

Analysis of Current South African Semi-Trailer and B-double Vehicles using a Performance-based Standards Approach

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South African heavy vehicles are currently designed according to suggested standards designed and enforced by the National Department of Transport (DoT); these standards are regulated in terms of mass, dimensions and vehicle configuration. However, the current prescriptive standards leave little room for innovation in terms of heavy vehicle design. Performance Based Standards (PBS), originated in Canada and New Zealand, followed by Australia, as a new based innovative alternative to the current heavy vehicle prescriptive standards. PBS seeks to align actual vehicle performance efficiencies, productivity and safety objectives as well as road and bridge infrastructure to the current road network. Vehicle performance measures are based on engineering and science, supporting superior safety and known road and bridge wear performance criteria. PBS produces a result orientated approach to improved heavy vehicle operations and safety rather than a one size fits all approach utilised by the current prescriptive legislation. Currently, dynamic vehicle simulations are not carried out on South African manufactured vehicle combinations. Evidence exists that this has, in some cases, resulted in safety compromises. The computer dynamic vehicle simulation technology developed and validated could be employed for the credible assessments of the vehicle design concepts/prototypes for compliance with PBS. This service, which includes vehicle performance simulation and testing, development of high productivity vehicle concepts, assessment and development of risk management strategies and the advice on safety and productivity issues, would have a substantial commercialisation potential for the implementation in the larger transport industry in South Africa. This paper investigates different simulation tests performed on semi-trailer and B-double trailers on vehicles commonly used within South Africa.

Additional keywords: Semi-Trailer; B-double; Trailer; Vehicle

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1 Introduction

South Africa's social and economic development is directly influenced by its current transportation system, as a large percentage of manufactured goods overheads are derived from transportation and logistical costs. With an expected increased growth of approximately four percent per annum¹, about 89% of the freight moved in South Africa is done on road². A major increase in the cost of rail transportation, a move by the rail industry towards the transportation of fewer commodities and an increased need by companies to move towards a more time efficient door-to-door logistical approach, has forced many organisations to transition towards road transportation.

The number of heavy goods vehicles on the South African road network has doubled over the period of the years 1970 to 2000, in comparison to the 400 000 km of national and provincial road network available². One of the major areas of concern for the South African transportation industry is heavy vehicle overloading and road safety. However, even with increased efforts by the Department of Transport and road traffic authorities, this issue is still an area of great concern. Overloading not only has a direct impact on the damage caused to the road network infrastructure, but also to the handling, stability and safety of heavy vehicles³.

Thus the introduction of a new modernised regulatory system such as Performance Based Standards (PBS) in conjunction with higher management standards such as Road Transport Management Systems (RTMS), aims not only reduce the damage to road network infrastructure, but also improve the safety and productivity of heavy vehicles on South African roads as well as promote long term sustainability.

With the rapid increase in modern technological advancements of vehicle safety and design, such as Electronic Braking Stability (EBS), Central Tyre Inflation (CTI), and active distance control, the transportation industry struggles to exploit the opportunities, as it is constantly hampered by the slow evolution of the current prescriptive standards.

The need for the introduction of a self-regulatory initiative, such as PBS, was first identified by the National Overload Control Strategy³, which aims to limit the amount of overloading by heavy vehicles on South African roads. Thus another very important reason for the introduction of PBS in South Africa is due to the excessive amount of heavy vehicle overloading and the resultant damage caused by these vehicles on the South African road infrastructure. All vehicles which aim to achieve PBS status must first be certified in accordance with the RTMS accreditation scheme.

Some of the main outcomes for the introduction of PBS in South Africa are to improve the current transportation productivity, improve the safety and stability of the vehicles on South African roads, and obtain a more sustainable transport system. The need for the introduction of a demonstration project came about from the need to gain practical experience in the design, manufacture and operation of various PBS projects as well as to determine the potential positive and negative productivity and safety outcomes of this initiative in the South African environment⁴.

The demonstration projects are commissioned by Mondi Business Paper (Mondi) and Sappi Forests (Pty) Ltd (Sappi). Each company have a single PBS vehicle in operation, a 24.0 m, 64 100 kg GCM B-double vehicle, and a 27.0 m, 67 500 kg GCM rigid draw-bar vehicle, respectively. These demonstration projects have shown a dramatic positive improvement in comparison to the base line, 22.0 m and 56 000 kg, vehicle. Both vehicles indicate an increased payload efficiency of approximately 18.5%, a fuel consumption saving of approximately 12.5% and a fleet size reduction of 17%⁴.

The objective of the research is to develop a benchmark of current South African heavy vehicle configurations according to the Australian PBS initiative. Computer simulation models for each safety performance measure were investigated and a selection of vehicles which closely resemble the current SA fleet were considered. The benchmark for the current South African heavy vehicle fleet, according to PBS standards, was analysed. This paper describes the results that were validated through the simulated field testing or an analytical approach.

2 Performance Based Standards

The introduction of PBS provides an improved regulatory system that encourages innovation and provides a better match for heavy vehicles and the road network upon which they travel. PBS is a new innovative national alternative to the current heavy vehicle prescriptive standards which regulates the mass, dimensions and vehicle configuration of current heavy vehicles. PBS seeks to align actual vehicle performance efficiencies, productivity, safety objectives and road and bridge infrastructure to the current road network. PBS produces “a result orientated approach” to improve heavy vehicle operations and safety⁵ rather than a “one size fits all approach”⁶ utilised by the current prescriptive legislation.

PBS regulates the performance of a vehicle, how it is driven and operated, and the characteristics of the road network directly, rather than indirectly by limiting it with regard to dimensions, mass, and vehicle configuration. PBS aims to improve productivity by reducing the number of vehicles on the road network and thus reducing the crash risk exposure rate, improve vehicle safety, reduce the wear and damage on the road network infrastructure and create an improved cohesion between the vehicles and the road network upon which they travel. The benefits that result are the encouragement for innovative designs, an increased regulatory transparency, improved heavy vehicle safety, a reduction in vehicle down time and thus an increase in overall fleet productivity.

Prior to 1999, Australian heavy vehicles were regulated by stringent prescriptive standards, which regulated the mass and size limitation of various vehicle configurations. However, these prescriptive standards have continuously evolved over the years and as such, seemed to differ between various States and Territories⁷. In 1999 the National Road Transport Commission (NRTC) and Austroads initiated a joint venture into the development of a new set of standards which would regulate the dynamic performance of vehicle capabilities, rather than regulate vehicle design according to mass, size and vehicle configuration.

NRTC has undertaken numerous studies into the rapid growth forecast of the road freight vehicles operating on the Australian road network. These studies have indicated that the number of heavy freight vehicles is to increase substantially over the next 5-10 years.

