BENCHMARKING THE PERFORMANCE OF HIGH CAPACITY VEHICLES IN SOUTH AFRICA

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ABSTRACT

The Smart Truck or Performance-Based Standards (PBS) pilot project in South Africa has been running since 2007, and currently comprises approximately 280 vehicles operational in seven provinces, spanning fourteen different industries or commodities. These high capacity vehicles operate under special permit concessions, which allow for additional mass and dimensions, but still adhere to the permissible axle loads. Each participating vehicle in this pilot project must be assessed for its vehicle dynamics performance against fifteen performance standards, as well as its road wear impact performance as assessed against eight representative road structures in South Africa. For each PBS vehicle design, the equivalent "baseline" vehicle is also assessed. This is the standard legal vehicle (with no mass or dimension concessions) which performs the same freight task on the same route for the same operator alongside the PBS vehicle. Assessing both PBS and baseline vehicles and logging their operational performance provides insights into the operating cost benefits of PBS vehicles as well as their safety and road impact performance as compared to standard legal vehicles in South Africa. In this paper some of the latest data for both PBS and baseline vehicles will be assessed, and extract insights into heavy vehicle freight transport in South Africa. This comparative study is the first of its kind for the South African PBS pilot project and lays the foundation for important future studies in this area.

1. INTRODUCTION

1.1 Background

The Smart Truck (or PBS) pilot project is a government-supported initiative that has been piloted in South Africa since 2007 (Nordengen, Berman, & de Saxe, An overview of the Performance-Based Standards pilot project in South Africa, 2018). PBS has been successfully implemented in Australia, New-Zealand and Canada (OECD, 2011). The PBS approach permits the use of high capacity vehicles and is not restricted to prescriptive South African mass and length limits (56 tonnes and 22 m respectively). This creates scope for more productive, innovative, and road-friendly heavy vehicles. Ongoing monitoring data collected for all PBS vehicles in South Africa demonstrates increased safety and efficiency, and reduced road wear, fuel consumption and emissions (Steenkamp, Nordengen, Berman, & Kemp, 2017).

South Africa is notorious for high heavy vehicle crash and fatality rates compared to other countries. Figure 1 shows that South Africa has more than five times higher fatal heavy vehicle crash rates per 100 million kilometres travelled in relation to other countries (OECD, 2011).

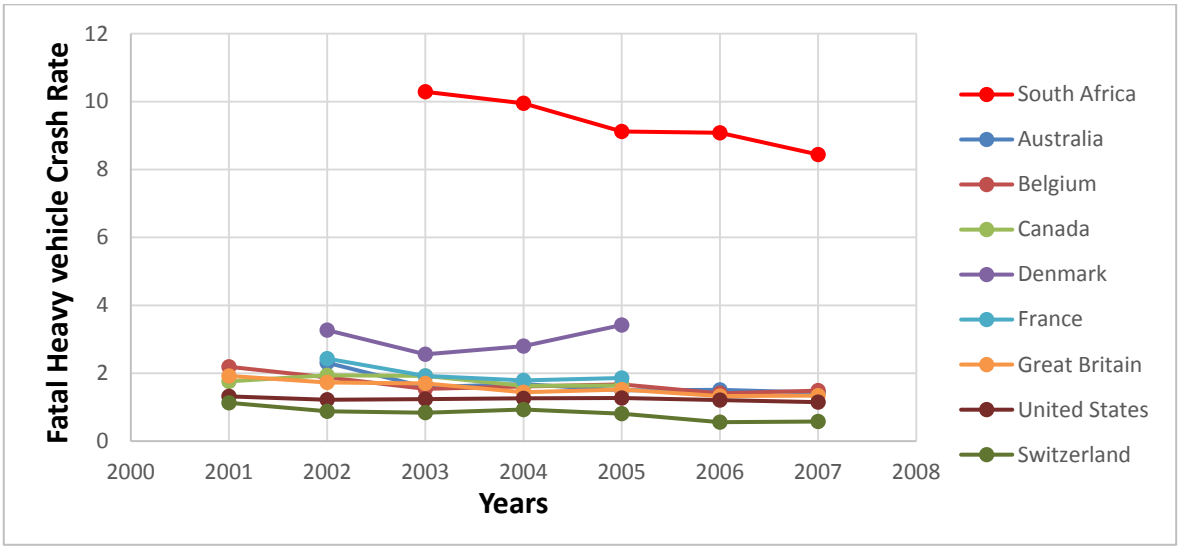


Figure 1: Fatal heavy vehicle crashes per 100 million kilometres travelled

For a proposed heavy vehicle combination to participate in the PBS pilot project, assessments of the vehicle safety, road wear impact and bridge loading must be conducted for both the proposed PBS vehicle and the corresponding baseline vehicle. The vehicle safety assessment involves an extensive computer simulation-based analysis of the vehicle in terms of low-speed manoeuvrability, high-speed stability, and longitudinal performance. There are fifteen performance standards in total. For example, one of the important performance standards is the "Static Rollover Threshold" (SRT), which is a measure of the vehicle's proneness to rollover when subjected to lateral acceleration. SRT has shown to be highly correlated with crash risk, as shown in Figure 2. (De Pont, Baas, Hutchinson, & Kalasih, 2002).

