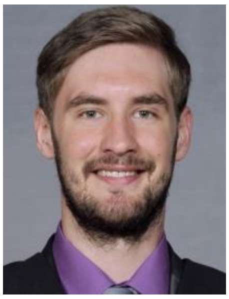
HIGH CAPACITY VEHICLES ROAD WEAR IMPACT IN SOUTH AFRICA



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Abstract

The substantial road maintenance backlog in South Africa, coupled with an inadequate budget allocation, requires high impact solutions in order to preserve the 158 000 km paved road network. Focussing efforts on the heavy vehicles operating on these routes, by ensuring they are more road friendly and payload-efficient, could potentially preserve and extend the pavement structure life. The Smart Truck demonstration project in South Africa permits high capacity vehicles to operate on approved routes outside the prescriptive South African combination mass and length limits, promoting innovation in productivity, safety and road-friendliness. Each vehicle combination participating in the project is subjected to an infrastructure assessment as a measurement of road-friendliness. The Smart Truck project has already shown an estimated $3.6 million savings in road wear over the past six years. This paper reviews the latest data on the road consumption characteristics of high capacity vehicles participating in the demonstration project and estimates the annual monetary savings of road consumption of these vehicles relative to conventional heavy vehicles.

Keywords: High capacity vehicles, road wear, payload efficiency

1. Introduction

South Africa's substantial road maintenance backlog was again emphasised at the 38th Southern African Transport Conference (SATC) in 2019. According to findings by the University of Cape Town, it is estimated that the country's poor road condition translates into a $29.8 billion technical maintenance backlog, for both gravel and paved roads. This is more than double the amount budgeted in the South African National Road Agency's Committee of Transport Officials Condition and Budget Needs report (Ross & Townshend, 2019).

Transport logistics is a key contributor to the South African economy and its effectiveness is highly dependent on the condition of the road network. The state-owned power utility, ESKOM, relies on an average estimated 600 000 kilometres per day of truck transport to move coal in order to meet the required electricity demand in South Africa (Ratshomo & Nembahe, 2017). The road network responsible for the distribution of coal is under increasing pressure to maintain both its structural and functional integrity, especially in the Mpumalanga province where most of the coal transport takes place. Given the inadequate budget for road maintenance, an alternative approach is to focus efforts on the heavy vehicles operating on these routes, by ensuring they are more road friendly and payload efficient in order to extend the life of the pavement structure.

The Smart Truck demonstration project in South Africa (also referred to as the Performance-Based Standards, or "PBS", project) is a government-supported initiative that has been piloted in South Africa since 2007 (Nordengen, et al., 2014). PBS has previously been successfully implemented in Australia, New-Zealand and Canada (OECD, 2011). The PBS approach permits the use of high capacity vehicles, for which relaxations of the prescriptive South African combination mass and length limits (56 tonnes and 22 m respectively, while axle load limits are kept unchanged) may be approved, promoting innovation in productivity, safety and road-friendliness. Ongoing monitoring data collected for all PBS vehicles in South Africa demonstrates increased safety and efficiency, as well as reduced road wear, fuel consumption and emissions (Steenkamp, et al., 2017).

