MONITORING RESULTS OF TWO PBS DEMONSTRATION VEHICLES IN THE FORESTRY INDUSTRY IN SOUTH AFRICA

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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 demonstration vehicles in order 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. To this end, two PBS demonstration projects were implemented in the forestry industry; the vehicles were designed and manufactured to comply with the Level 2 safety standards of the Australian PBS system. This paper presents a summary of the monitoring data compiled during the first nine months of operation of the two PBS demonstration vehicles, which were commissioned in November and December 2007. Initial results indicate a number of improvements in performance of both PBS vehicles compared with the baseline vehicles. This has resulted in the approval of 30 additional permits for PBS demonstration vehicles in the forestry industry, some of which will incorporate additional modifications in order to further improve safety and productivity performance.

Keywords: Performance-Based Standards for heavy vehicles, Road Transport Management System (RTMS), heavy vehicle productivity, heavy vehicle safety, payload, vehicle dynamics simulation, road wear

1. Introduction

In most countries throughout the world, heavy vehicle use on the road network is controlled predominantly by prescriptive regulations. These regulations, in many cases, differ significantly from one country to another. Efforts in various parts of the world to achieve regional harmonisation and effective road use have had limited success. Another approach is to consider performance-based standards (PBS); in this case standards 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 more flexibility for vehicle designers to utilise innovative solutions and the latest available technology to meet the required performance standards with improved safety outcomes and more effective use of the road infrastructure. The PBS approach also allows a more optimum "match" between the PBS vehicle and the road infrastructure (roads and bridges) which it uses. Heavy vehicles operated under a PBS framework are typically limited to travel on a subset of the network to ensure protection of the road infrastructure and acceptable safety levels. As a result of initiatives in Australia, New Zealand and Canada, the application of performance-based standards in the heavy vehicle sector in South Africa was identified by the 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.

2. PBS demonstration vehicles

As part of the PBS research programme, a need was identified to design, manufacture and operate a number of PBS demonstration projects in South Africa in order to gain practical experience in the performance-based standards approach for heavy vehicles and to quantify and evaluate the potential safety and productivity benefits of this approach for road freight transport. To this end, two PBS demonstration projects, commissioned by Mondi and Sappi, have been implemented in the forestry industry. Operators of these vehicles are required to be accredited through the Road Transport Management System (RTMS) self-regulation accreditation scheme (Nordengen and Oberholzer, 2006; Standards South Africa, 2007). The two PBS vehicles were designed and manufactured to comply with Level 2 of the Australian PBS system (National Transport Commission, 2007; Nordengen *et al*, 2008). Further research work is planned to develop an appropriate PBS framework for South Africa.

The vehicle performance standards that have been used to design the two PBS demonstration vehicles cover high and low speed directional and non-directional manoeuvres such as startability, gradeability, acceleration capability, frontal swing, tail swing, slow speed swept path, tracking ability on a straight path, static rollover threshold, rearward amplification, yaw damping and high speed transient off-tracking.

The Sappi PBS vehicle has an overall length of 27.0 m and a maximum combination mass of 67 500 kg. The Mondi PBS vehicle has an overall length of 24.0 m and a maximum combination mass of 64 100 kg. These PBS vehicles compare with the baseline (legal) vehicle of similar configuration, which has a maximum overall length of 22.0 m and maximum combination mass of 56 000 kg. All the axle and axle unit loads of the PBS vehicles comply with the requirements of the South African National Road Traffic Act. The layout of the baseline and the two PBS vehicles are shown in Figure 1 and the PBS vehicles are illustrated in Figures 2 and 3.

