

MAXIMUM OF DIFFERENCE ASSESSMENT OF TYPICAL SEMITRAILERS: A GLOBAL STUDY

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Abstract

Tractor semitrailer car-carrier designs operating in South Africa are required to demonstrate Level 1 compliance as legislated by the Australian PBS in order to be granted productivity concessions. A stumbling block in demonstrating compliance has been the Maximum of Difference (MoD) performance measure, which must be no greater than 0.40 m. The MoD performance of 480 tractor semitrailer combinations were analysed. The study compared the MoD performance of semitrailers specified to have the maximum allowable width and frontal overhang as stipulated by legislation from Australia, the European Union, Canada, the United States and South Africa. The majority of the Australian, EU and Canadian semitrailer combinations and all of the South African semitrailer combinations analysed did not demonstrate performance within the MoD limit of 0.4 m set by the Australian performance based standards. This would suggest that the MoD limit of 0.4 m is overly strict. An MoD limit of 0.6 m is suggested as an appropriate limit to be implemented in South Africa.

Keywords: Performance-Based Standards, Car-Carrier, Maximum of Difference, Frontal Overhang

1. Introduction

Since 01/04/2013 (Nordengen, 2014), tractor semitrailer car-carrier designs operating in South Africa are required to demonstrate Level 1 compliance as legislated by the Australian performance based standards (PBS) (NTC, 2008) and adhere to the Road Transport Management System (RTMS) if operated up to a 4.6 m height limit and with maximum combination length with load projections of 19.5 m. Without PBS Level 1 compliance, the vehicle must adhere to the prescriptive road legislation and operate with a reduced maximum height of 4.3 m and length of 18.5 m. These reduced dimensional allowances have a significant negative impact on productivity. Industry has invested in commissioning PBS assessments of car-carrier combinations to demonstrate Level 1 compliance, making design changes to vehicle designs, and becoming RTMS compliant.

A stumbling block in South African tractor semitrailer car-carrier designs demonstrating Level 1 compliance has been the Maximum of Difference (MoD) performance measure. The measure is defined as the maximum of the difference between the frontal swing-out distances between adjacent vehicle units in a prescribed 90° low-speed turn. For all Levels 1 to 4, the MoD must be no greater than 0.40 m (See Figure 1).

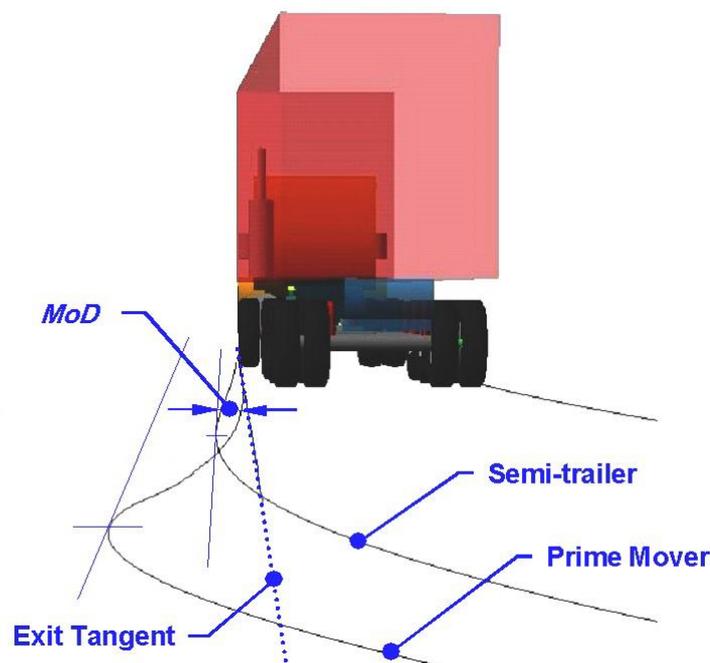


Figure 1 Illustration of MoD for a semitrailer combination (NTC, 2008) – abridged

The vehicle parameters which most significantly affect the MoD are the x, y co-ordinates (SAE definition) of the tractor front bumper relative to the outer steer tyre and the x, y co-ordinates of the semitrailer front outside corner. To a lesser extent the MoD is affected by the tractor wheelbase, semitrailer wheelbase and hitch offset.

To gain further insight into the MoD performance measure, the MoD is evaluated for typical tractor semitrailer combinations as found in Australia, the European Union, Canada, the United States and South Africa.

