



NATIONAL ROAD TRANSPORT COMMISSION

**STEERABLE AXLES TO IMPROVE
PRODUCTIVITY AND ACCESS**

Final Report

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**Prepared by
Brendan Coleman
Peter Sweatman**

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Steerable Axles to Improve Productivity and Access

Report Prepared by: **Brendan Coleman and Peter Sweatman**

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Objectives:	Increased road transport productivity through the use of steerable axles.
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Abstract:	<p>The NRTC commissioned Roaduser Systems Pty Ltd to investigate the performance of steerable axles including their benefits and costs. The assessments were made using the Performance Based Standards (PBS) criteria at the time of the study (late 2001).</p> <p>Part of the brief included the investigation of the benefits and impacts of marginal increases in semi-trailer length and in particular to the wider application of the length increase from 14.6m (48ft) to 14.9m (49ft) recently granted to refrigerated trailers in New South Wales.</p> <p>The report suggests that a 15m semi-trailer incorporating a steerable axle would offer substantial productivity based economic benefits within current vehicle performance parameters. However, it would involve increasing the current overall vehicle length from 19m to 20m.</p> <p>It identifies that the existing regulatory regime does not include quad axle groups. The treatment of this axle type, with road friendly suspension, is therefore not currently defined. The use of a steerable axle on a quad group appears to be a promising vehicle configuration for the industry but there are no clear guidelines on how it might be assessed.</p> <p>There is potential for significant productivity gains from B-doubles using steerable axles. However, inevitably the trade-off for any productivity gains is vehicle length (and mass, if an additional axle is used).</p>

The report suggests that a number of combination vehicles could be assessed within an expanded regulatory framework (based on performance standards). It argues for an extension of the current regulatory framework to accommodate vehicle combinations that could emerge with the acceptance of steerable axles as a means for improving manoeuvrability.

Purpose:

To identify opportunities for increasing vehicle access and road transport productivity through the use of steerable axles.

Key words:

Steerable axles, road transport productivity, performance based standards, improved manoeuvrability, optimal trailer length, improved accessibility, B-doubles, quad axle groupings

FOREWORD

The purpose of this project was to assess the performance of steerable axles including their benefits and costs. As steerable axles improve the maneuverability of vehicle combinations, the study focused on the benefits that increased length would bring to road transport productivity. The assessments were made using the Performance Based Standards (PBS) criteria at the time of the study (late 2001). At the present time, these criteria are under review and may change from those used in the project.

The refrigerated road transport industry had identified operational limitations to the 14.6m (48ft) refrigerated semi-trailers. They claimed that significant advantages could be achieved for their industry by increasing the maximum length of trailers (used in semi-trailer combinations) to 14.9m (49ft). The overall length of the semi-trailers would remain at 19m. However, the NRTC preferred to address the more generic question of trailer length and included the issue for consideration in this steerable axles project.

A number of important issues emerged from the research including the notion of a standard trailer length and the opportunity for increasing overall vehicle length for vehicles fitted with steerable axles, without compromising safety. Steerable axles also offered the potential for increasing the network available for B-doubles. This would bring productivity gains even if length were not increased. The report also highlights that quad axle groups are not adequately catered for in the current regulatory framework.

The report raises a number of important issues for jurisdictions and industry in the potential application of PBS and the Commission is keen to receive comments from all stakeholders. They should be addressed to:

Mr Tony Wilson
Chief Executive
National Road Transport Commission
PO Box 13105
LAW COURTS VIC 8010

L5/326 William Street
MELBOURNE VIC 3000

Telephone: (03) 9321 8444
Facsimile: (03) 9326 8964

Email: nrtc@nrtc.gov.au
Website: www.nrtc.gov.au

SUMMARY

The National Road Transport Commission (NRTC) commissioned Roaduser Systems Pty Ltd (with assistance from Alross Pty Ltd) to carry out a study of the benefits, costs and potential for length increases under PBS and performance effects of steerable axles. The study included investigation of regulations affecting the use of steerable axles, and whether there are any current impediments to the use of steerable axles.

The NRTC also commissioned Roaduser to investigate the benefits and impacts of marginal increases in semi-trailer overall length; in particular, consideration was given to the wider application of the length increase from 14.6m (48ft) to 14.9m (49ft) recently granted to refrigerated trailers in New South Wales.

The study included investigation of:

- current practices with steerable axles (including current regulations affecting steerable axle use);
- benefits of steerable axles for a wide range of vehicle configurations (as perceived by key stakeholders);
- benefits of marginal semi-trailer length increases;
- potential for productivity increases (through increased length and mass) with the wider use of steerable axles throughout the Australian fleet (as defined by the prime constraints of low-speed geometric performance);
- geometric and safety impacts of these initiatives; computer simulation assessment of a wide range of vehicle configurations fitted with steerable axles was carried out; and
- productivity benefits, costs and net economic benefits of a range of initiatives deploying steerable axles.

Setting aside the primary (front) steering axles fitted to trucks and prime movers, a wide variety of steerable axles are available for use on multi-axle vehicles. These steerable axles are designed for both trailing (unpowered) axles and driven axles. All of these steerable axle types address, in different ways, the fact that vehicle tyres operate in a sub-optimal way as soon as a vehicle unit is fitted with more than two axles and/or more than one “fixed” axle. This degradation in tyre and vehicle performance can be exhibited in:

- increased tyre wear;
- increased vehicle swept path;
- increased pavement surface wear;
- increased resistance to forward motion (and increased fuel consumption); and
- potentially undesirable effects on vehicle steering control.

Steerable axles offer performance improvements for all classes of heavy vehicle and provide direct benefits to transport operators who choose to use them. Such performance improvements also open the way to productivity gains in road freight transport operations because longer or heavier vehicles may be enabled within the constraints of the infrastructure, traffic and safety.

Steerable axles may also adversely affect certain areas of heavy vehicle performance, depending on the vehicle configuration and the characteristics of the steerable axle. To address these issues, the dynamic performance of selected vehicles fitted with steerable

axles was compared with that of currently-operating vehicle configurations and with the performance parameters being developed in the Performance Based Standards (PBS) project being carried out by the NRTC and Austroads.

Current Practices with Steerable Axles

While steerable axles come in a range of generic types, the most common are “automotive type” steerable axles used on semi-trailers; this type of steerable axle is also available for rigid trucks and prime movers. Other types include linked-articulation axle group steering systems for semi-trailers.

Steerable axles are not currently in widespread use in Australia. Current users of automotive-type steerable axles on triaxle semi-trailers report improved tyre wear and improved swept path. Linked-articulation steerable axles are new and are not currently being used in road transport, but offer a large improvement in swept path performance.

Current Australian regulations mitigate against the use of automotive-type steerable axles on trailers because the rear overhang dimension may be exceeded if the rearmost fixed axle is replaced with a steerable axle. There are no current regulatory impediments to the use of steerable axles on rigid trucks, but little use is currently evident on this vehicle type.

The literature suggests that steerable axles on rigid trucks may in certain cases adversely affect vehicle handling and control; this is much less likely on trailers. Most of the research involving steerable axles and vehicle dynamics has been carried out on potential “problem” areas for steerable axles, such as rigid trucks and “C-dollies” for multi-combination vehicles.

Semi-Trailer Length Limits

The tractor-semi-trailer – which is a dominant Australian freight vehicle - is the only combination where the trailer unit has a specific length limit. The existence of this limit – and its value at any point in time – are of considerable significance to the productivity, flexibility and re-equipping practices of Australian trucking fleets.

While there are some subtle differences in the way in which semi-trailer lengths are controlled in national and state regulations, the key points in controlling semi-trailer length are:

- the forward projection is a key dimension for interchangeability of prime movers and semi-trailers (it can also affect swing-out in low-speed turns);
- the s-dimension affects low-speed offtracking (as well as the ability to achieve balanced load distribution);
- the rear overhang affects tail swing in the initiation of low-speed turns;
- the distance from the kingpin to the rear end affects the overall length of the combination vehicle (although this is limited separately to 19m in the Australian Vehicle Standards Rules 1999); and
- in addition to the 13.7m long semi-trailer defined in the Australian Design Rules, general permits are available for 14.6m (48ft) long semi-trailers and, in NSW, 14.9m (49ft) long refrigerated semi-trailers.

The longer (14.6m) semi-trailers available under general permit are sub-optimal and remain in the minority of current semi-trailer production in Australia. There would be value in extending the 14.9m general permit to other States and Territories and to a wider

range of body and commodity types. However, this would be likely to remain a sub-optimal minority semi-trailer with limited overall economic benefits.

The introduction of a 15m long triaxle semi-trailer incorporating a steerable axle would offer substantial productivity-based economic benefits within current vehicle performance parameters; however, this vehicle would be most effective in vehicle combinations up to 20m in overall length and this issue lies outside the scope of the current study.

Performance Effects of Steerable Axles

In addition to the known benefits of reduced swept path and reduced tyre wear, steerable axles also affect vehicle dynamic performance. Provided that steerable axles have at least a threshold level of self-centring, their effects on dynamic stability and tracking behaviour of the common Australian freight vehicle configurations are modest. Only in road trains of conventional configuration were dynamic performance impacts found to be of concern.

In the case of linked-articulation steerable axle group systems, the effects on improving swept path performance can be dramatic. In the case of an automotive-type steerable axle introduced into a triaxle group, there is a modest but worthwhile improvement in low-speed offtracking and swept path.

Steerable Axle Potential Under Current Regulatory Regime

Steerable axles have the potential to improve access of vehicle combinations in the road network and into sites and depots. This has the greatest potential for B-doubles, where access is often tight and the use of steerable axles could provide substantial gains. Operators should give more consideration to the benefits of fitting steerable axles to B-doubles.

Steerable axles could also be fitted to rigid trucks, leading to R13 and R23 configurations with increased GVM and productivity for mass-limited loads. Although not currently impeded by regulations, these applications currently find little uptake and there are likely to be useful gains available to some operators.

Steerable Axle Potential Under Minor Regulatory Changes

It is suggested that the rear overhang limit is increased from 3.7m to 4.7m for both 13.7m and 14.6m triaxle semi-trailers. The benefits of this regulatory change would be transport operators' freedom to opt for improved manoeuvrability, improved access and reduced tyre wear for semi-trailers; the disbenefit would be an increase in tail swing (but within proposed PBS standards). This regulatory change would also contribute to some of the productivity-based initiatives discussed below.

This regulatory change would need to be accompanied by certain requirements to ensure that dynamic performance of the vehicle combination is not degraded: the aligning stiffness of the automotive-type steerable axle should be at least equivalent to the medium stiffness value used in this report. There should also be a limit of one automotive-type steerable axle per triaxle group, and the steerable axle should be fitted in the rear position. Consideration should also be given to the need for any specific requirements for load sharing performance of steerable axles when incorporated in an axle group.

Steerable Axle Potential Under National Regulatory Review

In order to realise the significant productivity-based economic potential of steerable axles, it would be necessary to re-assess and extend certain aspects of the current regulations.

Quad axle groups are not currently recognised in the regulations: there is no relevant axle group mass limit for the dual-tyred quad group and the treatment of such axle groups, with road-friendly suspension, in the axle spacing mass schedule is not currently defined. It is recommended that these issues are reviewed on a national basis.

The current axle spacing mass schedule for limited access vehicles is not defined for GCM over 68t. The appropriate axle mass schedule for GCM over 68t and up to approximately 77t needs to be considered.

B-doubles are currently restricted to 25m overall length. Review of this limit for vehicles which meet all current performance parameters including swept path would permit substantial productivity gains to be considered with B-doubles using steerable axles. To encompass the potential productivity gains, an overall length range up to 28.5m should be considered; the issue of B-double overall length limits is outside the scope of the present study.

Worthwhile productivity initiatives which could be brought to the horizon by the above type of national regulatory review are: (i) 50t A124 tractor-semi-trailer with quad axle incorporating one steerable axle, (ii) 72.5t GCM B1234 B-double with quad axle incorporating one steerable axle on the rear trailer and (iii) 38 pallet B1233 B-double with one steerable axle on each trailer.

Steerable Axle Potential Under PBS

Linked-articulation steerable axle group systems should be earmarked as a priority PBS application and considered for a case study or “blueprint” PBS application. Strength requirements for linked-articulation steerable axle group systems should be included in the performance assessment.

A further candidate for PBS blueprint applications is the 77t B1244 B-double incorporating quad axle groups incorporating steerable axles on both trailers. The extended overall length of this vehicle and the significantly reduced swept path performance would make this vehicle subject to PBS assessment.

Potential Economic Role of Steerable Axles

The wider deployment of steerable axles offers substantial financial and economic benefits in cases where productivity gains are able to be exploited with high-utilisation vehicles. The net benefits to the Australian economy depend on the take-up rate of such initiatives, and take-up can only be estimated.

The economic benefits of minor regulatory change in relation to improved access and reduced tyre wear are difficult to estimate. However, as the necessary changes are small and no significant costs to agencies have been identified, such changes are recommended.

National regulatory review in relation to quad axles, axle spacing mass schedule and B-double length (for B-doubles with steerable axles) would allow a net benefits package in excess of \$20 million per year to be addressed.

National regulatory review in relation to overall length of tractor-semi-trailers and the introduction of a 15m long triaxle semi-trailer incorporating a steerable axle would allow a net benefits package in excess of \$20 million per year to be addressed.

The establishment of PBS blueprint applications for linked-articulation semi-trailers and 77t B1244 B-doubles incorporating steerable axles would allow a net benefits package of approximately \$20 million per year to be addressed.

Safety Effects of Facilitating Steerable Axles

Assessment of the effects of steerable axles on heavy vehicle dynamic performance has shown that, provided certain requirements for the performance and deployment of steerable axles are followed, there are no adverse effects on dynamic performance.

Wider use of steerable axles under modified regulations would facilitate more productive vehicle configurations which should result in less heavy vehicles on the road and consequently less exposure of other road users to heavy vehicles. As a further safeguard, each of the potential productivity initiatives has been assessed for compliance with proposed PBS standards.

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1. INTRODUCTION

Vehicles fitted with steerable axles are currently used in limited numbers in Australian road transport operations but must operate within the restrictions of the legislative system. Steerable axles enable longer vehicles to minimise the amount of road space they require in low-speed turns. Conversely, the length (and therefore cubic load capacity) could be optimised for a fixed geometric capacity in the road system.

The industry contends that vehicles with steerable axles offer considerable benefits but to date it has been unable to take full advantage of these benefits.

The National Road Transport Commission (NRTC) commissioned Roaduser Systems Pty Ltd (with assistance from Alross Pty Ltd) to carry out a study of the benefits, costs and potential for length increases under PBS and performance effects of steerable axles. The study included investigation of regulations affecting the use of steerable axles, and whether there are any current impediments to the use of steerable axles.

The NRTC also commissioned Roaduser to investigate the benefits and impacts of marginal increases in semi-trailer overall length; in particular, consideration was given to the wider application of the length increase from 14.6m (48ft) to 14.9m (49ft) recently granted to refrigerated trailers in New South Wales. This issue has been combined with the broader issue of length increases in the context of steerable axles. The potential benefits of marginal semi-trailer length increases were investigated for other freight commodity classes and body types.

This report documents the work carried out, including investigation of:

- current practices with steerable axles (including current regulations affecting steerable axle use);
- benefits of steerable axles for a wide range of vehicle configurations (as perceived by key stakeholders);
- benefits of marginal semi-trailer length increases;
- potential for productivity increases (through increased length and mass) with the wider use of steerable axles throughout the Australian fleet (as defined by the prime constraints of low-speed geometric performance);
- geometric and safety impacts of these initiatives; and
- productivity benefits, costs and net economic benefits of a range of initiatives deploying steerable axles.

The study was carried out taking into account the current development of a performance-based approach to the regulations of heavy vehicle mass, dimensions and configuration throughout Australia. A Performance Based Standards (PBS) project is being carried out by Austroads and the NRTC. The implementation of PBS may provide a framework for facilitating the deployment of steerable axles.

2. CURRENT PRACTICES WITH STEERABLE AXLES

Setting aside the primary (front) steering axles fitted to trucks and prime movers, a wide variety of steerable axles are available for use on multi-axle vehicles. These steerable axles are designed for both trailing (unpowered) axles and driven axles. All of these steerable axle types address, in different ways, the fact that vehicle tyres operate in a sub-optimal way as soon as a vehicle unit is fitted with more than two axles and/or more than one “fixed” axle. This degradation in tyre and vehicle performance can be exhibited in:

- increased tyre wear;
- increased vehicle swept path;
- increased pavement surface wear;
- increased resistance to forward motion (and increased fuel consumption); and
- potentially undesirable effects on vehicle steering control.

In this section of the report, the various types of steerable axles are defined and consideration is given to their current usage, in terms of:

- how they are currently applied to different vehicle configurations;
- the heavy vehicle regulations which affect their use; and
- the available technical literature on steerable axles and related subjects.

These considerations concentrate on Australian practices but also take into account overseas practices of particular interest.

2.1 Steerable axle types

A survey of the different steerable axle types available was conducted to encompass as many of the possible benefits available to the Australian transport industry with the use of steerable axles; 14 manufacturers of steerable axles were identified. While there are many steerable axles brands available, there also exist several different steerable axle design types each utilising different steering mechanisms, that result in different steering characteristics when fitted to a vehicle. Therefore certain definitions have been developed in this report to classify the different steerable axle types within the study. A useful exposition of “self-steering” axle theory and practice [1] has provided some of the definitions adopted here.