An initial set of over 100 standards were proposed⁷, which were then narrowed down to a set of 20 standards. 16 of the 20 standard assess the dynamic performance and safety of vehicles, whilst the remaining 4 deal with the safety and preservation of the road infrastructure⁸. These 20 performance measure are listed in table 1.

Table 1: The 20 safety and infrastructure performance measures

Safety performance measures	
1	Startability
2	Gradeability
3	Acceleration Capability
4	Overtaking Provision
5	Tracking Ability on a Straight Path
6	Ride Quality
7	Low Speed Swept Path
8	Frontal Swing
9	Tail Swing
10	Steer Tyre Friction Demand
11	Static Rollover Threshold
12	Rearward Amplification
13	High Speed Transient Off-tracking
14	Yaw Damping
15	Handling Quality
16	Directional Stability Under Braking
Infrastructure related performance measures	
17	Pavement Vertical Loading
18	Pavement Horizontal Loading
19	Tyre Contact Pressure Distribution
20	Bridge Loading

A further study of the Australian road and highway network was conducted, classifying the routes into four major categories, known as Level 1 to Level 4, as indicated in table 2⁹.

From the 20 performance measures, in conjunction with the relevant four major road categories, a set of values, known as performance levels, were developed. In order for a vehicle to operate under the PBS scheme on a specific route, it must ensure that the vehicle fully complies with the performance levels laid down by the National Road Transport Commission.

Table 2: The four road classification levels and their respective access routes

Level	Access Route
1	General Access
2	Restricted access – Major arterials and approved routes
3	Major freight routes and remote area combinations
4	Remote area designation for larger combinations

Since the implementation of PBS, Australia has refined and developed each performance measure and performance level specific to the four road classification levels applicable and are now considered the world leaders in the heavy vehicle performance-based approach. A list of the 13 investigated PBS measures and the corresponding performance levels, according to road classification level 1 and level 2, is summarized in table 6¹⁰. A detailed description of the 20 performances can be seen in the dissertation discussion that this paper is based on¹⁰.

3 Software Analysis

Hellberg Transport Management's (HTM) software package, Transolve, aims to simplify the process of selecting the correct vehicle for a specific application, and calculating the costs incurred through the running of the vehicle. Transolve consists of various software modules, namely:

- Loading
- Routing
- Performance
- Finance
- Maintenance
- Costing Specification
- Reference

This software allows one to optimise the vehicle configuration design and determine: the maximum legal payloads for each vehicle unit; the operating costs of the vehicle; and various finance options. The software also manages vehicle performance and generates a comparison between different vehicles in the same vehicle class.

Transolve software was utilised in order to determine the maximum gross combination mass of each specific vehicle configuration, the tare mass of each vehicle unit and the maximum legal payload of each vehicle unit. The software was also used to generate eight of the ten vehicle configurations that were utilised in the PBS computer simulation analysis.

Manex and Mancas are in-house software packages developed for MAN Truck and Bus Company. These software packages were obtained from MAN South Africa and were utilised to determine various mass and parametric data, as well as various drive-line performance characteristics of the prime movers.

Trucksim allows the user to model, simulate and analyse the dynamic behaviour of various truck-trailer configurations. Trucksim was utilised throughout the PBS analysis to model each vehicle configuration, develop the required PBS manoeuvres, simulate and analyse the output data of each run.

Additional multi-bodied simulation software packages, such as MSC ADAMS/Car (Automated Dynamic Analysis of Mechanical Systems), SIMPACK and DADS (Dynamic Analysis and Design System) were investigated, in order to

determine which software package was best suited for the needs of this research. Numerous factors, such as financial limitations, software capability, training, assistance and data recourses, which is beyond the scope of this research, led to that these alternate software packages were not being incorporated during the modelling process of this research.

4 Vehicle Fleet Selection

A short description into the key parameters and vehicle components selected is discussed below, as well as any relevant assumptions that were made during the computational modelling process.

4.1 Vehicles

From a survey it was evident that there are four main heavy vehicle configurations, namely: rigid truck, semi-trailers, rigid draw bar and B-double (interlink). The dynamic stability and handling of the rigid truck is relatively good in comparison to that of other heavy vehicle configurations and was therefore excluded for the purpose of this analysis. The two vehicle configurations selected for analysis were the semi-trailer and the B-double. The data collected for each vehicle was sourced from various truck-trailer manufacturers and retailers, Hellberg Transport Management (HTM), Council for Scientific and Industrial Research (CSIR), Organisation for Economic Co-operation and Development (OECD), as well as other publicly accessible information.

4.2 Selected Vehicles

From the two vehicle configurations investigated during this research study, the semi-trailer and B-double (interlink) configurations, five vehicles were selected from each vehicle class, thus providing a total of ten vehicles that were computationally modelled and analysed during the PBS evaluation process¹⁰. Each of the five vehicles selected from the relevant vehicle class, were chosen from different transportation sectors, taking into consideration the varying types of freight products transported on the South African road network, thus allowing for the variation in CG heights according to the vehicles specific freight task. One of the five vehicles from each vehicle class was selected, from a previous international Organisation for Economic Co-operation and Development (OECD), who studied the performance of heavy vehicles¹¹. South Africa submitted four of their most common vehicles in order to be analysed according to selected Australian, Canadian and New Zealand PBS. Dynamic Load Transfer Ratio is not included in the Australian standards, but is used in Canada and New Zealand. It was therefore determined that this would be a control vehicle in order to analytically validate the results of the remaining four vehicle simulations.

South Africa submitted four of their main workhorse vehicles for comparative analysis, namely ZA 1, ZA 2, ZA 3, and ZA 4 corresponding to a six axle articulated semi-trailer, 7 axle articulated B-double, 5 axle articulated semi-trailer and a 8 axle articulated B-double, respectively. Of these four vehicles, ZA 1 and ZA 2 were selected for analysis and verification process, and are referred to in this paper as OECD 1 and OECD 2, respectively.