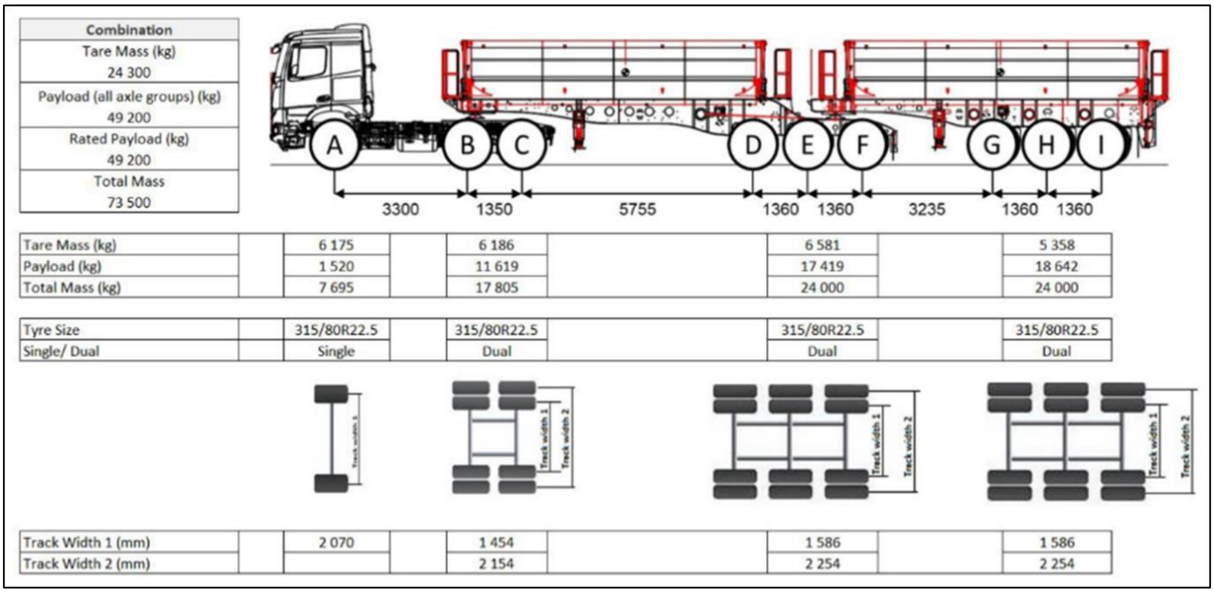
This paper reviews the latest data on the road consumption characteristics of the high capacity vehicles participating in the demonstration project and estimate the annual monetary savings of road consumption relative to conventional heavy vehicles.

2. Background

According to the South African Smart Truck Rules document (STRP & CSIR, 2020), it is mandatory for high capacity vehicles participating in the PBS pilot project to undergo an infrastructure impact assessment. The assessment consists of two components: road wear impact and bridge impact. These assessments are conducted to ensure that all PBS vehicles fall within safe bridge-loading allowances, and that the vehicle has an acceptable level of road wear impact when considering the road wear per tonne of payload transported compared to the baseline vehicle. A baseline vehicle refers to the "conventional" vehicle performing the same freight task on the same route by the same operator and continues to run alongside the PBS vehicles.

A road wear impact assessment expresses the road wear caused by a specific vehicle in terms of the number of "standard axles" that would cause the same road wear. A Standard Axle is defined as a single axle with dual wheels with a total mass of 8 200 kg (80 kN) and a tyre contact stress of 520 kPa. The CSIR developed a Road Wear Analysis Tool which utilises a custom Pavement Analysis and Design Software (mePADS) to analyse and estimate road consumption. mePADS is based on the South African Mechanistic-Empirical Design Method and calculates the critical pavement layer life and bearing capacity of a pavement structure. The Road Wear Analysis Tool uses the output from mePADS to express road wear as a Load Equivalence Factor (LEF). The LEF for a vehicle or vehicle combination is calculated as the sum of the estimated critical pavement layer life of each individual axle of the vehicle relative to the Standard Axle bearing capacity. This is calculated for each of the typical road pavement structures analysed. A total of eight representative road pavement structures is assessed in a typical road wear impact assessment (De Beer, et al., 2009).

For the road wear impact assessment, the Road Wear Analysis Tool requires vehicle input parameters in order to calculate the loading and contact pressures for each tyre. The typical vehicle inputs are shown in Figure 2-1. The required pavement input for each structure layer includes: material type, layer thickness, Poisson's ratio and elastic modulus. The mePADS software is used as a comparative tool, thus the same assumptions and material properties used to calculate the LEF for the PBS combination has been used for the baseline vehicle. Vehicles are assessed in a fully laden condition.



	A	B, C	D, E, F	G, H, I
Tare Mass (kg)	6 175	6 186	6 581	5 358
Payload (kg)	1 520	11 619	17 419	18 642
Total Mass (kg)	7 695	17 805	24 000	24 000
Tyre Size	315/80R22.5	315/80R22.5	315/80R22.5	315/80R22.5
Single/ Dual	Single	Dual	Dual	Dual
Track Width 1 (mm)	2 070	1 454	1 586	1 586
Track Width 2 (mm)		2 154	2 254	2 254

Figure 2-1: Vehicle input parameters

As part of the PBS pilot project, it is a requirement for all PBS operators to submit monthly monitoring data. The data include vehicle kilometres travelled, tonnes of payload transported, number of vehicles operational and the commodity transported. Data are reported for both the PBS and baseline combinations. The monitoring data give insights to the payload efficiency of the PBS vehicles and the potential trips saved when vehicles operate to full capacity.