The two main distinct categories of steerable axle types are (i) forced steering axles and (ii) self-steering axles. Forced steering axles utilise a steering mechanism that applies a direct force to the axle steering system in order to influence the steering behaviour of the vehicle. Self-steering axles are axles that have a self-centring or zero steer angle biased forcing system that is used to offset the effects of unbalanced braking forces between wheels of the axle and to assist in returning the axle to the zero steer angle position quickly and smoothly. Self-steering axles will only steer when the tyres develop a sufficient cornering force to overcome the self-centring force. [1]

Subgroups have been identified for each of the major steerable axle categories; these are defined by the generic operating concepts for the steerable axles. In many cases a number of mechanical designs are known to exist within each subgroup. However the investigation herein concentrated on the performance potential of the concept rather than the performance of any specific design example.

The following definitions are proposed for the purposes of distinguishing the various steerable axle types that have been developed and deployed in Australia and overseas.

Automotive Type – A self-steering heavy vehicle axle type that usually uses a steering kingpin and tie-rod assembly to alter tyre steer angle, similar to that of a heavy truck front-end [1]. The mechanism will change the steer angle when the tyres on the axle develop a sufficient cornering force to overcome the self-steering axle centring force. The self-steering axle centring force is the self-centring or zero steer angle biased forcing system that is usually supplied to the axle by springs or a spring loaded mechanism. This mechanism also helps to offset the effects of unbalanced braking forces between wheels of the axle and as an assistance mechanism to return the axle to the zero steer angle position quickly and smoothly.

Command Steering – Any heavy vehicle steerable axle that uses an actuated force to change the steer angle of its tyres relative to the chassis rails to which the axle and its suspension are attached.

Free Castering – A self-steering heavy vehicle axle type that typically uses a steering kingpin and knuckle mechanism to alter its steer angle. The steering mechanism allows the steer angle to change freely on the axle with only the friction resistance within the steering mechanism providing a resisting force to the articulation of the axle steering system. There are not many of these axle types available as they have been found to demonstrate [1, 2] a reduction in overall vehicle handling performance, yaw stability and brake steer performance.

Linked-Articulation (or Turntable) Type – A force-steering axle type that uses a steering linkage mechanism that typically alters the steer angle of an axle group as a function of fifth wheel articulation angle between the vehicle unit the axles are attached to and the hauling unit [3].

Self-Steering – A heavy vehicle steerable axle that will alter steer angle (relative to the chassis rails to which the axle and its suspension is attached) without force steering.

Figure 1 shows a tree diagram of the different steerable axle categories and subgroups found in the survey, including some examples of the steerable axle manufacturers and where they fit within this structure.

It is apparent that steerable trailing axles, and the automotive steering type in particular, dominate currently available products.

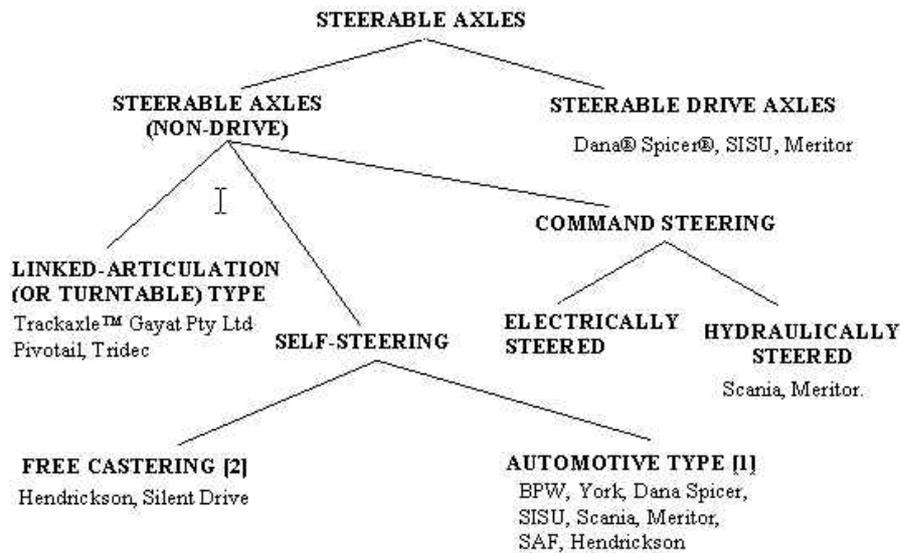


Figure 1 Tree diagram of steerable axle types

2.2 Current applications

A survey of representatives from Australian transport operators, steerable axle manufacturers, suppliers and regulatory authorities was conducted to determine the current use of steerable axles on heavy vehicles and the potential vehicle combinations likely to be affected with the application of steerable axles in future PBS applications. Details of the survey participants are listed in Annex A. Initially contact was made with trailer manufacturers producing self-steering axles on heavy vehicle trailer combinations. From these initial consultations the main transport operators and vehicle applications currently using steerable axles in Australia were identified.

It was found that usage of steerable axles is not widespread, but certain responses provided useful “case studies” in their use.

A refrigerated and general freight transport operator for a supermarket chain in NSW had been using steerable trailer axles on all of its new fleet since 1995, involving approximately 45 vehicles. The vehicle configuration using steerable axles is the 6-axle tractor-semi-trailer (A123). These vehicles transport refrigerated and general freight food products to supermarkets with tractor-semi-trailer utilising a self-steering automotive type axle in the rear position of the trailer triaxle group. The main reasons why this operator uses steerable axles are a reported 300mm improvement to vehicle swept path when turning a corner, cost savings in terms of tyre wear and a general improvement in on-road fleet performance.

Some milk transport operators utilise steerable trailer axles on approximately 30 vehicles in the Murray-Goulburn region of Victoria to improve access and reduce road damage on dairy farms. These operators commented on the benefits they receive in terms of tyre wear performance, and manoeuvrability. They also noted some additional maintenance costs in terms of training and equipment. They found that the use of steerable axles pleased their customers (farmers) and improved overall vehicle operations. The main milk transport vehicles using steerable axles are tractor-semi-trailer milk tankers fitted with automotive type self-steering axles to the rear axle of semi-trailer triaxle groups.

Some dangerous goods / petroleum tanker operators have also started to utilise steerable trailer axles on B-doubles and semi-trailer combinations. One operator has begun using self-steering trailer axles on the rear axles of both B1233 B-double triaxle groups in combination with an automated lift axle on the front axle for each triaxle group. These B-

double trailers are required by ADR 43/04 [4] to have an automated control system that will only raise the lift axles when in an unladen operating condition. These vehicles have been in operation for some 6 months and a reduction has been reported in vehicle maintenance costs due to improved tyre and brake wear performance. This has been encouraged because one steerable axle manufacturer has packaged a steerable axle with low profile (19.5 inch) tyres in combination with disc (rather than conventional drum) brakes with the option of a lift axle.

Another dangerous goods transport operator has developed a quad axle A124 tractor-semi-trailer combination using an automotive type self-steering trailer axle on the rear axle of the trailer. The quad axle semi-trailer would potentially allow for an increased GCM of 50t and this facilitates the use of a larger capacity tank within an overall vehicle length of approximately 17.5m. This concept has received a PBS-style assessment covering the key areas of:

- low-speed geometric performance;
- stability and steering control;
- general infrastructure effects; and
- lateral tyre forces applied to the pavement surface.

Both of these tanker transport operators use self-steering trailer axles to minimise tyre wear costs and enhance manoeuvrability delivering to petrol stations. Other tanker operators have for many years occasionally used automotive type self-steering trailer axles where the semi-trailer tanker application has required improved access for deliveries to petrol stations.

Some operators of low mass high volume freight have been requesting increased semi-trailer length, and hence increased cubic capacity, for several years now. The current request from these transport operators is for the use of the ISO standard 16.2m (53ft) intermodal shipping container in extended length tractor-semi-trailer combinations. These operators are now showing some interest in the potential to use steerable trailer axles on increased length semi-trailer combinations although they have not yet used these axles in their operations.

With a view to such applications, an Australian company has developed a linked articulation type steerable trailer axle group with the potential for significant reductions in vehicle swept path. This designer has performed tests to show that his design can steer a 16.2m (53ft) tractor-semi-trailer easily within the proposed PBS standards for low speed offtracking, while maintaining adequate stability and high speed dynamic performance [5].

Surveys of representative transport operators, manufacturers and regulatory authorities have indicated that the following heavy vehicle configuration types are those most likely to benefit from the use of steerable axles in the future:

- tri-drive rigid trucks;
- 14.9m (49ft) semi-trailer refrigerated vans;
- 15.8m (53ft) cubic freight semi-trailers;
- semi-trailer milk tankers;
- quad axle tanker semi-trailers;
- 36/38 pallet B-doubles; and

- B-double tankers.

2.3 Regulations affecting steerable axles in Australia

In Australia no regulations have been put in place specifically to address the application of steerable axles on heavy vehicles. However, some of the current Australian Vehicle Standards Rules [6] and Australian Design Rules (ADRs) do affect the use of steerable trailer axles in Australia.

ADR No.43/04 - Vehicle Configuration and Dimensions and particularly clause 6, 'Dimensions of Vehicles' provides some restriction to the application of steerable trailer axles on heavy vehicles in Australia. Rules 6.1 Total length and 6.2 Rear Overhang of this subsection specify certain maximum dimension limits on all heavy vehicle units including rigid trucks, tractor semi-trailers, dollies (drawbar length) and all vehicle units on multi-unit combinations. This rule also specifies several maximum dimension limits measured from the rear overhang line on a semi-trailer (Figure 2). These same requirements are in the Australian Vehicle Standards Rules.

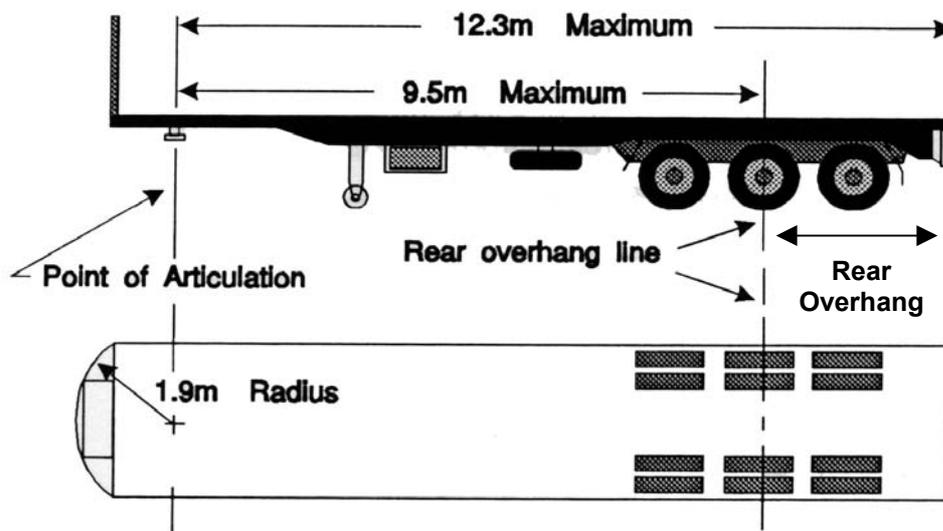


Figure 2 Definition of maximum dimensions of a semi-trailer [6]

The ADR definition of rear overhang is from the rear end to the centre of the axle group; where the axle group incorporates a steerable axle, only the non-steerable axles are considered for determining the centre of the axle group. Similarly, the Road Transport Reform (Mass and Loading) Regulations, Statutory Rules 1995 No. 56 define the rear overhang line, stating that it shall be determined “without regard to the presence of any steerable axle”.

Figure 3 illustrates the position of the rear overhang line when the rearmost axle in the triaxle group is a steerable axle. Fitting of a steerable axle at the rear of a trailer axle group will bring the rear overhang line forward, while fitting it at the front of the trailer axle group will move the trailer rear overhang line backwards. As the use of steerable trailer axles changes the definition of the trailer rear overhang line, semi-trailers constructed with steerable axles would tend to be in breach of the rear overhang regulations; while the entire axle group could theoretically be moved rearward to retain compliance with the rear overhang requirement, this would degrade the combination vehicle's load distribution.

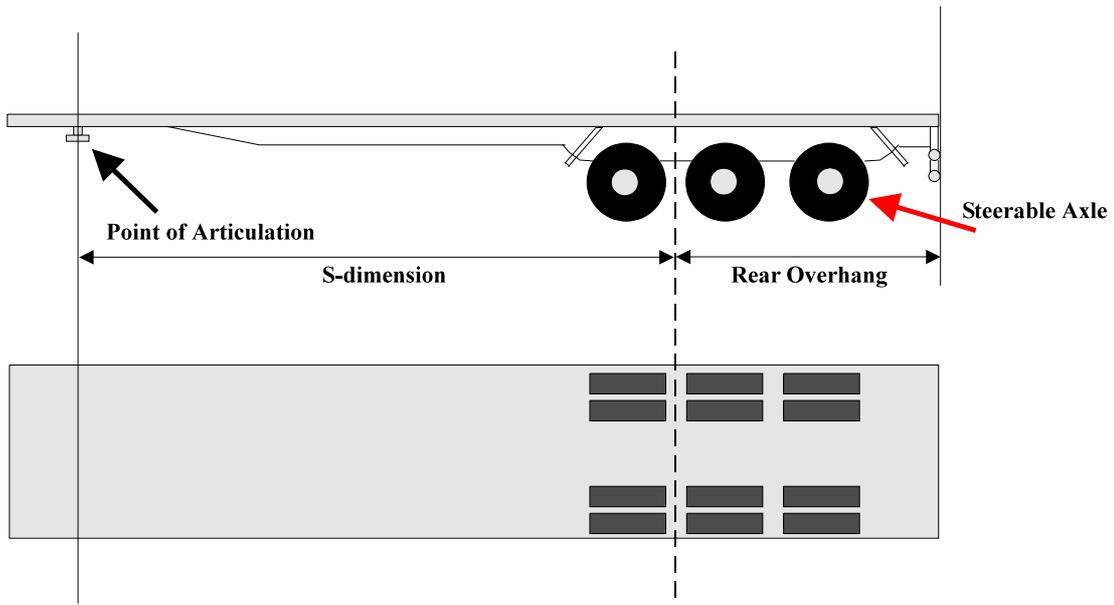


Figure 3 Effect of steerable axle on rear overhang dimension

For example if a refrigerated transport operator wanted to fit a steerable trailer axle to the rear of a 14.9m (49ft) long refrigerated semi-trailer it would be likely that this trailer would have a trailer rear overhang of approximately 3.9m- 4.4m. This would no longer comply with ADR and Vehicle Standards requirements of a maximum rear overhang of 3.7m, or 60% of the distance from the trailer kingpin to the rear overhang line, whichever is less.

The other subsection of ADR 43/04 that will indirectly relate to the use of steerable axles is Clause 9 'Retractable Axle Requirements'. The survey responses indicated that steerable trailer axles are likely to be used in combination with lift axles on some vehicle combinations. This part of the rule specifies control system requirements for deployment of retractable axles in relation to axle loads. Clause 9 also requires that lift axles comply with all the relevant requirements of clauses 6.1 and 6.2.

2.4 Overseas Regulations for Steerable Axles

German Road and Traffic Regulations (Article 38 Steering Equipment) relate to the use of steerable axles on heavy vehicles. In the case of semi-trailers with three or more axles, only one axle may be equipped with self-tracking wheels. In the case of force-steered semi-trailers, minimum requirements for steering power are specified. Articulated axles of semi-trailers must be force-steered on a pivoted bogie by means of exclusively mechanical transmission equipment.

The Land Transport Safety Authority of New Zealand issued a steerable rear axles policy for heavy vehicles in October 1996. This policy outlines a new set of regulations specifically for vehicles fitted with steerable trailer axles and redefines the maximum dimension limits and configuration of a semi-trailer when fitted with steerable axles.

This policy allowed certain increases in semi-trailer length (300mm in most cases, and semi-trailer length of 13.6m for ISO containers) provided the overall length does not exceed 17m. In order to comply, the following requirements must be met:

- tractor-semi-trailers only;
- triaxles only, with the steerable axle in the rear position;

- for speeds above 40km/h, a restoring moment must be provided, or the steerable axle must be automatically locked;
- dynamic performance assessment against a maximum high-speed dynamic offtracking of 0.60m is required;
- braking stability test on a wet road is required; and
- maintenance and compliance requirements are included.

In Europe there is a general regulation governing vehicle swept path within the EEC 70/311, 92/62 directive. These European turning circle regulations EEC 70/311, 92/62 require that a maximum length heavy vehicle, when completing a turn with an outer edge turning radius of 12.6m, must have a total swept path width within an inner radius of 5.5m.

In the UK, steerable trailer axle manufacturers claim that the provision of higher axle mass limits due to “road friendly suspension” concessions has made steerable trailer axles more popular in recent times. Forty-four tonne tractor-semi-trailer combinations are now allowed to operate on the road network in the UK. The configurations must have 6-axles (A123) and both the drive axle and the trailer axle suspensions must be certified as “road friendly”.

While general vehicle dimension limits (length and width) have remained unchanged for these combinations, they must still comply with the existing turning circle regulations in EEC 70/311, 92/62. To operate at 44t GCM within the constraints imposed, fleet operators need to take care with axle loadings and load distribution. In principle, in order to get sufficient loading on the fifth wheel coupling, the trailer triaxle group needs to be positioned further back, thus increasing the trailer s-dimension (ie kingpin to the centre of the trailer fixed axle group) and challenging this combination’s turning circle compliance.