2. Prescriptive Legislations

The following section reviews the prescriptive legislated dimensions in Australia, the European Union, Canada, the United States and South Africa which influence the MoD standard. The MoD performance is legislated using prescriptive standards by limiting the swing radius. The swing radius is the greatest horizontal distance from the fifth wheel to any point on the semitrailer ahead of the fifth wheel, including loads and auxiliary equipment.

The Australian Design Rule 43/04 – Vehicle Configuration and Dimensions (ADR 43/04, 2016) specifies the requirements for vehicle dimensions in Australia. The maximum trailer width is 2.5 m and for a semitrailer the forward projection from the point of articulation must be contained within a radius of 1.9 m.

The maximum weights and dimensions of vehicles in the European Union are legislated by Council Directive 96/53/EC (1996). The maximum allowable width of all vehicles are 2.55 m and the distance measured horizontally between the axis of the fifth-wheel king pin and any point at the front of the semitrailer must not exceed 2.04 m. Certain regional differences have been allowed in Europe.

In Canada, each state implements its own road legislation. However, a memorandum of understanding on interprovincial weights and dimensions (Canada, 2005) has been implemented to provide improved uniformity in weight and dimension limits through establishment of minimum and maximum thresholds acceptable to all jurisdictions for eight configurations of vehicles commonly used in interprovincial transportation. According to this agreement vehicle widths should not exceed 2.6 m, and the fifth wheel setback radius should not be greater than 2.0 m (See Figure 2).

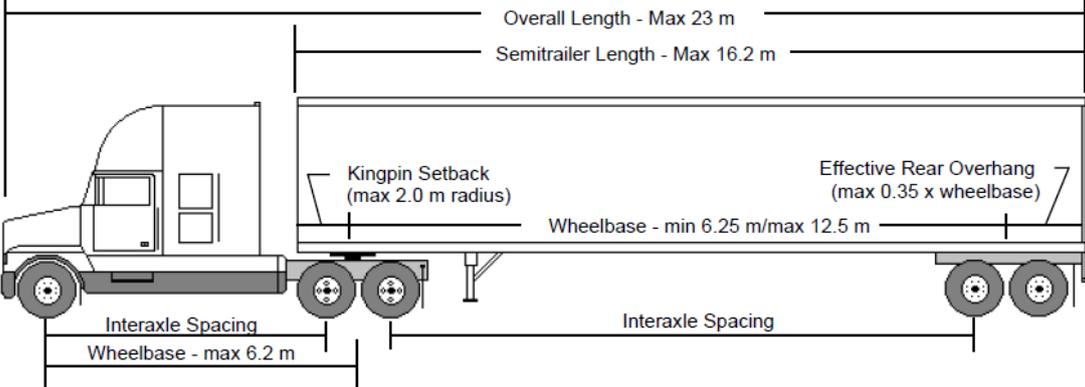


Figure 2 Tractor semitrailer dimensional limits in Canada (Canada, 2005)

In the US, each state implements its own road legislation. States that wish to allow vehicles more than 102 inches wide (± 2.6 m) to operate on the national network, must issue special overwidth permits (FHWA, 2004). No swing radius is specified. The American Association of State Highway and Transportation Officials (AASHTO, 2011) gives a typical frontal overhang for a 55 ft semitrailer as 0.91 m.

