AUTHORS

Paul A Nordengen (corresponding)
CSIR Built Environment
PO Box 395
Pretoria, 0001
South Africa
Phone: +27 12 841 3945
Email: pnordengen@csir.co.za

Michael P Roux
CSIR Built Environment
PO Box 395
Pretoria, 0001
South Africa
Phone: +27 12 841 2666
Email: mproux@csir.co.za

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EVALUATION OF A PERFORMANCE-BASED STANDARDS APPROACH TO HEAVY VEHICLE DESIGN TO REDUCE PAVEMENT WEAR

P A NORDENGEN AND M P ROUX

ABSTRACT

As a result of successful initiatives in Australia, New Zealand and Canada, the introduction of a performance-based standards (PBS) approach in the heavy vehicle sector in South Africa was identified by the Council for Scientific and Industrial Research (CSIR) as a research area warranting funding because of the potential benefits in terms of transport efficiency, road/vehicle safety and the protection of road infrastructure. Whereas most countries throughout the world regulate heavy vehicle use predominantly by prescriptive regulations, some countries have implemented a PBS approach, which 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. As part of the "Smart Truck" or Performance-Based Standards (PBS) research programme for heavy vehicles in South Africa, demonstration projects have been designed and manufactured to comply with the safety standards of the Australian PBS system while the infrastructure performance standards are based on South African bridge and pavement design standards. In order to optimise road wear per ton of payload, the South African Mechanistic-Empirical Design Method, which is the basis of the South Africa Pavement Design Manual, was used to determine a Load Equivalency Factor for each baseline and each "PBS" vehicle combination. Eight typical South African pavement designs, both in the wet and dry conditions, were used in the analyses. This paper presents a summary of the assessment of 19 vehicle designs and the corresponding baseline vehicles in terms of their road wear effects. The paper shows that using such a performance-based standards approach, more road-friendly heavy vehicle design solutions can be found, resulting in vehicle combinations with improved performance in terms of road wear, efficiency, safety and environmental impact.

1 INTRODUCTION

As a result of successful initiatives in Australia, New Zealand and Canada, the introduction of a Smart Truck or Performance-Based Standards (PBS) approach in the heavy vehicle sector in South Africa was identified by the Council for Scientific and Industrial Research (CSIR) as a research area warranting funding because of the potential benefits in terms of transport efficiency, road/vehicle safety and the protection of road infrastructure. 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. This approach allows a more optimum 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 in order to gain practical experience in the PBS approach and to quantify and evaluate the potential benefits. Operators of Smart Trucks are required to be certified through the Road Transport Management System (RTMS) self-regulation accreditation scheme (*1, 2*). The RTMS originated from recommendations of the South African National Overload Strategy (*3*), 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 by which 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, which were designed and manufactured to comply with Level 2 safety standards of the Australian PBS system (*4*). These include directional and non-directional manoeuvres such as acceleration capability, slow speed swept path, static rollover threshold and rearward amplification. The positive performance of the demonstration project has resulted in the approval to date of more than 60 permits for PBS demonstration vehicles in the forestry and other sectors, some of which incorporate additional modifications in order to further optimise performance. Guidelines for participation in the Smart Truck demonstration project have been developed by the national Department of Transport's Smart Truck Review Panel (*5*)

2 RESEARCH METHOD AND PRELIMINARY RESULTS

2.1 Monitoring Programme

The first two PBS vehicles, commissioned by two global forestry companies, Mondi Business Paper SA (Mondi) and Sappi Forests (Pty) Ltd (Sappi), for transporting logs from forest plantations to pulp and paper mills, went into operation in November and December 2007 respectively. The general layout of the baseline and PBS designs are shown in FIGURE 1.