A semi-trailer is “deemed to comply” to the regulations if the trailer s-dimension does not exceed a set dimension limit calculated from an agreed formula. For a common 38t and above GCM semi-trailer this s-dimension limit is approximately 8.1 metres. As the need to get correct axle loading will become crucial to fleet operators, this “deemed to comply” dimension limit is likely to be exceeded. In any circumstances where the s-dimension limit is exceeded, the use of a steerable trailer axle is necessary in order for the vehicle combination to meet the turning circle regulations.

Generally for a British 44t GCM tractor semi-trailer, the trailer s-dimensions would have to be approximately 8.3m for the correct load distribution. This would normally exceed the “deemed to comply” limit of 8.1m for trailer s-dimension. However, by fitting a rear steerable trailer axle, the trailer s-dimension would be reduced to approximately 7.95m, which is within the “deemed to comply” dimension limit for the turning circle requirements. The advent of 44t GCM limits for tractor-semi-trailers with no change to the overall dimensional envelope has made the use of steerable trailer axles a popular proposition for transport operators in the UK and manufacturers report that sales have increased.

2.5 Literature Review

Winkler [2], examined the potential de-stabilising influence of rear mounted self-steering axles on the yaw behaviour of straight trucks and tractor semi-trailer combinations. The freely-castering ‘booster’ axle is found generally to degrade vehicle handling characteristics and yaw stability, but it is suggested that a substantial performance improvement might be obtained with the use of more advanced steerable axle designs.

The results presented in [2] show that for a rigid truck the addition of the self-steering 'booster' axle promotes an oversteer response for the vehicle and the attendant tendency toward yaw instability. When applied to the trailer of a tractor semi-trailer combination, self-steer axles were shown to promote excessive steady-state offtracking while apparently producing a sluggish trailer response in transient manoeuvres. In all cases increasing the load on the steerable axles tended to produce a greater degradation of handling quality. The transfer of load from tyres on fixed axles capable of generating a side force to self-steering tyres that are incapable of generating side force is the essential reason for the loss of handling quality when using freely castering 'booster axles' [2].

Winkler hastens to point out that the destabilising effects reported are caused by the "free castor steering" axle and not in the characteristic, extreme rearward location of the booster axle. The extreme axle positioning should actually improve the yaw stability of the vehicle combination. However due to the free caster steering axle no additional lateral tyre forces are applied to the vehicle and the yaw stability worsens. It follows that the booster axle may hold potential for improving vehicle stability provided the side force capability of the steerable axle design is improved. Controlled steering axles or caster steer axles with a significant centring force mechanism in the design potentially can offer improvements in vehicle handling and stability [2].

Le Blanc and El-Gindy [1] also investigated the effects of self-steering axles on the stability and control of rigid trucks. They found that the presence, characteristics, positioning and loading condition of the self-steering axle affect stability and handling quality of the rigid truck. They recommended that, when a self-steering axle is fitted to a 3-axle truck: (i) the vertical load on the self-steering axle should be restricted to 6.5 tonnes, (ii) the minimum roll stiffness should be 12,000 Nm/deg and (iii) the distance from the centre of the tandem group to the self-steering axle should be in the range 25 – 50 % of wheelbase.

Woodrooffe and Senn [3] investigated the on road performance of an over length semi-trailer combination hauling 26.5m (87ft) long pipes and utilising a four axle dolly fitted with linked articulation (or turntable) type steerable axles. The study included analysis and on-road testing of a 30.5m (100ft) long A12A22 multi-combination vehicle and found that, using the two linked articulation type steering axles, the whole tandem axle group on the front of the dolly could steer as the articulation angle of the dolly fifth wheel changed.

The test results showed that this non-standard over length vehicle combination with a steerable dolly had no indication of lateral instability (such as yaw oscillations and/or hunting of the dolly) during turning manoeuvres, and had only 13% worse offtracking behaviour when compared to a standard tractor-semi-trailer [3].

In this study, and in previous work by Woodrooffe [7], it was found that a certain amount of yaw damping is required within the steering mechanism of the dolly in order to overcome any propensity to initiate unstable steering or yaw behaviour. The existence of sufficient yaw damping within the axle steering system eliminates the need for external dampers. The most likely sources of yaw damping within the steerable axle mechanism used are likely to be the 'cup and saucer' type fifth wheel used and the through shaft that transfers the steering linkage to the tandem axle group at the front of the dolly.

More recently, steerable axles have received a considerable amount of research attention in the context of the use of "C-dollies" in the US and Canada. A C-dolly is a double-drawbar dolly connected to the rear of a tractor-semi-trailer combination, for supporting and towing a second semi-trailer. This arrangement represents an approximation to a B-double, but using a standard semi-trailer as the lead unit. The C-dolly has a single axle which needs to

be steerable because it is located a significant distance rearward of the lead semi-trailer axle group.

Canadian researchers [8] analysed and recommended certain self-centring characteristics for steerable axles on C-dollies and a major US testing program [9] was devoted to the performance of “C-trains”. It was found that C-dollies improve the dynamic performance of double trailer combinations, but at a cost: tyre costs were higher on C-dollies and certain costs are associated with maintenance of the steerable axle (although these were modest). While tyre costs would certainly be much higher on C-dollies if steerable axles were not employed, the results showed that the automotive-type steerable axles deployed on C-dollies were not able to compensate for all of the tyre scrubbing introduced by the rearward location of the C-dolly relative to the lead semi-trailer axle group. The results also showed that the use of one steerable axle in the double trailer combination did not harm the dynamic performance of the combination vehicle.

The subject of innovative dollies for doubles combinations was fully examined by Winkler [10] who identified and tested a range of dolly types including:

- conventional A-dolly;
- C-dolly (automotive-steer and turntable-steer);
- various double-drawbar dollies;
- forced-steer dolly (where the dolly is forced to articulate relative to the lead trailer); and
- linked-articulation dolly (where the normal movement of the rear trailer is partially restricted).

This work showed that innovative dollies offered significant performance advantages. Specifically considering steerable axles, it was found that the yaw damping of a doubles combination is significantly influenced by the level of steering resistance of the C-dolly’s steerable axle.

3. SEMI-TRAILER LENGTH LIMITS

All heavy vehicle configuration types (rigid trucks, tractor-semi-trailers, truck-trailers, B-doubles, road trains, etc) are subject to vehicle length limits. These limits comprise (i) external dimensions (such as overall length, width and height) and (ii) “internal” dimensions (such as rear overhang). However, the tractor-semi-trailer – which is a dominant Australian freight vehicle - is the only combination where the trailer unit has a specific length limit. The existence of this limit – and its value at any point in time – are of some significance to the productivity, flexibility and re-equipping practices of Australian trucking fleets.

The requirements of ADR 43/02 effectively limit semi-trailer length to 13.7m. However, general permits are available to operate semi-trailers up to 14.6m in length. Current indications are that, in semi-trailer body types which utilise maximum length (ie non-high-density bulk), 80 – 85% of semi-trailers are currently built at 13.7m and 15 – 20% are built at approximately 14.6m. It would appear that the reasons for the relatively low take-up of the longer semi-trailers are:

- demand for 14.6m (48ft) length was driven by the need to transport intermodal containers of this length;
- while this length potentially allows palletised operations to switch from 13.7m to 14.6m trailers and add one pallet along the side of the trailer (increasing from 11 pallets to 12), it is not sufficient for 12 pallets in practice;
- semi-trailer types which require front and rear walls and ancillary equipment (such as refrigerator units and airflow systems) are particularly pressed to load 12 pallets within 14.6m length;
- current restrictions on the semi-trailer “s-dimension” (see below) mean that the 14.6m trailer cannot position the triaxle group in an optimum manner with regard to load distribution: the triaxle group tends to be overloaded and therefore the combination vehicle cannot achieve maximum Gross Combination Mass (GCM) while also remaining in compliance with axle group load limits; and
- the use of 14.6m semi-trailers in B-doubles is specifically excluded from the general permits (although there are no other trailer length restrictions currently applicable to B-doubles) and the flexibility of the fleet use of 14.6m semi-trailers is therefore significantly curtailed for many operators.

The above discussion is somewhat over-simplified because semi-trailer length limits are not expressed as simple maximum length values. Figure 2 shows the ADR (and Australian Vehicle Standards Rules 1999) length factors which combine to affect semi-trailer length:

- the distance from the kingpin to the rear end is limited to 12.3m;
- the forward projection from the kingpin is limited by a “swing radius” of 1.9m maximum; taken together with the ADR maximum vehicle width of 2.5m, this equates to a forward dimension limit of 1.43m measured along the side of the trailer;
- the distance from the kingpin to the centre of the axle group is limited to 9.5m; and
- the rear overhang is limited to the lesser of 3.7m or 60% of the s-dimension.

NSW Government Gazette No 59 (1999) permits the following semi-trailer maximum dimensions (with the exception of livestock vehicles, B-doubles and road trains):

- the length is limited to 14.63m (not including any equipment or items of reduced width in the forward projection area);
- the forward projection from the kingpin is limited by a “swing radius” of 1.9m maximum; taken together with the ADR maximum vehicle width of 2.5m, this equates to a forward dimension limit of 1.43m measured along the side of the trailer;
- the distance from the kingpin to the centre of the axle group is limited to 9.5m; and
- the rear overhang is limited to 3.7m.

While there are some subtle differences in the way in which semi-trailer lengths are controlled in national and state regulations, the key points in controlling semi-trailer length are:

- the forward projection is a key dimension for interchangeability of prime movers and semi-trailers (it can also affect swing-out in low-speed turns);
- the s-dimension affects low-speed offtracking (as well as the ability to achieve balanced load distribution);
- the rear overhang affects tail swing in the initiation of low-speed turns; and
- the distance from the kingpin the rear end affects the overall length of the combination vehicle (although this is limited separately to 19 m in the Australian Vehicle Standards Rules 1999).

Recently, refrigerated transport operators and refrigerated trailer manufacturers have strongly supported marginal increases in semi-trailer length beyond 14.6m. Refrigerated semi-trailers benefit from marginal length increase to 14.9m (49ft) because:

- 12 pallets can be practically and consistently accommodated (while this is only theoretically achievable within 14.6m (48ft));
- insulating properties of the front and rear walls can be improved;
- high-capacity refrigerator units may be used; and
- internal flow of refrigerated air and return air may be enhanced.

Representatives of this sector have shown that tractor-semi-trailers incorporating 14.9m (49ft) semi-trailers will meet the Austroads General Arterial swept path envelope, and remain within an overall length of 19m provided that a cab-over-engine (COE) prime mover is utilised and the prime mover wheelbase does not exceed approximately 4m.

NSW Government Gazette No 37 (1999) permits the following semi-trailer maximum dimensions for refrigerated trailers (with the exception of B-doubles and road trains):

- the length is limited to 14.9m (not including any equipment or items of reduced width in the forward projection area);
- the forward projection from the kingpin is limited by a “swing radius” of 1.9m maximum; taken together with the ADR maximum vehicle width of 2.5m, this equates to a forward dimension limit of 1.43m measured along the side of the trailer;
- the distance from the kingpin to the rear end is limited to 13.6m;
- the distance from the kingpin to the centre of the axle group is limited to 9.9m; and
- the rear overhang is limited to 3.7m.

It is apparent that the refrigerated trailer sector were the group most affected by the inability to fit 12 pallets, trailer structures and ancillary services within a length of 14.6m. However, the benefits of marginal length increases extend well beyond refrigerated trailers. Curtainsiders today represent the major class of semi-trailer manufactured in Australia. In order to accommodate the front and rear walls plus supports for mezzanine floors and realistically allow for 12 imperfectly-stacked pallets per side, it is estimated that 15m overall length is required.

In considering the benefits and impacts of marginal increases in semi-trailer dimensions it is appropriate to consider two options:

- the introduction of a 15 m semi-trailer with a fixed (conventional) triaxle (and s-dimension set to permit effective load distribution); and
- the introduction of a 15m semi-trailer with an axle group comprising two fixed axles and one steerable axle (and s-dimension set to permit effective load distribution).

3.1 Potential 15m Semi-Trailer (Fixed Axle Group)

Figure 4 shows the potential 15m semi-trailer with a fixed axle group in combination with the longest prime mover which will allow the vehicle to comply with the Austroads General Access Swept Path Specification. The 15m semi-trailer should have an s-dimension of 10m in order to provide effective load distribution. It is apparent that this combination remains within an overall length of 19m, but the wheelbase of the prime mover is somewhat limited.

Candidate 15m Tractor-semi-trailer (A123) with fixed axles

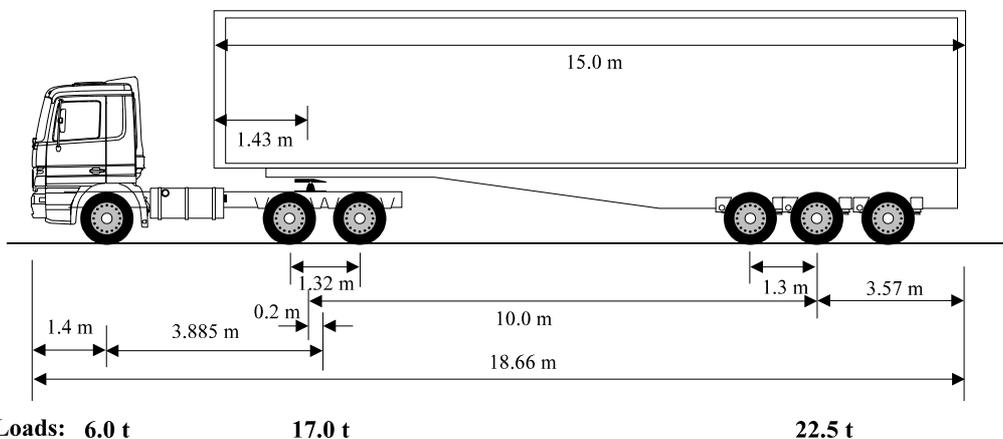


Figure 4 15m semi-trailer (fixed axle group) combination

If such a semi-trailer were to be permitted under a regulatory scheme of prescriptive limits, it should be noted that combinations involving prime movers which result in an overall length of 19m will slightly exceed the General Access Swept Path Specification. If this were accepted, effective prescriptive limits for this semi-trailer would be:

- the length is limited to 15m (not including any equipment or items of reduced width in the forward projection area);
- the forward projection from the kingpin to be limited by a “swing radius” of 1.9m maximum; taken together with the ADR maximum vehicle width of 2.5m, this equates to a forward dimension limit of 1.43m measured along the side of the trailer;
- the distance from the kingpin to the centre of the axle group to be limited to 10m; and

- the rear overhang to be limited to 3.7m.

As the overall length of the combination would be limited to 19m, there is no need to limit the distance from the kingpin to the rear end.

3.2 Potential 15m Semi-Trailer (Steerable Axle Included)

Figure 5 shows the potential 15m semi-trailer with an axle group comprising two fixed axles and one steerable axle in combination with the longest prime mover which will allow the vehicle to comply with the Austroads General Access Swept Path Specification. This 15m semi-trailer has an s-dimension of less than 10m, but the distance from the kingpin to the load-bearing centre of the triaxle group remains at 10m in order to preserve effective load distribution. It is apparent that this combination exceeds 19m in overall length and the wheelbase of the prime mover is less restricted.

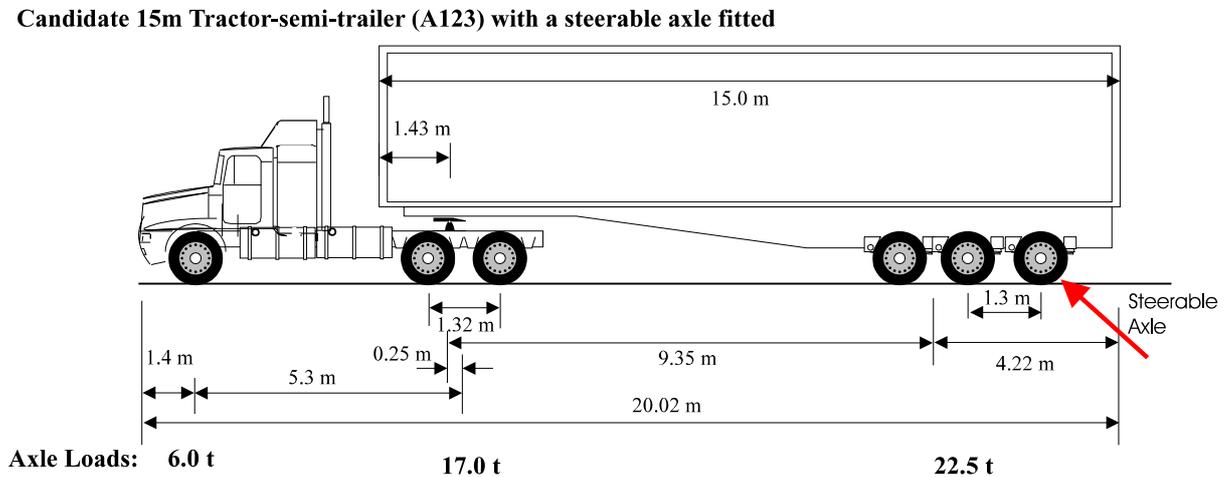


Figure 5 15m semi-trailer (steerable axle included) combination

If marginal exceedence of 19m overall length were to be accepted and such a semi-trailer were to be permitted (for example, under a general permit), effective prescriptive limits for the 15m steerable semi-trailer would be:

- the semi-trailer length to be limited to 15 m (not including any equipment or items of reduced width in the forward projection area);
- only one steerable axle is permitted and must be fitted in the rear position;

- the forward projection from the kingpin to be limited by a “swing radius” of 1.9m maximum; taken together with the ADR maximum vehicle width of 2.5m, this equates to a forward dimension limit of 1.43m measured along the side of the trailer;
- the distance from the kingpin to the centre of the axle group (as currently defined, taking into account the presence of the steerable axle) to be limited to 9.35m;
- the rear overhang to be limited to 4.7m; and
- the overall length of the combination to be limited to 20m.