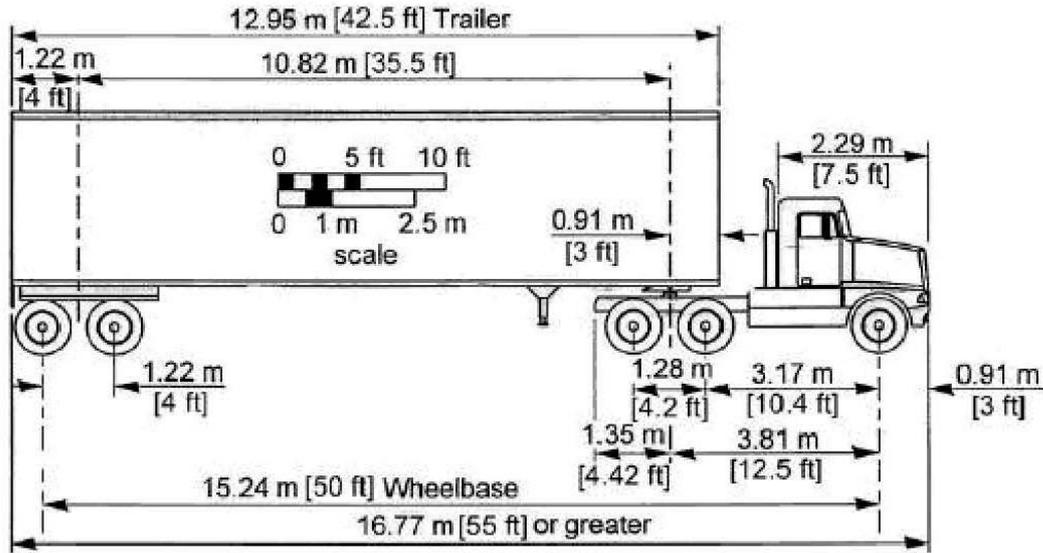


Figure 3 Typical dimensions of a 55 ft interstate tractor semitrailer (AASHTO, 2011)

In South Africa the maximum allowable vehicle width is 2.6 m for vehicles with a gross vehicle mass which exceeds 12 000 kg (Fleetwatch, 2011). The allowable frontal overhang of a semitrailer is 1.8 m and the maximum swing radius is 2.22 m.

A summary of the global prescriptive legislation limiting frontal overhang and swing radius is given in Table 1.

Table 1 Global prescriptive legislation limiting frontal overhang and swing radius

Country	Vehicle Width [mm]	Frontal overhang [m]	Swing Radius [m]	Source
Australia	2.50	1.431 [†]	1.90	(ADR 43/04, 2016)
European Union	2.55	1.592 [†]	2.04	(EU 96/53/EC, 1996)
Canada	2.60	1.520 [†]	2.00	(Canada, 2005)
United States	2.55	0.91	1.57*	(FHWA, 2004)
South Africa	2.60	1.800	2.22	(Fleetwatch, 2011)

[†] Calculated using the swing radius

* Calculated using the frontal overhang

3. Literature Review

The Australian National Transport Commission (NTC, 2008) stipulate that any vehicle conforming to the PBS Levels 1 to 4 must be measured as having an MoD no greater than 0.4 m. The vehicle being assessed must be driven through a 90° circular arc turn at a speed no

greater than 5 km/h with the outer most point on the outer tyre sidewall nearest to the ground, on the forward most outside steered-wheel, on a 12.5 m radius.

The MoD performance measure is listed once in a review document by the NTC (2009) but otherwise no further literature on the development of the MoD performance measure is found in the NTC reports detailing the development of PBS in Australia.

Fancher and Winkler (2007) have extensively reviewed the directional performance issues in evaluating and designing tractor semitrailer combinations. The review discusses swept path, frontal swing, tail swing and steer tyre friction demand but does not discuss MoD.

4. Objectives

The objectives of this study were to:

1. determine the MoD performance for a typical 4x2 tractor and semitrailer combination from a) Australia, b) the European Union, c) Canada, d) the United States, and e) South Africa.
2. make recommendations on the appropriate allowable maximum for the MoD performance measure.

5. Methodology

A parametric study was conducted in which the semitrailers from a) Australia, b) the European Union, c) Canada, d) the United States, and e) South Africa, were specified to have the maximum allowable width and frontal overhang (See Table 1). A semitrailer can have a range of possible wheelbases, typically has two or three axles and can be hauled by a number of different tractor types. The parametric study analysed a population of 480 vehicle combinations as summarised in Table 2.

Table 2 Summary of the parameters used to assess the MoD performance

Trailer front geometry	Tractor Model	Tractor wheelbase [mm]	Hitch position [mm]	Number of trailer axles	Trailer wheelbase [mm]	Loading
a) Australia	Tractor 1	3 560	300	2	8 000	Unloaded
b) EU	Tractor 2	3 700	750	3	11 000	Loaded
c) Canada	Tractor 3					
d) US						
e) S. Africa						

Three tractors, which are typically used for tractor semitrailer car-carrier combinations, were used in this study. The manufacturer and model details are kept confidential but the vehicle parameters are shown in Table 3. All three tractors use a 4x2 drive system. A semitrailer car-carrier is limited by space constraints to transporting a maximum of six vehicles. Assuming the heaviest vehicle from a database of 32 vehicles (Heydinger, et al., 1999), which is 2 562 kg, the maximum payload is 15 372 kg. Assuming a trailer of 9 000 kg and a tractor of

7 000 kg, the maximum combination mass of the vehicle is 31 372 kg. The maximum gross combination mass (GCM) for an EU six-axle tractor semitrailer combination is 44 000 kg and in South Africa 49 700 kg. Comparing these GCMs to the maximum combination mass one would typically expect of 31 372 kg, suggests that the use of 4x2 drive system for a tractor hauling a semitrailer car-carrier vehicle is a reasonable assumption.