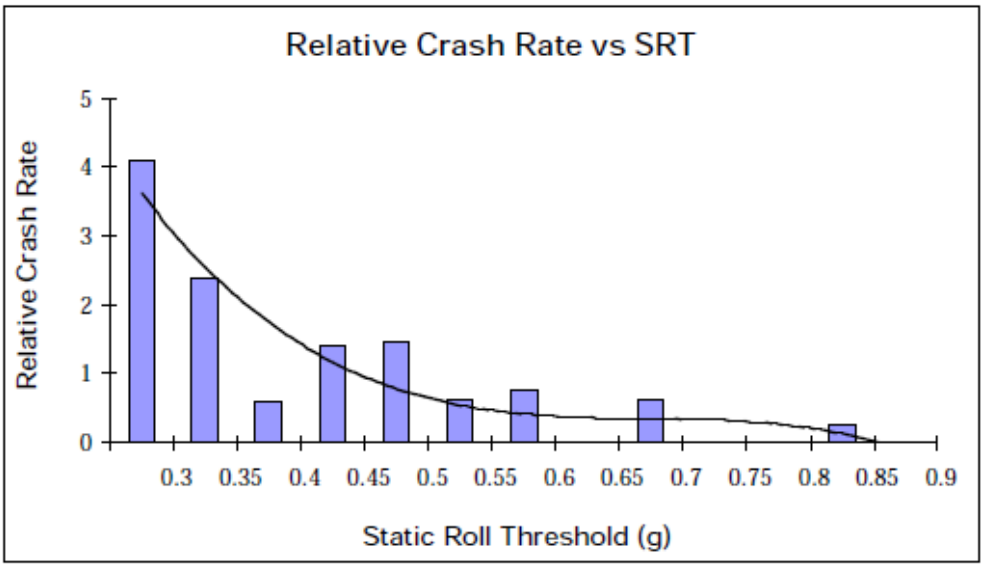


Figure 2: Relationship between relative crash rate and SRT (De Pont, Baas, Hutchinson, & Kalasih, 2002)

The pass criteria for many of these standards are divided into four levels which are used as the criteria for a PBS vehicle to operate on a certain route. The four defined road access levels are Levels 1 to 4, each level increasing in restricted access. Level 4 has the most restricted road access but the least strict criteria. Table 1 summarises the fifteen performance standards and the pass criteria for each level. The highest level of performance standard is the overall governing safety assessment level of the vehicle combination. A vehicle combination will fail the safety assessment if any of the minimum performance standards requirements have not been met. For definitions of all the standards, please refer to: (Australian National Transport Commission, 2008). The standards considered in this study will be described in more detail later.

Table 1: Performance standards level criteria

Performance Standard	Level 1	Level 2	Level 3	Level 4
Startability (%)	≥ 15%	≥ 12%	≥ 10%	≥ 5%
Gradeability A (Maintain motion) (%)	≥ 20%	≥ 15%	≥ 12%	≥ 8%
Gradeability B (Maintain speed) (km/h)	≥ 80 km/h	≥ 70 km/h	≥ 70 km/h	≥ 60 km/h
Acceleration Capability (s)	≤ 20.0 s	≤ 23.0 s	≤ 26.0 s	≤ 29.0 s
Tracking Ability on a Straight Path (m)	≤ 2.95 m	≤ 3.05m	≤ 3.15 m	≤ 3.35 m
Low Speed Swept Path (m)	≤ 7.4 m	≤ 8.7 m	≤ 10.6 m	≤ 13.7 m
Frontal Swing (m)	≤ 0.7 m			
Difference of Maxima (m)	≤ 0.25 m			
Maximum of Difference (m)	≤ 0.55 m			
Tail Swing (m)	≤ 0.30 m	≤ 0.35 m	≤ 0.35 m	≤ 0.50 m
Steer-Tyre Friction Demand (%)	≤ 80%			
Static Rollover Threshold (g)	≥ 0.35·g			
Rearward Amplification	≤ 5.7·SRT_rrcu*			
High-Speed Transient Offtracking (m)	≤ 0.6 m	≤ 0.8 m	≤ 1.0 m	≤ 1.2 m
Yaw Damping Coefficient @ 100 km/h	≥ 0.15			
* 5.7·SRT_rrcu (g)				

1.2 Aim & Scope

The aim of this paper is to compare the vehicle safety performance of the PBS vehicles participating in the pilot project with the baseline vehicles performing the same freight task. This is done by investigating the vehicle safety assessment results for all PBS vehicles participating in the pilot project, as well as all the corresponding baseline vehicles. By comparing performance in selected performance standards, insights can be gained into the overall safety performance of the PBS vehicles compared to conventional vehicles, which can then help to explain the reduction of crash and fatality rates observed in the monitoring data for the PBS vehicles. Furthermore, performance standards failed by the baseline vehicles can offer insights into any potential safety concerns of the baseline fleet, and by extension the general heavy vehicle fleet on SA roads. (By definition, a PBS vehicle is not permitted to fail any of the standards, otherwise it would not be permitted into the programme.)