Some simple criteria for the performance of the automotive steering axle would also be needed.

3.3 Summary – Potential for Marginal Semi-Trailer Length Increases

Marginal changes in semi-trailer length limits would permit more effective use of longer semi-trailers within the constraints of the road and traffic system.

General permitting of 15m long semi-trailers would allow 12 pallets to be loaded with effective load distribution in the combination vehicle. This would greatly improve the practicality and usage of maximum-length trailers in the “48 ft” class.

This could be done based on a 15m long fixed triaxle semi-trailer within the current 19m overall length limit. While the increased pallet loading would be a clear benefit, some combinations would have slightly increased swept path and prime movers would be very limited in wheelbase.

Alternatively, the 15m long semi-trailer could be introduced with an axle group comprising two fixed axles and one steerable axle. Advantages would be:

- increased pallet loading in a broad range of operations;
- reduced tyre wear, and tyre and pavement scrubbing in turns;
- ability to use prime movers with a broader range of wheelbases;
- swept path performance would not be subject to “creep”;
- and disadvantages would be:
- increased trailer cost related to the steerable axle; and
- increased overall length (beyond 19m).

4. PRIME MOVER LENGTH

Unlike semi-trailers, prime movers are not subject to any length limitations per se. It is only when used in combination with semi-trailers of fixed dimensions that the length dimensions of the prime mover impact on dimensional compliance, and this occurs in relation to the overall length limit. This can be a particular issue for tractor-semi-trailer and B-double combinations.

The prime mover length dimensions of significance are:

- wheelbase (this is measured from the steering axle to the centre of the rear tandem axle group);
- front overhang (the distance from the steering axle to the front end – either the bumper or bull-bar if fitted);
- fifth wheel lead (the distance from the centre of the rear tandem axle group to the centre of the fifth wheel jaws);
- and these dimensions are illustrated in Figure 6.

Prime Mover Dimensions affecting overall combination length

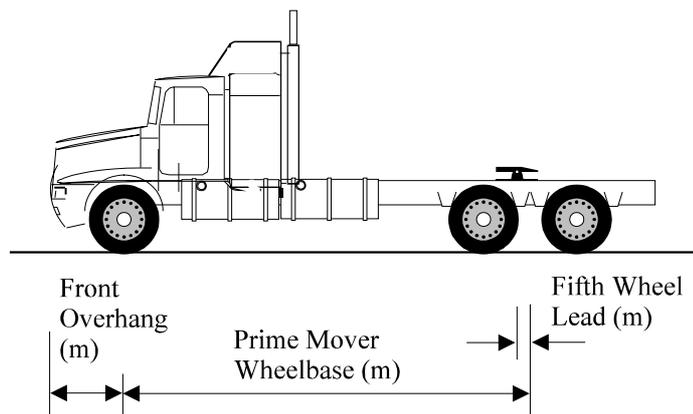


Figure 6 Prime mover dimensions affecting combination overall length

Prime movers are produced in two basic designs: conventional, or bonnetted, prime movers and cab-over-engine (COE) prime movers. There are some designs which are effectively a hybrid of these two basic types.

Conventional prime movers tend to have the following dimensional characteristics:

- longer wheelbase, typically covering the range 4.4 m through 7.0m;
- shorter front overhang, typically 0.8m; and
- greater fifth wheel lead, typically 200 – 300mm (because steering axle tare weights are generally lighter and greater fifth wheel lead places more of the trailer weight on the steering axle).

COE prime movers tend to have the following dimensional characteristics:

- shorter wheelbase, typically covering the range 3.2m through 4.4m;
- longer front overhang, typically 1.2 – 1.4m; and

- shorter fifth wheel lead, typically 100 – 200mm (because steering axle tare weights are generally heavier).

In terms of their effect on overall length of the combination, conventional prime movers lead to greater overall length due to their significantly greater wheelbases; however, this is tempered by the fact that their front overhangs are shorter and their fifth wheel leads are greater.

Prime mover wheelbase is therefore a significant issue. The wheelbase dimension – and related generic type (conventional vs COE) - has an influence on a number of aspects of combination vehicle operation and performance:

- the overall length of the combination vehicle – longer wheelbase challenges overall length limits;
- available space for the driver's cabin and sleeper cab, if fitted – longer wheelbase provides more space;
- ride quality – longer wheelbase tends to improve ride;
- directional stability – longer wheelbase tends to be more stable;
- fuel capacity – longer wheelbase allows more fuel to be carried; and
- driver entry and egress – longer wheelbase tends to improve driver access.

When it comes to low-speed geometric performance, the dimensional characteristics discussed above in relation to length (wheelbase, front overhang and fifth wheel lead) all have an effect, but additional factors also make a contribution:

- wheel cut (the maximum steering angle available at the front wheels); and
- the extent of front corner rounding treatments (the width of the prime mover across its frontal plane).

In recent times, 14.6m (48ft) semi-trailers have been permitted general access and 14.9m (49ft) refrigerated semi-trailers have been permitted in NSW; all combinations using such trailers must comply with the overall length limit of 19m. This places significant constraints on prime mover length dimensions, including wheelbase and “bumper to back of cab”. The latter dimension determines whether a conventional bonnetted cab may be accommodated, or COE style is required, and the presence and size of the sleeper cab.

In the case of B-doubles, there has been increasing pressure on prime mover length dimensions: the overall length limit has remained at 25m and the aggregate trailer length has increased so that pallet capacity has increased from 32 to 34 pallets, and in some cases to 36 pallets. This has meant that relatively short COE prime movers are the norm for B-doubles.

Taking into account the lengths of current semi-trailers and B-double trailers, and the prevailing overall length limits of 19m and 25m respectively, prime mover selection and utilisation may be adversely affected in that:

- shorter wheelbase COE prime movers need to be used in most B-doubles;
- shorter wheelbase COE prime movers need to be used with most 14.6m (48ft) or 14.9m (49ft) semi-trailers; and
- longer wheelbase conventional prime movers may be used with the industry-dominant 13.7m semi-trailer.

The increasing attention being paid to driver occupational health and safety issues such as ride quality, fatigue and cab ergonomics, and to the analysis of dynamic performance (including the development of PBS), is likely to create a demand for increased prime mover length dimensions. In such cases, the inclusion of a steerable trailer axle may permit longer prime movers to be used while the low-speed geometric performance of the combination is retained.

For example, the use of a steerable axle on the 14.9m (49ft) semi-trailer may allow a wider choice of prime movers, including longer wheelbases and conventional cab designs, while maintaining an acceptable swept path. This would also be true for the 14.6m (48ft) semi-trailer, where prime mover usage is somewhat restricted.

While the economic benefits of this flexibility of prime mover usage are difficult to quantify, some operators believe that the benefits of greater flexibility would be substantial. Some operators also believe that the current level of pressure on prime mover length factors is detrimental to the safety and welfare of heavy vehicle drivers.

5. POTENTIAL FOR PRODUCTIVITY INCREASES WITH STEERABLE AXLES

Steerable axles potentially offer productivity benefits in (i) increased cubic capacity for road freight vehicles and (ii) increased gross mass for road freight vehicles (within existing axle mass limits).

Increased cubic capacity is related to increased trailer length and increased length of rigid trucks, leading to increased “load length” of the vehicle or vehicle combinations. Such length increases will be constrained in the first instance by low-speed geometric performance considerations, and may be further constrained by considerations of dynamic performance (tracking and stability behaviour or infrastructure impacts).

Increased mass is a less direct consequence of the use of steerable axles, but could arise from:

- the ability to place additional axles on existing configurations without incurring unacceptable tyre scrub; for example, a quad axle semi-trailer with one steerable axle in the quad group; and
- the ability to introduce heavier axle groups spaced further apart (to maintain compliance with bridge formulae) and still retain acceptable low-speed geometric performance.

All of these potential mass increases refer to gross mass and current axle group mass limits are not exceeded. In the case of the quad axle group, there is no current axle group mass limit; for the purposes of this draft report, a value of 27 tonnes has been assumed for the road-friendly quad axle mass limit.

Each of the following key vehicle configuration types have been considered to determine the potential for increased length with the use of steerable axles:

- rigid trucks and prime movers
- tractor-semi-trailers
- B-double combinations
- double and triple road trains.

This potential has been judged in two ways:

- against currently-proposed PBS standards; and
- against current benchmark vehicles based on the investigations of the current Australian fleet carried out under the PBS project.

The following low-speed geometric performance measures have been evaluated:

- swept path width
- tail swing
- frontal swing

and the well-accepted VPath program was used for this work.

For this investigation, the available steerable axles types were reduced to two generic concepts which encompass the range of potential benefits:

- automotive-steering steerable axle type with minimal restoring moment; and

- linked-articulation steerable axle type where the trailer axle group steers in proportion to the articulation angle between the prime mover and trailer.

Increased vehicle length will also impact on other PBS measures, and important issues such as dynamic stability and high-speed dynamic offtracking are evaluated in Section 6 of the report.

5.1 Increased Cubic Capacity

The potential for increased length on candidate steerable axle combinations was investigated using the Vpath computer simulation program. This software was used to simulate the low-speed swept path turning performance of heavy vehicle combinations fitted with and without steerable axles. Vpath accommodates the simulation of vehicles fitted with the self-steering type axles. It does not accurately simulate the performance of vehicles fitted with linked-articulation type systems. Vehicle models built using the Autosim® software package and RATED simulation models have been used to represent these more complex steering system.

These simulations were used to evaluate the standard low-speed geometric performance measures outlined in the Austroads-NRTC Projects A3 & A4 [11]. The measures that were used are:

- maximum swept path width (in the recommended 90 degree turn)
- frontal swing
- tail swing.

The automotive-type steerable axle used in the simulations represented the best swept path performance likely to be available with the type of product most likely to be used on Australian roads. The survey revealed that automotive-type steerable axles were currently the most widely accepted and used steerable axle in the Australian transport industry. However there are an increasing number of innovative steerable axle systems and products that have been developed and are under consideration by regulatory authorities for use on the public road system. The linked-articulation system considered was based on one such Australian innovation.

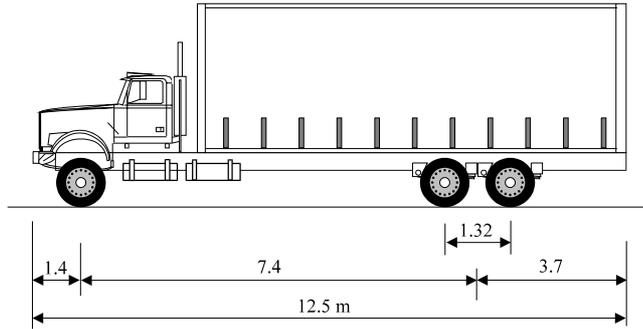
Low-speed performance measures were evaluated at increments of increased overall vehicle length. These simulations were performed for the following vehicle configurations:

- rigid trucks
- tractor-semi-trailers
- B-doubles.

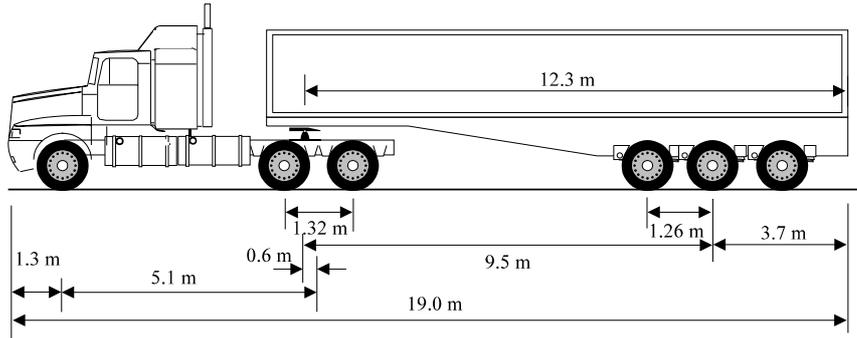
Increased length was included in both rear overhang and s-dimension for each candidate vehicle type. A self-steering automotive type axle was fitted to the rear axle of each trailer group in these configurations. As the linked-articulation system was developed specifically for semi-trailers, it was considered for the tractor-semi-trailer vehicle configuration only.

The baseline vehicles used are shown in Figure 6. The dimensions for these vehicles were determined from previous work in the Austroads-NRTC Projects A3 & A4 characterising the Australian heavy vehicle fleet [12]. The baseline vehicle simulation results were compared against those at increased vehicle lengths for vehicles fitted with steerable axles.

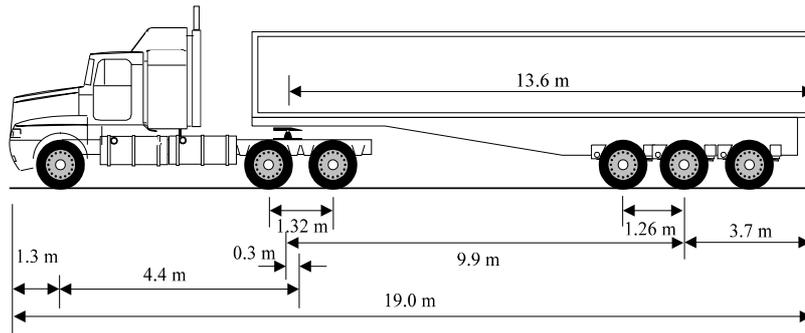
Baseline Rigid Truck (R12)



Baseline Articulated (A123) Heavy Vehicle (48ft semi)



Baseline Articulated (A123) Heavy Vehicle (49ft semi)



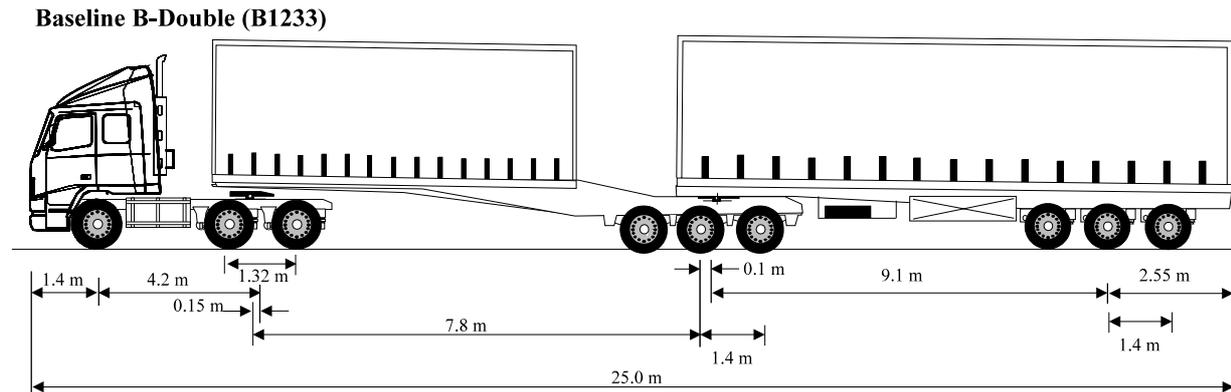


Figure 7 Baseline vehicles simulated to investigate increased length potential

5.1.1 Rigid truck (R12) with rear axle steerable conversion

The results showing the effect of an increase in vehicle rear overhang are shown in Figure 8. Here we can see that the use of a steerable axle will keep the vehicle total swept path width below the proposed Austroads/NRTC standard of 5m for vehicle total swept path width on local roads even when length increases up to 2m. We can also see that frontal swing is not effected by an increase in trailer rear overhang and the 1.5m standard is not approached. The tail swing for this vehicle is shown to increase with an increase in rear overhang. The results show that rear overhang can increase by approximately 350mm before the proposed tail swing standard is breached.