3. Road Wear Impact

The road wear impact of approximately 100 different PBS vehicle combinations and their associated baseline vehicles have been analysed to date. These data include B-doubles, A-doubles, tractor semi-trailers, and truck full-trailer combinations, ranging from 38 to 89 tonnes and 15 to 30 meters. The road wear impacts of vehicle combinations are compared in terms of their payload efficiency and expressed a LEF per tonne of payload transported.

The road wear impact results of the PBS combinations compared to the baseline vehicles are shown in Figure 3-1. As stipulated in the Smart Truck rules document, a vehicle is considered "road friendly" if the LEF per tonne of payload is equal or below 0.2. There are two exceptions to the defined rule. Rigid truck and drawbar combinations must have an LEF per tonne of payload of equal or below 0.25, and tractor semi-trailer combinations with quad axle semi-trailers must have an LEF per tonne of payload of equal or below 0.34. The initially requirement was for PBS vehicles to do less road wear per tonne of payload than the baseline vehicle in order to pass the assessment. These limits have been altered as the pilot project progressed and more realistic limits could be defined based on the analysed data.

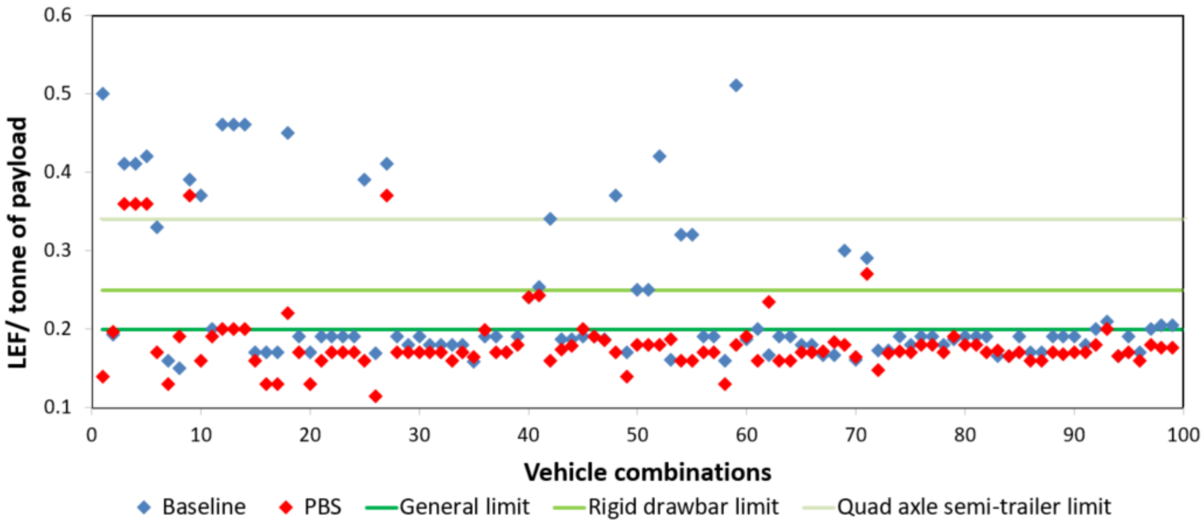


Figure 3-1: Road wear results for PBS and baseline vehicles

High capacity vehicles typically cause less road damage per tonne of payload transported compared to the baseline vehicles, primarily due to the fact that fewer trips are required to perform the same freight task, while axle load limits are kept unchanged.

3.1 Cost Savings

To quantify the actual road wear savings generated by the pilot project, road wear was converted to a monetary value using a combination of the assessed road wear impact in LEF/vehicle and the monitoring data. The monthly monitoring data collected included the average tonnes of payload transported per PBS combination for each operation. The total payload transported per PBS combination was used to estimate the equivalent baseline vehicle trips required to perform the same freight task. The monitoring data also included the total kilometres travelled. The cost of road wear was estimated using the following calculation:

COST = Number of vehicle trips × km of road × Unit cost (R/ LEF-km) × LEF/ vehicle

The LEF per vehicle calculated for the PBS combinations and baseline vehicles in the road wear impact assessments were assigned to the specific operation.