1.3 Methodology

The mandatory vehicle safety assessments are conducted by various accredited “PBS assessors” in South Africa and Australia, typically vehicle dynamics simulation experts highly familiar with the specifics of heavy vehicles and PBS. The assessments are typically performed using a combination of multibody dynamics software packages and other custom software algorithms and first principle calculations. All fifteen safety standards must be assessed, in line with the rules of the Australian PBS Scheme as compiled by the

Australian National Commission (NTC) and governed by the Australian National Heavy Vehicle Assessment Rules. (South Africa has largely adopted the Australian rules for the pilot project.)

Of the participating vehicles, 39 PBS vehicle designs were conducted locally by local PBS assessors. This study will focus on only these locally assessed vehicles, as assessment data is available for both the PBS *and* baseline vehicles, allowing for a comparative study to be made. Here the baseline vehicle is the "conventional" vehicle performing the same freight task on the same route by the same operator, which continue to run alongside the PBS vehicles once they are introduced. Local PBS assessments have been carried out variously by one of five accredited PBS assessors at CSIR and Wits University. For the local assessments, the TruckSIM multibody dynamics software was used, in combination with custom algorithms and first principle calculations. Although simulation models and methods may differ between PBS assessors, all assessors and their models have undergone a pre-accreditation blind validation exercise to ensure consistency. Although the PBS assessment reports are confidential, examples of the PBS assessment process in South Africa may be found in: (Nordengen, Kienhofer, & de Saxe, Vehicle safety performance inprovements using a performance-based standard approach: four case studies, 2014), (de Saxe, Nordengen, & Kienhofer, 2013) and (Dessein, Kienhofer, & Nordengen, 2010)

All PBS assessment results must be detailed in PBS reports, submitted to the Smart Truck Review Panel for approval. These reports form the basis of this study. The reports were obtained from the Review Panel, and the PBS performance results extracted into a simple database. For this study, four of the 15 safety standards were isolated, as these were the standards in which baseline vehicles exhibited frequent poor performance:

- Static rollover threshold (SRT)
- Rearward amplification (RA)
- Yaw damping coefficient (YDC)
- High-speed transient off-tracking (HSTO)

2. RESULTS AND DISCUSSION

2.1 Overall safety assessment level

Considering the results of the fifteen performance standards, the PBS and baseline vehicles were categorised according to the overall highest level obtained in the safety assessment (i.e. Level 1, 2, 3, 4 or Fail). Recall that a lower level equates to better (safer) performance. The percentage of assessed PBS and baseline vehicles in each of the four levels is shown in Figure 3.

Comparing the overall safety performance level of the vehicle combinations, 98% of the PBS vehicles conform to Level 1 and Level 2 performance. Level 1 vehicles are allowed general road access whilst level 2 vehicles require route approval to ensure the road and bridge infrastructure are suitable. There was only one PBS Level 3 combination studied, which operates on a highly restricted approved route.

Considering the baseline vehicles, 56% of the combinations failed one or more performance standards and consequently failed the entire safety assessment (worst result). If these vehicles were assessed as a PBS vehicle they would not be permitted to participate in the Smart Truck pilot project. The baseline vehicle designs are legal vehicles which adhere to the regulations stipulated in the road traffic act and are permitted to

operate on any route. However, these results suggest that the prescriptive regulations do not necessarily ensure safe performance on the road.