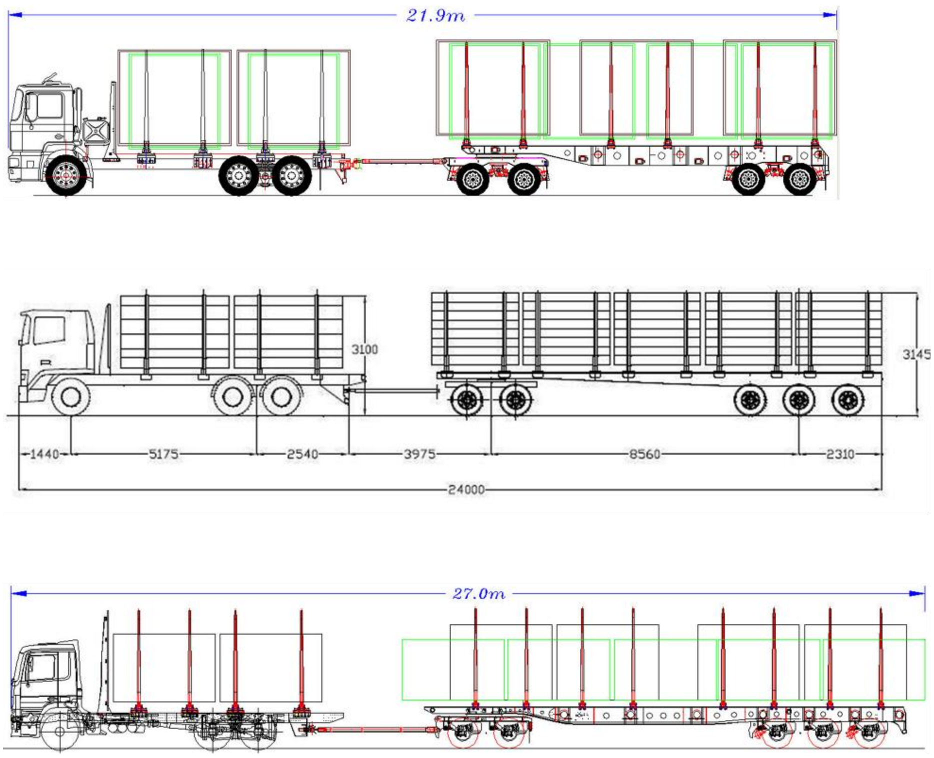

FIGURE 1 Layout of baseline and first two PBS vehicles operating in the forestry industry.

Monitoring of the PBS demonstration vehicles commences once an approved PBS vehicle has been commissioned. Data, including combination mass and payload per trip, average trip speeds, number of trips and distance travelled per month, average monthly fuel consumption, record of routes travelled (vehicle tracking reports), maintenance costs and records of incidents and crashes, are collected on a monthly basis. The monitoring of the first eight months of operation of the first two PBS vehicles was reported on in March 2010 at the 11th Heavy Vehicle Transport Technology conference in Melbourne (*6*).

As a result of the positive performance of these two PBS vehicles, the KwaZulu-Natal Department of Transport decided to increase the number of permits for PBS demonstration vehicles in their area of jurisdiction. To date, 62 PBS permits have been issued, most of which are for vehicles operating in the forestry and mining transport sectors in the provinces of KwaZulu-Natal and Mpumalanga. A number of other PBS vehicles for operation in other sectors are in the design phase. Two Level 4 PBS road trains (with overall lengths of 40.48 m and 42.67 m and combination masses of 148 and 174 tons respectively) have been approved for operation at mines in the Northern Cape and KwaZulu-Natal. Two of these road trains commenced operation in January 2012 (Northern Cape) and a further eleven in November 2012 (KwaZulu-Natal). TABLE 1 shows the number of demonstration projects underway per industry and per province. Figures in round brackets ( ) indicate projects that have been approved but are not yet operational. Figures in square brackets [ ] indicate projects that are in the design phase, but have not yet been approved.

TABLE 1 Summary of Current and Planned Smart Truck Demonstration Projects in South Africa per Province

Industry	KwaZulu-Natal	Mpuma-langa	Lim-popo	Gau-teng	Free State	N. Cape	E. Cape	W. Cape	North West
Forestry	39	10 + [14]							
Wattle bark	[12]	[4]							
Mining	11 + [20]	[17]	[29]			2			
Car carriers	2	[2]	[2]	(1)	(2)	[2]	(2)	[2]	[2]
General freight	(1)	(1)		(1)	(1)				
Cement							(15)	[15]	
Sugar (processed)	(2)								
Beef						(1)			(1)
Passengers (bus)		[20]							

2.2 Safety and Infrastructure Performance Standards

For the purpose of the PBS research and demonstration programme in South Africa, it was decided to make use of existing international heavy vehicle PBS research, development and implementation. After reviewing the PBS initiatives in Australia, Canada and New Zealand, the Australian PBS scheme (*7*) was selected as the basis for the South African PBS project. It was recognised that if this scheme was adopted by the South African national Department of Transport (DoT) in the long term, it would need to be adapted to accommodate South African-specific conditions e.g. the maximum vehicle width is 2.5 m in Australia and is 2.6 m in South Africa. It was further decided to only make use of the Australian PBS scheme safety standards and that the infrastructure performance standards should be aligned with South African road traffic regulations and design codes of practice. Thus all axle and axle unit loads of PBS vehicles that operate on public roads must comply with the requirements of the South African National Road Traffic Act and Regulations (NRTA and NRTR) (*8, 9*).

