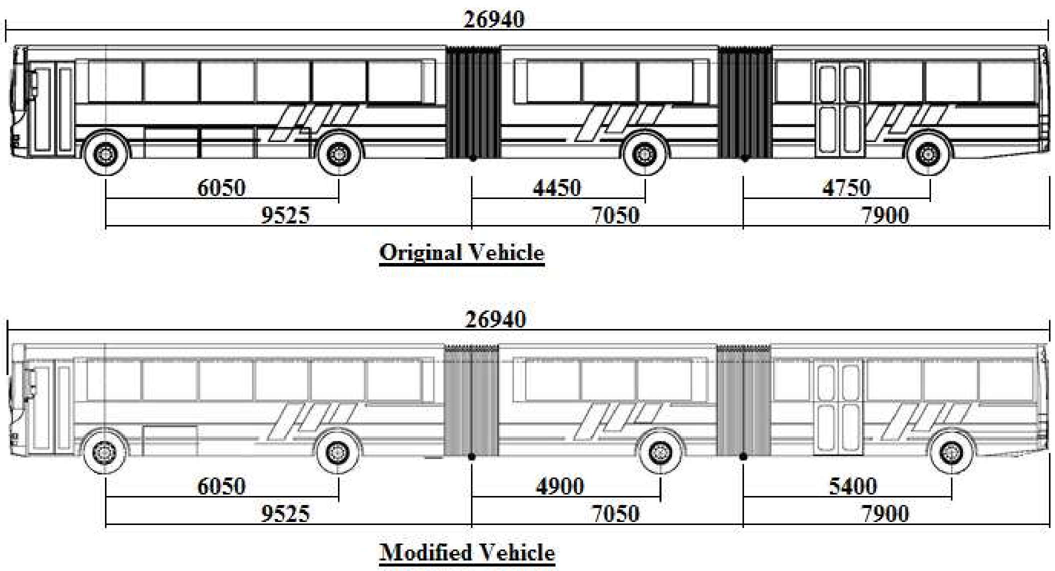

Figure 5 Wheelbase dimensions of the original and modified bi-articulated buses

Figure 6 Bi-articulated bus manufactured by MAN Bus & Coach

Table 3 – Summary of PBS assessment: original and modified bi-articulated buses

Performance Standard	Original Vehicle		Modified Vehicle		PBS performance requirements			
	Result	Level	Result	Level	Level 1	Level 2	Level 3	Level 4
Static rollover threshold (g)	0.45	All	0.45	All	≥ 0.4	≥ 0.4	≥ 0.4	≥ 0.4
Yaw damping coefficient	0.09	None	0.26	All	≥ 0.15	≥ 0.15	≥ 0.15	≥ 0.15
Rearward amplification†	2.26	All	1.88	All	≤ 2.574[1] ≤ 2.591[2]	≤ 2.574 ≤ 2.591	≤ 2.574 ≤ 2.591	≤ 2.574 ≤ 2.591
High-speed transient offtracking (m)	0.7	L2	0.6	All	≤ 0.6	≤ 0.8	≤ 1.0	≤ 1.2
Tracking ability on a straight path (m)	2.7	All	2.7	All	≤ 2.9	≤ 3.0	≤ 3.1	≤ 3.3
Low-speed swept path (m)	6.2	All	6.6	All	≤ 7.4	≤ 8.7	≤ 10.6	≤ 13.7
Tail swing (m)	0.42	L4	0.30	All	≤ 0.3	≤ 0.35	≤ 0.35	≤ 0.5
Frontal swing (m)	1.4	All	1.4	All	≤ 1.5	≤ 1.5	≤ 1.5	≤ 1.5
Maximum of difference (m)	0.01	All	0.01	All	≤ 0.4	≤ 0.4	≤ 0.4	≤ 0.4
Difference of maxima (m)	0.01	All	0.01	All	≤ 0.2	≤ 0.2	≤ 0.2	≤ 0.2
Steer-tyre friction demand	25%	All	25%	All	≤ 80%	≤ 80%	≤ 80%	≤ 80%

†RA limits are calculated $5.7SRT_{rrcu}$ for all levels, [1] = 2.574 for the original vehicle, [2] = 2.591 for the modified vehicle

3.5 Summary of results and discussion

Figure 7 provides comparisons of the four baseline and selected PBS vehicle assessment results, where, in most cases, significant improvements in safety performance results were observed. The performance results are shown as percentages of the minimum or maximum requirement. SRT and YDC have minimum requirements while RA, HSTO and TS have maximum requirements. The shaded areas on the graph thus represent “failure zones” in terms of the requirements of each performance standard. For example, the minimum requirement for SRT is 0.35 g (0.4 g for buses) i.e. the minimum lateral acceleration to cause rollover of any of the vehicle combination components.

The figure shows that the SRT of the timber and mining baseline vehicles is below the minimum requirement whereas the both PBS vehicles meet the SRT performance requirement. In the case of the car carrier, the baseline vehicle had a tail swing that exceeds the performance requirement of 300 mm by more than 200%. In each of the cases shown, the baseline vehicle, which meets all the prescriptive regulations in the National Road Traffic Regulations, had one or more poor performance characteristics in terms of the PBS safety performance measures. The corresponding PBS vehicles, by definition, meet these performance requirements and hence can be considered safer vehicles.

