

APPLICATION OF TRACKAXLE® TO MULTI-COMBINATION VEHICLES

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ABSTRACT

In Australia the inception of the Trackaxle® steerable axle system in 2000 was met with widespread acclaim. Since then a number of safety and performance enhancing improvements have been developed and tested on 6-axle prime mover and semi-trailer prototypes. Early prototypes were subjected to comprehensive and wide-ranging assessments and demonstrations involving numerical modelling, full-scale physical testing and in-traffic trials. When compared with conventional, 6-axle articulated vehicles, the equivalent Trackaxle® equipped vehicles consistently demonstrated better offtracking in low-speed turns, lower tyre-force related pavement and vehicle impacts (scrubbing and vertical loads), reduced power requirement for turning, and acceptable in-traffic behaviour. The further benefits of Trackaxle® in multi-combination vehicle installations has not yet been fully explored or formally quantified and documented. This paper considers a wide range of performance aspects of a number of innovative single-, double-, triple- and quad-trailer heavy-vehicle combinations that feature the Trackaxle® steerable axle system. Using a performance-based standards (PBS) approach, and drawing on the formal standards that are now in place in Australia developed jointly by the National Transport Commission (NTC) and Austroads, the performance of select multi-combination vehicles that feature single and multiple Trackaxle® installations is compared and contrasted with equivalent conventional vehicles. When compared with equivalent baseline vehicles, the Trackaxle® multi-combination vehicles considered in this paper were found to have substantially better safety performance, increased productivity and would be less damaging to the infrastructure. The main challenge for fleet operators and road agencies is to address overtaking provision issues associated with operating longer vehicles on two-lane two-way roads constrained by road sight distance, traffic volume and overtaking opportunities.

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1 INTRODUCTION

In Australia the inception of the Trackaxle® steerable axle system in 2000 was met with widespread acclaim. Since then a number of safety and performance enhancing improvements have been developed and tested on 6-axle prime mover and semi-trailer prototypes. Early versions were subjected to comprehensive and wide-ranging assessments and demonstrations involving numerical modelling, full-scale physical testing and in-traffic trials (Atley, 2006). When compared with conventional, 6-axle articulated vehicles, the equivalent Trackaxle® equipped vehicles consistently demonstrated better offtracking in low-speed turns, lower tyre-force related pavement and vehicle impacts (scrubbing and vertical loads), reduced power requirement for turning, and acceptable in-traffic behaviour (Prem and Atley, 2002; Atley, 2006).

The further benefits of Trackaxle® in multi-combination vehicle installations has not yet been fully explored or formally quantified and documented. Through numerical modelling the study described in this paper considers a wide range of performance aspects of a number of innovative single-, double-, triple- and quad-trailer heavy-vehicle combinations that feature the Trackaxle® steerable axle system. Road network access and fleet vehicle implications are also discussed.

2 GENERAL DESCRIPTION OF TRACKAXLE® SYSTEM

Trackaxle® is a steerable axle group that is designed to follow the swept path of the axle-group of the preceding vehicle unit (prime mover, semi-trailer or dolly). In its most general form Trackaxle® comprises a bogie frame, a set of two or more axles, and mechanisms to control and steer the bogie frame and select axles relative to the chassis and bogie frame, respectively.

A plan view schematic of a typical semi-trailer tri-axle Trackaxle® arrangement – as used in early installations – is shown below in Fig. 1. Through the main steer mechanism, controlled by the bogie frame steer rods, the bogie frame steers in response to articulation angle between the semi-trailer chassis and the unit immediately ahead of it. A second steer mechanism located on the bogie frame, comprising two short tie-rod linkages, steers the front and rear axles at equal and opposite angles relative to the centre of the bogie frame (and centre axle) as shown. In a tri-axle arrangement, the centre axle is not steered relative to the bogie frame but in tandem- and quad-axle arrangements all axles would be steered. A full description is given in Prem and Atley (2002).