The wheelbases, hitch positions, and frontal geometry of the tractors are shown in Table 3. The wheelbases of 3 560 mm and 3 700 mm as well as the hitch positions of 300 mm and 750 mm in Table 2 are reasonable and suitable values to be used in the parametric study. The reference points in Table 3 were measured from CAD drawings of the vehicles.

Table 3 Dimensions of three typical 4x2 tractors

Wheelbase [mm]	Hitch Position [mm]*	Vehicle Width [mm]	Frontal overhang [mm]	Point 1 [mm,mm]	Point 2 [mm,mm]	Point 3 [mm,mm]
3 560	300...400 [†]	2 298	1 440	1303,1097	1191,1128	0,1149
3 700	450...625 [‡]	2 490	1 362	1171,1222	604,1235	0,1245
3 560	522 622 722 ⁺	2 498	1 508	1222,1142	1119,1182	0,1249

* Hitch point measured forward of the drive axle.

[†] Hitch point can be varied in steps of 50 mm forward. A range of 300...400 is typical.

[‡] Hitch point can be varied in steps of 25 mm forward. A range of 450...625 is typical.

⁺ Hitch point can be varied to the three points listed.

The maximum tractor semitrailer length in Australia is 19 000 mm (ADR 43/04, 2016), and in certain EU countries it can be as low as 16 500 mm (EU 96/53/EC, 1996). Using the Australian maximum length of 19 000 mm, a frontal overhang of the tractor of 1 362 mm, a tractor wheelbase of 3 560 mm, a hitch offset of 722 mm (See Table 3), and a trailer rear overhang of 3 700 mm (ADR 43/04, 2016), a trailer wheelbase of 11 100 mm is possible. On the other hand using the EU maximum length of 16 500 mm, a frontal overhang of 1 508 mm, a tractor wheelbase of 3 700 mm, a hitch offset of 450 mm (See Table 3), and a trailer rear overhang of 4 000 mm typical of European car-carriers, a trailer wheelbase of 7 742 mm is possible. The trailer wheelbase is not only influenced by legislation governing the overall vehicle combination length but low-speed swept path requirements, bridge loading legislation and axle loading legislation. Car-carrier semitrailer wheelbases which have been manufactured in Europe and South Africa use wheelbases of 9 500 mm and 9 750 mm. The chosen wheelbases of 8 000 mm and 11 000 mm used in the parametric study are extreme values either side of what would typically be expected.

The study considered each vehicle combination in the unladen and laden state. For the laden state the payload was assumed to be 15 372 kg. The centre of gravity position of the payload was assumed to be 1 000 mm forward of the centre of the semitrailer axle group position.

The multi-body vehicle dynamics software package (TruckSim 8.2) and Matlab were used to analyse the performance of the vehicle. The vehicles were simulated to complete a low-speed 90° turn at a speed of 5 km/h as per the Australian PBS assessment rules (NTC, 2008). The

outermost point on the outside tyre sidewall of the steer axle was steered along the prescribed path of a straight entry tangent, a 90° arc of 12.5 metre radius and a straight exit tangent. The positions of points 1, 2, and 3 (See Table 3) were plotted to determine the maximum swing out of the front of the tractor and the position of the outside, front of the semitrailer was plotted depending on the trailer front geometry (See Table 2). The MoD was determined to be the largest difference between the semitrailer front swing out and the tractor front swing out measured perpendicular to the exit straight line.

6. Results and Discussion

A representative plot of the outside steer tyre position (steer), outside front of the tractor (unit 1) position and outside front the trailer (unit 2) is shown in Figure 4. The plotted points are used to calculate the MoD of 0.31 m. The steer path should ideally converge to an X-coordinate value of 17.5 m as the steer path exits the turn but the TruckSim driver controller overshoots the set path. The overshoot is within the allowable error of 50 mm (NTC, 2008).