The vehicles that were used in the analysis consisted of the following:

Semi-Trailer:

- OECD 1
- Skeletal
- Refrigeration
- Side Curtain
- Tipper

B-double:

- OECD 2
- Skeletal
- Cane
- Side Curtain
- Tipper

Some of the assumptions made during the modelling process include:

- The payload mass was assumed to be symmetrical and cover the entire base of the trailer.
- The payload centre of gravity height was assumed to be 40 % of the available load space height of the trailer.
- Least Favourable Load Condition (LFLC) was assumed to be the maximum dimension of the available load space of the trailer.
- The tare mass, dimensions and payload were specified by the OECD report and the HTM vehicle selection analysis.
- A maximum width of 2.6 m was used for all ten vehicles.
- The centre of gravity height of the prime mover was set as 1.1 m above the ground.
- A single tyre selection of 315/80 R22.5 was used for axles: steer, drive and trailing.
- All axles were assumed to have dual tyres, except steer axles.
- Each axle steer, drive and trailing was assumed to have a mass of 527 kg, 735 kg and 800 kg, respectively, unless otherwise stated by OECD report.
- A single set of generic suspension data was used for all vehicle suspensions.
 - Leaf / steel spring suspension was used for the steer and trailer axles
 - Air suspension was used for the drive axles
- The same coupling (fifth wheel) was used throughout the modelling process for all ten vehicles
- The MAN TGA 26.480 prime mover was used for eight of the ten vehicles, whilst the remaining two OECD prime movers were specified by the OECD report.
- The maximum allowable mass and heights are specified by each country.
- The centre of gravity height for the prime mover / tractor unit was taken to be 1.1 metres above the ground.
- The same generic suspension parameters were used for all vehicle as follows:
 - Parabolic springs used for the steer axle
 - Standard air suspension for the trailers and drive axles
- The same tyre type (11R22.5 tyres) was used on each axle, through whether dual tyre or single tyre axles were used were specified by each member country.

5 Test and Results

This section of the paper provides the results for both the semi-trailer and B-double vehicle configurations. Due to the same prime mover being used for the majority of the simulations, the startability, gradeability and acceleration

capability performance measures are grouped together in their own section. This section also provides a means for analytical validation of simulated results through a comparison of two vehicles (semi-trailer, OECD 1, and B-double, OECD 2) from a published OECD report and a discussion on the performance results achieved. Graphs of the results of the different characteristics have been plotted on the same axes to allow for a comparison of the different vehicles. The different ranges have been grouped in the graphs to allow for a zoom-in effect of the results.

5.1 Startability, Gradeability and Acceleration Performance

Since the same prime mover was used for the majority of the simulations, the startability, gradeability and acceleration capability performance measures are grouped together and discussed below.

5.1.1 Startability

Startability of a heavy vehicle is directly related to critical parameters such as gross combination mass and the overall length of the vehicle⁶. An increase in either parameter would result in a negative effect on the vehicles startability. Other factors such as driveline gear ratios and axle loads also influence this performance measure, an increase and decrease respectively, have a positive effect on the vehicle startability. A general much utilised industrial rule suggests that the startability of a vehicle is equal to the gradeability of that vehicle less the tractive slip at the commencement of forward motion. This tractive slip, or skid point, for a MAN TGA 26.480 BLS prime mover loaded to 56 tons travelling on an asphalt road, at an engine speed of approximately 900 rpm, in low gears is 21%. This condition is satisfied by the gradeability of the MAN prime mover in first gear at an engine speed of 1000 rpm, providing a gradeability of 39.6%. This gradeability less the tractive slip provides a vehicle startability of 30%, thus surpassing the minimum percentage requirement of 15% for Level 1 road classification. Thus ensuring that the prime mover has the capability to start and commence motion on an inclined grade for a vehicle loaded to a maximum combination mass of 56 tons, minimising the safety risk to other road users.

5.1.2 Gradeability

Vehicle gradeability, similar to that of startability, is affected by gross combination mass and overall length, whilst other factors such as an increase in engine power / torque speed, an increase in driveline gear ratios and a decrease in axle loads have a positive influence on the vehicle's ability to climb on a graded surface.

(a) Maintain forward motion on maximum grade

A gradeability in first gear of 38.82% is given by the manufacturers, whilst HTM provides a gradeability of 39.6%. Due to this 2% variation in results, the lower more conservative value of 38.8% was therefore selected. This result of 38% gradeability is greater than the required minimum performance requirement of at least 15%, thus qualifying for Level 1 road classification.

(b) Maintain minimum speed on a 1% grade

HTM allow one to calculate the maximum speed obtainable on a 1% grade. A maximum speed of 87.4 km/h

is obtainable at a grade of 1.1%, whilst a maximum speed of 98.4 km/h is obtainable on a 0.7% grade. A linear interpolation process was therefore utilised in order to determine that a maximum speed of 90.1 km/h is obtainable on a 1% grade. This result of 90 km/h gradeability is greater than the minimum stipulated performance requirement of at least 80 km/h, thus satisfying the Level 1 road classification. The results of the gradeability performance measure ensure that the vehicle has the ability to maintain forward motion on a grade of 38%, and also to maintain a minimum speed of 90 km/h on a grade of 1%, therefore limiting the risks of other road users.

5.1.3 Acceleration capacity

Acceleration capability, is negatively affected by gross combination mass and overall length of the vehicle. Other factors such as an increase in engine torque and a decrease in driveline gear ratios have a positive effect on the vehicle acceleration capability. Unlike startability and gradeability, acceleration capability is concerned with engine and gearbox characteristics across the entire speed range. Time delays and duration associated with automatic and manual gear changes also have a critical effect on the acceleration capability of heavy vehicles. A vehicle, of length 22 m and loaded to maximum allowable gross combination mass of 56 tons, to undertake an acceleration capability test. However, the prime mover used in the field tests was not the same as the MAN TGA 26.480 that was modelled throughout the other performance manoeuvres, but rather a Mercedes Benz Actros 33.50. Both the MAN and the Mercedes Benz vehicles have similar 12 gear gearboxes, with similar gear ratios.

Two sets of simulations were undertaken; firstly acceleration from a standing start changing through gears automatically and secondly changing through gears manually. Tables 3 and 4 represent the time a fully laden heavy vehicle requires to travel a distance of 100 m with automatic and manual gear changes respectively. The results from tables 3 and 4 range from 20.89 to 22.42 seconds, thus ensuring that this vehicle satisfies the Level 2 performance requirement of less than 23 seconds for a vehicle to accelerate from rest and travel a distance of 100 m, for both automatic and manual gear changes. This result ensures that the vehicle has the capability to clear intersections and overtake additional vehicles in an acceptable period of time, thus reducing congestion and safety risk posed to other road users. According to personnel at MAN, a recent study of a similar vehicle was undertaken by Hans Prem at Mechanical Simulation Dynamics (MSD) Pty Ltd, which provided the vehicle with a Level 2 performance classification.