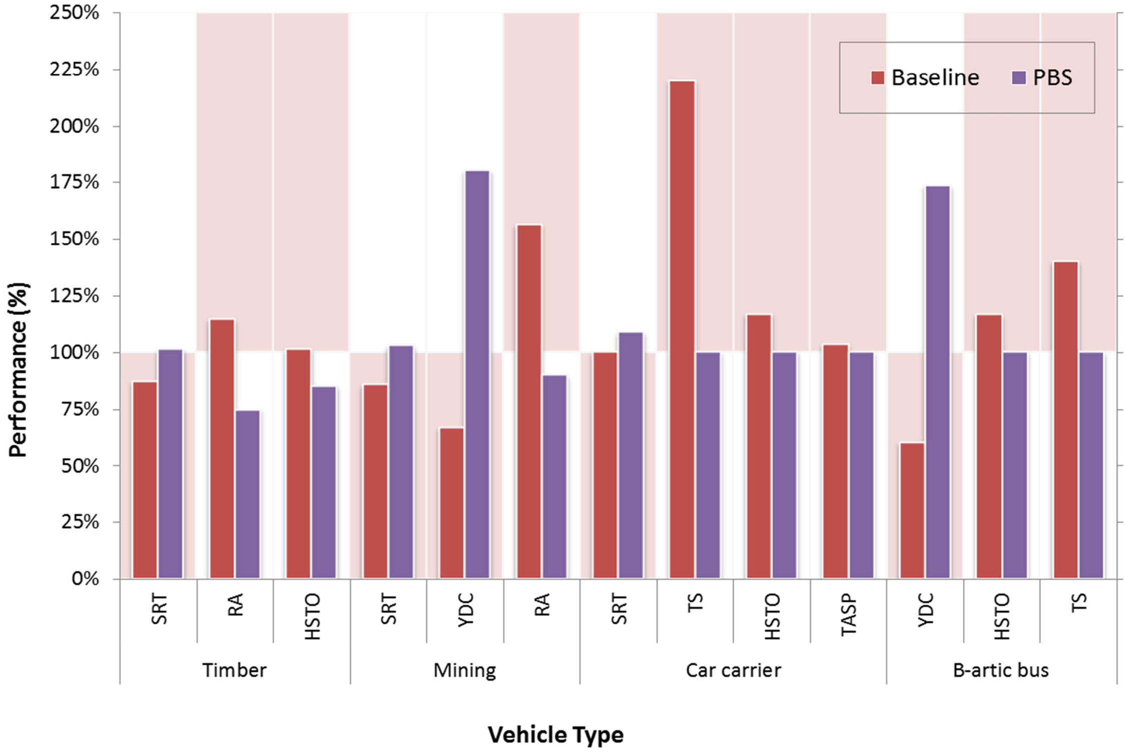

Figure 7 Summary of selected baseline and PBS vehicle assessment results for four vehicles

A number of observations are relevant regarding the measured safety improvements:

- One of the solutions for addressing the poor SRT, RA and HSTO of the initial timber truck and drawbar trailer baseline vehicle was to decrease the truck hitch offset resulting in an "underslung" tow hitch. This modification, although previously not uncommon, has been implemented to a large extent on similar legal timber vehicle combinations by various trailer manufacturers, thereby having a positive impact on the safety performance of legal vehicles in the forestry industry (Prem and Mai, 2006).
- The mining baseline A-triple road train was in operation for approximately 10 years, with stability problems being experienced with the third trailer. The PBS assessment of this baseline vehicle highlighted poor performance characteristics of the design, particularly with respect to RA and YDC as indicated in Figure 7. The PBS BAB-quad road train, by virtue of its compliance with all the PBS performance measures, is likely to demonstrate improved safety performance over time. Eleven of these road trains have been operational at the RBM mine in KwaZulu-Natal province since January 2013. During 2013, the vehicles travelled 1.33 million kms (26 000 trips) with no major or minor crashes or incidents (except for flat tyres) recorded.
- The survey of the tail swing performance of car-carriers in South Africa (De Saxe *et al*, 2012), found that due to a shortcoming in the South African prescriptive regulations, which limit rear overhang to a maximum of 60% of the wheelbase of a vehicle (with no absolute maximum limit), very large overhangs (up to 7 m) are possible, resulting in large tail swings of up to 1.25 m. The study showed that 80% of car-carriers operating

in South Africa have tail swings that exceed the 300 mm limit for Level 1 PBS vehicles as required by the Australian PBS scheme (NTC, 2008). Five car-carrier combinations assessed during 2012 and 2013 are all PBS-compliant with tail swings of ≤ 300mm (De Saxe and Kienhöfer, 2012; De Saxe and Kienhöfer, 2013; De Saxe and Nordengen, 2013b; De Saxe, 2013a; De Saxe, 2013b).

- PBS assessments of a 27 m bi-articulated bus train guided the redesign to ensure satisfactory performance in terms of YDC, HSTO and TS (Figure 7). Increasing the wheelbases of the second and third "trailers" resulted in a design that meets all the PBS requirements and a safer and more comfortable ride for passengers, particularly due to the significantly improved YDC from 0.09 to 0.26 (Kienhöfer *et al.*, 2012; Kienhöfer, 2013).

4 Conclusions

Since the first two South African PBS demonstration projects were commissioned in 2007, more than 100 additional permits for PBS vehicles have been approved. PBS assessments of various baseline vehicles have highlighted various safety performance improvements that can be achieved through the PBS approach for vehicle design. These include a timber truck and drawbar trailer combination, a mining side-tipper road train, a truck and tag-trailer car-carrier combination and a bi-articulated bus train. The results of the baseline vehicle and PBS vehicle assessments show that compliance with the prescriptive regulations (or abnormal load permit conditions) does not necessarily ensure satisfactory on-road safety performance.

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