A conservative unit cost range of R0.40 to R0.50 (\$0.03 to \$0.04) per LEF-km were used to estimate the road wear cost saving. This unit cost was calculated in an analysis of road infrastructure and maintenance cost in relation to freight traffic as part of a life cycle cost analysis for the N3 Gauteng to Durban freight corridor (corridor with one of the highest heavy vehicle taffic volumes in South Africa). The study used the N3 Toll Road traffic predictions for the period 2006 to 2029 and predicted an equivelant of 108 300 million E80.km over the 23 year period (Morton, et al., 2007) (Morton, et al., 2007). The total estimated road infrastructure cost and the total maintenance cost as calculated in the study and adjusted for South African inflation is \$4.072 billion. A unit cost of \$0.038/LEF-km can thus be calculated. This unit cost range was also used in a study done for Namibia, estimating the cost of road wear due to heavy vehicles on the Namibian paved road network (Kemp, et al., 2018).

The total road wear cost saving results for 2020 are summarised in Figure 3-2 using a unit cost of \$0.04/ LEF-km. The results grouped by sector and vehicle type for the past 6 year period are shown in Table 3-1 and Figure 3-3. The figure shows the savings calculated for the upper and lower bounds of the unit cost per LEF-km.

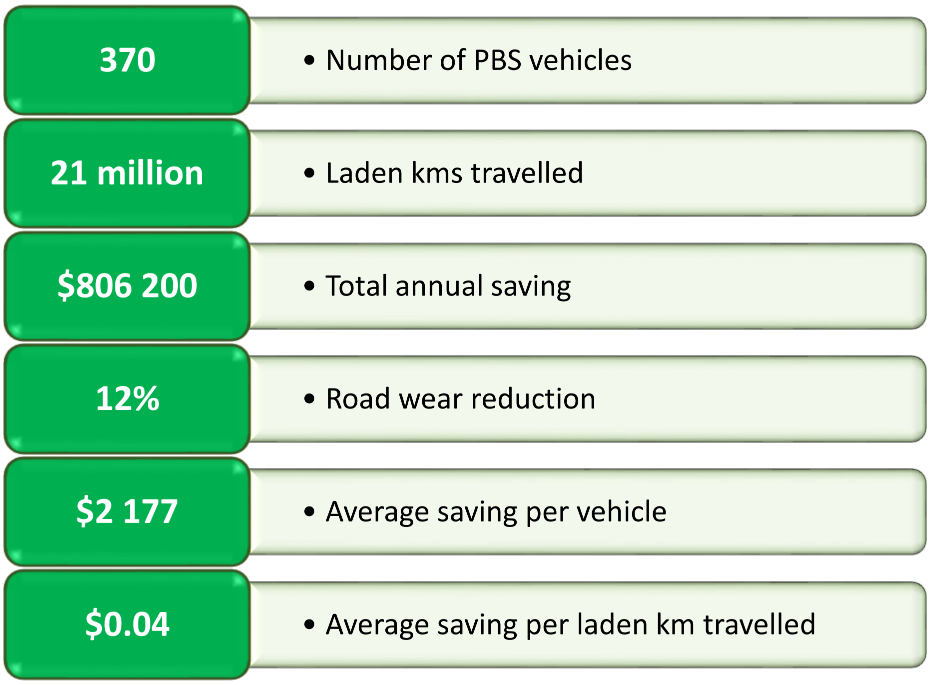


Figure 3-2: Summary of 2020 road wear cost savings

Table 3-1: Road wear cost savings for 2020

	Number of Vehicles	Laden km Travelled (km)	Road Wear Saving ($)	Saving per Laden km ($/km)
Timber	134	8 740 157	78 017	0.01
Fuel	26	1 295 071	79 680	0.06
Side Tippers	157	8 087 551	453 982	0.06
Processed Sugar	17	987 821	180 108	0.18
Tautliners	37	1 904 270	14 449	0.01
TOTAL	**370**	**21 014 870**	**806 236**	