Table 3: Acceleration capability performance results for 56 ton heavy vehicle with automatic gear changes

Distance travelled	Time [seconds]				
	Run 1	Run 2	Run 3	Run 4	Avg.
20 m	7.82	8.49	7.98	8.08	8.09
40 m	12.14	12.94	12.34	12.81	12.56
60 m	15.48	16.13	15.48	16.16	15.81
80 m	18.30	18.99	18.52	19.06	18.72
100 m	20.97	21.78	21.22	21.79	21.5

Table 4: Acceleration capability performance results for 56 ton heavy vehicle with manual gear changes

Distance travelled	Time [seconds]				
	Run 1	Run 2	Run 3	Run 4	Avg.
20 m	8.11	7.90	7.80	7.78	7.90
40 m	12.59	12.41	12.24	11.91	12.29
60 m	16.09	16.70	15.45	15.51	15.94
80 m	19.23	19.72	18.55	18.28	18.95
100 m	21.87	22.42	20.94	20.89	21.53

From these results in table 5, it is evident that the MAN prime mover has the ability to start on a grade, climb on a grade and accelerate from rest on a zero grade, with results exceeding that stipulated by the PBS guidelines and as such does not pose any concern.

Table 5: Startability, Gradeability and Acceleration Capability performance results of a MAN TGA 26.480 BLS prime mover Performance Measure

	Result	Level Passed
Startability	30%	Level 1
Gradeability		
Part A - maintain forward motion	38%	Level 1
Part B - maintain minimum speed	90 km/h	Level 1
Acceleration Capability	Pass	Level 2

5.2 Semi-Trailer and B-double Trailer Comparisons

Figures 1, 2 and 3 show the graphs that compares the Semi-Trailer (ST) and B-double (BD) trailers. The units of the graphs are shown in the legend of the graph. Figure 1 indicates the comparison of values between -0.4 units to 0.6 units. Figure 2 shows the comparison of values between 0 m and 3.5 m. Figure 3 shows therefore the values between 0 units and 90 units.

5.2.1 Tracking Ability on a Straight Path

Numerous points on the vehicle of concern include: the centre of steer axle – in order to ensure the vehicle follows the desired path within the prescribed limitations, the outside edges of the steer tyre and the outside edges of the trailer. Figure 2 is a representation of performance results for the trailers, represented as TASP, indicating the swept path (summation of the absolute values of the maximum and minimum lateral deviations).

From figure 2 it can be seen that the values of TASP range from 2.86 m to 3.02 m. Two of the ten vehicles (Skeletal and Tipper) qualify for the Level 1 road classification of not greater than 2.9 m, whilst the remaining three ST vehicles (OECD 1, Refrigeration and Side Curtain) qualify for the Level 2 road classification, by not exceeding the 3.0 m limit stipulated. Four of the five BD vehicles (OECD 2, Skeletal, Cane and Tipper) achieved Level 2 the classification of not greater than 3.0 m, whilst the remaining vehicle (Side Tipper) achieved the Level 3 classification of not exceeding a swept width of 3.1 m. Failure to comply

with Levels 1 and 2, the Side Tipper, therefore requires more lane width when travelling at high speeds down a straight even surfaced road. This increased tracking poses an increased safety risk to other road users and well as other road side objects.

The results from figure 2 indicate a correlation of the TASP with the centre of gravity (CG) height shown also in figure 2. An increase in the centre of gravity height results in a negative effect on the vehicles tracking ability performance. Centre of gravity height is the most dominant factor concerned with tracking ability; this is evident between Side Curtain and OECD1 vehicles. Other factors that influence the tracking ability include: number of trailers, the locations and type of coupling between vehicle units, tyre cornering stiffness, vehicle speed and road surface unevenness. From these results it is evident that the tracking ability of the five semi-trailer combinations does not pose a concern as all five vehicles track well within the minimum South African lane width of 3.25 m, therefore imposing no unacceptable risk to other road users or the road side infrastructure.

The reason for the slight variation in trend between the Side Curtain and OECD 2 vehicles is due to the fact that the Side Curtain vehicle is slightly longer than that of the OECD 2 vehicle, hence the greater tracking result. Tracking-ability on a straight path for the five B-double configuration vehicles does not pose an immediate concern, as it tracks within the South African minimum lane width of 3.25 m.

5.2.2 Low Speed Swept Path

The low-speed swept path performance measure is designed to measure the lateral inward tracking of a vehicle when performing a tight turn at low speed. Figure 3 shows the low-speed performance (LSSP) results for the five semi-trailer combinations, under both laden and unladen conditions. The performance results for the ten combinations range from 6.00 m to 7.56 m. All five of the semi-trailer vehicles achieved the less than 7.4 m requirement in order to qualify for Level 1 road classification. Figure 3 also provides a summary of the low-speed performance results for the five B-double configurations, under both laden and unladen conditions. Four of the five B-double vehicles (OECD2, Skeletal, Side Curtain and Tipper) achieved a performance requirement of less than 7.4 m and thus qualify for the Level 1 road classification, whilst the remaining vehicle (Cane) qualified for the Level 2 road classification, by achieving a swept path of less than 8.7 m. It must be noted that these performance plots do not incorporate the overall vehicle width of 2.6 m.

The gross combination mass (figure 2) and vehicle length (figure 3) has an effect on the low-speed swept path of the five semi-trailer combinations, under both laden and unladen conditions. Figure 3 shows a slight tendency of increased swept path with an increase in vehicle length. Other factors that influence low-speed swept path include: wheelbase of all vehicle units, frontal overhang of the hauling unit and coupling rear overhang. An increase in each of these parameters has a negative influence on the vehicle's tracking capability.

5.2.3 Frontal Swing

Frontal swing is designed to measure the amount of road space a vehicle requires when performing a low speed turn. The results are given for the hauling unit, Maximum Difference and Difference of Maxima for the ten combination vehicles, with a description of the results and the various factors which influence their performance, under both laden and unladen conditions.

Figure 1 shows the results for the hauling unit frontal swing for the five semi-trailer combination vehicles. The results range from 0.37 m to 0.46 m, thus ensuring that all ten vehicles achieved a performance result of less than the maximum stipulated 0.7 m performance requirement, therefore ensuring that the prime mover of the vehicle combination will remain within its own lane throughout the low speed manoeuvre. Due to the same prime mover being used with the vehicle combinations, there was little variation in prime mover frontal overhang. It must be noted that an increase in prime mover frontal overhang will result in an increase in frontal swing. From the results in figure 1, it can be seen that an increase in mass results unfavourably to an increase in frontal swing.