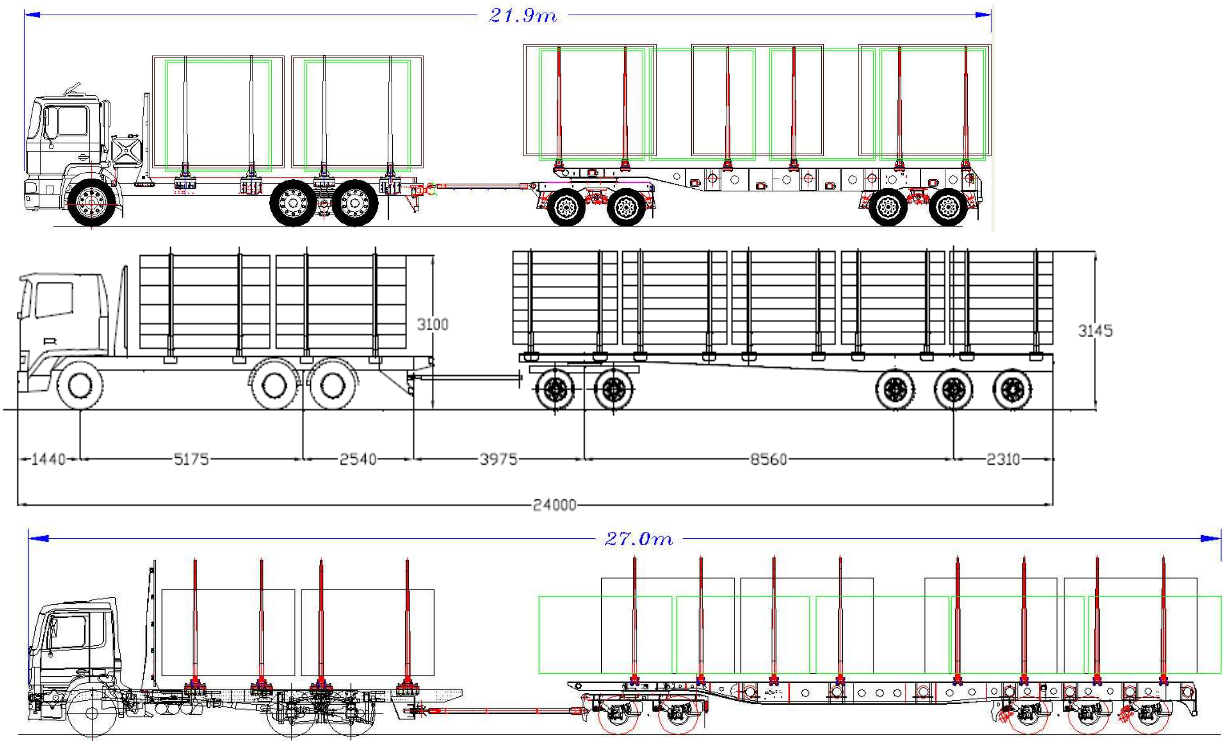

Figure 1: Layout of the 22 m baseline (legal), Mondi (24 m) and Sappi (27 m) PBS demonstration vehicles

Figure 2: Mondi PBS demonstration vehicle

Figure 3: Sappi PBS demonstration vehicle

3. Monitoring of PBS Demonstration Vehicles

Monitoring of the PBS demonstration vehicles commenced once the vehicles had been commissioned. Data including payload per trip, average trip speeds, kilometres travelled per month, average monthly fuel consumption, maintenance costs and records of incidents and accidents are collected on a monthly basis.

3.1 Payload

During the monitoring period, the Sappi and Mondi PBS vehicles had average combination masses of 65 397 kg and 64 248 kg respectively compared with the corresponding baseline vehicles of 56 178 kg and 56 063 kg. The average monthly combination masses for the Sappi (PBS 1) and Mondi (PBS 2) demonstration vehicles are shown in Figure 4.