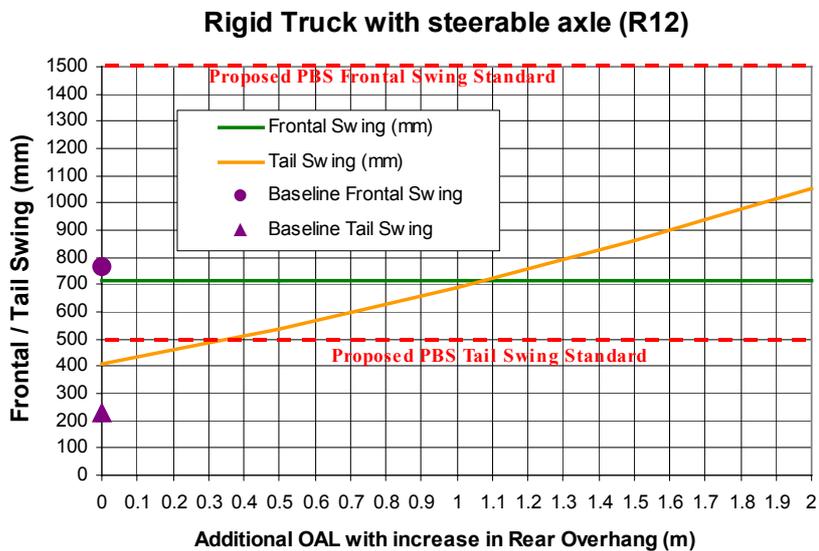
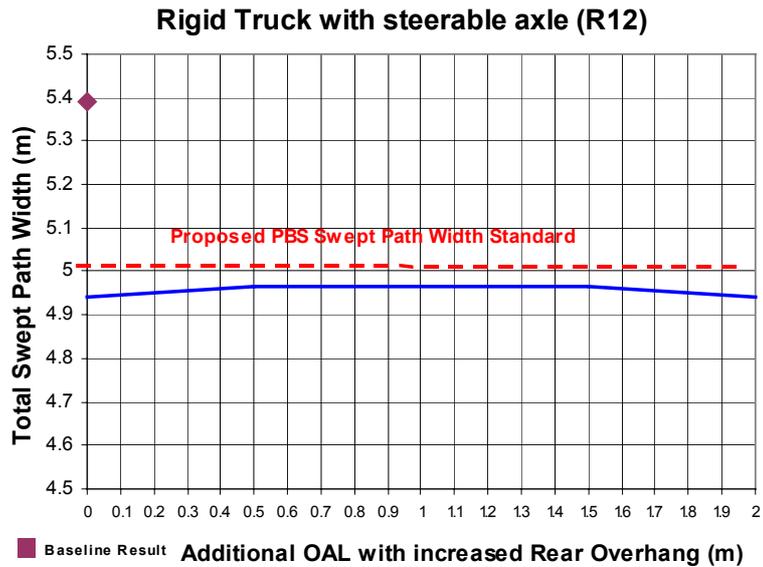


Figure 8 Geometric performance for a rigid truck (R12) with a rear axle steerable conversion and increased rear overhang

Figure 9 shows simulation results for the rigid truck when the wheelbase dimension was incrementally increased up to 2m. The top chart shows that a 150mm length increase would be possible for a rigid truck with a steerable rear axle before the proposed total swept path width standard is breached. However, the baseline vehicle already breaches the proposed PBS standard. The results also show that an increase in truck wheelbase does not significantly increase frontal swing or tail swing.

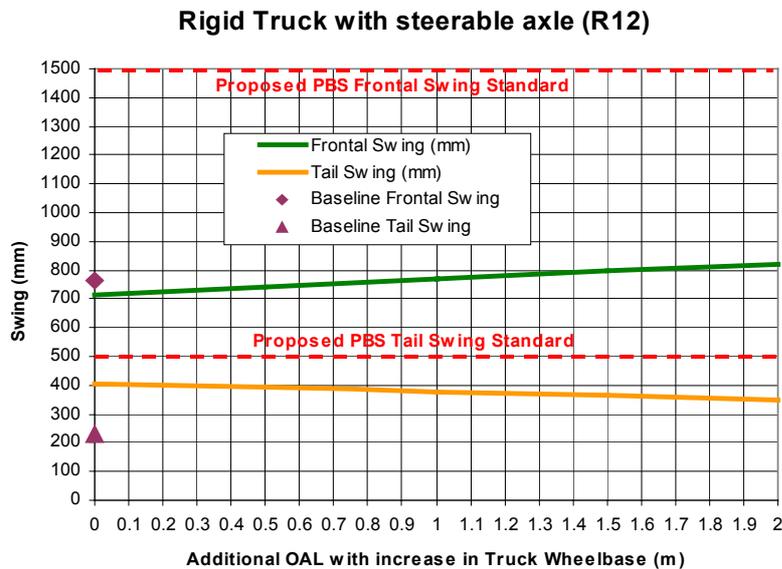
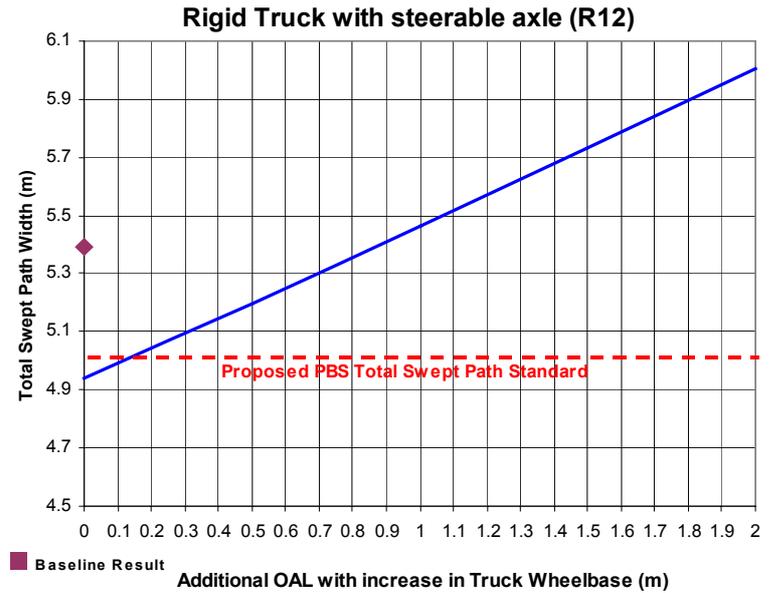


Figure 9 Geometric performance for a rigid truck (R12) with a rear axle steerable conversion and increased wheelbase

5.1.2 Tractor-semi-trailer (A123) with steerable trailer axle on rear

The results showing the effect of an increased trailer rear overhang can be seen in Figure 10. Here the top chart shows that use of a steerable axle will keep the vehicle total swept path width below the proposed Austroads /NRTC standard of 7.4m (for arterial roads) even when length is increased by 2m. It is also apparent that frontal swing is not affected by an increase in trailer rear overhang and the 1.5m standard is not approached. The tail swing for this vehicle is shown to increase with an increase in rear overhang. The results show that rear overhang can increase by approximately 1250mm before the proposed tail swing standard is breached.

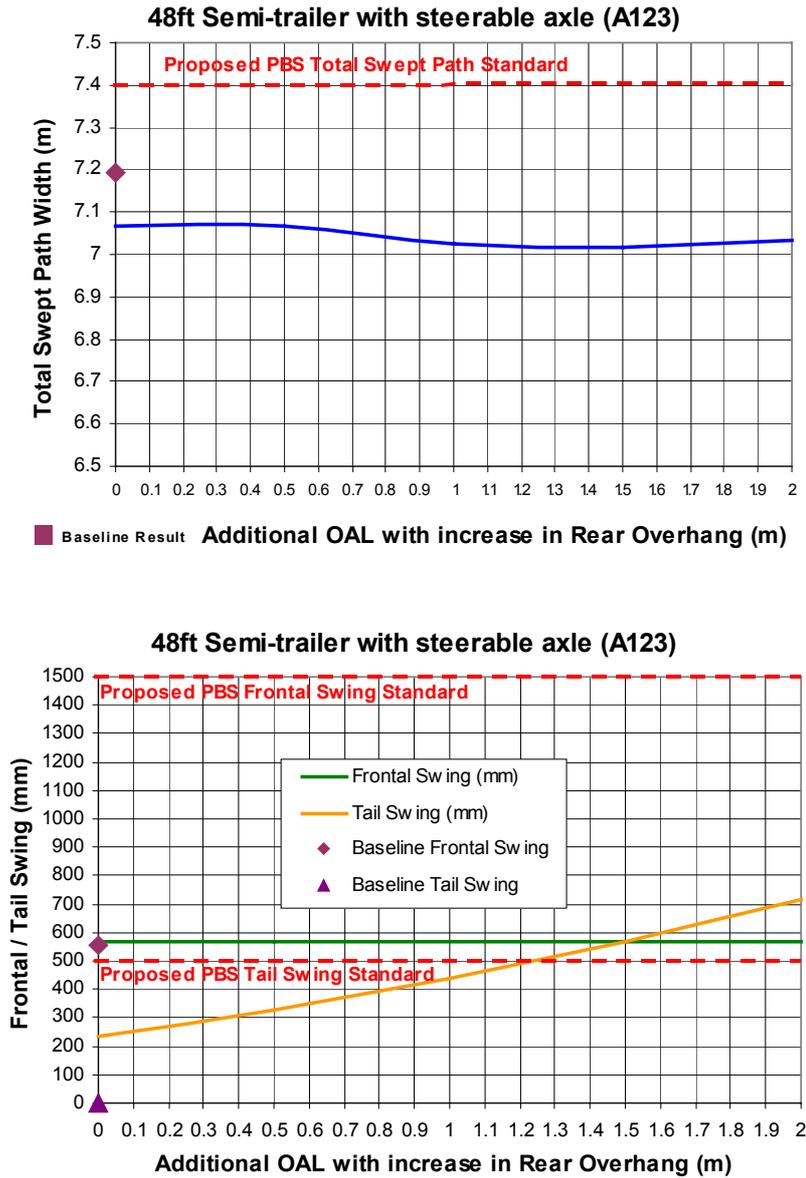


Figure 10 Geometric performance for the tractor semi-trailer (A123) with a rear axle steerable conversion and increased trailer rear overhang

Figure 11 displays simulation results for the where the semi-trailer s-dimension was incrementally increased to 2m. The top chart shows that a 750mm length increase would be possible for a 14.6m (48ft) long semi-trailer with a steerable rear axle before the proposed total swept path width standard is breached. The results also show that an increase in trailer s-dimension is does not affect frontal swing. The tail swing was found to breach the proposed standard only when overall vehicle length increased by up to 1250mm.

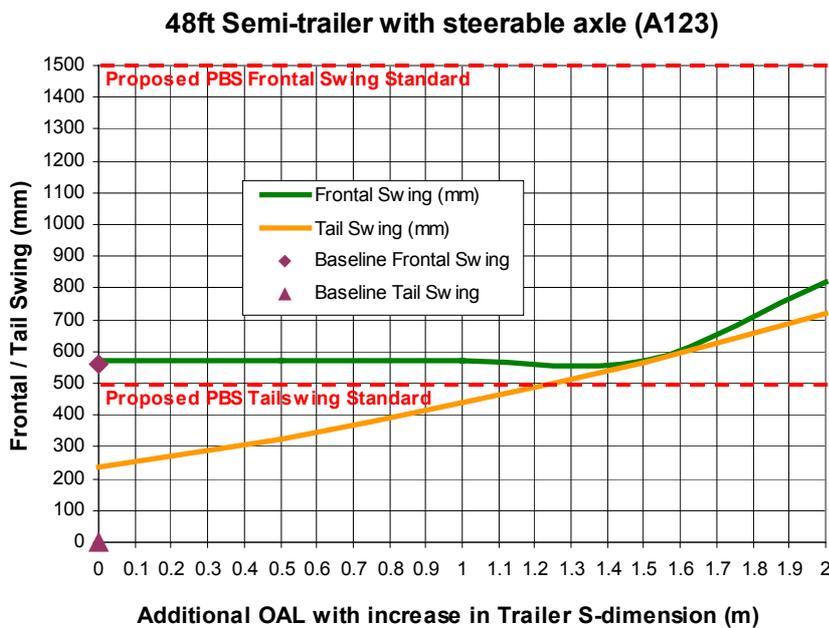
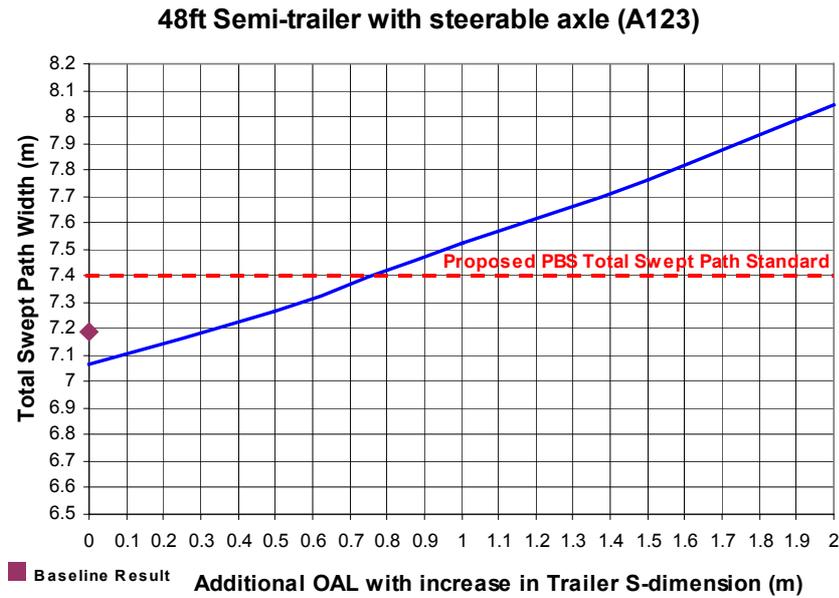


Figure 11 Geometric performance for the tractor semi-trailer (A123) with a rear axle steerable conversion and increased trailer s-dimension

5.1.3 Tractor-semi-trailer (A123) - marginal length increases

With reference to the case for marginal semi-trailer length increases beyond “48/49ft” (see Section 3), swept path simulations were carried out for the baseline 14.9m (49ft) combination, to determine the effects of increased length on swept path width and tail swing. These results are given in Figure 12. It is apparent that the following marginal increases in semi-trailer length dimensions may be sustained without breaching standards, provided that a steerable axle is used:

- 0.4m increase in s-dimension
- 1.2m increase in rear overhang.

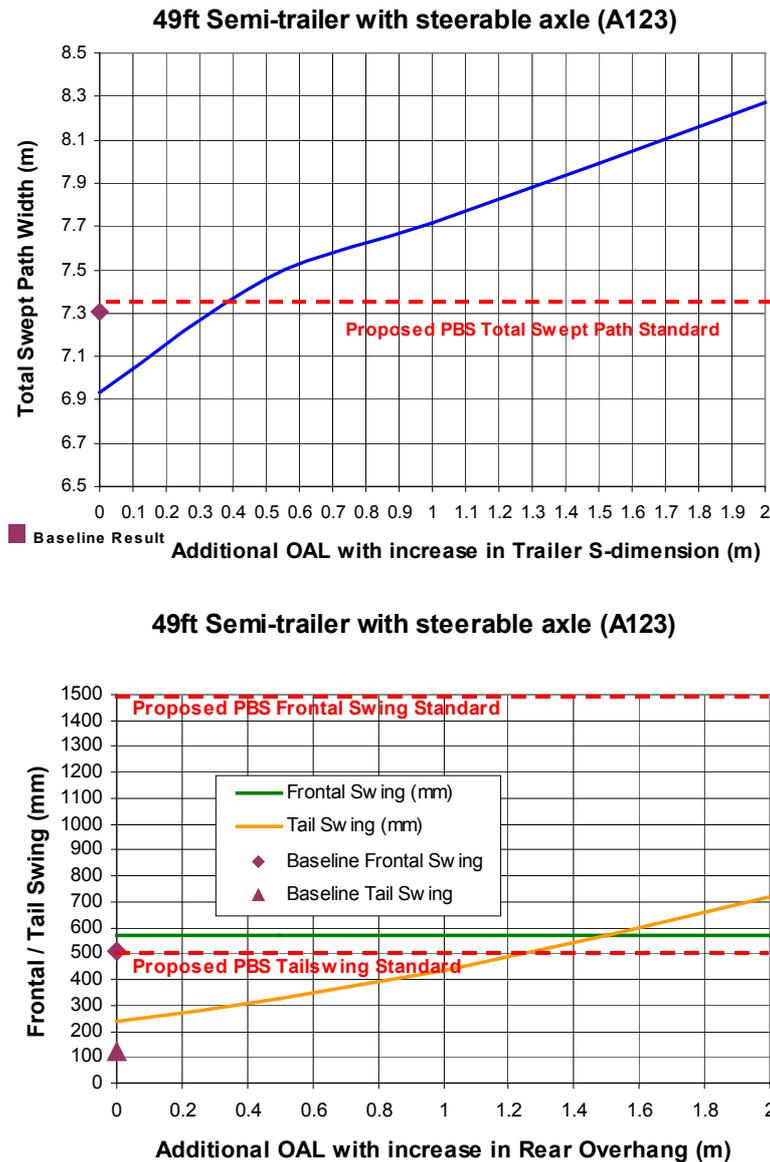


Figure 12 Geometric performance for the 14.9m (49 ft) tractor semi-trailer (A123)

5.1.4 Tractor-semi-trailer (A123) with linked-articulation steering

Previous work [11] has demonstrated that a linked-articulation system can improve a 16.2m (53ft) long semi-trailer total swept path width by up to 600mm when compared to a standard 14.6m (48ft) vehicle without steerable axles. The total swept path width for this 21.08m long semi-trailer combination with linked-articulation trailer axle steering was found to be 6.7m. Based on these results, the following initial estimates were made for semi-trailer potential length increases when using a linked-articulation system.

The linked-articulation steering system dramatically improves vehicle swept path and it is estimated that an additional 3.0 - 3.5m overall length could be added to this vehicle before it breaches the proposed NRTC/Austrroads standard of 7.4m total swept path width. It is also estimated that the an increased overall length of 3.8m could be possible before the tail swing of the combination breach the proposed NRTC/Austrroads tail swing standard of 0.5m. The frontal swing of the vehicle combination is dependent on the prime mover geometry of the combination and hence it would not change with increased trailer length.