Figure 1 shows the results for the Maximum of Difference (MoD) frontal swing for the ten combination vehicles. The MoD results range from 0.09 m to 0.52 m, thus resulting in three of the five semi-trailer vehicles (OECD1, Side Curtain and Tipper) achieving the required performance requirement. The remaining two semi-trailer vehicles (Skeletal and Refrigeration) exceeded the 0.4 m maximum requirement, and were therefore not deemed to comply. The failure to meet this standard indicates that the forward most outside point of the first semi-trailer, when performing a tight turn at low speed, will tend to track outside its specified lane width, which may result in collisions with road side objects as well as other vehicle users. All of the five B-double vehicles achieved the required performance of less than the 0.4 m.

The relationship is shown between frontal swing MoD (figure 1) and frontal overhang (figure 2), under both laden and unladen conditions. It illustrates that an increase in frontal overhang of the vehicle results in a direct increase in the frontal swing, for both laden and unladen conditions. It also illustrates that mass also has an effect on the frontal swing of a vehicles. An increase in mass results in an increase of MoD frontal swing.

Figure 1 also shows the results for the Difference of Maxima (DoM) frontal swing for ten combination vehicles. The DoM results range from -0.28 m to 0.27 m. Four of the five semi-trailer vehicles (OECD1, Skeletal, Side Curtain and Tipper) achieving the 0.20 m required performance requirement, whilst the remaining vehicle (Refrigeration) did not satisfy this requirement and was therefore deemed not to comply. The failure of compliance increases the risk towards other road users, as the vehicle will require more lane width in order to perform a tight turn at low speeds. All of the five B-double vehicles achieved the required performance measure of less than 0.2 m.

From the results in figure 1, all vehicles have shown that an increase in mass results positively on the DoM frontal swing of the vehicles. It is evident that frontal overhang is

the single most significant factor that influences frontal swing, other factors such as prime mover and trailer wheelbase, vehicle width and mass have a much lesser influence on the performance result. An increase in each factor would result in an increase in frontal swing. Two of the five semi-trailer combination vehicles that were assessed did not achieve the required performance levels stipulated in the PBS guidelines, thus imposing a safety concern to other road users as well as road infrastructure, further research needs to be undertaken in order to improve the frontal swing of these vehicles. As with frontal swing MoD, the increase in wheelbase for the Side Curtain B-double resulted in a variation in trend relating to a decrease in frontal swing. The frontal swing does not pose a concern for the five B-double configuration vehicles analysed.

5.2.4 Tail Swing

The tail swing performance measure has been designed in order to limit the amount of road space a vehicle requires when performing a tight turn at low speed. The tail swing results (figure 1) of the ten combination vehicles, illustrating the swing out under both laden and unladen conditions, is shown for the entry section of the turn while the rear overhang that is related to these results are shown in figure 2. The tail swing results range from 0 m ("no swing out" at the exit section of turn) to 0.12 m, thus all ten vehicles, under both laden and unladen conditions, achieved the required performance requirement of less than 0.3 m, and therefore achieving Level 1 road classification. This ensures that when the vehicles assessed perform a tight turn at low speeds that the furthest rear most outside point of the last trailer, does not track outside its specified lane, and as such does not pose a concern to other road users.

Factors which influence the tail swing performance measure include; width of the vehicle (an increase in vehicle width increases tail swing), and wheelbase of the unit with the critical rear overhang dimension (an increase in vehicle wheelbase reduces the vehicles tail swing).

5.2.5 Steer Tyre Friction Demand

Steer tyre friction demand is designed to measure the possibility of a vehicle losing steering control when performing a tight turn at low speeds. Figure 3 shows the steer tyre friction demand results for the ten combination vehicles; it illustrates the percentage steer tyre friction requirement for the left hand side (LHS) and right hand side (RHS) of each vehicle, under both laden and unladen conditions. The results of this performance manoeuvre range from 13.1% to 40.2%, and as such all ten vehicles assessed in this section achieved the required performance requirement of less than 80% of the available friction limit.

The influence of the gross combination mass has on the steer tyre friction limit for the right and left hand side of the prime mover respectively is shown in figure 3, under both laden and unladen conditions. These results illustrate the major increase in steer tyre friction requirement between the laden and unladen conditions. One of the factors which have a major influence on steer tyre friction demand is that of mass; an increase in mass has a dramatic increase in the required steer tyre friction demand. The reason for the variation in trend for the OECD 1 vehicle in comparison to

the other four semi-trailer vehicles, under both the laden and unladen condition, is due to the other influencing factors such as, increase wheelbase of prime mover, increase in drive axle group spread and as such a reduction in the steer axle load, all of these factors jointly influence the required OECD 1 vehicle steer tyre friction. The five B-double combination vehicles were restricted by mass to the maximum legal gross combination mass limit of 56 tons, however, it can be clearly see that the steer tyre friction limit for both the left and right hand side of the vehicle increase dramatically under laden conditions compared to that of unladen.

This performance measure is generally of concern for vehicles with tri-axle drive units, however, due to the fact that this performance measure is determined from the same manoeuvre that analyses low speed swept path, frontal and tail swing, it has therefore been included in the analysis. Other factors that influence steer tyre friction demand performance measure include: wheelbase and steer axle load of the prime mover (an increase in each would result in a decrease in friction demand), and drive group axle spread (increase in this parameter would result in an increase in required friction limit).

5.2.6 Static Rollover Threshold

This performance measure is arguably the most important as it is strongly linked to rollover incidents. It is designed to measure the lateral acceleration a vehicle is capable of withstanding before rollover occurs. The performance results for the static rollover circular test, indicating the most important parameters concerned when analysing static rollover threshold, namely: height of CG above ground (figure 2), track width to height ratio (figure 3) and the vehicle's respective SRT values (figure 1). From these graphs, it can be seen that the results from this performance measure range from 0.31 g to 0.4 g, thus indicating that three of the five semi-trailer vehicles (OECD 1, Skeletal and Tipper) achieved the minimum required performance measure, whilst the remaining two vehicles (Refrigeration and Side Curtain) did not achieve the minimum performance requirement of 0.35 g. The Tipper semi-trailer combination vehicle obtained a reading of 0.4 g due to its low centre of gravity. As for the B-double configuration vehicles, four of the five vehicles (OECD 2, Skeletal, Cane and Tipper) achieved the required minimum performance requirement, whilst the remaining vehicle (Side Curtain) did not achieve the minimum performance requirement. Other factors that influence the outcome of this performance measure are namely: height of centre of gravity above ground, tyre track width of each vehicle unit, and the suspension and tyre characteristics.

The two most important factors which influence SRT are the height of centre of gravity and the tyre track width. A reduction in the centre of gravity height or an increase in the track width results favourably to the roll stability of the vehicle. Due to the fact that many of the heavy vehicles make use of the maximum available track width; the CG height is the most significant parameter when looking at static rollover threshold. Whilst suspension and tyre characteristics do influence the vehicle stability it is

negligible in comparison to that of CG height and track width.