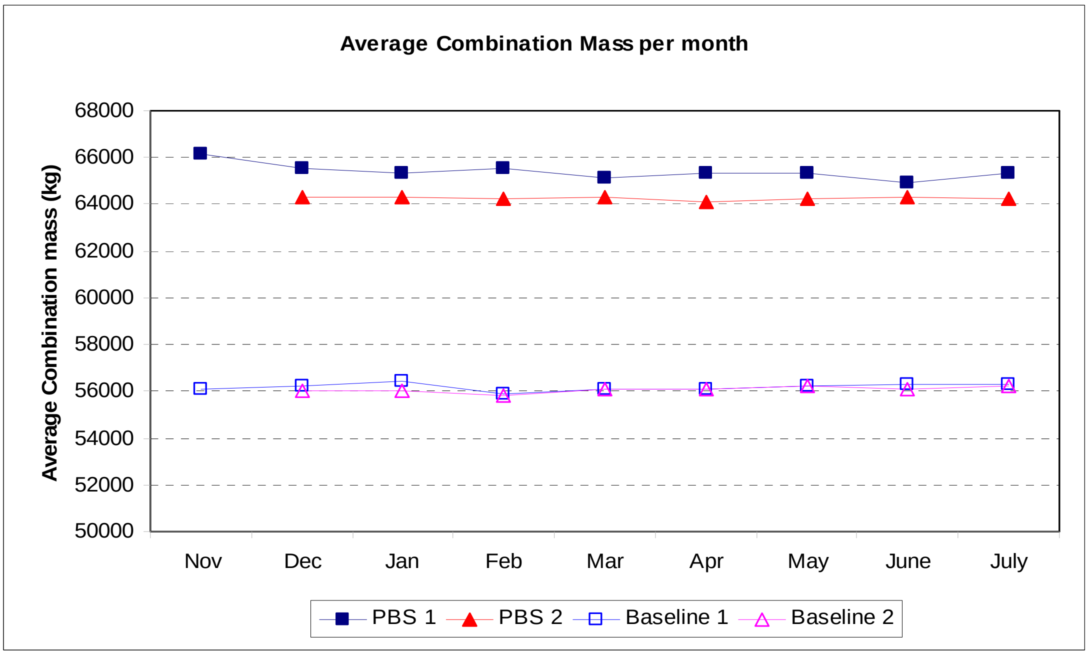

Figure 4: Average combination masses per month of the Baseline, Sappi (PBS 1) and Mondi (PBS 2) demonstration vehicles, Nov 2007 to July 2008

The average payloads of the PBS vehicles during the monitoring period were 45 590 kg and 45 226 kg compared with the corresponding payloads of the baseline vehicles of 38 844 kg and 38 101 kg. This represents increases in payload of 19.9 % and 18.7 % respectively. The Payload Efficiency Factors (PEF) of the Sappi and Mondi PBS vehicles (based on average payloads and combination masses) were 70.6 % and 70.4 % compared with the PEFs of the baseline vehicles of 69.2 % and 68.4 % respectively as shown in Table 1. Figure 5 shows the payload and combination mass consistency of the Sappi PBS vehicle.

Table 1: Payload Efficiency Factors for the Mondi and Sappi PBS and baseline vehicles based on average payloads for the period Nov 2007 to July 2008

	Combination mass (kg)	Tare mass (kg)	Max. Legal Payload (kg)	PEF (%)
Sappi PBS vehicle	65 397	19 230	46 167	70,6
Mondi PBS vehicle	64 248	19 010	45 238	70,4
Sappi baseline vehicle	56 178	17 300	38 878	69,2
Mondi baseline vehicle	56 063	17 700	38 363	68,4

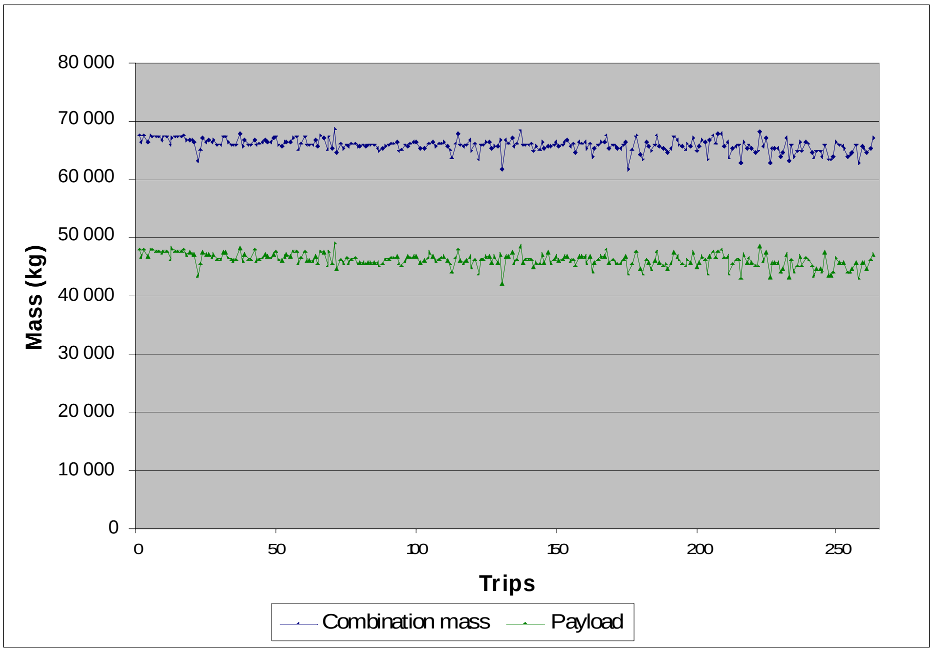

Figure 5: Variation of combination mass and payload of the Sappi PBS vehicle

The Sappi and Mondi PBS vehicles transported an average of 2 953 and 2 301 tons per month compared with the baseline vehicles of 2 462 and 1 938 tons, representing increases of 19.9 % and 18.7 % respectively. The average speeds of the Sappi and Mondi PBS vehicles were 46 and 51 km/hr compared with the baseline vehicle speeds of 50 and 52 km/hr (Table 2).