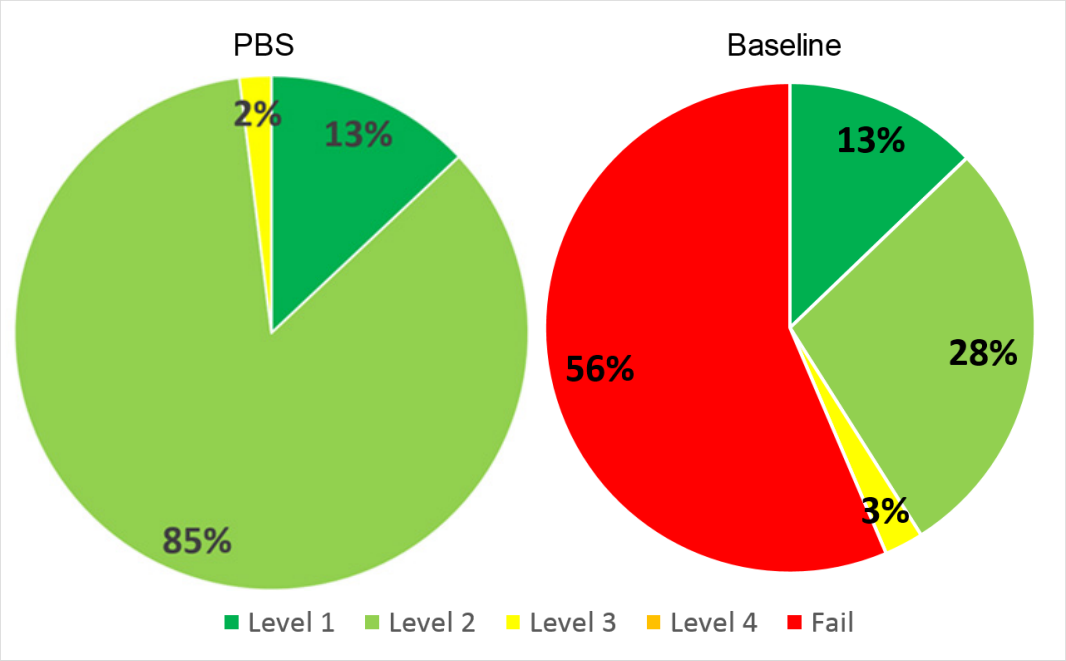
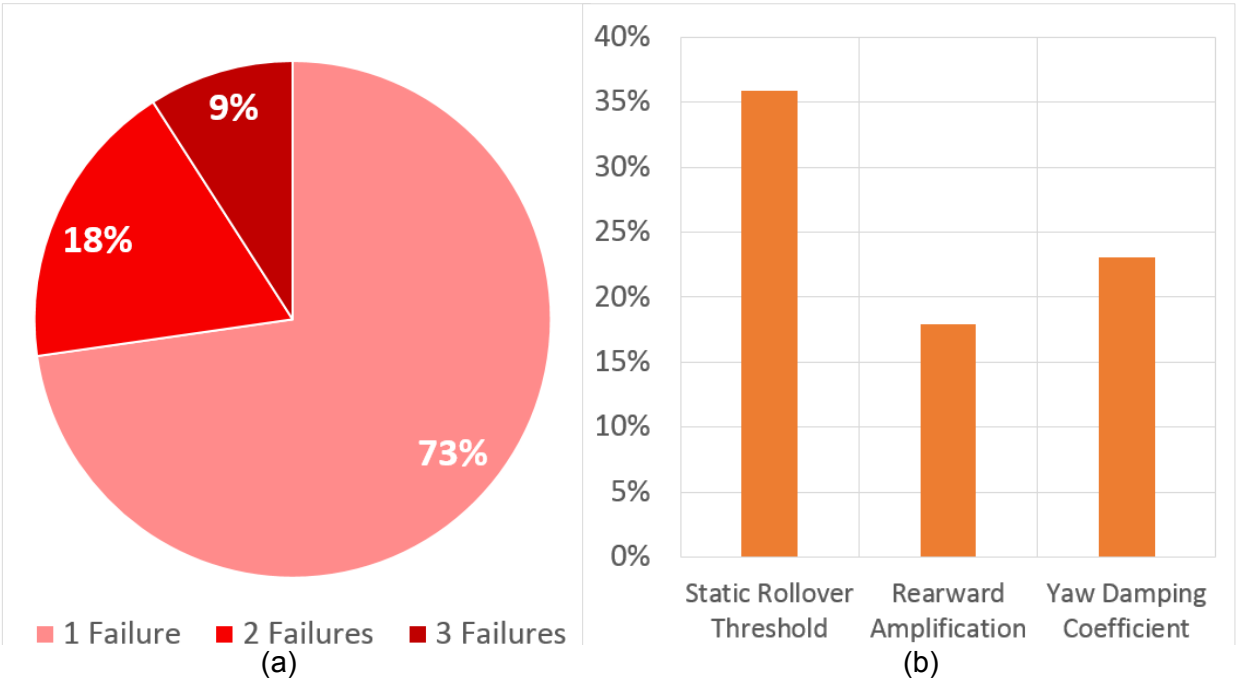


Figure 3: Overall safety assessment level

2.2 Baseline vehicles: poor performance areas

Of the 56% of baseline vehicles which failed the overall safety assessment, 27% failed two or more of the performance standards as shown in Figure 4(a). As mentioned, by definition, the PBS combinations did not fail any of the performance standards. The failed baseline performance standards were: Static Rollover Threshold (SRT), Rearward Amplification (RA) and Yaw Damping (YD) Coefficient. The percentage of failures of each of these performance standards are shown in Figure 4(b).



(a) (b)

Figure 4: Baseline performance standards failures

Although none of the baseline vehicles failed High-Speed Transient Off-tracking (HSTO), a high percentage were recorded in the Level 3 category.

The following sections will define each of these mentioned performance standards and the safety concerns associated with such failures.

2.2.1 Static Rollover Threshold

SRT is the maximum steady-state lateral acceleration that can be sustained by a vehicle in a constant-radius, high-speed turn and directly measures the vehicle's rollover stability. For most vehicles, the PBS threshold is set at a minimum of 0.35 g, with dangerous goods requiring a minimum SRT of 0.4 g (Australian National Transport Commission, 2008).

Figure 5 shows the SRT performance results of all the PBS and baseline vehicles. A total of 36% of the baseline vehicles failed this standard, with an SRT lower than 0.35 g.