From figures 1 and 2, it can be seen that the ratio of overall track width to CG height is directly related to a vehicle SRT. An increase in this ratio has a positive influence on the Stability of all vehicle combinations.

Static rollover tilt table test were conducted. The results of the tilt table test performance manoeuvre range from 0.31 g to 0.39 g. Three of the five semi-trailer vehicles (OECD 1, Skeletal and Tipper) achieved the minimum required performance measure, whilst the remaining two vehicles (Refrigeration and Side Curtain) did not achieve the minimum performance requirement of 0.35 g. Four of the five B-double vehicles (OECD 1, Skeletal, Cane and Tipper) achieved the required minimum performance requirement, whilst the remaining vehicle (Side Curtain) did not achieve the minimum performance.

These performance results closely mirror those of the circular test, indicating that the same seven out of ten vehicles passed the performance measure, whilst the remaining three vehicles failed. The percentage deviations between the two static rollover threshold tests for each of the five semi-trailer combination vehicles range from 0.77% to 3.47%. The variation in results between the two tests is due to the engine performance characteristics as well as the drive tyre slip at the commencement of rollover. The percentages range for the B-double vehicles were from 3.1% to 5.0%. The reason for the deviation between the two performance tests is due to the drive-train characteristics, for example tractive forces slow the drive during rollover due to loss of tyre contact surface area etc.

Other factors which influence the static rollover of heavy vehicles include: chassis torsional flexibility, suspension and tyre characteristics and gross combination mass and length, however, these factors have a minor influence in comparison to those factors discussed above. SRT is considered the most important performance measure with regard to PBS. Failure to comply with this performance measure, indicates that the vehicle is dynamically unstable, and would require less lateral force to result in a roll over, in comparison to vehicles which achieved the 0.35 g minimum limit, posing a major safety concern to the driver and occupants of the vehicle, road side objects and other road users

5.2.7 Rearward Amplification

The rearward amplification performance measure was developed in order to determine the lateral acceleration experienced by multi-articulated vehicles, when performing evasive manoeuvres at high speed. Figure 2 shows the rearward amplification performance results for the ten combination vehicles. The performance results for the ten combination vehicles range from 1.04 – 1.34. From the results it can be seen that none of the ten combination vehicle results exceeded the maximum performance requirement of 5.7 x SRT, thus were deemed to pass with this performance measure.

The gross combination mass has a negative effect on the rearward amplification. However, the reason for the Tipper vehicle to deviate from this norm has to do with another significant influencing factor, that of semi-trailer wheelbase,

a decrease in semi-trailer wheelbase increases the vehicle's rearward amplification. Similarly, an increase in vehicle centre of gravity height also impacts negatively on a vehicle's rearward amplification. The reason for the variation of the Tipper semi-trailer is due to the semi-trailer wheelbase, whilst the variation in OECD 1 vehicle is due to the increase in prime mover wheelbase. An increase in prime mover wheel base has a positive effect on a vehicle rearward amplification. As for the B-double vehicles, the centre of gravity generally negatively influences the rearward amplification, but this is not evident in this instance due to the variation in prime mover and trailer wheelbase. Figure 2 illustrates a slight tendency that an increase in the combined trailer wheelbase has a positive influence on the rearward amplification of the five B-double combination vehicles. Other factors that influence rearward amplification include: chassis torsional flexibility (an increase in rigidity proves to positively improve rearward amplification), tyre cornering characteristics and coupling lead or coupling rear overhang.

5.2.8 High Speed Transient Off-tracking

This performance measure is designed to limit the lateral deviation of the last trailer axle of the last vehicle unit from the desired path, when performing an evasive manoeuvre at high speeds. Figure 1 shows the results of the high speed transient off-tracking performance for the ten combination vehicles. The performance results for the vehicles range from 0.18 m to 0.34 m and all the combinations achieved the necessary performance measure of less than 0.6 m in order to classify for the Level 1 road classification.

An increase in the gross combination mass has negative effect on the vehicle tracking capability. An increase in the centre of gravity height has a negative effect on the vehicle's tracking ability. The reason for the OECD 1 vehicle to be less than Side Curtain, even though it has a higher centre of gravity height, is due to the increased wheel base of the OECD 1 prime mover in comparison to the MAN 26.480. An increase in the centre of gravity height has a slight tendency to cause a negative effect on the B-double vehicle's tracking-ability. The reason for the variation in trend of the Cane vehicle from the remaining four B-double configurations is because this vehicle configuration has a larger first trailer wheelbase, a high unsprung centre of gravity, a low payload and a small rear overhang in comparison to the other four configurations. All of these factors combined influence the vehicle's improved tracking capability.

Other factors that influence high speed transient off tracking include: tyre cornering stiffness, trailer wheel base and coupling lead or coupling rear overhang, an increase in each will have a positive effect on the vehicle tracking ability.

5.2.9 Yaw Damping coefficient

This performance measure was designed in order to limit the time taken for oscillation to decay after a severe manoeuvre has been performed at high speed. Figure 1 shows the yaw damping performance measure for the ten combination vehicles. The performance results for the ten combination vehicles range from 0.188 – 0.408 and as such all the

vehicles assessed satisfy the necessary performance level of not less than 0.15.

Various factors that influence this performance measure include: centre of gravity height, gross combination mass, overall length, wheelbase, and tyre cornering characteristics.

5.2.10 Directional Stability under braking

This performance measure was designed in order to minimise the instability of a vehicle when braking in a turn or on a slope. However, in accordance to Section C16.3 (b) "Deemed to comply provision" of the PBS guidelines it states that "a vehicle that has a functioning anti-lock brake system that effectively prevents gross wheel lock-up on each axle group is defined to comply with this standard". All of the combination vehicles therefore comply with this standard, as under South African legislation all new trailers, tractors and trucks have to have anti-lock brake systems in place.

6 Validation and Conclusion

The startability of the ten vehicles assessed was calculated from a much utilised industrial rule, where by the startability is determined from the gradeability less the tractive slip. Due to the fact that a single prime mover was utilised for the low speed longitudinal performance measure, a startability of 30% was calculated. This resulted in all ten vehicles satisfying the Level 1 performance result of not less than 15%.