The Australian PBS scheme safety standards revolve around the evaluation of various parameters when a vehicle undergoes a number of predefined low and high speed directional and non-directional manoeuvres. These include: (a) Startability, (b) Gradeability, (c) Acceleration capability, (d) Tracking Ability on a Straight Path, (e) Low Speed Swept Path, (f) Frontal Swing, (g) Tail Swing, (h) Steer Tyre Friction Demand, (i) Static Rollover Threshold, (j) Rearward Amplification, (k) High Speed Transient Offtracking and (l) Yaw Damping.

2.3 Road Structures

Initially, PBS vehicles had to comply with Regulation 241 of the NRTR, the “bridge formula”, which limits the load intensity of a vehicle and any part of a vehicle. This only applied to the first two PBS vehicle designs and more performance-based approaches have since been introduced. At the beginning of 2010, the national DoT’s Smart Truck Review Panel decided to apply the more complex, but less conservative “Abnormal Load” bridge formula (ALBF) (*10*), which is based on South African bridge design loading, TMH7 NA + NB30 (*11*), to PBS vehicles rather than the standard bridge formula that is applicable to all legal heavy vehicles. The adoption of the ALBF for PBS demonstration projects is based on the premise that the PBS vehicles operate in a more controlled environment (including the RTMS self-regulation accreditation requirement) than the general heavy vehicle fleet. Hence the risk of overloading and speeding is considerably reduced. In fact, it is likely that the operations involving PBS vehicles are considerably more controlled and compliant than many abnormal load operations.

The adoption of the ALBF enabled one of the original PBS vehicles to be shortened by 1.24 m from 27.00 m to 25.76 m by reducing the length of the trailer drawbar without compromising on the permissible maximum payload. This combination, at 67 500 kg, has a minimum factor of safety of 44.8% in terms of the ALBF. A reassessment of the safety standards showed an improved performance in terms of Tracking Ability on a Straight Path, Low Speed Swept Path, Steer Tyre Friction Demand and Static Rollover Threshold. Although there was a reduced performance in terms of Rearward Amplification (2.8%), High Speed Transient Offtracking (5.6%) and Yaw Damping Coefficient (15%), the modified vehicle combination still meets all the requirements of a Level 2 PBS vehicle. The Australian PBS scheme has four categories of PBS vehicles (Levels 1 to 4). Compliance with the Level 1 standards allows the PBS vehicle general accessibility to the entire network whereas Level 4 PBS vehicles (typically “road trains”) are restricted to remote routes with low traffic volumes and many overtaking opportunities).

During 2012, the Smart Truck Review Panel decided to investigate another more fundamental approach for assessing the safety of structures. A computer application that was originally developed for assessing the effect of abnormal load all-terrain mobile cranes on structures, compares maximum bending moments and shear forces generated on a range of span lengths (including two- and three-span continuous structures) by the vehicle being assessed with those of a reference load, in this case the TMH7 NA + NB30 design load. Currently all proposed PBS projects are being assessed in terms of structures using both methods. It is likely that the assessment approach comparing maximum bending moments and shear forces will be adopted for the PBS assessment of structures.

2.4 Road Pavements

As indicated in Section 2.2, the infrastructure performance standards for the PBS demonstration project are based on South African pavement and bridge design loading approaches. For road pavements, the current South African Mechanistic-Empirical Design and Analysis Methodology (SAMDM) (*12*), which is the basis of the South African pavement design manual for flexible pavements, TRH4 (*13*), is used to assess the relative road wear of the proposed PBS vehicle combination and a representative baseline vehicle. The baseline vehicle is usually the vehicle that is being used in the transport operation for which the proposed PBS vehicle is intended. The requirement for PBS demonstration vehicles is that the roar wear per ton of payload of the PBS vehicle must be less than the equivalent road wear of the baseline vehicle. As the number of different PBS demonstration vehicles increases, the intention is to develop a set of road wear benchmarks (for different vehicle configuration categories) against which proposed PBS vehicles can be assessed.