When compared with conventional multi-axle arrangements, the above described features serve to significantly reduce the effective wheelbase of the vehicle unit, allowing small radius, small swept width low-speed turns to be performed, and path curvature effects minimised that would otherwise lead to significant levels of tyre scrubbing and changes in vertical tyre loads within the axle group (Prem and Atley, 2002).

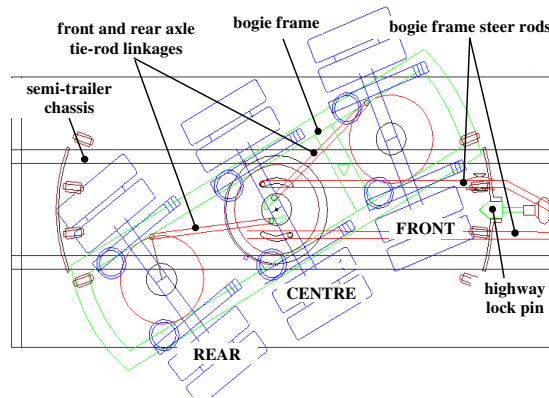


Fig. 1 - Schematic of typical Trackaxle® arrangement (adapted from Prem and Atley, 2002).

In addition, to cater for a wide range of in-service conditions several design features have been incorporated into Trackaxle®. For example, when the input articulation angle is less than 2° the bogie frame is held in the straight-ahead position using a locking pin (see Fig. 1). This leads to improved vehicle dynamics at highway speeds while also reducing component wear and tear. Further, through careful design, to control and limit the degree of steering in low-speed turns, precise combinations of self- and force-steer are achieved. These are fully described in Prem and Atley (2002).

Recent innovations include a command steer function allowing the driver to actively steer Trackaxle® while reversing, easing vehicle operation and delivery of unusual loads, and improving general utility and route access.

A typical prime-mover and semi-trailer combination equipped with Trackaxle® is shown below in Fig. 2 performing a standard low-speed turn at the demonstration day, held at Mangalore Airport in Victoria, Australia, of the recent PBS International Seminar (National Transport Commission, 2003).



Fig. 2 - Trackaxle® demonstrator performing a low-speed turn at the PBS International Seminar (National Transport Commission, 2003).

3 MULTI-COMBINATION VEHICLES

3.1 Trackaxle®-Based Variants

For this paper a range of combination vehicles were developed that feature Trackaxle®. In total five configurations were considered comprising single-, double-, and triple- and quad-trailer arrangements. The final configurations were selected on the basis that in Australia they represent the most widely used fleet vehicles in line-haul applications as well as being either accepted or emerging innovative long-combination vehicles.

Axle group loads for the five variants were set at the national maximum legal limits for vehicles running on road friendly suspensions. These loads are, respectively, 6.0 t on a single steer axle, 17.0 t on tandem axle groups and 22.5 t on tri-axle groups.

The prime mover in each combination vehicle was selected from design vehicles published by Austroads (Austroads, 2006) to match the prime mover of the corresponding baseline vehicle described in the following section. A key determinant in setting overall length was the load length of each load carrying vehicle unit. This was designed to accommodate an integer number of standard sized pallets (1220 mm) and standard size (40 and 48 ft) shipping containers.

The general layout, key dimensions, gross combination mass (GCM) and overall lengths of the five combination vehicles are presented below in Fig. 3 and Table 1.