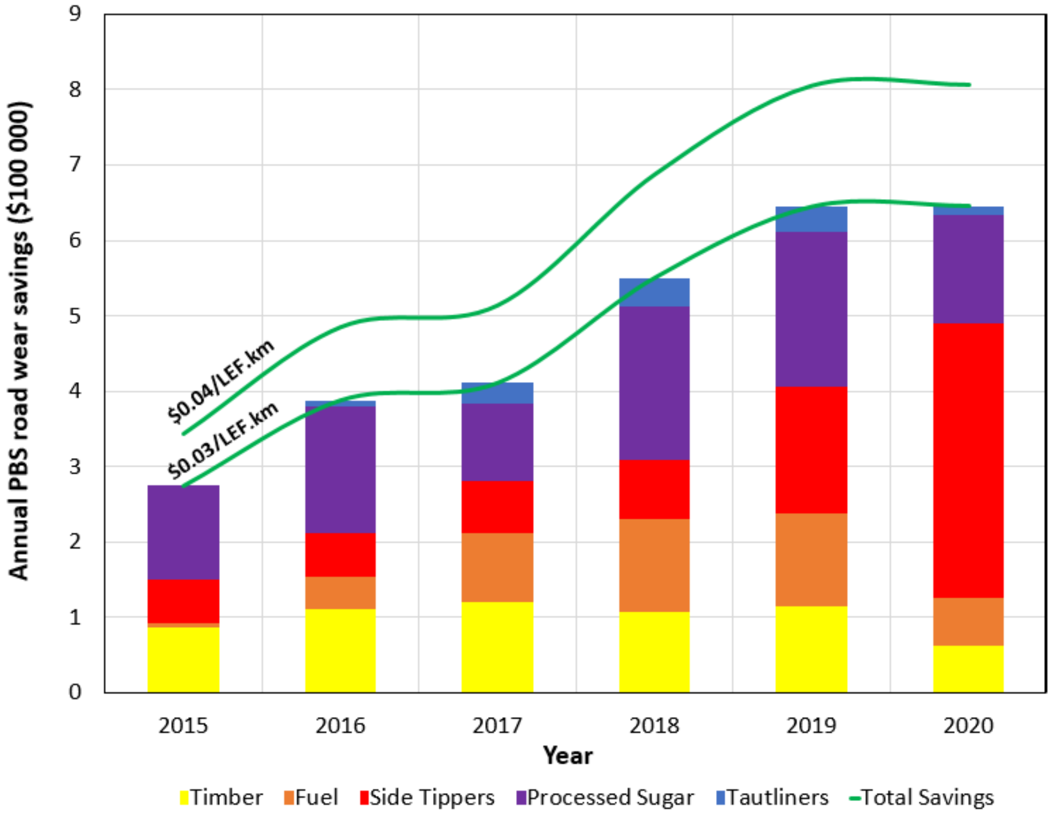


Figure 3-3: Total road wear savings for PBS vehicles

According to these results, the PBS pilot project in South Africa has saved an estimated $3.6 million in road wear over the past six years and will continue to increase as more vehicles participate in the project. The timber and mining side tipper industries represent 80% of the total PBS vehicles and thus had the most laden kilometers travelled. However, the industry showing the highest cost saving per laden kilometer travelled is processed sugar. These PBS vehicle combinations are B-Double tridem/tandem semi-trailer bottom dumpers, and utilise the maximum allowable axle masses for optimum payload efficiency, showing up to 131% reduction in road wear considering the LEF per tonne of payload compared to their baseline vehicles. Fuel tankers and mining side tippers have the second highest cost saving per laden kilometer travelled. Both these PBS combination designs have additional axles compared to their baseline vehicles and the increased tyre contact patch area, thus distributing the load to the pavement structure more evenly. The PBS fuel tankers are quad-axle tractor semi-trailer combinations, and the mining side-tippers are 9-axle B-Double tridem/ tridem combinations. It should be noted that the number of participating side tippers increased by 130% from 2019 to 2020.

The LEF per tonne of payload for the participating PBS combinations in 2020 and their corresponding assessed baseline vehicle results are shown in table Table 3-2.