5.1.5 25 metre B-double (B1233) with two steerable trailer axles

The results showing the effect of an increased trailer rear overhang can be seen in Figure 13, showing that the use of steerable axles will keep the vehicle total swept path width well below the proposed Austroads /NRTC standard of 10.1m, even when length is increased by 3m. The results also show that rear overhang can increase by approximately 2.8m before the proposed tail swing standard is breached.

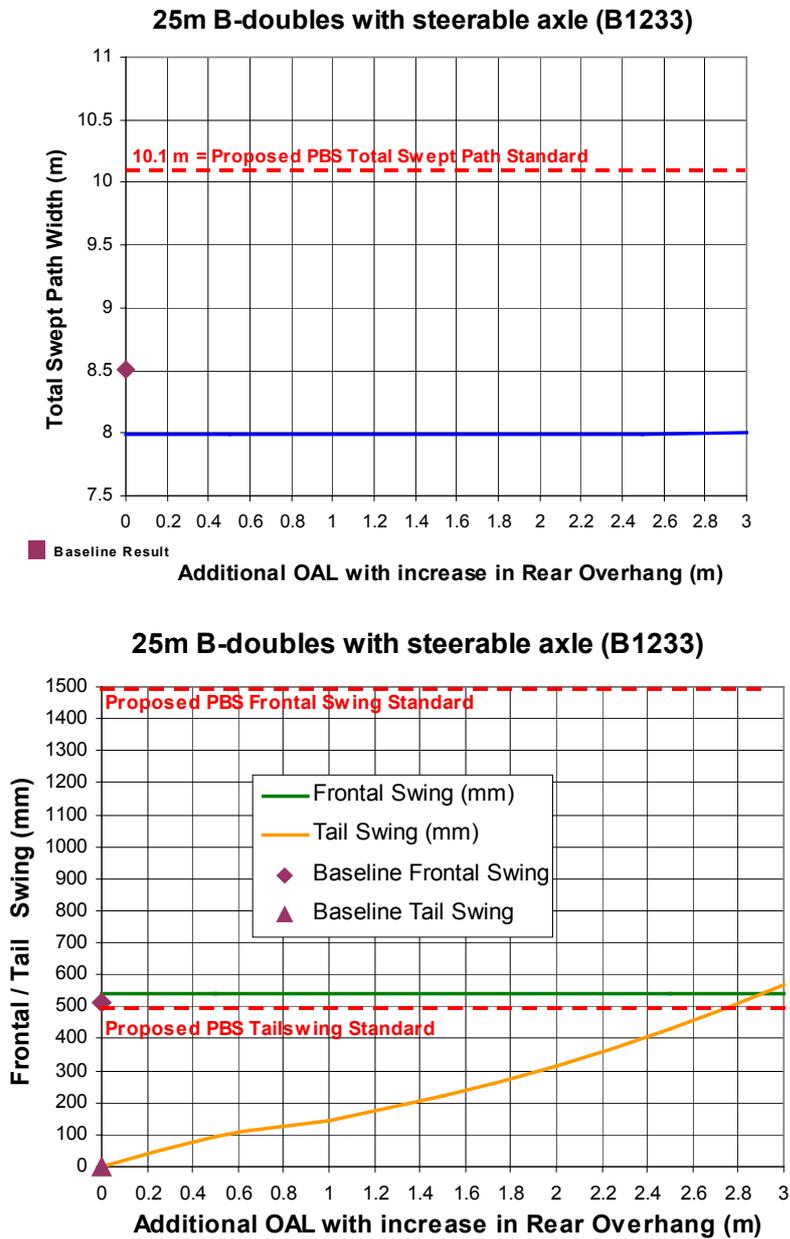


Figure 13 Geometric performance for the for the 25m B-double (B1233) with 2 rear axle steerable conversions and increased trailer rear overhang

Figure 14 displays simulation results for the case where the rear trailer s-dimension was incrementally increased to 3m. The top chart shows that an additional 3.0m length results in 9.4m total swept path width for this combination, a result well below the proposed standard. The results also show that an increase in trailer s-dimension does not affect frontal swing. The tail swing was shown to be inconsequential.

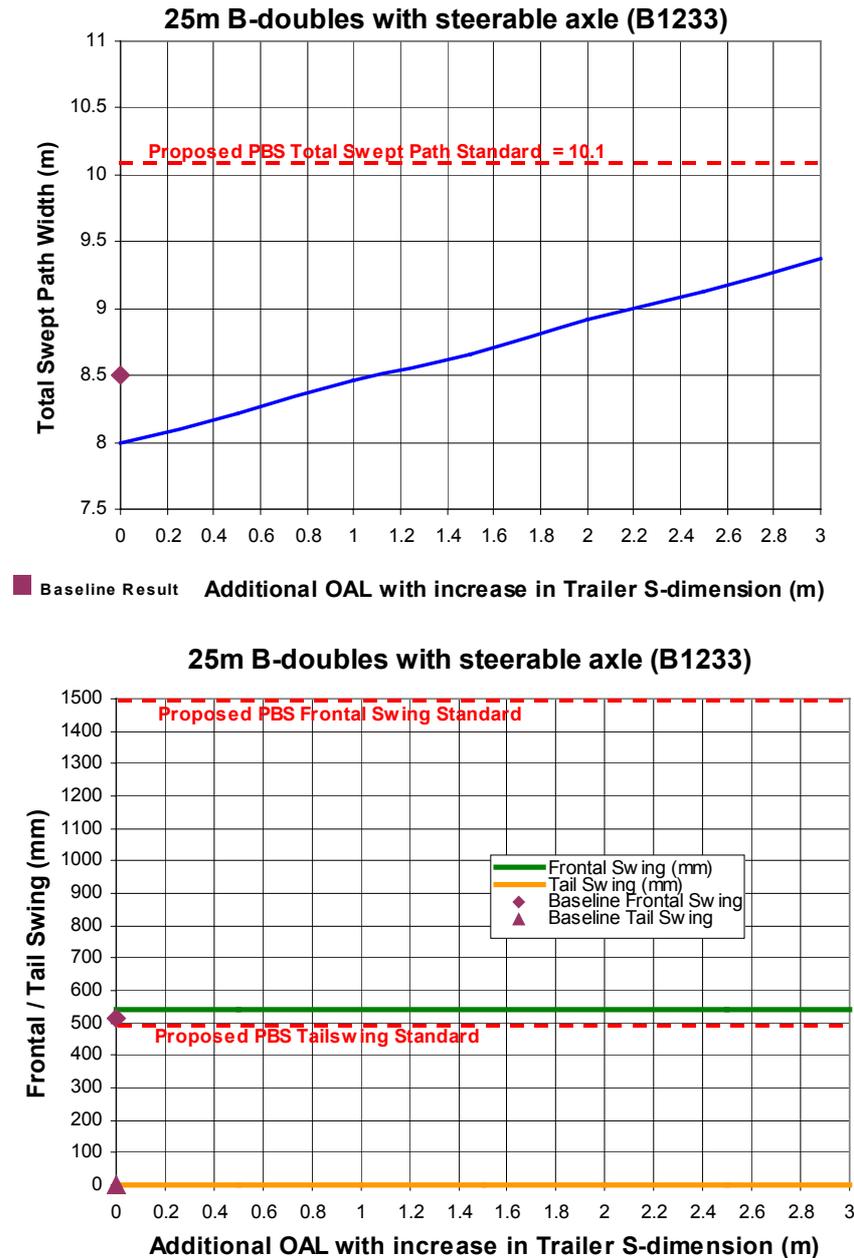


Figure 14 Geometric performance for the for the 25m B-double (B1233) with 2 rear axle steerable conversions and increased trailer s-dimension

It should be noted that the above variations in B-double length parameters encompassed the case of a standard 14.6m (48ft) trailer being used as the rear trailer of the B-double set. Currently, 14.6m (48ft) semi-trailers may not be used in B-double combinations. With increasing numbers of 14.6m (48ft) semi-trailers in fleets, there will be increasing industry interest in using 14.6m (48ft) semi-trailers in B-double combinations. This flexibility of trailer usage would have certain economic benefit, but this would need to be weighed against the cost of steerable axle conversion.

5.1.6 Road trains

In the case of road trains (double and triple), the prime constraint on the use of steerable axles is likely to be dynamic performance, rather than low-speed geometric performance. It

is also unlikely that conventional double and triple road trains will be specific candidates for high-cube innovation using steerable axles; rather, there will be eventual interest in applying innovations developed for semi-trailers in road train combinations.

5.2 Increased Mass Capacity

In the case of rigid trucks, it is possible to add a steerable axle to a 6x4 or 8x4 rigid truck, potentially increasing the allowable gross mass.

In the case of articulated vehicles, if “heavier” axle groups may be spaced further apart to meet applicable bridge formulae and the vehicle configuration can still meet relevant low-speed geometric performance standards, there is potential for increased payload mass as a result of the use of steerable axles. This could occur for tractor-semi-trailers and B-doubles.

In the case of road trains (double and triple), concessional mass concepts already exist in the form of:

- tri-drive prime movers (although these have raised some specific infrastructure concerns);
- concessional triaxle group mass up to 23.5 tonnes; and
- triaxle dollies;

and these concepts have significantly improved road train productivity with perhaps some concerns about dynamic performance impacts.

The use of steerable axles in road trains offers the following possibilities:

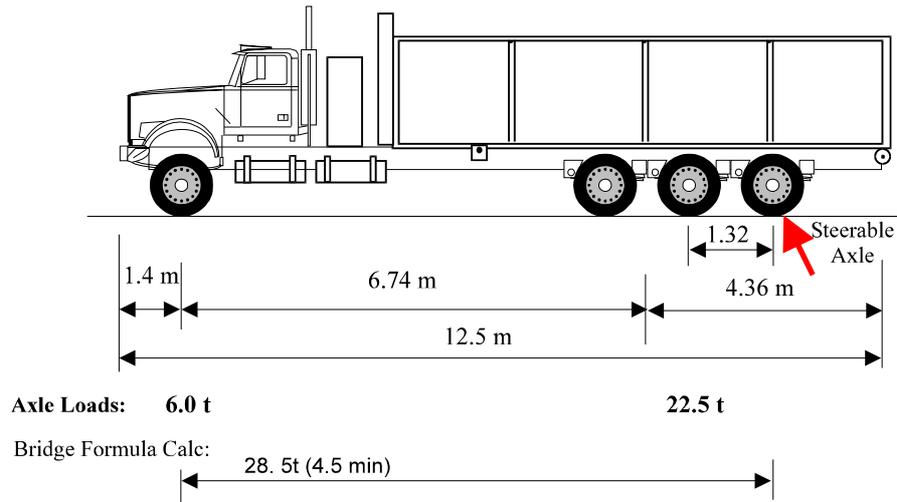
- reduction of pavement surface effects from tri-drive prime movers, although the engineering may not be straightforward and the incremental capital costs could be significant;
- conversion of concessional-mass triaxle groups to quad axle groups, reducing pavement impacts and improving dynamic performance (if necessary); and
- the introduction of high-mass road trains for high-density products, incorporating quad axle groups including steerable axles (in areas where bridge limitations are of lesser concern, or on specific routes).

5.2.1 Rigid Trucks

Figure 15 shows examples of rigid trucks fitted with rear-mounted dual-tyred steerable axles. Provided such arrangements are load sharing, the following gross mass increases would be possible:

- an additional 5.5 tonnes on road-friendly 6x4 rigid trucks; and
- an additional 5.5 tonnes on road-friendly 8x4 vehicles.

Rigid Truck (6x4) with added steerable axle



Rigid Truck (8x4) with added steerable axle

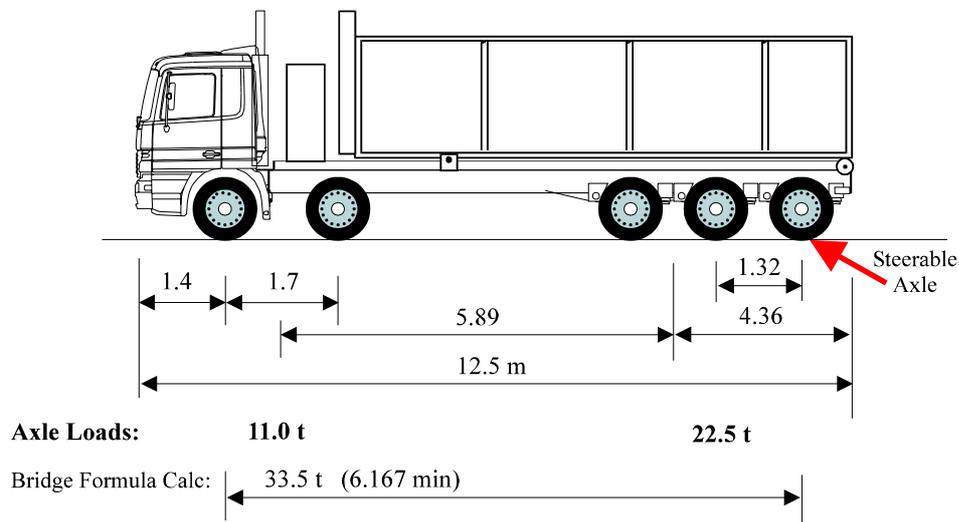


Figure 15 Examples of rigid 6x4 and 8x4 trucks with rear mounted dual-tyred steerable axles

5.2.2 Maximum loading on 14.6 m (48 ft) semi-trailers

Industry experience with 14.6m (48ft) semi-trailers indicates that it is difficult to achieve the correct load distribution under current requirements for s-dimension and at current (non-road-friendly) mass limits. Specifically, the tri-axle group tends to be loaded more than 20t when the s-dimension is maximised. If it were possible to move the axle group rearward with the fitment of a steerable axle, this problem could be overcome and the productivity benefits would be:

- ability to load 14.6m (48ft) semi-trailers consistently to the maximum of 42.5t; and
- encouragement to use more 14.6m (48ft) trailers (with associated benefits for operators who are also volume-constrained).

It should be noted that the use of road-friendly axle group mass limits, in particular 22.5t on the tri-axle group), tends to reduce the existing mass distribution problem for 14.6m (48ft) semi-trailers. Therefore, the magnitude of the productivity benefits discussed above will

depend on the rate of full introduction and network coverage of road-friendly mass limits in key States.

5.2.3 High-mass tractor-semi-trailers

The introduction of the quad axle semi-trailer incorporating a steerable axle would potentially offer:

- increased mass in relation to the additional semi-trailer axle; recent consideration of such a concept, in conjunction with a State transport agency, utilised a load of 27t on the road-friendly quad axle group, representing a significant gross mass increase of 4.5t; the 27t axle group loading was discussed with Vicroads, including bridge engineers, as has received favourable consideration; and
- control over potential adverse impacts of a fixed quad axle group (which may include increased swept path, tyre wear and pavement surface wear).

The practical embodiment of such a vehicle would depend on:

- compliance with the general access bridge formula (for both extreme axles and axle 2 to axle 7);
- correct positioning of the quad axle group on the semi-trailer in order to maintain the optimum load distribution between the drive axle group and trailer axle group;
- semi-trailer overall length which would accommodate the minimum s-dimension needed to meet the bridge formula, along with sufficient rear overhang as to not overload the drive axle group;
- minimising the overall length of the combination while accommodating the above requirements; and
- maximising the flexibility of prime mover specification (in terms of cab type (conventional or cab-over-engine (COE), wheelbase and front overhang).

Figure 16 shows an example of the quad axle (steerable) semi-trailer combination which meets the general access bridge formula for road-friendly vehicles, is capable of optimum load distribution for a water-level load and utilises a standard-length 14.6m (48ft) semi-trailer. This vehicle has the following characteristics:

- overall length of 1875m (with a conventional prime mover of moderate wheelbase);
- semi-trailer length of 14.6m;
- s-dimension of 9.5m; and
- rear overhang of 4.35m (in excess of current limit).

Simulation of this vehicle with Vpath showed that:

- swept path width is 6.65m
- tail swing is 230mm
- frontal swing is 316mm

and all of these values meet proposed PBS requirements for general access; swept path is better than that of the baseline 14.6m (48ft) semi-trailer combination.