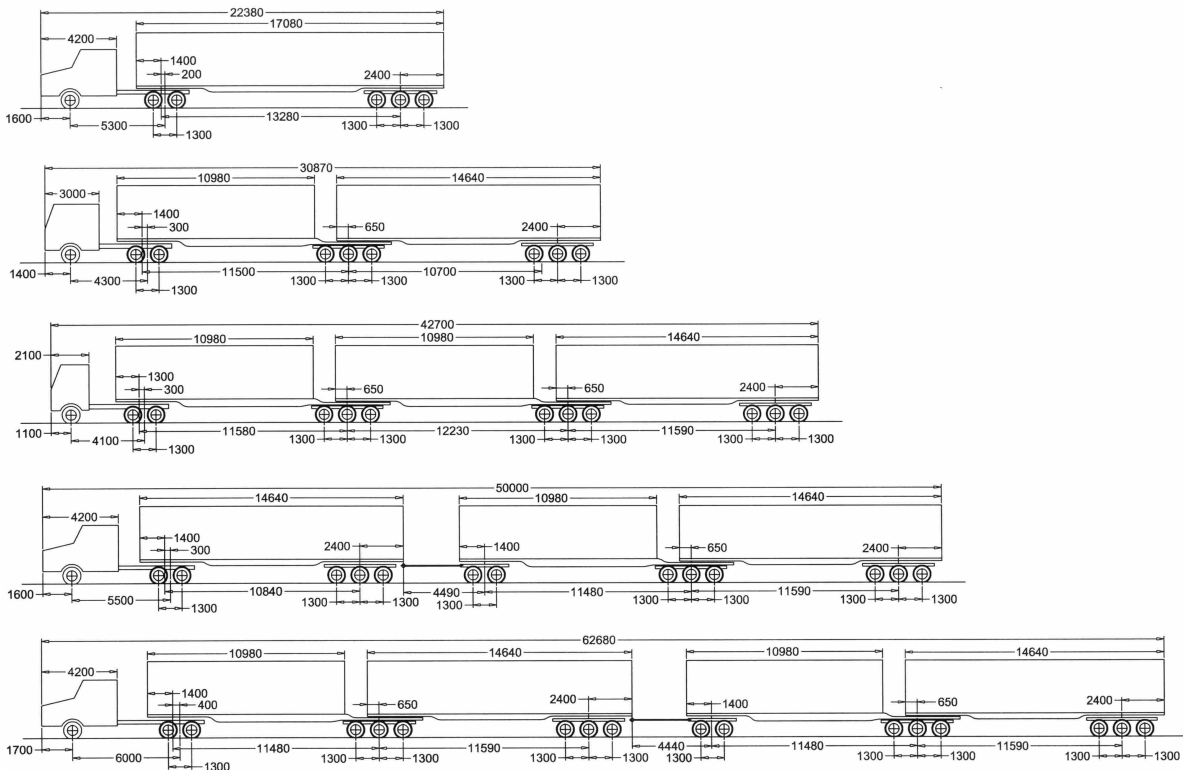


Fig. 3 – Trackaxle® combination vehicles.

In the analysis only tri-axle groups were Trackaxle® equipped. Tandem axle groups, primarily on dollies were conventional but also could be Trackaxle® variants. For this study this added complexity was considered not necessary.

Table 1 – GCMs and overall lengths of Trackaxle® combination vehicles

Vehicle	GCM (tonnes)	Overall Length (m)
Prime-mover and semi-trailer	45.5	22.4
B-double	68.0	30.9
B-triple	90.5	42.7
AB-triple	107.5	50.0
BAB-quad	130.0	62.7

In Australia, under current prescriptive regulations, presently accepted standard levels of route access are defined in terms of maximum vehicle lengths, as follows: for general access up to 19.0 m, on B-double routes up to 25.0 m (and up to 26.5 m on approved routes), on Type 1 road train routes up to 36.5 m, and up to 53.5 m on Type 2 road train routes. In general terms these represent, respectively, unrestricted access, access to significant freight routes, access to major freight routes, and remote areas access.

While Table 1 shows that the Trackaxle® combination vehicles have overall lengths significantly in excess of the maximum length limits set under current prescriptive regulations, the assessment presented later in this paper draws on the performance-based standards (PBS) being developed jointly by the National Transport Commission (NTC) and Austroads (Edgar, Prem and Calvert, 2002; National Transport Commission, 2006). Under PBS the interactions of vehicles with the roads they will be used on are taken into account more explicitly and overall length, though important, is not the only consideration.

3.2 Baseline Vehicles

In order to compare and contrast the performance of the Trackaxle®-based vehicle variants described above, a set of reference or baseline vehicles was selected. Drawing on the latest updates to the design vehicles developed by Austroads (Austroads, 2006), five were selected whose configuration best matched the Trackaxle® vehicle configurations. General layout, key dimensions, GCM and overall length of each of the five baseline combination vehicles are presented below in Fig. 4 and Table 2.