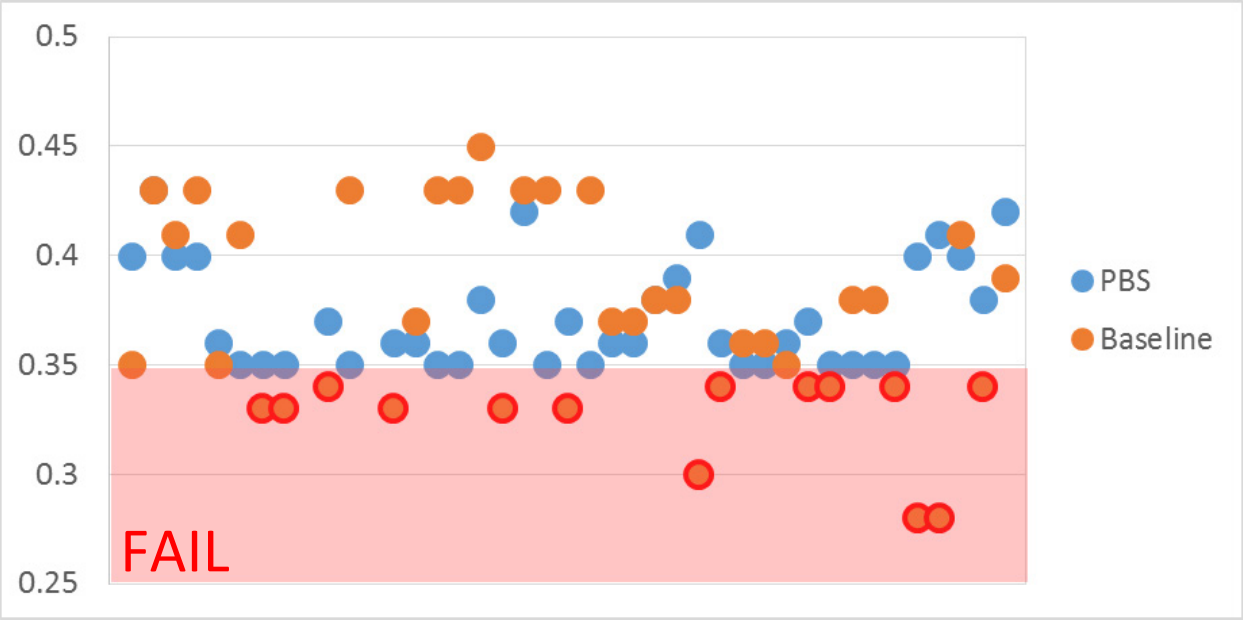


Figure 5: SRT results for PBS and baseline combinations

Rollover stability is arguably the most import safety consideration and performance measure related to a heavy vehicle due to the consequences associated with a vehicle overturning (Australian National Transport Commission, 2008). The relationship between SRT and heavy vehicle crashes is clearly shown in Figure 2.

Of particular concern when considering the specific sample set, is that some of the worst performing baseline vehicles were from the tipper, flat deck and volume van industry which account for almost 70% of the heavy vehicles in South Africa (Havenga, Le Roux, & Simpson, 2018).

An additional consideration when calculating SRT is that the assumption is usually made that the vehicle is correctly and symmetrically loaded as well as being well maintained. SRT performance will worsen with poorly maintained and incorrectly loaded vehicles (for example when asymmetrically loaded which will produce a larger overturning moment). Therefore, the higher standards imposed on PBS vehicles with respect to their monitoring and loading specifications via Road Transport Management System (RTMS) will definitely increase the safety of heavy vehicles on the South African roads (Nordengen & Naidoo,

2014). Note that these practical issues are not considered in the assessments, which consider perfectly loaded cargo.

SRT is primarily influenced by the centre of gravity height of the payload and the vehicle's track width, and to a lesser extent by suspension parameters. Maximising the track width and minimising the payload centre of gravity height is therefore essential for good SRT performance (Australian National Transport Commission, 2008). PBS vehicles are permitted to exceed the 22 m length limit, which offers greater scope to distribute a given load over a longer loading area, resulting in a reduced centre of gravity in order to meet the SRT requirement. For baseline vehicles, there is no consideration given to SRT or centre of gravity height, and so trucks with lower density loads can easily fail to meet the safe SRT level.

2.2.2 Rearward Amplification

RA is only applicable to vehicles that have one or more articulation points. RA is a measure of the degree to which the lateral acceleration of the towing unit is amplified in the trailing units in a high-speed single lane-change manoeuvre. This is important for predicting the likelihood of rollover of the rearmost unit during a rapid avoidance manoeuvre. RA is defined as a ratio of the lateral acceleration of the rearmost roll couple unit to the maximum lateral acceleration experienced by the leading vehicle unit during the evasive manoeuvre. The ratio is limited to 5.7 times the SRT of the rear most roll coupled unit (Australian National Transport Commission, 2008).

Figure 6 shows the normalised results of all the PBS and baseline RA, were a pass result is 1 or below, and a fail is above 1. A total of 18% of the baseline vehicles assessed failed this standard.