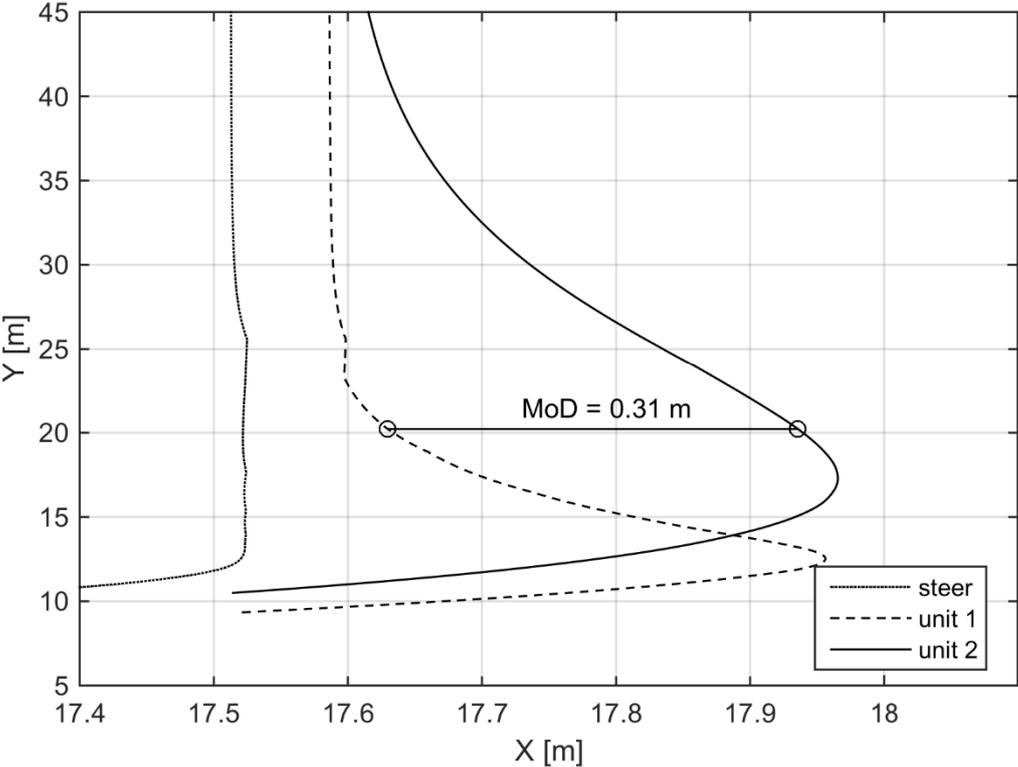


Figure 4 Representative MoD plot

MoD values for tractor semitrailer combinations with trailer front geometry at the legislation limit set by the road authorities in Australia, European Union, Canada, United States and South Africa are compared in Figure 5. The individual MoD values are shown as circles and the average values are shown as thin straight lines.

The average MoD value of the Australian semitrailer combinations was calculated to be 0.427 m. This average value is above the maximum limit of 0.4 m set by the Australian performance based standards (NTC, 2008). Only 35 out of the 96 Australian vehicles (36%) analysed passed the MoD standard. The average MoD value of the EU semitrailer

combinations was calculated to be 0.517 m. Only 6 out of the 96 EU vehicles (6%) analysed passed the MoD standard. The average MoD value of the Canadian semitrailer combinations was calculated to be 0.509 m. Only 9 out of the 96 Canadian vehicles (9%) analysed passed the MoD standard. All of the US semitrailer combinations analysed passed the MoD standard and the average value was calculated to be 0.257 m. The average MoD value of the South African semitrailer combinations was calculated to be 0.632 m. No South African vehicles analysed passed the MoD standard i.e. was calculated as having a value below 0.4 m.