Table 3-2: PBS and Baseline vehicle LEF/ tonne of payload for 2020

	Operator	Baseline	PBS
Timber	1	0.25	0.24
Timber	2	0.19	0.18
Timber	3	0.20	0.19
Timber	4	0.19	0.17
Timber	3	0.19	0.19
Timber	6	0.19	0.17
Timber	7	0.19	0.19
Fuel	1	0.41	0.36
Fuel	2	0.41	0.37
Side Tippers	1	0.18	0.17
Side Tippers	2	0.19	0.17
Side Tippers	3	0.32	0.16
Side Tippers	4	0.18	0.17
Side Tippers	5	0.19	0.17
Side Tippers	6	0.19	0.17
Processed Sugar	1	0.19	0.15
Processed Sugar	2	0.37	0.16
Processed Sugar	3	0.33	0.17
Tautliners	1	0.17	0.16
Tautliners	2	0.17	0.14
Tautliners	3	0.17	0.14
Tautliners	4	0.16	0.17
Tautliners	5	0.17	0.14
Tautliners	6	0.16	0.19

From Table 3-2 it can be seen that most vehicles have an LEF per tonne of payload of less than 0.2. There are some operations were the baseline vehicles causes significantly more road damage than the PBS combination. Considering the LEF per tonne of payload, the baseline vehicle of side tipper Operator 3 causes 100% more road wear than the PBS combination. This specific baseline vehicle is a 7-axle tandem/tandem B-Double combination, with single tyre configuration on the last axle unit. This is not a common baseline combination found for this specific vehicle configuration and therefore would tend to skew the data slightly.

Some of the tautliner PBS combinations have a higher LEF per tonne of payload compared to their baseline vehicles, though the PBS combinations still fall within the 0.2 limit. The road wear savings for some of these operations are thus negative. These baseline combinations are however considered to be already very road-friendly and the economic benefit of the PBS vehicles outweighs the marginal increase in road wear costs.

According to the live vehicle population data as per the National Traffic Information System (eNaTIS) end of November 2019, there were approximately 380 000 heavy vehicles with a gross vehicle mass (GVM) higher than 3.5 tonnes in South Africa. Over several years, the total sales of extra heavy vehicles (GVM of more than 16.5 tonnes) have represented approximately 40% to 43% of total commercial vehicle sales for vehicles heavier than 3.5 tonnes) (Department of Transport, 2014). Depending on the uptake of PBS in South Africa, the impact of PBS vehicles could vary substantially. Table 3-3 shows the estimated cost saving in road wear should a certain percentage of the total commercial vehicles, with a GVM higher than 3.5 tonnes, in South Africa be converted to PBS vehicles, by simply extrapolating from the current data available from the PBS fleet. A more detailed study would need to be conducted based on the heavy actual heavy vehicle fleet in South Africa and which commodities are being transported.

Table 3-3: Estimated cost savings by PBS uptake in the South African heavy vehicle fleet

Percentage PBS Vehicles in Fleet	# PBS Vehicles	Annual Road Wear Cost Saving
1%	3 800	US$ 8 273 558
5%	19 000	US$ 41 367 792
10%	38 000	US$ 82 735 584
20%	76 000	US$ 165 471 168
30%	114 000	US$ 248 206 752

In Australia there are already more than 10 000 PBS combinations as of 2020 and the rate of uptake is still increasing (TruckSales, 2020). Although the classifications are different between Australia and South Africa, Australia had 358 834 heavy rigid trucks and 105 137 articulated trucks in 2020. Given these values, it would imply that the PBS fleet accounts for approximately 2.5% of their heavy vehicle fleet and is still growing rapidly (Australian Bureau of Statistics, 2020). It is therefore not unreasonable to expect PBS in South Africa to also reach similar values if nurtured correctly.

If only 5% of the total heavy vehicles in South Africa were converted to PBS vehicles, an estimated $41.4 million per year could potentially be saved in road maintenance according to this simplified extrapolation. A more detailed study would however be needed to include the exact vehicle configurations and distribution in the heavy vehicle fleet in South Africa.

In addition to these road wear savings, the actual cost savings by PBS vehicles will also have a substantial impact on the transport industry. According to the latest unpublished data from the Smart Truck pilot project, the PBS vehicles in South Africa are currently showing a weighted average saving of 18.8% per tonne.km compared to the baseline vehicle fleet (Steenkamp, et al., 2021). The savings is weighted by the relative kms completed by all of the operators that participated in the survey study. The financial impact of PBS in South Africa could therefore represent several hundred million dollars per annum.

3.2 ESKOM Case Study

As mentioned previously, the state-owned power utility, ESKOM, moves coal by truck an estimated 600 000 kilometres per day in order to meet the required electricity demand in South Africa. ESKOM transports an estimated 30% of the total 120 million tonnes of coal by road (Ratshomo & Nembahe, 2017), which amounts to 36 million tonnes. The road network responsible for the distribution of coal is under increasing pressure to maintain both its structural and functional integrity.