It is important to note that the Austroads design vehicles are 85th percentile worst-case dimensioned vehicles that have been developed for road design and analysis of vehicle swept path performance in low-speed turns. Further, to make the performance comparisons more meaningful, inspection of Fig. 3 and Fig. 4 reveals that each Trackaxle® combination vehicle and its corresponding baseline vehicle share both the same prime mover and the same forward projection dimensions of the first semi-trailer.

4 NUMERICAL MODELLING AND PERFORMANCE ASSESSMENT

4.1 Models

Numerical models were created of the Trackaxle® and baseline vehicle configurations using the ADAMS multi-body dynamics simulation software package (MSC.Software, 2006) and the Mechanical System Dynamics Pty Ltd (MSD) *Atruck*TM toolbox. Mechanical properties were assigned to the models consistent with a previous major study of the performance of the Australian heavy vehicle fleet (National Transport Commission, 2002). In particular, sprung mass centre-of-gravity (CG) heights were identical for like vehicle units, and 11R22.5 size tyres

were used in all positions. An underside view of the Trackaxle®-based BAB-quad model partway through the PBS 90° low-speed turn is shown below in Fig. 5.

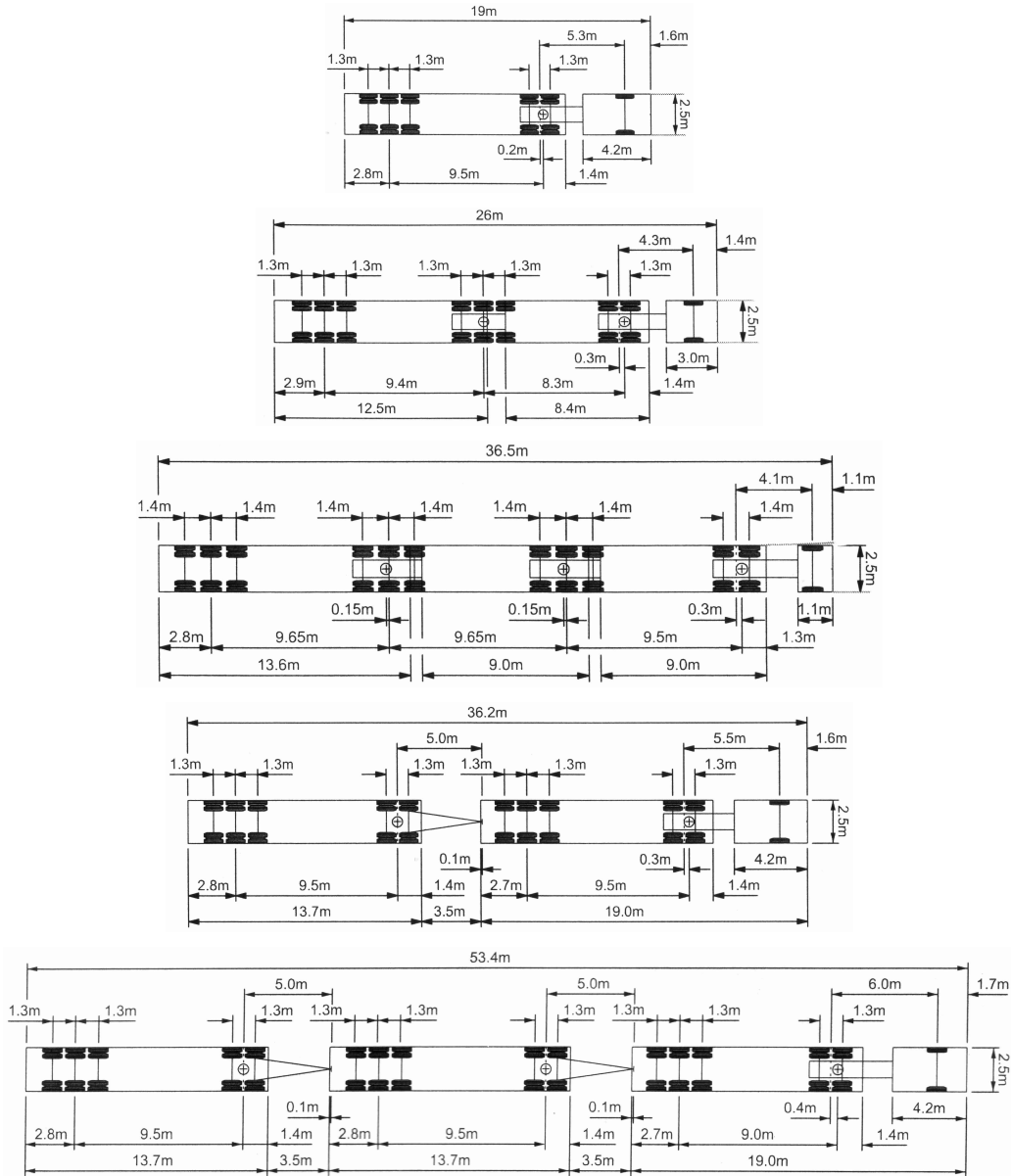


Fig. 4- Baseline combination vehicles (from Austroads, 2006).

Table 2 - GCMs and overall lengths of baseline combination vehicles

Vehicle	GCM (tonnes)	Overall Length (m)
Prime-mover and semi-trailer	45.5	19.0
B-double	68.0	26.0
B-triple	90.5	36.5
A-double	85.0	36.2
A-triple	124.5	53.4

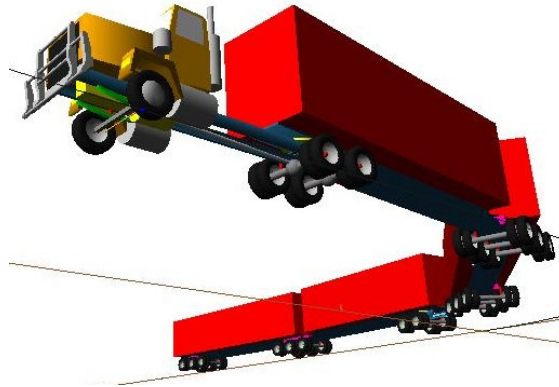