The CSIR Pavement Design Software MePads (*14*) is an electronic version of the SAMDM and is currently being used to assess baseline and proposed PBS vehicles. Should the PBS approach to heavy vehicles be accepted into South African legislation, it is intended that this methodology will be used to develop a pavement infrastructure performance standard for Smart Trucks in South Africa. The software combines a stress-strain computational engine with pavement material models developed in South Africa. Pavement layer life is expressed in terms of the number of repetitions of an axle load until failure. Layer life is based on the typical linear-log damage functions (or "transfer functions") obtained (and calibrated) from experience and from the results of Heavy Vehicle Simulator (HVS) testing on the various pavement types carried out in South Africa since 1975.

The SAMDM approach is used to estimate the Load Equivalency Factors (LEFs) of each vehicle under static loading based on the critical pavement layer life approach (*15*, *16*). The philosophy of "Equivalent Pavement Response - Equivalent Pavement Damage" (EPR-EPD) is used rather than reducing a vehicle to a single Equivalent Standard Wheel Mass (ESWM), or to an Equivalent Standard Axle Load (ESAL). With the EPR-EPD approach, no "fixed equivalencies" are used per se, and each vehicle is considered with its full axle/tyre configuration (i.e. tyre/axle loading and its associated tyre inflation pressure) as input into the SAMDM and the road wear caused by the freight vehicle is directly estimated for the pavement type under consideration. With the EPR-EPD approach the stresses and strains (i.e. mechanistic pavement response parameters) are directly related through the associated transfer functions for pavement damage to layer life and hence "pavement life". With this approach, the pavement life is considered as being equal to the "critical layer life", i.e. the life of the structural layer with the shortest life in the pavement structure.

The pavement life or bearing capacity of the pavement under consideration is also determined under a Standard 80 kN axle with four tyres (two dual sets) at a tyre inflation pressure of 520 kPa. The Load Equivalency Factor of the vehicle (LEF) is calculated as the sum of the ratios (for all axles of a particular vehicle) between the critical layer life of the pavement determined from the Standard 80 kN axle with four tyres (two dual sets) at an inflation pressure of 520 kPa (i.e. the bearing capacity of the pavement), divided by the critical layer life under each individual axle load and its associated tyre pressures, using formula (1).

$$LEF\ of\ Vehicle = LEF_v = \sum_{i=1}^{n} \frac{N_{critical}\ from\ Standard\ Axle\ (80kN\ \&\ 520kPa)}{N_{critical}\ from\ Axle_i} \quad (1)$$

where:

n = number of axles on vehicle

$N_{critical}$ from Standard 80 kN/520 kPa Axle = Minimum layer life of pavement under the loading of the Standard axle of 80 kN and 520 kPa inflation pressure on 4 tyres (i.e. 20 kN per tyre @ 520 kPa contact stress (= inflation pressure))

$N_{critical}$ from $Axle_i$ = Minimum layer life of pavement under the loading of $Axle_i$ of vehicle under consideration

This is done for eight typical South Africa pavement design types in both wet and dry conditions (Figure 2). Load Equivalency Factors for a wet pavement are typically 50 to 100 per cent more than the same pavement in a dry condition, depending on the pavement type. For the purposes of comparison, and to simplify the presentation of results, an average wear cost is calculated for the 16 cases (8 pavement types, wet and dry conditions) for the baseline and PBS vehicles.

Pavement A: ES100

Layer	Poisson's Ratio	Elastic Moduli (MPa) Phase I	Phase II	Phase III
50 AG*	0.44	2000	2000	1500
150 G1*	0.35	450	450	350
150 C3*	0.35	2000	2000	500
150 C3	0.35	1500	550	250
SUBGRADE	0.35	180	180	180

Pavement B: ES100

Layer	Poisson's Ratio	Elastic Moduli (MPa) Phase I	Phase II	Phase III
50 AG*	0.44	2000	1800	1500
150 G1*	0.35	250	250	240
150 C3*	0.35	2000	1700	160
150 C3	0.35	1500	120	110
SUBGRADE	0.35	90	90	90

Pavement C: ES0.1

Layer	Poisson's Ratio	Elastic Moduli (MPa) Phase I	Phase II
S*	0.44	1000	1000
100 G4*	0.35	300	225
125 C4*	0.35	1000	200
SUBGRADE	0.35	140	140
	-	-	-

Pavement D: ES0.1

Layer	Poisson's Ratio	Elastic Moduli (MPa) Phase I	Phase II
S*	0.44	1000	1000
100 G4*	0.35	200	180
125 C4*	0.35	1000	120
SUBGRADE	0.35	70	70
	-	-	-