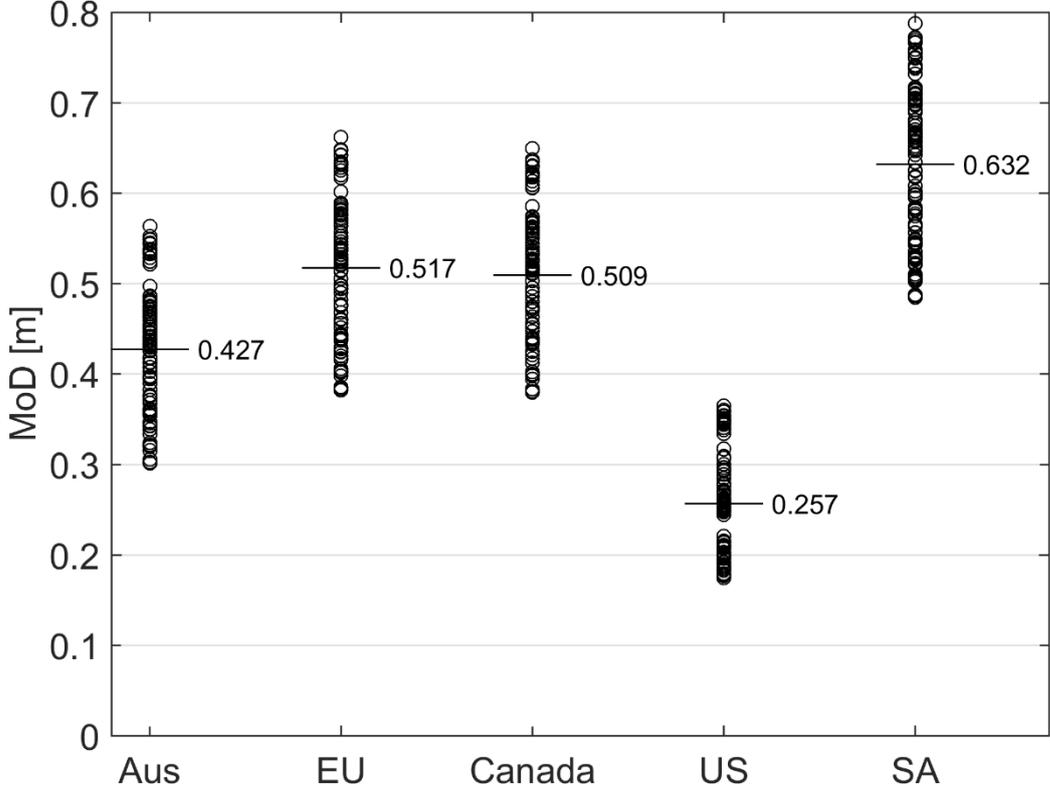


Figure 5 MoD values for semitrailer combinations: Australia, EU, Canada, US and SA

The result that none of the analysed South African semitrailer combinations were assessed as complying with the MoD standard requirement confirms the South African industry experience that car-carrier designs struggle to demonstrate Level 1 compliance. To meet the MoD requirement, South African car-carrier designs have needed to reduce the frontal overhang of the semitrailer or reduce the width of the front of the semitrailer or reduce both dimensions.

While all of the US semitrailer combinations complied with the MoD requirement, the majority of the Australian, EU and Canadian semitrailer combinations and all of the South African semitrailer combinations analysed did not demonstrate performance within the MoD limit of 0.4 m. This would suggest that the MoD limit of 0.4 m is overly strict. An MoD limit of 0.6 m is suggested as an appropriate limit to be implemented in South Africa. With an MoD limit of 0.6 m, 57 out of the 96 South African (59%), 17 out of the 96 EU (18%), and 16 out of the 96 Canadian (17%) vehicles analysed would still fail the MoD standard. At the new

limit of 0.6 m, implementation of PBS compliance would improve the MoD performance in the South African fleet but not overly restrict productivity. The 0.6 m limit would be aligned with the MoD performance shaped by the prescriptive legislation currently enforced in the EU and Canada.

7. Conclusions

The MoD performance of 480 tractor semitrailer combinations were analysed. The parametric study compared the MoD performance of semitrailers specified to have the maximum allowable width and frontal overhang as specified by legislation from Australia, the European Union, Canada, the United States and South Africa. The study looked at three tractor models and varied the tractor wheelbase, hitch position, number of trailer axles, trailer wheelbase and loading. Conclusions drawn in this study are summarised as follows:

- While all of the US semitrailer combinations complied with the MoD requirement, the majority of the Australian, EU and Canadian semitrailer combinations and all of the South African semitrailer combinations analysed did not demonstrate performance within the MoD limit of 0.4 m set by the Australian performance based standards.
- This would suggest that the MoD limit of 0.4 m is overly strict. An MoD limit of 0.6 m is suggested as an appropriate limit to be implemented in South Africa.
- At the new limit of 0.6 m, implementation of PBS compliance would improve the MoD performance in the South African fleet but not overly restrict productivity. The 0.6 m limit would be aligned with the MoD performance shaped by the prescriptive legislation currently enforced in the EU and Canada.

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