Table 2: Average speeds and maximum and minimum lead distances for the Mondi and Sappi PBS and baseline vehicles for the period Nov 2007 to July 2008

	Average speed (km/hr)	Lead distance (km)	
		Minimum	Maximum
Sappi PBS vehicle	46	183	220
Mondi PBS vehicle	51	153	175
Sappi baseline vehicle	50	183	220
Mondi baseline vehicle	52	153	175

3.2 Fuel Efficiency

From a productivity perspective, fuel efficiency is one of the most important parameters to monitor. This section describes the performance of the PBS vehicles compared with the baseline vehicles in terms of fuel efficiency.

Figure 6 shows the average monthly fuel consumption (ℓ/100km) for the Sappi and Mondi PBS vehicles and the baseline vehicles. During the period May to July, the Mondi vehicle was operated from the Underberg area (close to the Drakensberg mountain range) where steep gradients occur, hence the increase in fuel consumption. The Sappi PBS vehicle had an average fuel consumption of 61,4 ℓ/100km for the monitoring period, which is 4,1 % more than the baseline vehicle (59,0 ℓ/100km). Similarly, the Mondi PBS vehicle had an average fuel consumption of 59,5 ℓ/100km, which is 4,3 % more than the baseline vehicle (57,1 ℓ/100km). As mentioned in Section 3.1, the average increases in payload for the Sappi and Mondi PBS vehicles compared with the baseline vehicles for the same period were 19,9 % and 18,7 % respectively.

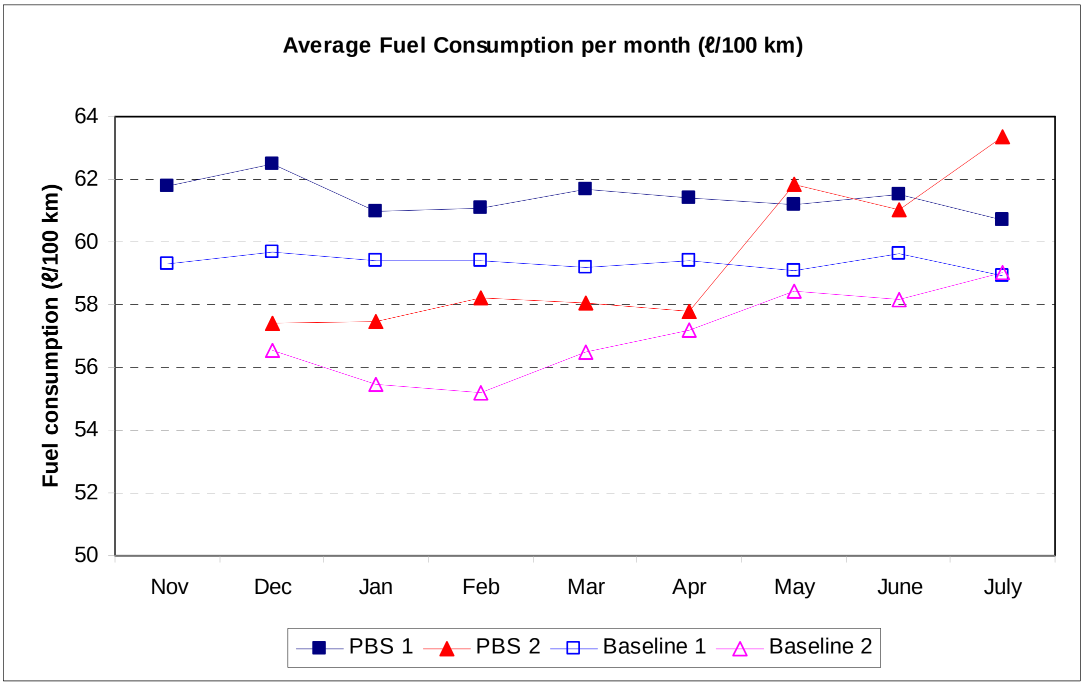

Figure 6: Average fuel consumption per month for the Sappi (PBS 1) and Mondi (PBS 2) demonstration and baseline vehicles, Nov 2007 to July 2008.

The average monthly fuel consumption in litres/tonne (i.e. fuel efficiency) for the PBS and baseline vehicles is shown in Figure 7. These figures are based on average lead distances of 218.2 km for the Sappi PBS and baseline vehicles and 155.0 km for the Mondi PBS and baseline vehicles. The average for the Sappi PBS vehicle for the monitoring period is 5.76 ℓ/tonne, which is 13.2 % less than the average for the baseline vehicle of 6.63 ℓ/tonne. Similarly, the average for the Mondi vehicle is 4.08 ℓ/tonne, which is 12.1 % less than the average for the baseline vehicle of 4.65 ℓ/tonne.