Pavement E: ES30/ES50

Layer	Poisson's Ratio	Elastic Moduli (MPa) Phase I	Phase II	Phase III
40 AG*	0.44	2500	2500	1600
120 BC*	0.44	3500	3500	1500
450 C3*	0.35	2200	1000	300
200 G7*	0.35	300	300	200
SUBGRADE	0.35	150	150	140

Pavement F: ES1.0

Layer	Poisson's Ratio	Elastic Moduli (MPa) Phase I	Phase II
S*	0.44	2000	1600
80 BC*	0.44	2000	1600
150 C4*	0.35	1000	300
SUBGRADE	0.35	140	140
	-	-	-

Pavement G: ES10

Layer	Poisson's Ratio	Elastic Moduli (MPa) Phase I	Phase II	Phase III
30 AG*	0.44	2400	2000	1600
150 C3*	0.35	2000	1800	250
300 C4*	0.35	1000	300	100
SUBGRADE	0.35	180	140	100
	-	-	-	-

Pavement H: ES0.3

Layer	Poisson's Ratio	Elastic Moduli (MPa) Phase I	Phase II	Phase III
S1*	0.44	2000	1000	200
100 C4*	0.35	2000	1500	100
100 C4*	0.35	1000	300	100
SUBGRADE	0.35	140	140	100
	-	-	-	-

*** Classification according to TRH 14 (CSRA, 1985)**

8 Pavement Structures-1.ppt

FIGURE 2 Eight flexible road pavement structures and their material properties used for the mechanistic analysis for the PBS road wear comparative analysis (Classification according to TRH14. (*17*)).

2.5 Road Wear Impact

As indicated in Section 2.4, the performance requirement in terms of road wear for a PBS demonstration vehicle is that it must generate less road wear per ton of payload than the baseline vehicle. A marginal increase in road wear may be allowed by the Review Panel if the other performance benefits of the proposed PBS vehicle are significant. Furthermore, as indicated in Section 2.2, and for the purposes of the PBS demonstration project, individual axle and axle unit loads must comply with the requirements of the NRTR.

As part of the road wear assessment of the first two PBS vehicles, three baseline vehicles that are in common use for transporting timber in South Africa were assessed. These comprised a 5-axle and a 6-axle articulated vehicle and a 7-axle rigid + drawbar trailer as indicated in TABLE 2. As would be expected, the Load Equivalency Factor (LEF) per vehicle combination increases as the combination mass increases. However, the LEF per ton of payload decreases as the combination mass increases. Both the initial two PBS demonstration vehicles have a LEF/ton of payload less than these three baseline vehicles.

A summary of the road wear assessment results for baseline and operational PBS vehicles in the forestry industry is given in TABLE 2. The LEFs/ton payload of the forestry baseline and PBS vehicles are shown in FIGURE 3.

TABLE 2 Road Wear Assessment Results for Baseline and PBS Vehicles in the Forestry Industry

Assess-ment Date	Client	Operator	Baseline/PBS vehicle	Overall Length (m)	Combination mass (kg)	Payload (kg)	PEF	Average LEF/ vehicle	Average LEF/ton payload
Nov-07			5-axle Baseline	18.50	43 200	28 150	0.65	7.34	0.261
			6-axle Baseline	18.50	49 200	31 900	0.65	7.62	0.239
			7-axle Baseline	22.00	56 000	38 500	0.69	8.50	0.221
Nov-07	Sappi	Timber 24	PBS-F01	25.76	67 500	48 200	0.71	8.99	0.187
Nov-07	Mondi	Super Group	PBS-F02	24.00	64 250	45 200	0.70	9.11	0.202
Sep-09	Sappi	TLS	PBS-F03	25.76	67 500	48 200	0.71	8.99	0.187
Sep-11 May-12	Sappi	TLS/ Buhle Betfu	Baseline-F04	22.00	56 000	40 400	0.72	7.46	0.185
			PBS-F04	25.62	67 500	48 200	0.71	9.04	0.188
Jun-12	Mondi	Timbernology/ Gaskells/ Unitrans timber	Baseline-F05	22.00	56 000	39 300	0.70	7.80	0.198
			PBS-F05a	25.08	70 000	50 840	0.73	9.80	0.193
			PBS-F05b	25.00	70 000	50 300	0.72	8.60	0.171
Nov-12	Sappi	Zabalaza Hauliers	Baseline-F06	22.00	56 000	39 300	0.70	7.85	0.200
			PBS-F06	22.80	67 500	50 060	0.74	9.40	0.188
Nov-12	Sappi	TLS	Baseline-F07	22.00	56 000	40 400	0.72	7.46	0.185
			PBS-F07	23.18	67 300	50 350	0.75	9.18	0.182
May-13	Mondi	Timbernology	Baseline-F08	22.00	56 000	40 000	0.71	7.39	0.185
			PBS-F08		63 000	45 246	0.72	8.32	0.184