Fig. 5 - Numerical model of the Trackaxle® BAB-quad combination vehicle.

4.2 Performance-Based Standards (PBS)

4.2.1 Safety Standards

Simulations were performed of a wide range of standardized low- and high-speed safety-related manoeuvres consistent with the latest set of formal performance-based standards that are now in place in Australia (National Transport Commission, 2005).

The following standards, with accompanying brief descriptions of what each measures, were considered in the analysis presented in this paper. Complete formal descriptions and detailed definitions of the standards are presented in National Transport Commission (2005).

- i) *Tracking ability on a straight path* – the vehicle’s total swept width during travel at a specified speed along a straight path in the presence of a specified level of road surface unevenness, cross-slope and driver steer perturbations;
- ii) *Low-speed swept path* – the maximum width of the vehicle’s swept path in a prescribed 90° low-speed turn;
- iii) *Static rollover threshold* – the steady state level of lateral acceleration that a vehicle can sustain without rolling over during a constant-radius turn;
- iv) *Rearward amplification* – the degree to which the trailing unit(s) amplify the lateral acceleration of the hauling unit in a prescribed lane change manoeuvre;
- v) *High-speed transient offtracking* – the lateral distance that the last-axle on the rearmost trailer tracks outside the path of the steer axle in a prescribed lane change manoeuvre;
- vi) *Yaw damping coefficient* – the rate at which “sway” or yaw oscillations decay after a short duration steer input at the hauling unit.