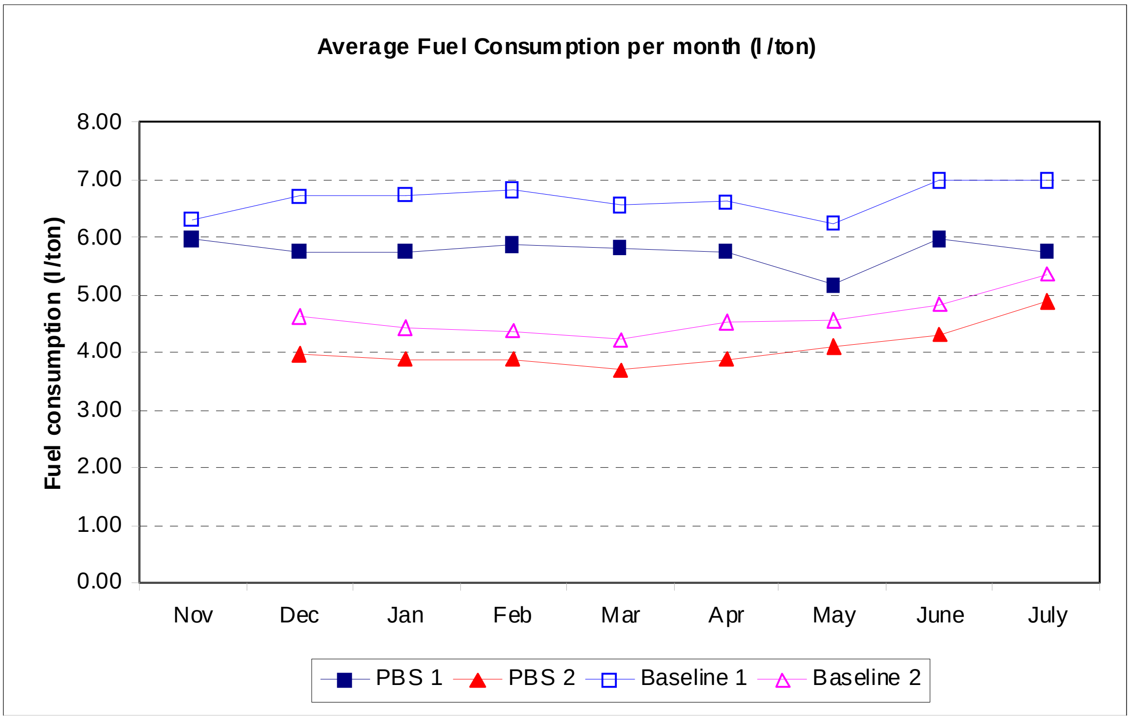

Figure 7: Average fuel efficiency per month for the Sappi (PBS 1) and Mondi (PBS 2) demonstration and baseline vehicles, Nov 2007 to July 2008

3.3 Fuel savings on a contract basis

Based on the average fuel consumption of the baseline and PBS vehicles, the fuel savings on a contract basis can be estimated for the two PBS vehicles. The Sappi PBS vehicle is operating in a fleet of 12 vehicles on a 300 000 tons per annum contract and the Mondi PBS vehicle in a fleet of 18 vehicles on a 400 000 tons per annum contract. Table 3 shows the estimated annual fuel savings for these two contracts and the percentage reduction in fleet size, assuming that the fleets of both contracts were converted to 100% PBS fleets. In both cases, the reduction in the fleet size would be approximately 17 per cent and the combined annual savings in fuel approximately 486 000 litres representing an annual savings of ZAR 5.4 million (US$ 0.72 million) at a diesel price of ZAR 11.17 per litre.

Table 3 Fuel consumption of the Mondi and Sappi PBS and baseline vehicles for the period Nov 2007 to July 2008

	Contract size (tons/annum)	Fuel consumption (ℓ/annum)	Annual Savings (litres)	Fuel price (ZAR/ℓ)	Annual savings (ZAR)	Fleet Size	Fleet size reduction (%)
Sappi baseline	300 000	1 998 404				12	
Sappi PBS	300 000	1 727 596	270 808	11.17	3 024 927	10	16,7
Mondi baseline	400 000	1 844 597				18	
Mondi PBS	400 000	1 629 119	215 477		2 406 883	15	16,7
Totals	**700 000**		**486 285**		**5 431 809**		

A savings in fuel efficiency also results in a reduction of CO_2 emissions. This is calculated on the basis of 2.63 kg of CO_2 per litre of diesel burnt. Assuming that a PBS vehicle fleet is operated for a 700 000 tonnes per annum contract, the reduction in CO_2 emissions would be approximately 1 280 tonnes per annum. Extrapolating to the transportation of 3.5 million tonnes of timber per annum using PBS vehicles (a realistic medium-term target in the forestry industry in South Africa) would realise a reduction in CO_2 emissions of approximately 6 400 tonnes per annum.