According to the Mpumalanga Road Asset Management System, the map in Figure 3-4 shows the ESKOM coal haulage routes and the condition of the provincial road network based on 2019 visual inspections. (Mpumalanga department of public works, roads and transport, 2019)

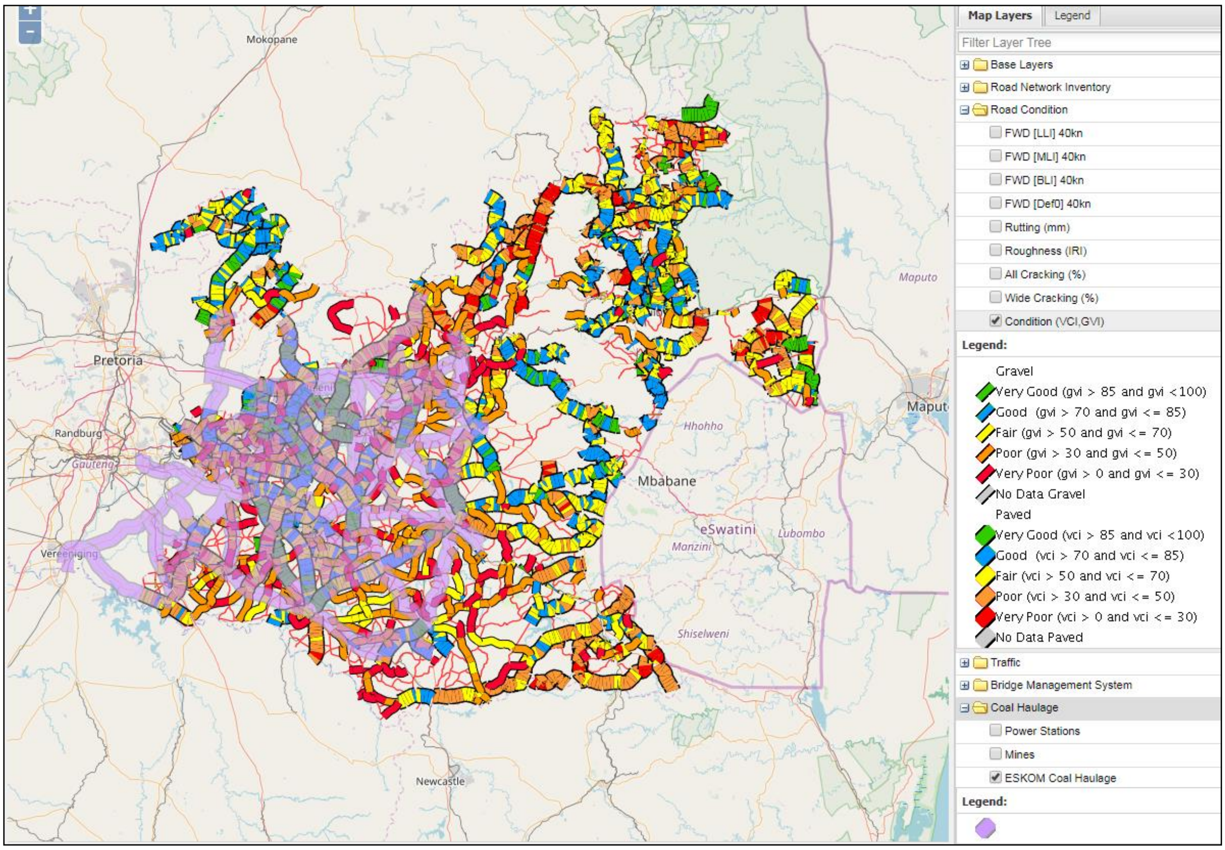


Figure 3-4: ESKOM haulage route in Mpumalanga (Mpumalanga department of public works, roads and transport, 2019)

Calculated from the 2019 road condition data, 16% of the Mpumalanga road network is classified as in a "Very Poor" condition and 34% in a "Poor" condition, as shown in Figure 3-5.

This indicates that half of the Mpumalanga road network is in need of urgent maintenance or rehabilitation.