Safety standards not considered in the analysis but part of the suite of PBS safety standards include startability, gradeability, acceleration capability, steer tyre friction demand, frontal swing, tail swing and overtaking provision. In this preliminary comparative analysis of combination vehicles, startability, gradeability, acceleration capability, steer tyre friction demand and frontal swing were considered not necessary because these standards involve power train details, and specific dimensions of the prime mover and the forward section of the first semi-trailer. In practice the prime-mover power train would be matched to vehicle-specific GCMs to achieve acceptable performance, and prime mover dimensions in the examples considered in this paper are identical for both the Trackaxle® combinations and the corresponding baseline combinations.

Tail swing relates largely to rear overhang dimensions of trailing units and could be considered an issue for a separate design study that is outside the scope of this paper.

Overtaking provision, which relates acceptable vehicle length for two-lane two-way roads to road sight distance, traffic volume and overtaking opportunities (barrier lines and overtaking lanes), warrants more careful consideration by the road agencies. On divided roads, where each of the two carriageways has two traffic lanes so that overtaking is possible, overtaking provision would be less of an issue. Full length Trackaxle® vehicles, of the type presented in this paper, could operate on suitable routes between major distribution centres and, if necessary, “broken down” into smaller units for local distribution of freight.

4.2.2 Infrastructure Standards

Nationally accepted standards for assessment of infrastructure impacts have not yet been formally established, though interim standards have been proposed and they are the subject of further studies and stakeholder review and input (National Transport Commission, 2003).

As the Trackaxle® vehicle combinations are operating at the same axle group loads but with longer overall lengths than their corresponding baseline counterparts, overall bridge impacts will be reduced. Further, compared with their baseline counterparts, pavement loading, due to both horizontal and vertical tyre loads, will be significantly lower for Trackaxle® equipped vehicles, as detailed and discussed in Prem and Atley (2002).

5 RESULTS AND DISCUSSION

The PBS performance results for the Trackaxle® and baseline combination vehicles considered in this paper are presented below in Table 3 and Table 4, respectively. They are shown both in terms of the actual performance values for each of the performance measures specified in National Transport Commission (2005) and the corresponding route access levels. The four levels of route access, which have been assigned interim generic classifications by National Transport Commission (2004), are presented below in Table 5. Under PBS a vehicle can only be granted access to a particular route if it meets the performance requirements specific to that route. That is, for a vehicle to operate on a route having a Level 1 (L1) classification, it must meet the L1 performance requirements across all the applicable performance standards.

Table 3 – PBS performance results for the Trackaxle® combination vehicles

Performance Standard (units)	Performance Value (Route Access Category)				
	PMSemi	B-double	B-triple	AB-triple	BAB-quad
Tracking ability on a straight path (m)	2.7 (L1)	2.8 (L1)	2.8 (L1)	2.9 (L1)	3.0 (L2)
Low-speed swept path (m)	7.4 (L1)	7.3 (L1)	8.2 (L2)	8.5 (L2)	9.6 (L3)
Static rollover threshold (g)	0.37 (L1)	0.36 (L1)	0.36 (L1)	0.37 (L1)	0.36 (L1)
Rearward amplification (-)	0.99 (L1)	0.68 (L1)	0.49 (L1)	0.97 (L1)	0.81 (L1)
High-speed transient offtracking (m)	0.2 (L1)	0.2 (L1)	0.2 (L1)	0.5 (L1)	0.4 (L1)
Yaw damping coefficient (-)	1.00 (L1)	1.00 (L1)	1.00 (L1)	0.53 (L1)	0.54 (L1)

For the Trackaxle® combinations and PBS safety standards considered, Table 3 shows the standards controlling route access to be low-speed swept path and tracking ability on a straight path. When tracking ability is considered alone, the longest Trackaxle® combination, the BAB-quad, would be restricted to L2 class routes (significant freight routes) and lower. Low-speed swept path would further restrict the B-triple and AB-triple to L2 class routes, and the BAB-quad to L3 class routes (major freight routes). Route access of the Trackaxle® combinations could be further improved through a more detailed design study.