3.4 Safety Performance

Improved safety performance is one of the key aims of a performance-based standards approach to heavy vehicle design and operations. Besides complying with the Level 2 performance standards, a number of features were incorporated in the design of one or both of the forestry PBS vehicles to enhance their safety performance including:

- ABS and EBS (Electronic Braking Systems)
- Air suspension
- Pneumatic straps (self-tightening) for load securement
- Lift axles
- Underslung drawbar
- On-board load cells for payload control
- Central tyre inflation
- Vehicle tracking system
- Anti-rollover devices
- Special driver training

During the monitoring period under consideration, no accidents or incidents were reported for the two PBS demonstration vehicles. However, these two vehicles and the combined kilometres travelled during the nine-month period (347 450 km) are insignificant in terms of generating meaningful road safety statistics. Data representing at least 5 million kms should be available before more meaningful results can be obtained.

During the design phase of the PBS vehicles, two of the transport operators that transport timber for Sappi were required to replace obsolete vehicles. The new designs, although not PBS vehicles, incorporate a number of the features of the actual PBS designs. The total number of new vehicle combinations was 43, and both transport companies had historical accident/incident records. Figure 8 shows the safety statistics of the old and new fleets from October 2006 to July 2008. The average number of incidents per month reduced from 3,1 per month (based on 7 months of data) prior to the introduction of the new fleets to 1,1 per month (15 months of data) after the introduction of the new fleets. Important features that were adopted from the PBS vehicle design included the drawbar dimensions, position of the drawbar coupling and suspension type.

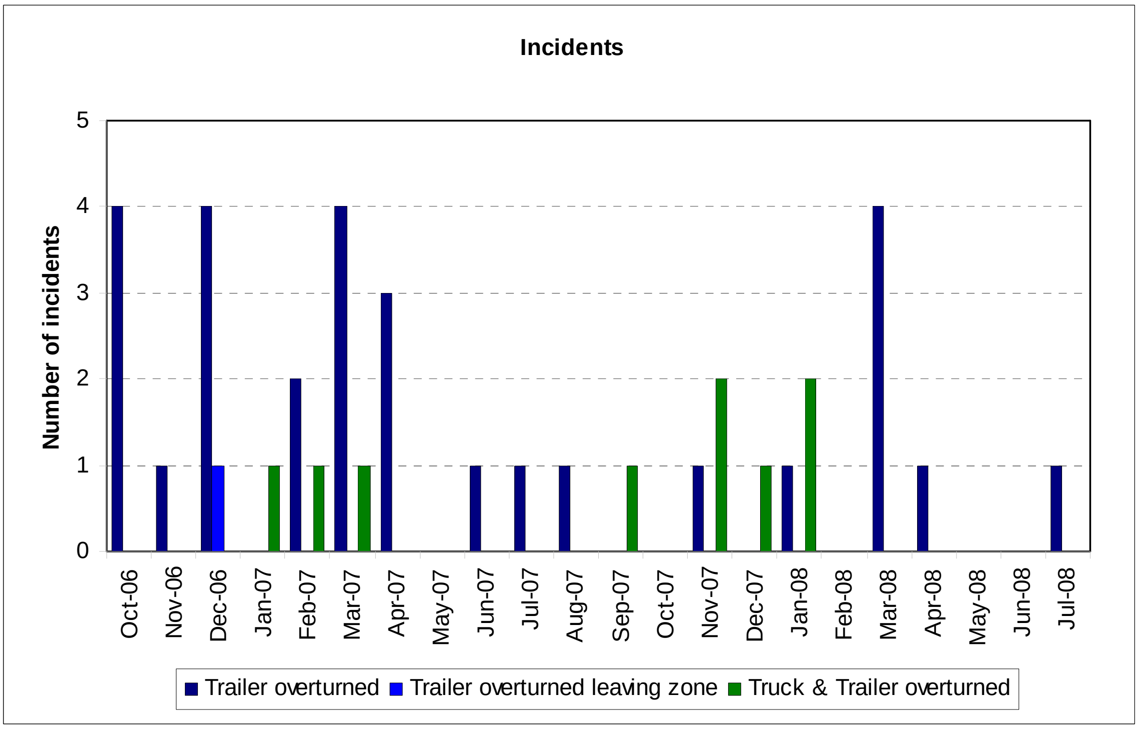

Figure 8: Incident statistics from two timber fleets (43 vehicle combinations), October 2006 to July 2008.