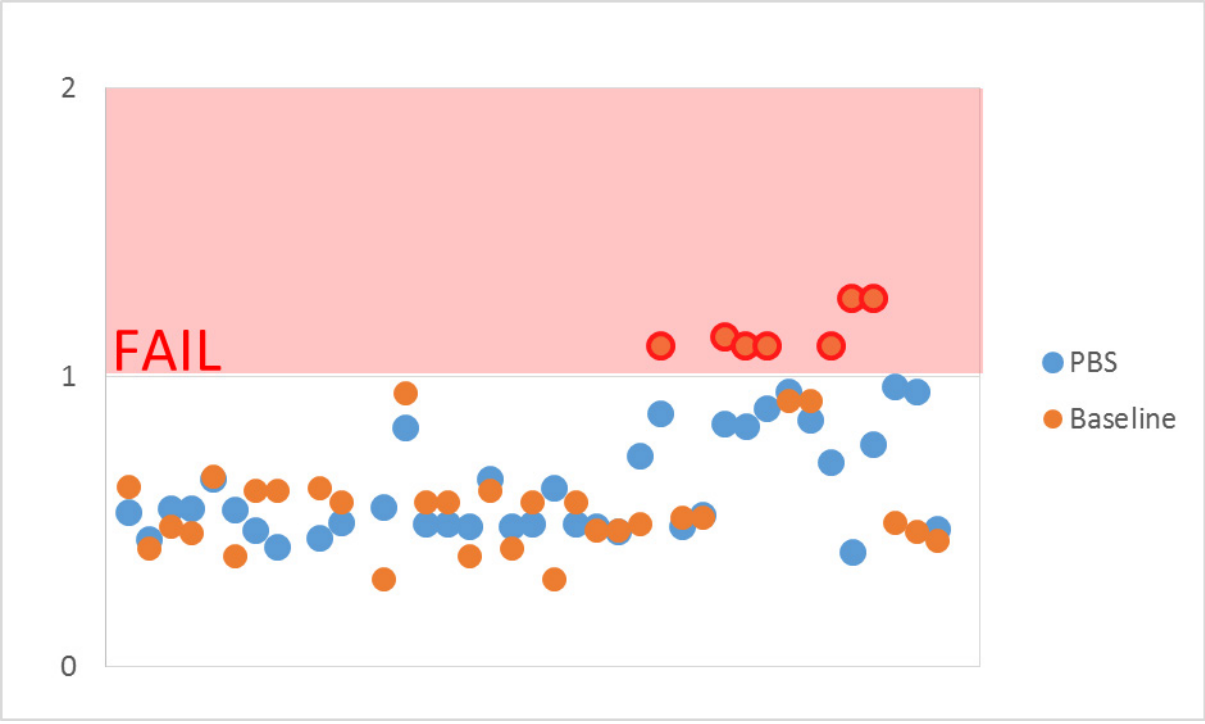


Figure 6: Normalised RA results of PBS and baseline combinations

Vehicles with poor RA performance on the roads significantly increase the potential for serious crashes associated with trailer rollover. This standard is important for a country with many potential road hazards such as potholes or pedestrians and animals on the roads (Australian National Transport Commission, 2008).

Parameters which primarily influence RA performance are the number of articulation points, the articulation point type and the hitch locations. The RA performance improves as the number of articulation points decreases, the wheelbases of units increases and turntables are used instead of pintle hitches. Tyre cornering stiffness also plays an important role and well-maintained tyres are therefore critical in heavy vehicle safety (Australian National Transport Commission, 2008). Hitch location and choice in the design of conventional vehicles is typically done only with consideration to low speed manoeuvrability and adequate loading distribution, and not with high-speed stability considerations. These results show that by considering high-speed stability implications through the PBS assessment process, the designs can be improved to be safer than conventional vehicles.

2.2.3 Yaw Damping Coefficient

The YD coefficient is a measure of the rate at which yaw oscillations or "snaking" decays after a severe steering input of an articulated vehicle at high speed. Vehicles that take longer to settle increases the driver's workload and increases the risk of a crash or accident due to the reduced handling capacity of the vehicle. The vehicle could become unstable and pose a serious danger to fellow road users. The minimum threshold of the YD coefficient is 0.15. (Australian National Transport Commission, 2008). The same parameters that influence RA, influence YD. Similar threats also exist when comparing RA and YD performance of heavy vehicles (Australian National Transport Commission, 2008).

Figure 7 shows the results of all the PBS and baseline YD Coefficient. A total of 23% of the baseline vehicles assessed, failed this standard. Again, the cause for these baseline vehicle failures can largely be attributed to the optimisation of hitch location and type, as discussed above.