Table 4 – PBS performance results for the baseline combination vehicles

Performance Standard (units)	Performance Value (Route Access Category)				
	PMSEmi	B-double	B-triple	A-double	A-triple
Tracking ability on a straight path (m)	2.7 (L1)	2.8 (L1)	2.8 (L1)	2.8 (L1)	3.0 (L2)
Low-speed swept path (m)	7.4 (L1)	8.9 (L2)	11.3 (L4)	10.3 (L4)	12.6 (L4)
Static rollover threshold (g)	0.36 (L1)	0.36 (L1)	0.36 (L1)	0.36 (L1)	0.37 (L1)
Rearward amplification (-)	1.20 (L1)	0.96 (L1)	0.91 (L1)	1.69 (L1)	2.33 (-)
High-speed transient offtracking (m)	0.3 (L1)	0.3 (L1)	0.3 (L1)	0.6 (L1)	1.1 (L3)
Yaw damping coefficient (-)	1.00 (L1)	1.00 (L1)	0.46 (L1)	0.39 (L1)	0.26 (L1)

Table 5 - The four levels of route access under PBS

Generic PBS Descriptor	Route Access Category	Close Present Description
Level 1, or L1	Unrestricted Access	General Access
Level 2, or L2	Significant Freight Route	B-double routes
Level 3, or L3	Major Freight Route	Type I road trains
Level 4, or L4	Remote Areas	Type II road trains

For the baseline combinations Table 4 shows the standards controlling route access to be low-speed swept path, rearward amplification, and high-speed transient offtracking. The A-triple fails to meet the rearward amplification standard and therefore would not qualify as a PBS vehicle. The B-double, and the B-triple and A-double, while qualifying as PBS vehicles, would be restricted to L2 and L4 class routes, respectively, on the basis of low-speed swept path performance.

Productivity and performance improvements of the Trackaxle® combinations taken relative to the nominated baseline vehicles are compared below in Table 6. Productivity gains in the form of volume loading derived from increased length are substantial and would range from about 17 to 38%. Productivity gains associated with increases in GCM are combination specific and in excess of 25% in some cases for the examples considered. If the tri- and quad-axle groups were used in place of tandems and tri-axle groups, respectively, the productivity improvements would be significantly larger, up to about 45% for the AB-triple when compared with the baseline A-double, for example.

Table 6 shows clearly that the majority of the Trackaxle® combinations have significantly better safety performance than the baseline combinations in low-speed swept path (almost 30%), rearward amplification (up to 65%), high-speed transient offtracking (up to 64%) and yaw damping coefficient (up to about 120%). Also, it is important to note that the Trackaxle® 30.9 m B-double, 50.0 m AB-triple and 62.7 m BAB-quad have smaller low-speed swept paths than the baseline 19.0 m prime-mover and semi-trailer, 26.0 m B-double, and 36.2 m A-double, respectively.

6 SUMMARY COMMENTS

This paper has shown that steerable axle systems, such as Trackaxle®, enable substantial improvements to be made in heavy vehicle productivity, safety and infrastructure impacts across a wide range of common and less-common combination vehicles. The main challenge for vehicle/fleet operators and road agencies is to address overtaking provision issues associated

with operating longer vehicles on two-lane two-way roads constrained by road sight distance, traffic volume and overtaking opportunities.

Table 6 – Trackaxle® combinations compared to baseline combinations

Parameter or Performance Standard	% Change – Trackaxle® relative to Baseline				
	PMSemi	B-double	B-triple	AB-triple A-double	BAB-quad A-triple
Overall length	17.9	18.8	17.0	38.1	17.4
Gross combination mass	0.0	0.0	0.0	26.5	4.4
Tracking ability on a straight path	0.0	0.0	0.0	3.6	0.0
Low-speed swept path	0.0	-18.0	-27.4	-17.5	-23.8
Static rollover threshold	2.8	0.0	0.0	2.8	-2.7
Rearward amplification	-17.5	-29.2	-46.2	-42.6	-65.2
High-speed transient offtracking	-33.3	-33.3	-33.3	-16.7	-63.6
Yaw damping coefficient	0.0	0.0	117.4	35.9	107.7

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