The gradeability for the ten vehicles assessed was determined from data collected from the prime mover manufacturer as well as from HTM software. The results of which had a 2% variation, thus in order to be conservative the lower value was selected. This proved that the vehicle had the ability to obtain a minimum specified speed on a 38.8% gradient, satisfying a Level 1 performance result for the first aspect of gradeability (maintain forward motion on a maximum grade). The second aspect of gradeability (maintain a minimum speed on a 1% grade) was calculated through a linear iterative process, which stipulated that the vehicle has the capability to achieve a speed of 90km/h, this surpassed the 80km/h limit specified, and as such all ten vehicle achieved a Level 1 performance result. The results of which indicated that a fully laden vehicle (GCM 56 tons) has the capability to accelerate from rest and travel a distance of 100 m in less than 23 seconds, changing through gears both automatically and manually. Thus the ten vehicles achieved a Level 2 performance result, of not more than 23 seconds.

The Tracking-Ability on a Straight Path (TASP) performance manoeuvre was simulated in order to determine the amount of road space a vehicle requires when travelling on a straight road, at high speed, on an uneven road surface. The performance results for the five semi-trailer combinations illustrated that two of the five vehicles (Skeletal and Tipper) achieved performance results within Level 1 classification, whilst the three remaining vehicles (OECD 1, Refrigeration and Side Curtain) obtained Level 2 classification by exceeding the maximum 2.9 m swept path stipulated by Level 1. The results for the five B-double configurations that were analysed showed that four of the five vehicles (OECD 2, Skeletal, Cane and Tipper) achieved

Level 2 classification, whilst the remaining vehicle (Side Curtain) achieved a Level 3 classification, by exceeding the maximum swept path of 3.0 m specified by the Level 2 classification. Failure to comply with Levels 1 and 2, the Side Tipper, therefore requires more lane width when travelling at high speeds down a straight even surfaced road. This increased tracking poses an increased safety risk to other road users and well as other road side objects.

A summary of the performance level of the vehicles are summarised in table 7.

13 of the 16 Australian Safety Performance Standards developed were modelled in Trucksim, a vehicle dynamic simulation software package, whilst the remaining three safety standards were excluded as they had not yet been fully developed. All ten vehicles were then modelled and simulated according to these 13 performance standards. These results illustrated that six of the ten vehicles analysed achieved Level 2 road classification, whilst the remaining four vehicles did not achieve PBS status for various reasons.

A percentage deviation ranging from 0.0 – 11.3 % was achieved. The objective of the research was to develop a benchmark of current South African heavy vehicle configurations according to the Australian PBS initiative. The results illustrate that 40% of the vehicles analysed, did not meet the minimum Australian requirements, for various reasons as discussed. The introduction of PBS in South Africa will have a positive impact on the stability and safety of our heavy vehicles, increasing vehicle productivity, reducing road infrastructure damage and costs, and reducing the safety risk imposed to other road users.

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Table 6: A summary of the 13 PBS measures and the corresponding performance levels, according to road classification level 1 and level 2

Safety Standard		Performance Level	
		Level 1	Level 2
Startability	At least	15%	12%
Gradeability			
Part A - maintain forward motion	At least	20%	15%
Part B - maintain minimum speed	At least	80 km/h	70 km/h
Acceleration Capacity	No greater than	20 sec	23 sec
Tracking Ability on a Straight Path	No greater than	2.9 m	3.0 m
Low-Speed Swept Path	No greater than	7.4 m	8.7 m
Frontal Swing			
Part A - Prime Mover		No greater than 0.7 m	
Part B - Trailing unit (MoD)		No greater than 0.4 m	
Part C - Trailing unit (DoM)		No greater than 0.2 m	
Tail Swing	No greater than	0.3 m	0.35 m
Steer Tyre Friction Demand	Not greater than 80% max. available tyre/road friction limit		
Static Rollover Threshold	Not less than 0.35 g		
Rearward Amplification	No greater than 5.7 x SRT		
High-Speed Transient off Tracking	No greater than	0.6 m	0.8 m
Yaw Damping Co-efficient	Not less than 0.15 at the certified vehicle speed		
		Semi Trailer	B-double
Directional Stability Under Braking	Avg. Deceleration	0.35 g	0.3 g

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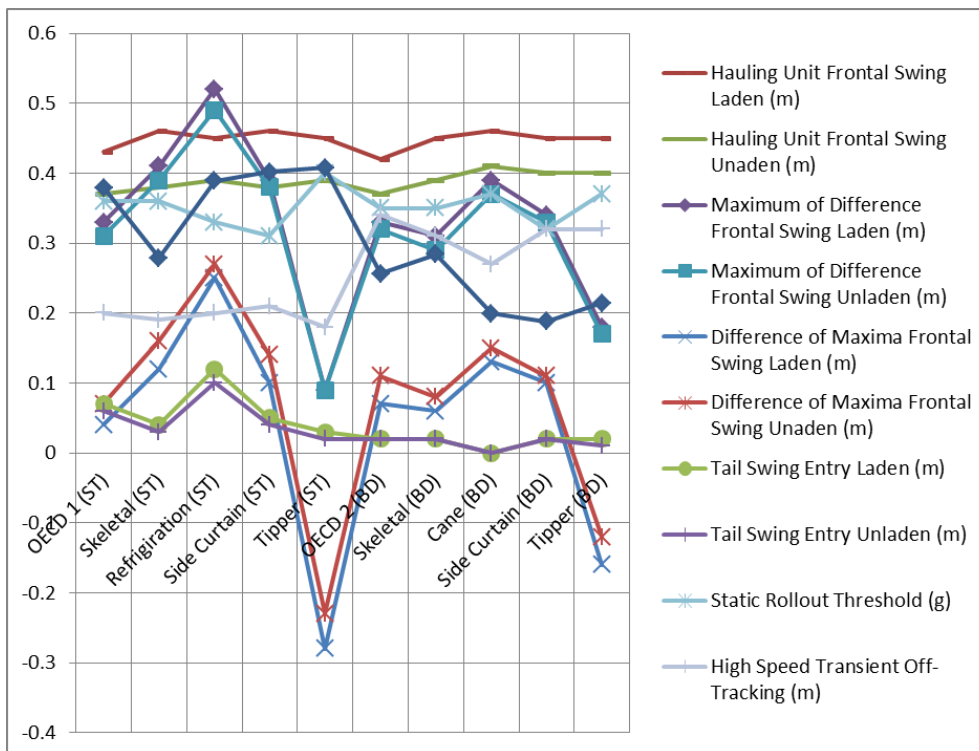