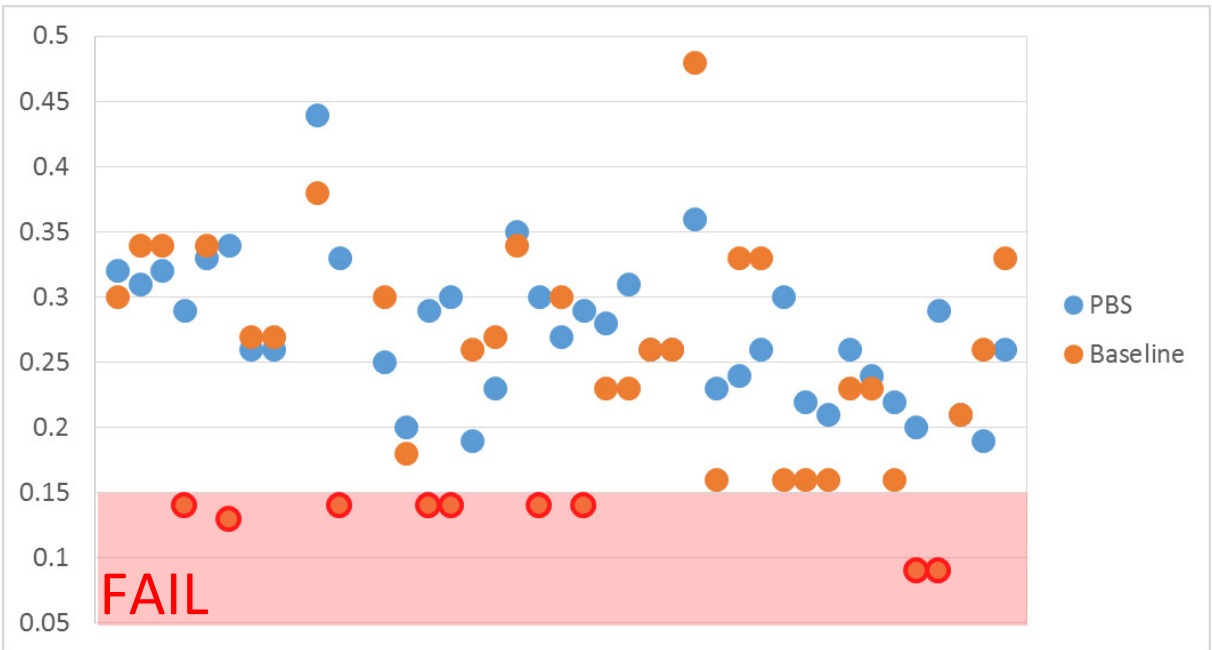


Figure 7: YD Coefficient results of PBS and baseline combinations

2.2.4 High-Speed Transient Off-tracking

HSTO is the excess lateral displacement, or overshoot, of the rearmost axle of the vehicle when performing the same prescribed lane-change manoeuvre as used for the Rearward Amplification test. This indicates the amount which the vehicle will deviate out of its own lane. The permitted overshoot value is 0.6 m for Level 1 performance and increases by 0.2 m for each successive level (Australian National Transport Commission, 2008).

Although none of the baseline vehicles failed the HSTO standard, a concerning number of baseline vehicles had Level 3 performance, with a few even approaching Level 4 performance, as seen in Figure 8. This would result in heavy vehicles occupying excessive dynamic road width, which could result in serious risk to other road users. With South Africa having numerous potential road hazards requiring an evasive manoeuvre such as potholes or pedestrians and animals on the road, HSTO performance is an important consideration.

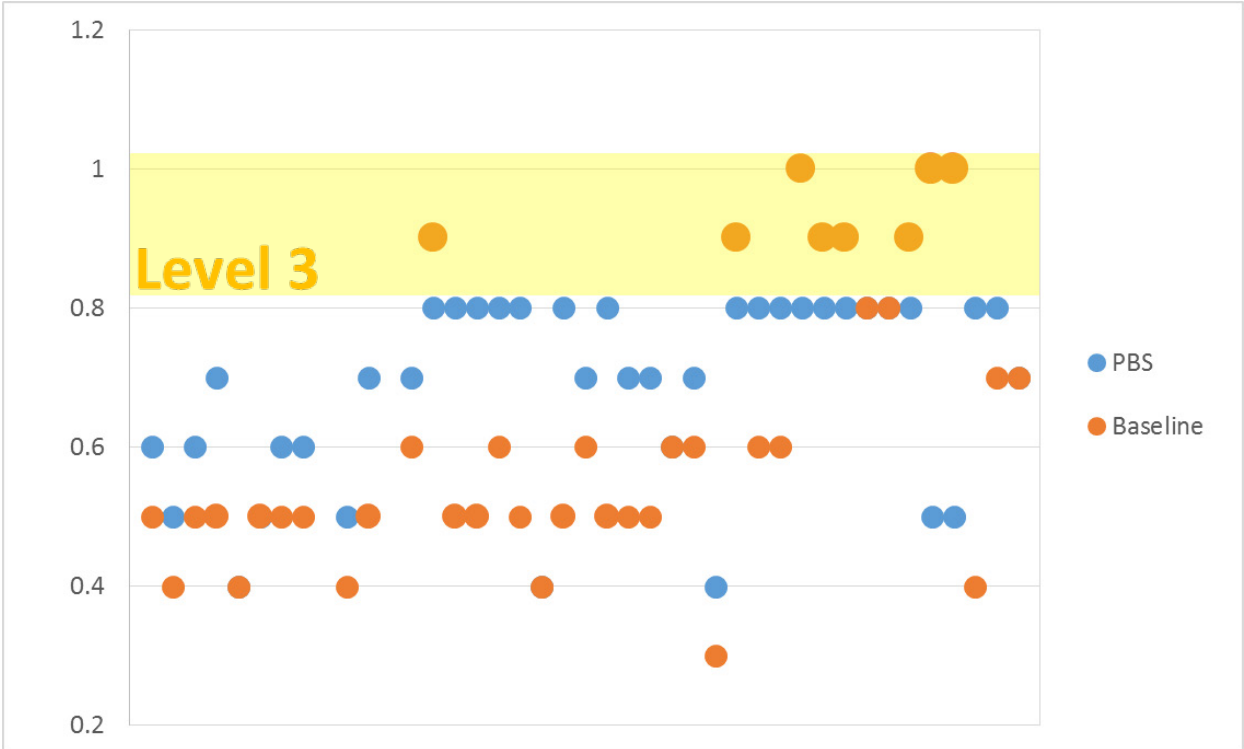


Figure 8: HSTO results of PBS and baseline vehicles

The same parameters that influence RA and YD influence HSTO, and so the poorer performance of the baseline vehicles can be attributed partly to the optimisation of hitch locations and type. PBS vehicles often have more axles and tyres, and longer wheelbases than their baseline vehicles, which also contributes to improved performance in HSTO exhibited here.