(A124) Tractor Semi-Trailer - (Increased mass capacity with additional steerable axle)

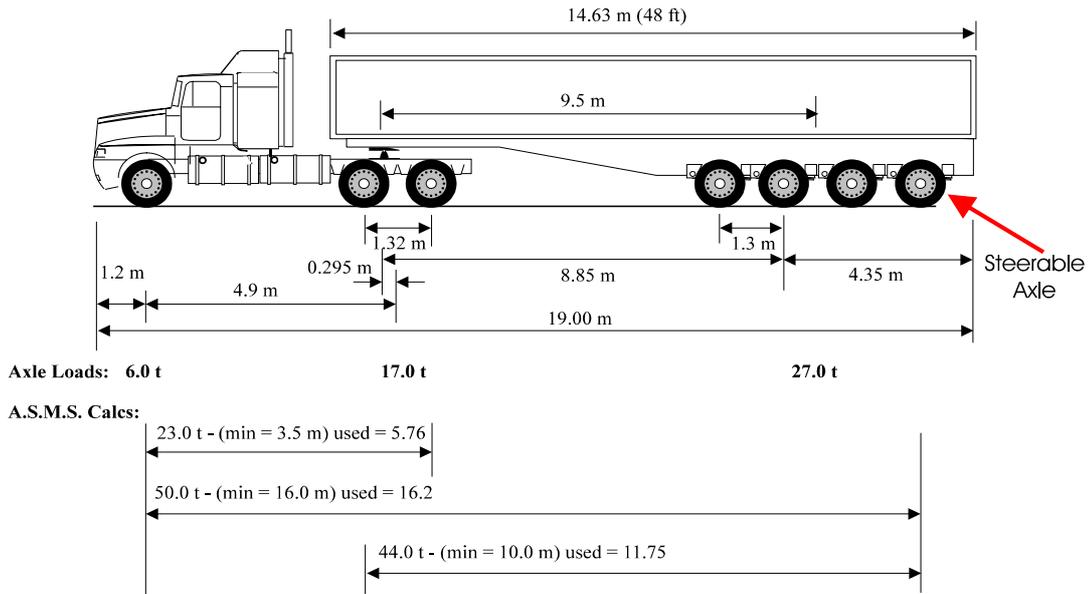


Figure 16 Example of general-purpose 50 t quad axle (steerable) tractor-semi-trailer (A124)

5.2.4 High-mass B-doubles

The potential for increased mass on longer B-double combinations utilising quad axle groups incorporating steerable axles has been investigated. Consideration has been given to quad axle loads of 27t (as for the semi-trailer considered above) and axle group locations to satisfy all road-friendly bridge formula requirements for B-double routes. Figure 17 shows the B1244 vehicle configuration, dimensions and mass considered. This vehicle would have a GCM of 77t and an overall length of 31.7m; the rear trailer would have an overall length of 15.8m (52ft). Simulation of this vehicle with Vpath showed that:

- swept path width is 10.1m
- tail swing is 95mm
- frontal swing is 620mm

and the low-speed geometric performance is therefore at the limit of the proposed PBS swept path width for major freight routes.

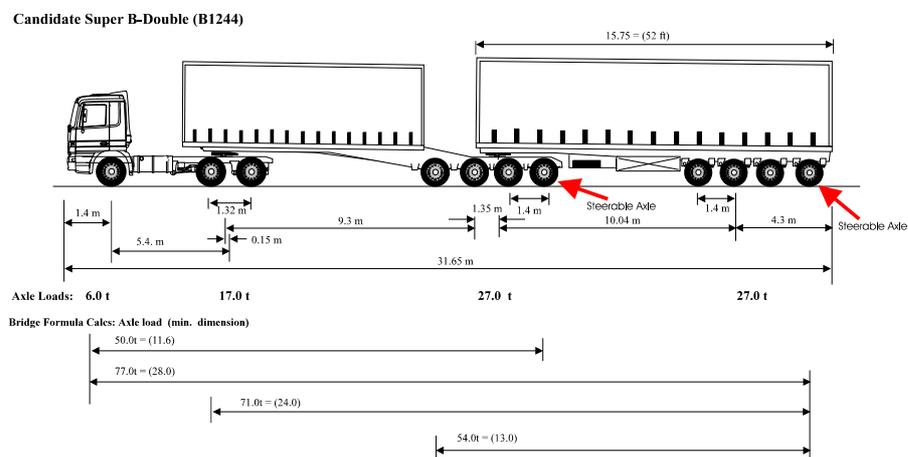


Figure 17 Candidate high-mass B-double using two steerable axles (B1244)

Note that the above treatment of the “road-friendly” allowance in the bridge formula assumes the same allowance for quad groups as is currently allowed for triaxle groups. Road-friendly allowances for quad groups with regard to bridges would need to be considered by relevant Austroads experts.

As a further, and shorter, option consideration has been given to a B1234 configuration, as shown in Figure 18. This vehicle would have a GCM of 72.5t and an overall length of 28.5m; the rear trailer would have an overall length of 14.63m (48ft). Simulation of this vehicle with Vpath showed that:

- swept path width is 8.52m
- tail swing is 169mm
- frontal swing is 620mm

and the low-speed geometric performance is therefore well within the proposed PBS swept path width for major freight routes. Compared with the benchmark 25m B-double that has a total swept path width of 8.54m, the total swept path width of the high-mass B1234 is virtually the same at 8.52m.

(B1234) Candidate B-Double - (Increased mass capacity achieved by adding 2 steerable trailer axles)

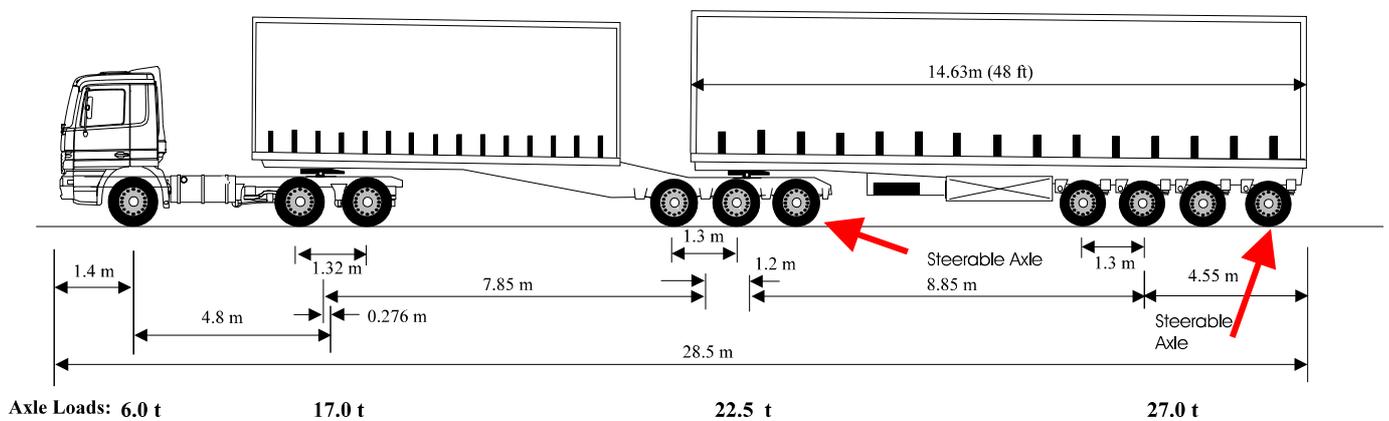


Figure 18 Candidate high-mass (B1234) B-double using two steerable axles

5.2.5 High-mass road trains

Figure 19 shows a potential triple road train configuration utilising quad axle groups (each incorporating one steerable axle). Depending on the axle group mass allowed on the quad axle, it is anticipated that the GCM of such a road train would be 158.2t and the overall length approximately 51m. This arrangement would provide a GCM increase of approximately 10.5t and could be attractive for the haul of high-density products such as mineral concentrates.

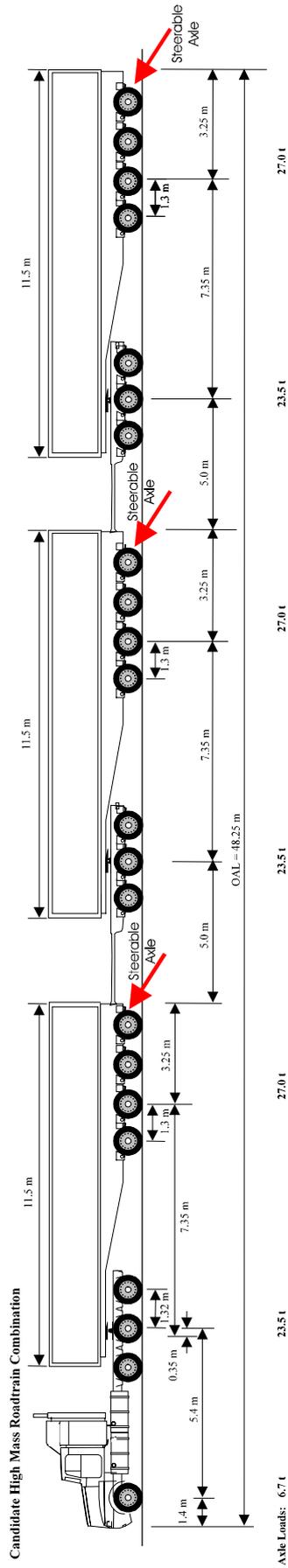


Figure 19 Potential high-mass road train using three steerable axles

5.3 Overall Potential for Productivity Increases

Investigations of the potential for steerable axles to overcome low-speed geometric constraints and generate productivity improvements in Australian road freight operations showed that:

- rigid trucks have little potential for cubic productivity increases with steerable axles (R12 & R22);
- the addition of one steerable axle to rigid trucks (6x4 and 8x4) would potentially add 5.5t in gross mass to these configurations (R13 & R23); effects on handling and stability are examined in Section 6;
- the range of cubic productivity (length) increases for semi-trailers (A123) ranges from 1.2m (1 pallet) for automotive-type steerable axles to 3.8m (over 3 pallets) for linked-articulation steering systems;
- a cubic productivity (length) increase of up to 2.8m (over 2 pallets) appears to be possible with the use of automotive-type steerable axles on B-doubles (one on each trailer) (B1233);
- a semi-trailer gross mass increase of 4.5t appears to be possible with a quad axle with one automotive-type steerable axle (B124); this concept works well with a standard 14.6m trailer length and could have wide appeal;
- a B-double gross mass increase of 9t appears to be possible with a quad axle (with one automotive-type steerable axle) fitted to each of the lead and rear trailers (B1244); this B-double would have a 15.8m rear trailer, an overall length of 31.7m and swept path on the limit of PBS recommendations for major freight routes; bridge experts would need to consider the appropriate value of “road-friendly” bridge allowances for road-friendly quad groups; and
- a B-double gross mass increase of 4.5t appears to be possible with a quad axle (with one automotive-type steerable axle) fitted to the rear trailer (B1234); this B-double would have a 14.6m rear trailer, an overall length of 28.5m and swept path virtually the same as the benchmark 25m B-double; bridge experts would need to consider the appropriate value of “road-friendly” bridge allowances for road-friendly quad group.

Current utilisation of 14.6m (48ft) semi-trailers is constrained by difficulties in achieving correct load distribution between axle groups (and hence maximum GCM) under current non-road-friendly mass limits and s-dimension limits. This could potentially be addressed by allowing the axle group to be located further rearward and the conversion of the rear axle to a steerable axle (to preserve swept path).

There appears to be significant potential for marginal semi-trailer length increases (less than 1 pallet), slightly beyond the current 14.6m general permit and the 14.9m 49ft refrigerated trailer length initiative. It would appear that a 15m semi-trailer with either a fixed triaxle group or two fixed axles and a steerable axle would have wide potential for increasing the industry take-up of longer semi-trailers in general.

Semi-trailers at “48ft/49ft” place limitations on the flexibility of prime mover usage within the 19m overall length limit. The use of one automotive-type steerable axle on these semi-trailers could significantly expand the available prime movers in terms of:

- general use of bonnetted, or conventional, cab types;

- increased prime mover wheelbase from 4.4m to 6m for 14.9m (49ft) trailers (while retaining the same swept path);
- and this would have the potential to reduce prime mover replacement costs and to offer improved handling and ride quality in some cases.
- A similar effect would occur with B-doubles: for a given set of B-double trailers, the prime mover wheelbase could be increased and the swept path performance retained.
- An increase in fleet equipment flexibility may also occur if 14.6m (48ft) semi-trailers fitted with steerable axles could be used in B-doubles. Acceptable low speed geometric performance of B-double combinations including 14.6m trailers could potentially be retained if the 14.6m trailer was fitted with one steerable axle.
- The 14.6m (48ft) triaxle semi-trailer incorporating one automotive-type steerable axle would have the dual potential of:
 - use in tractor-semi-trailers (A123) incorporating longer-wheelbase conventional cab prime movers; and
 - use in B-double combinations (not currently permitted).

Given that current semi-trailer production appears to be predominantly 13.7m, with 14.6m trailers having disadvantages and remaining in the minority, there would appear to be productivity synergy in the 15m triaxle semi-trailer incorporating one automotive-type steerable axle, in that:

- all types of palletised loads would be able to load 12 pallets per side;
- load distribution would be improved along with the ability to load consistently to maximum GCM without overloading the triaxle group;
- the 15m triaxle semi-trailer incorporating one automotive-type steerable axle also has the potential to allow more flexible prime mover use (including longer wheelbase conventional cab prime movers);
- this longer trailer could potentially be used in B-double combinations; and
- this conversion from 13.7m to 15m trailers would produce productivity benefits in semi-trailer operations as well as in B-double operations.

While steerable axles appear to offer limited productivity benefits to road trains, there is potential for high-mass, high-product-density road trains using quad groups incorporating one automotive-type steerable (subject to bridge considerations). Available GCM would increase by approximately 10.5t.

5.4 Field of Benefits

Table 1 summarises the field of potential productivity benefits associated with the use of steerable axles. Table 2 summarises the potential benefits in fleet equipment flexibility with the use of steerable axles. It should be noted that this is an “inclusive” list based on low-speed geometric considerations and engineering judgement only; analysis of safety, infrastructure and economic impacts is undertaken in Section 6.

Table 1 Field of potential benefits using steerable axles - productivity

Vehicle Configuration	Steerable Axle Use	Productivity Benefit	Likely Scope	Comment
1. Increased Cubic Capacity (Length)				
Tractor-semi-trailer (A123)	Rear axle converted to non-driven auto-steer type (A123)	1.2 m increase in load length (beyond 14.6 m)	Wide appeal for volume-limited operations; allows 1 additional pallet	Involves > 19 m overall length
Tractor-semi-trailer (A123)	Linked-articulation triaxle group fitted to trailer (A123)	Approx. 3.8 m increase in load length	Allows 3 additional pallets. Scope limited by adoption of technology	Overall length would greatly exceed 19 m
Tractor-semi-trailer (A123) (15 m long)	Rear axle converted to non-driven auto-steer type (A123)	Allows loading of 12 pallets per side for all commodities plus consistent loading to maximum GCM	Would increase take-up of maximum length semi-trailers	Involves > 19 m overall length
B-double (B1233)	Rear axle of each trailer converted to non-driven auto-steer type (B1233)	Approx. 2.8 m increase in load length	Significant appeal for volume-limited B-doubles	Overall length would increase to approximately 28 m
2. Increased Gross Mass (at current axle mass limits)				
6x4 rigid truck (R12)	Non-driven auto-steering type added in rear position (to R13)	5.5 t increase in GCM	High-density applications	Handling quality to be checked
8x4 rigid truck (R22)	Non-driven auto-steering type added in rear position (to R23)	5.5 t increase in GCM	High-density applications	Handling quality to be checked
Tractor-semi-trailer (A123) with 14.6 m (48 ft) trailer	Rear axle converted to non-driven auto-steer type (A123) (with associated rearward movement of triaxle group)	Ability to achieve maximum GCM without exceeding axle mass limits	Increased potential for conversion from 13.7 m to 14.6 m trailers (but still tight for 12 pallets per side)	Load distribution is poor with 14.6 m trailers
Tractor-semi-trailer (A123)	Non-driven auto-steering type added in rear position (to A124)	4.5 t increase in GCM	Wide appeal for mass-limited operations	Minimum trailer length (14.6 m) would not suit tippers etc
B-double (B1233)	Non-driven auto-steering type added in rear position to each trailer (to B1244)	Approx. 9 t increase in GCM	Access would be limited by increased swept path, which is on limit of PBS major freight route recommendation	Overall length in excess of 31 metres is likely; minimum length (and hence degree of access) would depend on bridge road-friendly factors approved for quad axle groups
B-double (B1233)	Non-driven auto-steering type added in rear position to rear trailer (to B1234)	Approx. 4.5 t increase in GCM	Significant potential as swept path is the same as benchmark 25 m B-double	Overall length (28.5 m) exceeds 25 m
Road train (A123T33T33)	Non-driven auto-steering type added in rear position to each trailer (to A124T34T34)	Approx. 10.5 t increase in GCM	High-density applications	

Table 2 Field of potential benefits using steerable axles – equipment flexibility

Vehicle Configuration	Steerable Axle Use	Productivity Benefit	Likely Scope	Comment
1. More Flexibility in Prime Mover Use				
Tractor-semi-trailer (A123)	Rear axle converted to non-driven auto-steer type (A123)	Flexibility to use longer-wheelbase prime movers with “48 ft/ 49 ft” trailers -potential reduction in capital cost	Limited - would require additional investment in equipment with current productivity level	Potential benefits in stability and driver comfort
B-double (B1233)	Rear axles of both trailers converted to non-driven auto-steer type (B1233)	Flexibility to use longer-wheelbase prime movers - potential reduction in capital cost	Limited - would require additional investment in equipment with current productivity level	Potential benefits in stability and driver comfort
2. More Flexibility in Trailer Use				
B-double (B1233)	Rear axle of 14.6 m (48 ft) rear trailer converted to non-driven auto-steer type (A123)	1.2 m increase in load length (1 pallet) plus the flexibility to use “existing” 14.6 m (48 ft) semi-trailers in B-doubles	Could develop wide appeal in B-double operations; 48 ft trailer with steerable axle could potentially be used in both (i) A123 with longer prime mover and (ii) B-double combination	Additional cost of steerable axle to be considered; feasibility of retrofitting to be considered

6. GEOMETRIC AND SAFETY IMPACTS OF STEERABLE AXLES

This section of the report documents the safety performance assessment carried out for all steerable axle vehicle combination options developed in Section 5. For each of the candidate steerable axle vehicles identified in Tables 1 and 2, a PBS safety performance assessment was performed with the aid of computer simulation. This was done by evaluating each candidate vehicle's performance against the draft NRTC PBS measures and initial standards (11) as well as benchmarking against currently operating Australian heavy vehicles.