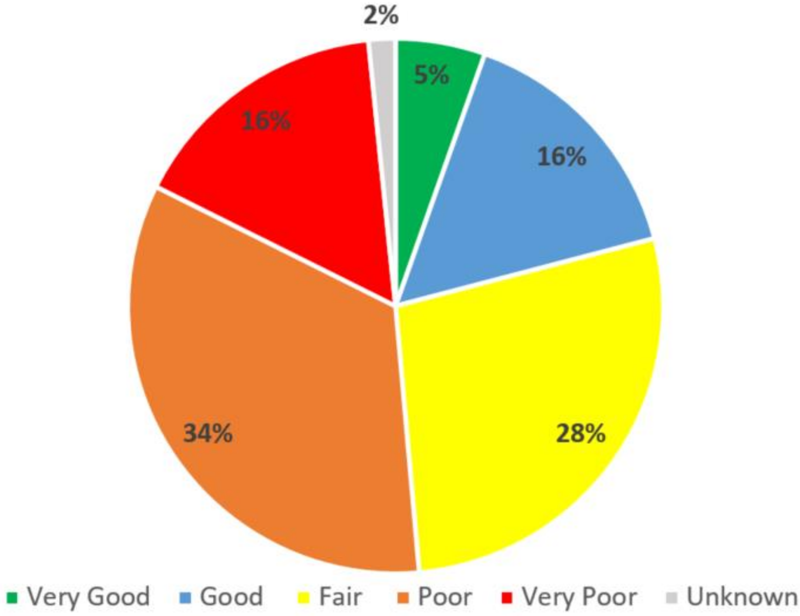


Figure 3-5: Mpumalanga paved road network condition

A short case study was carried out to calculate the potential road wear cost savings should the fleet of trucks carrying power station coal be replaced with PBS vehicles in order to transport the required 36 million tonnes of coal per year. For this study, the common 9-axle 72 tonne B-double PBS combinations (50 tonne payload) was compared to the standard 7-axle 56-tonne B-double baseline (35 tonne payload).

To meet the 36 million tonne coal demand the estimated number of trips required per year would be 720 000 using PBS combinations and 1 028 572 using baseline vehicles. The road wear cost savings were calculated and summarised in Table 3-4. Assuming that 50% of the 600 000 km travelled per day is laden, the calculated LEF per PBS vehicle is 8.37 and 6.46 per baseline vehicle. Using a unit cost of $0.04 per LEF-km, the total cost saving per year for both laden and unladen kms travelled for the ESKOM coal road transport translates to $5.4 million per year (De Saxe, et al., 2021).

Table 3-4: ESKOM annual freight task road wear cost saving estimation

	Freight Task (Tonnes per Year)	Kms Travelled (Per year)	Average Payload (Tonnes)		No of Trips		LEF per Vehicle		Cost Saving ($)
			Baseline	PBS	Baseline	PBS	Baseline	PBS	
Laden	36 000 000	109 500 000	35	50	1 028 571	720 000	6.46	8.37	3 364 838
Unladen	0	109 500 000	0	0	1 028 571	720 000	1.50	1.62	2 049 136
									5 413 974

4. Conclusions and Discussion

South Africa's valuable paved road network needs intervention from multiple angles to prevent its further rapid deterioration, especially given increasing logistics demands. Given the severe maintenance backlog, optimizing road freight tasks is one approach to help alleviate the problem. This includes the use of more road-friendly heavy vehicles and ensuring that the vehicles operate at maximum capacity by efficient loading.

By introducing high capacity vehicles, the number of heavy vehicles on the South African network will be reduced, relieving some of the current pressures. Currently, there are only approximately 370 vehicles participating in the PBS pilot project in South Africa. This is still a relatively small sample, but the cost saving in reducing road wear per tonne of payload transported is already significant. The road wear savings will continue to increase with an increase in the proportion of high capacity vehicles on South African roads.

The PBS pilot project in South Africa has saved a calculated $3.5 million in road wear consumption alone in the past six years and will continue to increase as more vehicles participate in the project. If only 5% of the 380 000 total heavy vehicles, with a GVM higher than 3.5 tonne in South Africa were converted to PBS vehicles, an estimated $41.4 million could potentially be saved in annual road maintenance costs. This is over and above the operational cost savings and safety benefits also demonstrated by the pilot project.

The ESKOM case study showed a potential saving of $5.4 million per year in road wear cost should the entire fleet be converted to PBS vehicles. This saving could be reinvested into road rehabilitation and maintenance programs, and can also help to reduce ESKOM's sizeable carbon footprint.

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