3. CONCLUSIONS

This paper has compared the safety performance of PBS vehicles to their baseline vehicle counterparts, by studying four of the most critical safety performance standards. From the assessed vehicles an alarming 56% of all baseline vehicles have failed one or more safety standards. The three standards failed relate to the dynamic stability of the vehicles and indicate that these vehicles will be more prone to serious crashes particularly related to rollover. It is also important to note that some of the worst performing baseline vehicles were from the tipper, flat deck and volume van industry which account for almost 70% of the heavy vehicles in South Africa (Havenga, Le Roux, & Simpson, 2018).

As the Smart Truck Pilot Project monitoring data has shown, PBS vehicles generally have an approximate 40% reduction in crash rates (Steenkamp, Nordengen, Berman, & Kemp, 2017). This study suggests that the PBS assessment results are potentially an important contributor of this. There are many other factors which may also be contributing, such as

the competency levels of the drivers of the PBS vehicles versus the drivers of the baseline vehicles for example. These other factors should be studied going forwards to isolate their contribution to the improved performance.

Although this is a very small sample set, it is still clear that although all the baseline vehicles in the study adhere to the South Africa national road traffic act, they are not guaranteed to be safe vehicles. Elements of PBS could, therefore, be incorporated into the act to increase vehicle safety, and assist in curbing the poor crash and fatality statistics in South Africa. Reducing crashes and fatalities would have a direct impact on the South African economy. During 2015 road crashes and fatalities cost the South African economy more than R143 billion, or almost 3.4% of GDP (OECD, 2017). A 40% reduction in crash rates in the heavy vehicle sector as exhibited by the PBS project, could therefore have significant implications for the economy.

4. FUTURE WORK

This dataset is still relatively small and further insights can be gained as the number of PBS assessments, including baseline vehicles, are conducted. Individual studies could also be conducted on very popular baseline combinations in order to obtain a better understanding of the performance of the South African baseline fleet.

Another area of interest would be to look at the safety performance of a number of actual operating vehicles as measured as overloaded at the weighbridges. South Africa has a serious problem with non-compliance regarding heavy vehicles that are severely overloaded and not well maintained. It is expected that these variations from the intended design would severely impact the already bleak safety stats of some of the baseline vehicle designs.

Future work can also investigate how the design of the most popular baseline combinations can be optimised to ensure that they meet all of the PBS safety standards. These design improvements could then be adopted by the heavy vehicle trailer manufacturers for future vehicles. Similarly, a blueprint could be created for a few baseline combinations that do pass all safety criteria and which could be immediately implemented by operators.

Conducting PBS assessments is an expensive and complex process and requires highly specialised software and expertise. It is therefore not generally accessible to heavy vehicle operators and trailer manufacturers. It may be useful to develop simplified tools that can be used by trailer manufacturers to quickly test with a high probability if a vehicle combination would meet the safety standards specified in PBS. This information could help shape the future of the transport industry and improve road safety in South Africa.

Road wear and infrastructure safety assessments also indicate that baseline combinations cause more road wear per tonne of payload when compared to PBS vehicles. Further investigations on the road wear caused by the different baseline combinations and vehicle types can give insights to identify more road friendly combinations and how road infrastructure benefits from PBS vehicles.

5. REFERENCES

Australian National Transport Commission, 2008. *Performance Based Standards Scheme: The Standards and vehicle Assessment Rules.*

De Pont, J, Baas, P, Hutchinson, D & Kalasih, D, 2002. Including Performance Measures in Dimensions and Mass Regulations. *7th International Symposium on Heavy Vehicle Weights and Dimensions.*

de Saxe, C, Nordengen, P & Kienhofer, F, 2013. A performance-based standards regime to regulate car-carriers in South Africa. *Southern African Transport Conference (SATC).* Pretoria.

Dessein, T, Kienhofer, F & Nordengen, P, 2010. A South African performance-based standards (PBS) to transport steel pipes. *11th Int. Symp. on Heavy Vehicle Transport Technologies (HVTT11).*

Havenga, JH, Le Roux, PP & Simpson, ZP, 2018. A heavy goods vehicle fleet forecast for South Africa. *Journal of Transport and Supply Chain Management*.

Nordengen, PA & Naidoo, OJ, 2014. Evaluation of the Road Transport Management System, a selfregulation initiative in heavy vehicle transport in South Africa. *Transport Research Arena 2014.* Paris.

Nordengen, P, Berman, R & de Saxe, C, 2018. An overview of the Performance-Based Standards pilot project in South Africa. *15th Int. Symp. Heavy Vehicle Transport Technology (HVTT15).* Rotterdam.

Nordengen, P, Kienhofer, F & de Saxe, C, 2014. Vehicle safety performance improvements using a performance-based standard approach: four case studies. *13th Int. Symp. on Heavy Vehicle Transport Technology (HVTT13).* San Luis.

OECD, 2011. *Moving Freight with Better Trucks: Improving Safety, Productivity and Sustainability .* OECD Publishing.

OECD, 2017. *Road Safety Anuula report 2017: Chapter 35- South Africa.*

Steenkamp, A, Nordengen, P, Berman, R & Kemp, L, 2017. Investigation into the Smart Truck Pilot Project: Progress Made and Way Forward. *SATC.* Pretoria.