4. Assessment of Road Wear Effects

In order to assess the relative road wear between the PBS and baseline vehicles, the CSIR Pavement Design Software MePads (*me*PADS, 2008) was used. MePads is the electronic version of the current South African Mechanistic-Empirical Design and Analysis Methodology (SAMDM) (Theyse *et al*, 1996). It is anticipated that a methodology will be developed using this approach, which could become part of the PBS assessment process in South Africa. The software combines a stress-strain computational engine with pavement material models developed at CSIR. 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 also on 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. 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 Load Equivalency Factor of the vehicle (LEFv) 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. This was done for each vehicle in question for eight typical South Africa pavement design types, two of which are shown in Figure 9. An average wear cost was calculated for the 16 cases (8 pavement types, wet and dry conditions) for each of the baseline and PBS vehicles. In addition, the effect of increasing the wheel spacing of the dual tyres on the drawbar trailer was also investigated. The standard wheel spacing for dual tyres is 350 mm. Road wear costs for the Sappi PBS vehicle with wheel spacings of 400 mm and 450 mm on the trailer tandem and tridem axle units were also calculated.

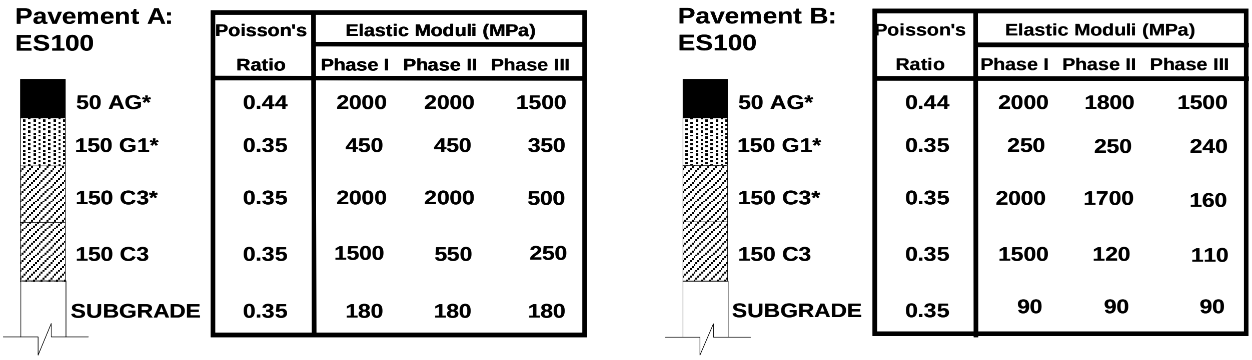

Figure 9: Examples of the eight road pavement structures and their material properties used for the mechanistic analysis for the PBS road wear comparative analysis (* classification according to TRH14, CSRA, 1985)

The average road wear costs (in South African cents) for each vehicle type are given in Table 4. Taking into account the different permissible maximum payloads on each vehicle, a road wear cost per km per ton of payload transported (c/ton km) was also calculated for each vehicle. These are also shown in Table 4 and in Figure 10.

Table 4: Road wear costs (in SA cents) for three baseline and the two PBS vehicles

Vehicle Description	Combination mass (kg)	Payload (kg)	Average Road Wear Cost (c/km)	Average Road Wear Cost (c/ton km)
Baseline: 5-axle articulated	43200	28150	296	10.6
Baseline: 6-axle articulated	49200	31900	299	9.4
Baseline: 7-axle rigid-drawbar	56000	38400	324	8.4
PBS 1 (Sappi)	65400	46200	375	8.1
PBS 1a (400mm wheel spacing)	65400	46200	337	7.3
PBS 1b (450mm wheel spacing)	65400	46200	324	7.0
PBS 2 (Mondi)	64250	45200	375	8.3
PBS 2a (Steer axle – 7 200 kg)	64250	45200	363	8.0