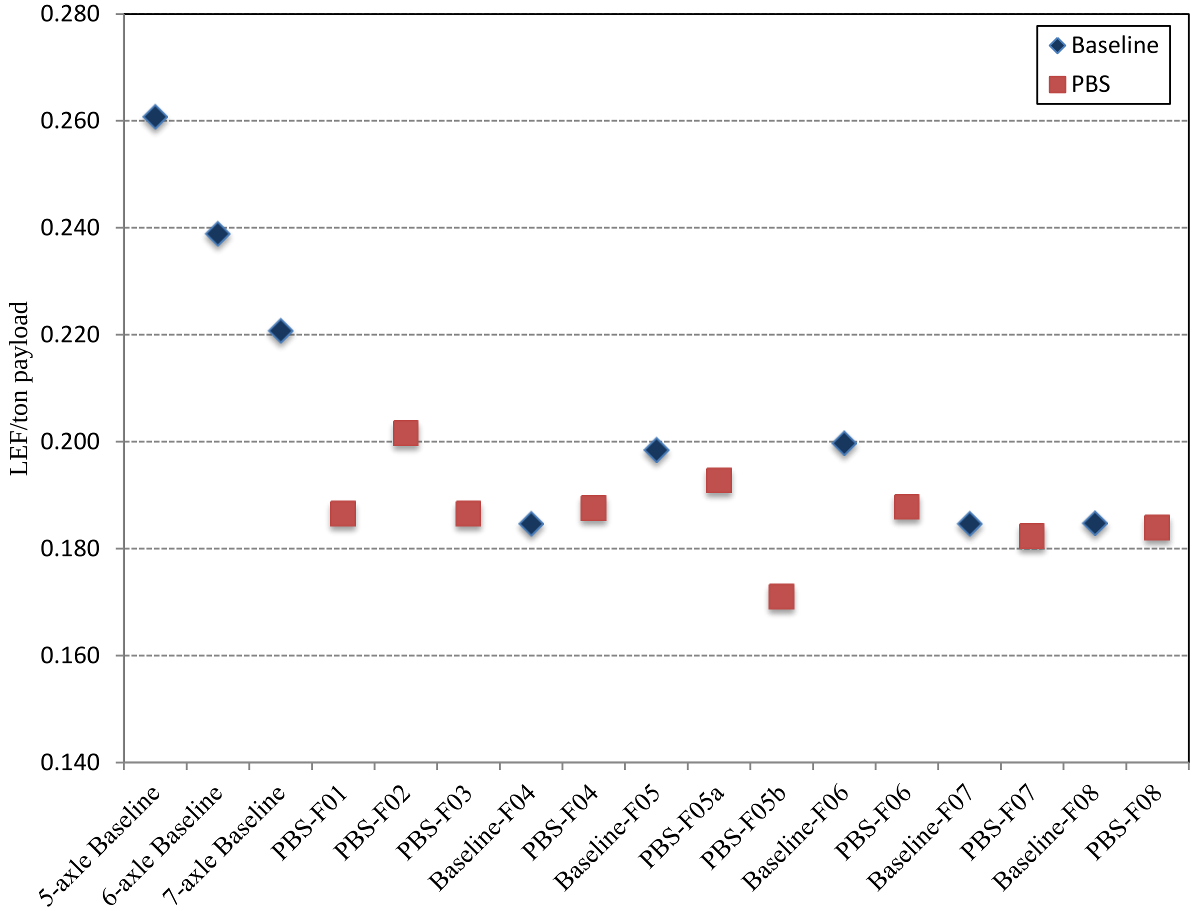

FIGURE 3 Summary of forestry industry PBS road wear assessments.

As can be seen in FIGURE 3, the LEFs/ton payload of the initial baseline vehicles, in particular the 5-axle and 6-axle baseline vehicles, are significantly higher than the other forestry baseline and PBS vehicles. TABLE 2 shows that in all cases except for the Sept 2011 TLS project (PBS-F04), the PBS vehicles have a lower LEF/ton payload than the corresponding baseline vehicles. In the case of the Sept 2011 TLS project, the baseline vehicle has a particularly high payload for a 56 ton legal vehicle and hence a low LEF/ton payload.