Figure 1: The comparison of values between -0.4 units to 0.6 units

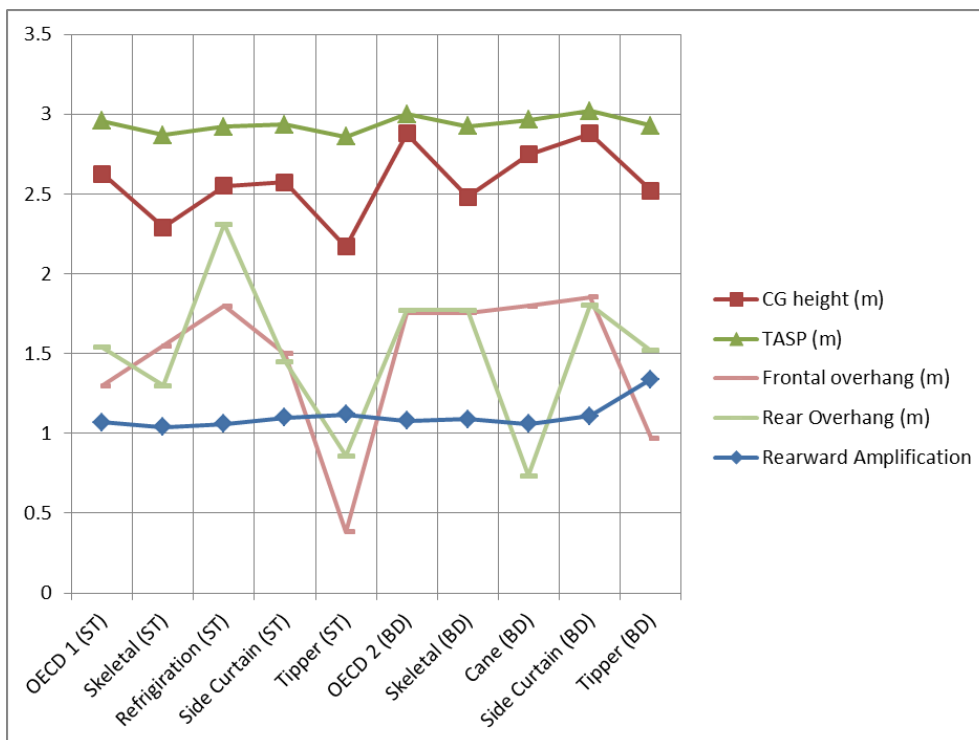


Figure 2: The comparison of values between 0 m and 3.5 m

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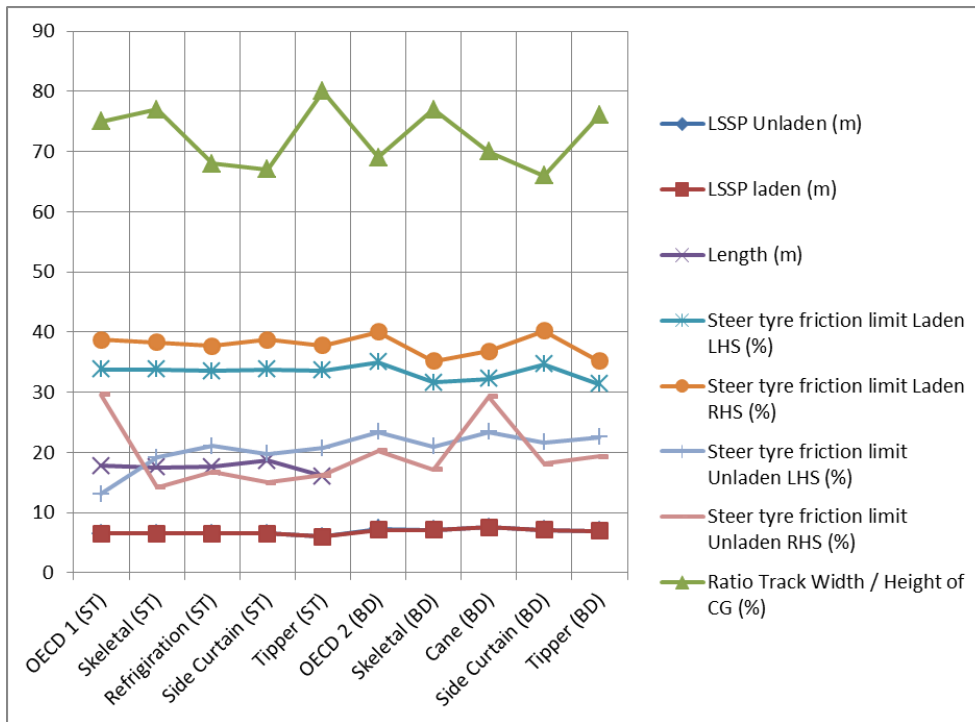


Figure 3: The comparison of values between 0 units and 90 units

Table 7: Performance level of the ten vehicle combinations investigated

Performance Measures	Semi-Trailer				B-double					
	OECD 1	Skeletal	Refrigeration	Side curtain	Tipper	OECD 2	Skeletal	Cane	Side Curtain	Tipper
Startability	Level 1	Level 1	Level 1	Level 1	Level 1	Level 1	Level 1	Level 1	Level 1	Level 1
Gradeability										
a) Maximum Grade	Level 1	Level 1	Level 1	Level 1	Level 1	Level 1	Level 1	Level 1	Level 1	Level 1
b) Speed on 1% Grade	Level 1	Level 1	Level 1	Level 1	Level 1	Level 1	Level 1	Level 1	Level 1	Level 1
Acceleration Capability	Level 2	Level 2	Level 2	Level 2	Level 2	Level 2	Level 2	Level 2	Level 2	Level 2
Tracking Ability on Straight Path	Level 2	Level 1	Level 2	Level 2	Level 1	Level 2	Level 2	Level 2	Level 3	Level 2
Low Speed Off-tracking	Level 1	Level 1	Level 1	Level 1	Level 1	Level 1	Level 1	Level 2	Level 1	Level 1
Frontal Swing										
a) Part A	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
b) Part B	Pass	Fail	Fail	Pass	Pass	Pass	Pass	Pass	Pass	Pass
c) Part C	Pass	Pass	Fail	Pass	Pass	Pass	Pass	Pass	Pass	Pass
Tail Swing	Level 1	Level 1	Level 1	Level 1	Level 1	Level 1	Level 1	Level 1	Level 1	Level 1
Steer Tyre Friction Demand	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
Static Rollover Threshold	Pass	Pass	Fail	Fail	Pass	Pass	Pass	Pass	Fail	Pass
Rearward Amplification	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
High Speed Transient Off-tracking	Level 1	Level 1	Level 1	Level 1	Level 1	Level 1	Level 1	Level 1	Level 1	Level 1
Yaw Damping Co-efficient	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
Direction Stability Under Braking	All Vehicles Pass									
PBS Level Achieved	Level 2	Fail	Fail	Fail	Level 2	Level 2	Level 2	Level 2	Fail	Level 2