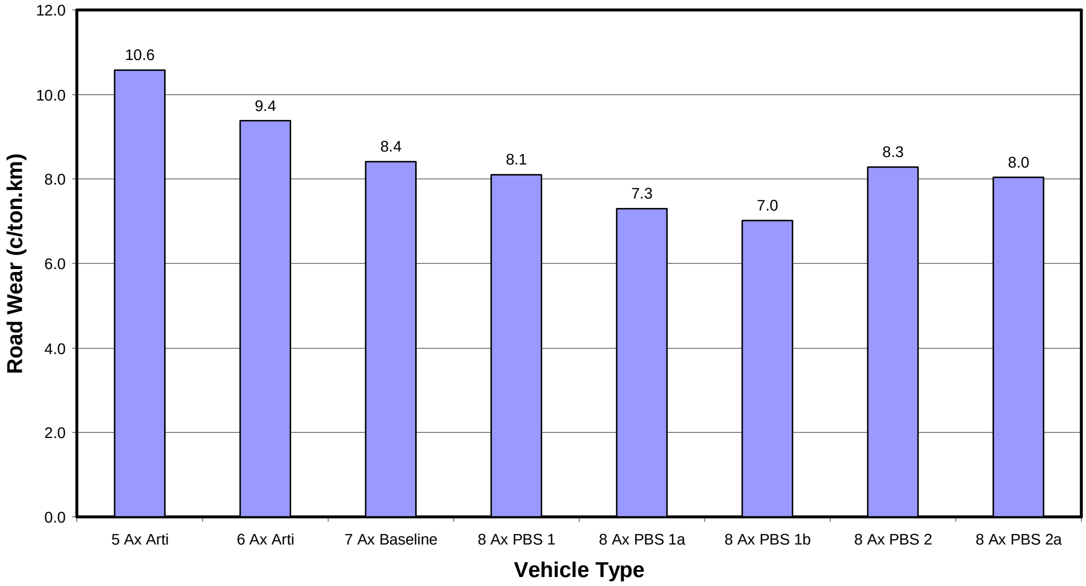

Figure 10: Average road wear costs *in cents per km per ton of payload* for the three baseline and two PBS vehicles calculated from MePads.

Figure 10 shows a comparison of the baseline and PBS vehicles in terms of road wear in cents per km per ton of payload. These results show that the 5- and 6-axle baseline vehicles are the least efficient in terms of road wear (10.6 and 9.4 cents/ton.km). Both the PBS vehicles (at 8.1 and 8.3 cents/ton.km) are significantly more efficient than these baseline vehicles (by 23 and 13 percent) and are slightly more efficient than the 7-axle baseline vehicle, despite the greater payload and combination mass of the PBS vehicles. A further reduction in road wear of the PBS 1 vehicle can be achieved by increasing the wheel spacing of the trailer dual wheels (to 400 and 450 mm). This modification improves the road wear efficiency of the PBS 1 vehicle by 9.9 and 13.6 per cent respectively. It should also be noted that the steering axle load (single tyres) has a relatively large influence on the road wear costs of the vehicle combination. The PBS 2 vehicle has an average steering axle load of 7 500 kg. By reducing the steering axle load to 7 200 kg (the same steering axle load as all the baseline vehicles and the PBS 1 vehicle) and maintaining the combination mass at 64 250 kg (i.e. a slight load redistribution), the road wear cost reduces by 3.6 per cent to 8.0 cents per ton km of payload.

5. Conclusions

An initiative to identify and evaluate the potential benefits of introducing a performance-based approach to the design and operation of heavy vehicles in South Africa has commenced with the implementation of two PBS demonstration projects in the forestry industry, commissioned by Mondi and Sappi. Operators of these vehicles are required to be accredited through the Road Transport Management System (RTMS) self-regulation programme. The two PBS vehicles were designed and manufactured to comply with Level 2 of the Australian PBS system. This paper summarises the monitoring results of the two PBS vehicles and respective baseline vehicles. Observed improvements are summarised in Table 5.

Based on these improvements, the KwaZulu-Natal Department of Transport has approved 30 additional permits for PBS demonstration vehicles in the forestry industry, some of which will

Table 5 Summary of measured operational, safety and infrastructure consumption improvements of the PBS demonstration vehicles

Performance indicator	Measured result
Payload	Average improvement: 19.3 %
Payload Efficiency Factor	Increase from 69.3 % to 70.5 %
Tons transported per month	Average increase: 19.3 %
Fuel consumption	Average savings: 12.7 %
Fuel savings (based on 700 000 tons/annum contract)	485 000 litres per annum
Fleet size	Reduction of 17 %
Incident/accidents*	Reduction from 3.1 to 1.1 per month
CO_2 emissions (based on 700 000 tons/annum contract)	Reduction of 1 280 tons of CO_2 per annum
Road wear	Reduction varies from 2 to 23 %

* Based on a fleet of 45 new vehicle combinations incorporating a number of PBS design features

incorporate additional modifications in order to further improve safety and productivity performance. By December 2009, 15 of the new PBS vehicles had been commissioned. The primary purpose for increasing the scale of the PBS project at this stage is to enable the generation of sufficient data to adequately evaluate the safety performance of heavy vehicles designed and operated in accordance with a PBS approach.

6. References

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