Based on the results of the road wear assessments in the forestry industry, the introduction of a maximum limit of 0.200 or 0.195 LEF/ton payload (assuming the eight typical SA pavements in both wet and dry conditions as the basis of the assessment) as a performance measure of the road infrastructure performance standard would appear to be reasonable.

A summary of the road wear assessment results of baseline and PBS demonstration vehicles in the mining industry is presented in TABLE 3. The LEFs/ton payload of the mining baseline and PBS vehicles are shown in FIGURE 4. As at September 2013, only the Unitrans road trains at Richards Bay Minerals and Loeriesfontein were operational. The remaining five projects were still in the design and/or approval stage(s).

TABLE 3 Road Wear Assessment Results for Baseline and PBS Vehicles in the Mining Industry

Assess-ment Date	Operator	Commodity	Baseline/ PBS vehicle	Overall Length (m)	Combination Mass (kg)	Payload (kg)	PEF	Average LEF/ vehicle	Average LEF/ton payload
Feb-12	Unitrans (Richards Bay Minerals)	Heavy Metal Concen-trate	Baseline-M01	34.95	145 100	105 000	0.72	35.75	0.340
Feb-12			PBS (single tyres)-M01	42.67	174 100	122 300	0.70	43.17	0.353
Feb-12			PBS (dual tyres)-M01a	42.67	174 100	120 800	0.69	18.87	0.156
Jun-13			PBS (dual tyres)-M01b	42.67	185 000	132 720	0.72	20.92	0.158
Apr-13	Unitrans (Loeries-fontein)	Gypsum	Baseline-M02	22.00	56 000	37 340	0.67	18.19	0.487
			PBS-M02	40.48	148 000	98 900	0.67	17.23	0.174
Nov-12	Unitrans (Namakwa Sands)	Heavy Metal Concentrate	Baseline-M03	22.00	95 500	66 000	0.69	11.18	0.169
			PBS-M03	31.29	121 250	82 000	0.68	11.93	0.145
Nov-12	**Unitrans (Empangeni)**	**Various**	**Baseline-M04**	**21.27**	**56 000**	**37 340**	**0.67**	**13.95**	**0.374**
			PBS-M04	20.54	73 250	46 000	0.63	7.99	0.174
Jun-12	Ngululu Bulk Carriers	Chrome ore	Baseline-M05	22.00	56 000	38 450	0.69	6.56	0.171
			PBS-M05	21.53	71 900	49 870	0.69	6.96	0.140
Aug-13	Barloworld Logistics	Platinum concentrate	Baseline-M06	22.00	56 000	35 640	0.64	16.14	0.453
			PBS-M06	22.00	72 000	45 950	0.64	7.14	0.155
Apr-13	Barloworld Logistics	Cement	Baseline-M07	22.00	56 000	40 760	0.73	16.77	0.411
			PBS ver 1-M07a	22.00	77 160	57 260	0.74	9.14	0.160
			PBS ver 2-M07b	22.00	70 630	49 680	0.70	6.78	0.136

Five of the seven mining baseline vehicles were fitted with single tyres on all the trailers. In all these cases the LEF/ton payload exceeds 0.300, ranging from 0.340 to 0.487. In some cases, the baseline vehicle has a road wear impact of more than 100 per cent greater than the corresponding PBS vehicle. In the two cases where the baseline vehicles were fitted with dual tyres (Unitrans Namakwa Sands and Ngululu Bulk Services), the baseline vehicles cause 16.5 and 22.1 per cent more road wear per ton of payload than the corresponding PBS vehicles.

One of the initial PBS mining road trains (174.1tons, PBS-M01) causes 9% more road wear (per ton of payload) than the baseline vehicle (145.1tons). Both these vehicle combinations have single tyres (425/65R22.5.5) on all the dollies and trailers. An alternative design (PBS-M01a) is fitted with dual tyres (315/80R22.5) on all the dollies and trailers and is more road friendly than the baseline vehicle by a factor of 3.4 – see TABLE 3 and FIGURE 4.

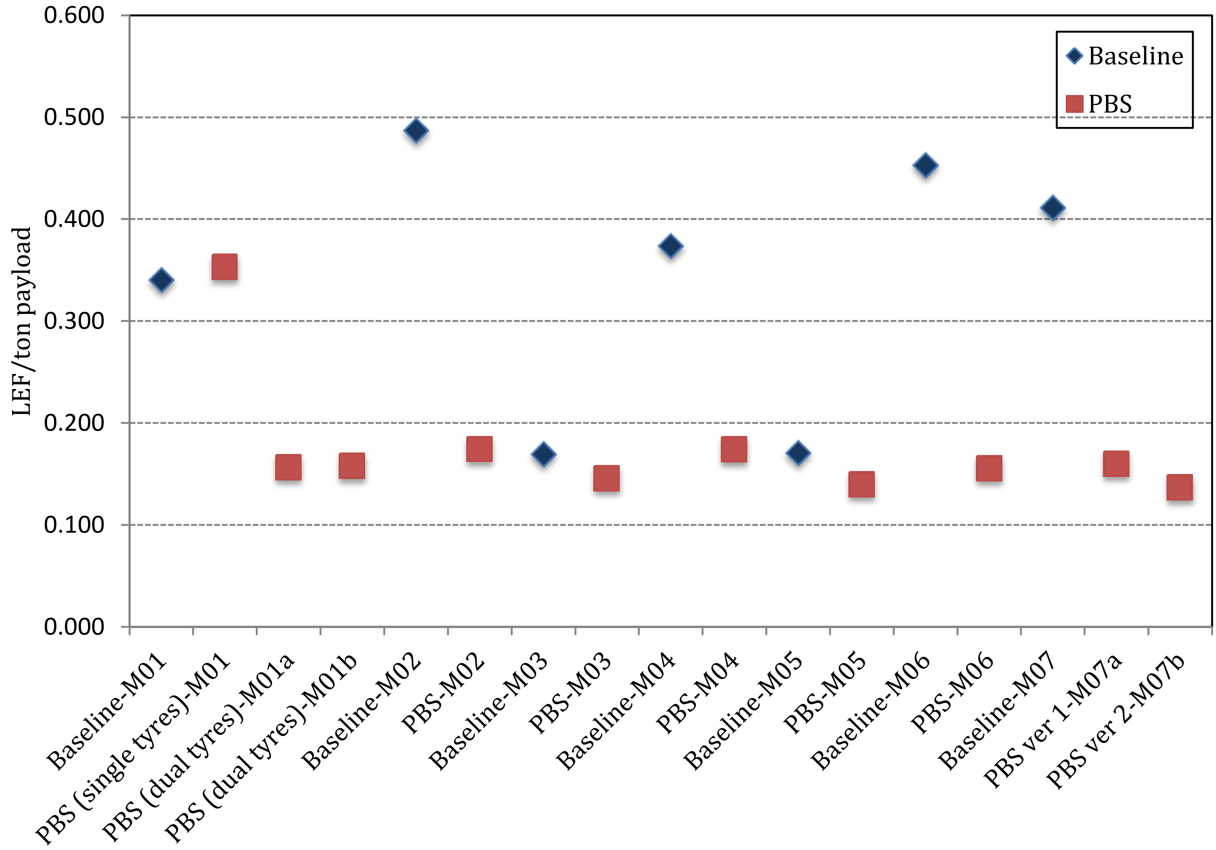

FIGURE 4 Summary of mining industry PBS road wear assessments.

As in the case of the forestry PBS vehicle road wear assessments, a maximum road wear limit of 0.200 or 0.195 LEF/ton payload would appear to be a reasonable performance measure of the road infrastructure performance standard.

Analysis of the road wear assessment results shows that the steering axle of a vehicle combination normally has a disproportionately high contribution towards the LEF of the vehicle combination due to the relatively high axle load - surface contact area ratio. Thus, although the South African National Road Traffic Regulations allow a maximum of 7 700 kg on a steering axle, Smart Trucks with a lower steering axle load as well as wider steering axle tyres can be significantly more road friendly than the corresponding baseline vehicles.

3 CONCLUSIONS

As part of the Performance-Based Standards demonstration project in South Africa, a Mechanistic-Empirical pavement analysis methodology has been used to assess the road wear characteristics of PBS demonstration vehicles compared with corresponding baseline vehicles. It has been shown that these PBS vehicles are more road-friendly than the typical baseline vehicles. It is proposed that this approach be used as the basis for a pavement infrastructure performance standard to ensure that proposed PBS vehicles are more road-friendly than the baseline vehicles. Based on the road wear assessments of PBS vehicles in the forestry and mining industries, and using eight typical South African pavement designs in wet and dry conditions for the assessments, a maximum LEF/ton payload of between 0.195 and 0.200 is recommended. Using this assessment methodology, other vehicle and tyre modifications can be implemented that result in more road-friendly vehicles while at the same time improving productivity and safety.

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