6.1 Computer simulations: safety performance measures

Simulation models developed by Roaduser Systems Pty Ltd were used to evaluate the dynamic performance of both the subject steerable axle vehicle combinations and the benchmark vehicles representing current practice for road freight vehicles.

Roaduser Autosim Truck Engineering Dynamics (RATED) models were used to simulate each of the candidate vehicle combinations and assess their dynamic performance against the following proposed NRTC performance measures and initial standards (11):

- static roll stability
- load transfer ratio
- rearward amplification
- high-speed dynamic offtracking
- high speed offtracking
- total swept path width
- frontal swing
- tail swing
- yaw damping.

Details of each of these relevant PBS performance measures are described in the next section of the report.

All of the vehicles were simulated with air suspension on drive axles and trailer axles, including any steerable axles. All of vehicles were simulated with standard 11R22.5 dual-tired axles throughout.

Special consideration was given to low-speed geometric performance, as this is strongly impacted by steerable axles and the more "active" types of steerable axles can challenge conventional assumptions and approaches.

6.1.1 Low-speed geometric performance

Low-speed turning performance was approached via the relevant NRTC low-speed directional performance measures and initial standards: low-speed offtracking (LSOT), tail swing, frontal swing and total swept path width. However, recent work (5) evaluating vehicle combinations that utilise self-steering trailer axles has shown that the conventional low-speed offtracking performance measures need to be re-considered.

The LSOT performance measure turns out to require careful definition when assessing the low-speed dynamics of vehicles that have rear mounted command (or force) steering axles. This can be seen in the forced steering action of a semi-trailer that is fitted with linked articulation type steerable trailer axles. As the trailer axles steer due to semi-trailer articulation in a low speed turn, point on the vehicle which encroaches most on the inside of the turn changes.

LSOT is the maximum distance from the rearmost axle path to that of the steer axle path in a defined low speed turn (11). For the linked articulation semi-trailer vehicle the resultant vehicle swept path in a low speed manoeuvre is as shown in Figure 20. It is apparent that the locus of the maximum point of offtracking for this vehicle is some distance forward of the rearmost axle, approximately half way between the trailer kingpin and axle group. However, the conventional LSOT metric is measured at the rear axle position and would under-estimate the actual swept path of the linked articulation vehicle. Accordingly, the swept path measure has been re-interpreted as required in this report. Considerable use has also been made of the Austroads Swept Path envelopes in this report: these envelopes are an effective performance measure for any type of vehicle combination and steering system.

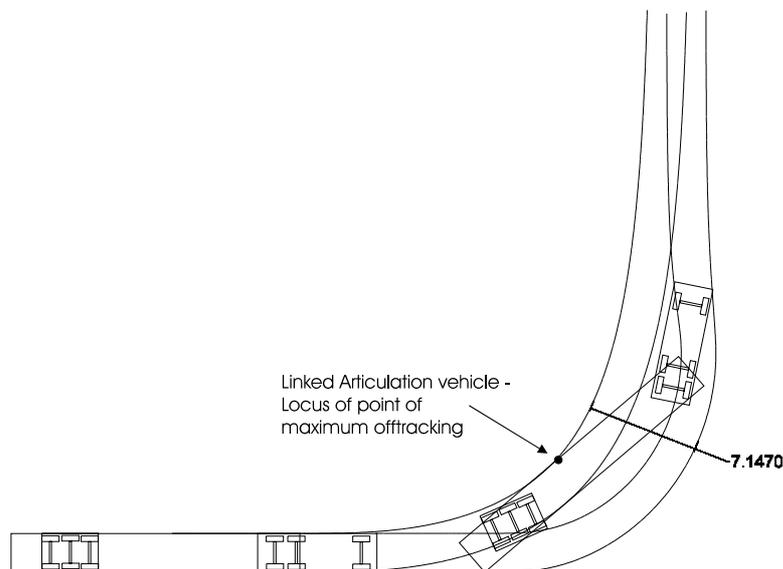


Figure 20 Swept path for maximum cubic capacity A123 with linked articulation steering axle group showing the locus point of maximum vehicle offtracking

6.1.2 Static roll stability

In the case of combination vehicles, the static-roll stability limit of each unit is the critical issue. This is expressed in terms of the lateral acceleration required to produce total rollover of the rear unit, and is given as a proportion of gravitational acceleration (g).

Total rollover occurs when all the wheels on one side of the combination vehicle (on the inside of the turn) lift off the road surface, and this situation is illustrated in Figure 21. Rollover occurs when the lateral acceleration equals or exceeds the vehicle's rollover limit (which may be assisted by roadway crossfall or camber). Lateral acceleration on a curve is highly sensitive to speed, and the speed required to produce rollover reduces as the curve radius reduces.

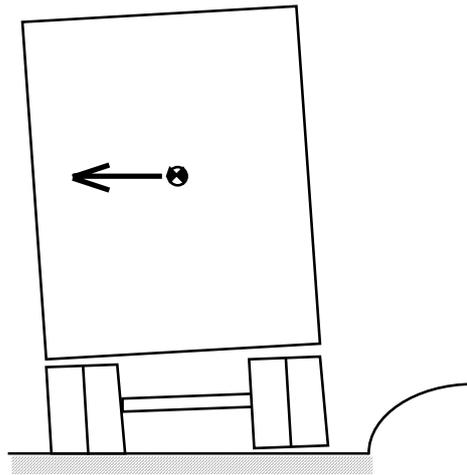


Figure 21 Rollover occurs after wheel lift on the inside of the turn

6.1.3 Load transfer ratio

Load transfer ratio (LTR) is defined as the proportion of load on one side of a vehicle unit transferred to the other side of the vehicle in a transient manoeuvre. Where vehicle units are roll coupled, as in B-doubles, the load transfer ratio is computed for all axles on the roll coupled unit. When the load transfer ratio reaches a value of 1, rollover is about to occur. The LTR is the ultimate measure of rollover stability.

The load transfer ratio was computed for the steering axle required to follow a specified path in a lane-change manoeuvre with a frequency of 2.5rad/s, as recommended in (15). The manoeuvre used is shown in Figure 22, evaluated at a speed of 90km/h for all vehicles. In each case, the vehicle was made to follow a path so that the lateral displacement of the vehicle steering path remained constant for each particular configuration.

The lateral offset of this lane change manoeuvre was reduced to 0.9m to provide meaningful comparisons for the triple roadtrains. The purpose of reducing the lateral offset was to prevent the most unstable vehicles from rolling over in the manoeuvre. While the lateral offset was reduced the frequency of the manoeuvre was unaffected.

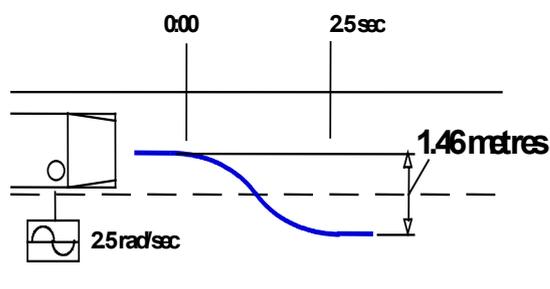


Figure 22 Standard SAE lane change manoeuvre (15).

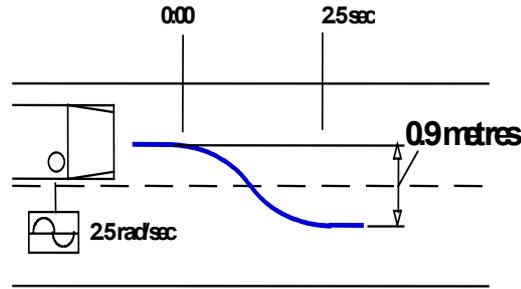


Figure 23 Reduced lane change manoeuvre for triple roadtrains

6.1.4 Rearward amplification

When multi-articulated vehicles undergo rapid steering, the steering effect at the rear trailer is magnified, and this results in increased side force, or lateral acceleration, acting on the rear trailer. This in turn increases the likelihood of the rear trailer rolling over under some circumstances.

Rearward amplification is defined as the ratio of the lateral acceleration at COG of the rearmost unit to that at the hauling unit in a dynamic manoeuvre of a particular frequency (16). Steering from side to side produces more lateral movement at the rear unit than at the hauling unit, as illustrated in Figure 24. Rearward amplification (RA) expresses the tendency of the vehicle combination to develop higher lateral accelerations in the rear unit when undergoing avoidance manoeuvres; it is therefore an important consideration, additional to roll stability of the rear unit, in evaluating total dynamic stability; it also expresses the amount of additional road space used by the vehicle combination in an avoidance manoeuvre.

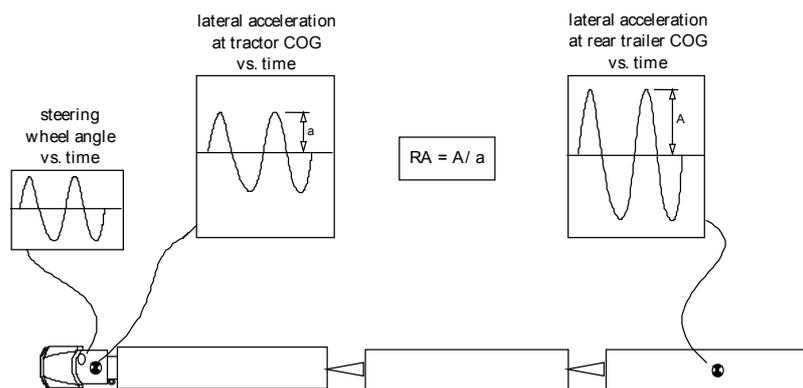


Figure 24 Rearward Amplification of lateral acceleration

Rearward amplification was computed for the steering axle required to follow a specified path in a lane-change manoeuvre with a frequency of 2.5rad/s. The standard SAE manoeuvre (15) used is shown in Figure 22, evaluated at a speed of 90km/h.

In each case, the vehicle was made to follow a path so that the lateral displacement of the vehicle steering path remained constant for each particular configuration, although the lateral offset was reduced for the triple roadtrain.

6.1.5 High-speed dynamic offtracking

High-speed dynamic offtracking (HSDOT) is the measure of the lateral excursion of the rear of the vehicle with reference to the path taken by the front of the vehicle during a dynamic manoeuvre. This expresses the amount of additional road space used by the vehicle combination in an avoidance manoeuvre. High-speed dynamic offtracking was computed for the lane change manoeuvre in Figure 22, at a speed of 90km/h. In each case, the vehicle was made to follow a path so that the lateral displacement of the vehicle steering path remained constant for each particular configuration, although the lateral offset was reduced for the triple roadtrains.

6.1.6 High-speed offtracking

High-speed offtracking is defined as the extent to which the rearmost tyres of the vehicle track outboard of the tyres of the hauling unit in a steady-turn at highway speed, as illustrated in Figure 25. High-speed offtracking relates closely to road width requirements for the travel of combination vehicles and is part of the total swept width of the combination vehicle (that is, the extent to which the lateral excursions of the rear of the vehicle exceed those of the hauling unit in normal operation).

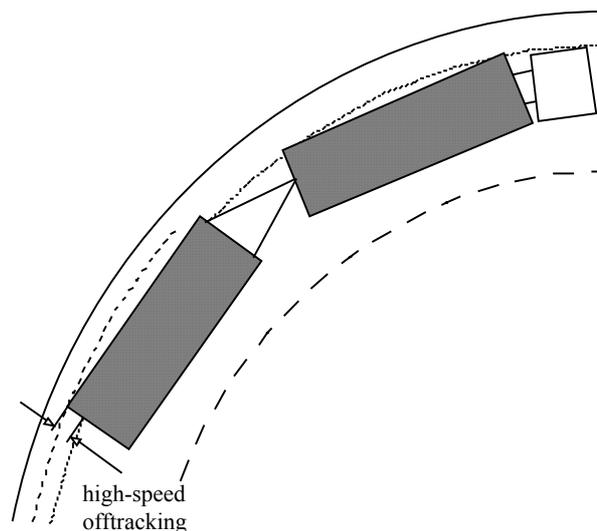


Figure 25 High-speed offtracking of the rear unit relative to the hauling unit

High-speed offtracking was determined for a turn of radius 318m, negotiated at a speed of 90km/h, which results in a lateral acceleration of 0.2g.

6.1.7 Total swept path width

The maximum lateral displacement between the path of the front outside corner of the vehicle (or vehicle unit) and the outer front edge of the front outside steered wheel of the hauling unit during a small radius turn manoeuvre at low speed. For all of the heavy vehicle simulations performed this measure was evaluated for the standard low-speed offtracking manoeuvre (11).

6.1.8 Frontal swing

The maximum lateral displacement between the path of the front outside corner of the vehicle (or vehicle unit) and the outer front edge of the front outside steered wheel of the

hauling unit during a small radius turn manoeuvre at low speed (11). For all of the heavy vehicle simulations performed this measure was evaluated for the standard low-speed offtracking manoeuvre.

6.1.9 Tail swing

The maximum lateral distance that the outer rearmost point on a vehicle moves outwards, perpendicular to its initial orientation, when the vehicle commences a small radius turn at low-speed. For all vehicle simulations this performance measure was evaluated for the standard low-speed offtracking manoeuvre (11).

6.1.10 Yaw damping

Yaw damping is defined as the rate at which ‘sway’ or yaw oscillations of the rearmost trailer decay after a short duration steer input at the hauling unit. To evaluate this measure each vehicle was simulated at the required test speed of 100 km/h in a straight line and then a pulse of steering input was applied at the hauling unit as defined in (11). The resultant vehicle body motions were then measured to estimate the yaw damping response for each vehicle.

6.2 Modelling the steerable axle

After consultation with industry it was found that the automotive type steerable axle was the most commonly used steerable axle within the Australian transport industry. Other steerable axle types such as the linked articulation type or hydraulic command (or force) steer types are not widely used by transport operators in Australia. For this reason most of the candidate steerable axle vehicles simulated were fitted with standard automotive type steerable axles. The linked articulation type steerable trailer axle group on a semi-trailer combination was also simulated.

6.2.1 Automotive type steerable axles

This standard automotive type steerable trailer axle was modelled by enhancing the existing RATED axle model to include the steering mechanism. A steerable axle self-centring force (or aligning spring) and damper were included in the model. The sensitivity of vehicle dynamic performance to the steerable axle self-centring force (ie aligning stiffness) in the model was investigated. This was done due to previous work had suggested handling problems for rigid trucks that are fitted with free-castering steerable axles (1,2). The effect of the steerable axle self-centring force on heavy vehicle dynamic performance was investigated for rigid trucks in the ramp steer manoeuvre. The 3-point handling diagram was evaluated for a rigid truck (R13) with a steerable tag axle fitted, at 4 different degrees of aligning spring stiffness. The results can be seen in Figure 26, showing that the handling performance of a rigid truck is not greatly influenced by the steerable axle self-centring force. In each case the transition point remained at approximately 0.25g even when the steerable axle aligning force was doubled in magnitude with a very stiff aligning spring.

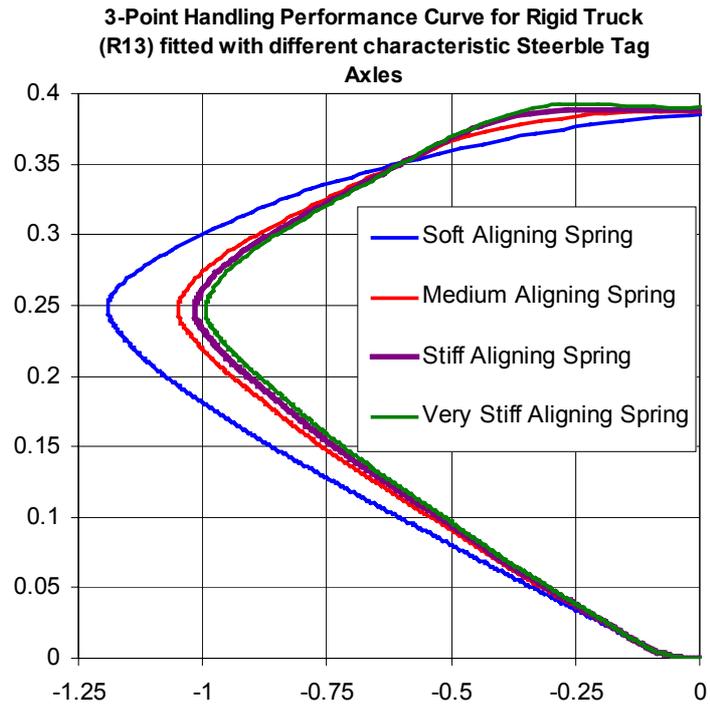


Figure 26 Handling results for rigid trucks (R13) with a steerable tag axle at different degrees of axle aligning spring

To further assess the impact of the steerable axle aligning force on heavy vehicle dynamic performance a number of standard SAE lane change (15) manoeuvres were simulated for the tractor-semi-trailer (A123) with varying levels of steerable axle self-centring force. The results are shown in Figure 27. It is apparent performance is not strongly affected by aligning stiffness until it is reduced to a low level. To represent a generic auto-steering axle, a medium value of aligning stiffness was used in all simulation models. This steerable axle model provides a significant level of lateral tyre forces (and hence stability) in the lane-change manoeuvre but not in the low-speed offtracking manoeuvre; this is illustrated in Figure 28 for the case of the quad axle semi-trailer (A124) with rear-mounted steerable axle.

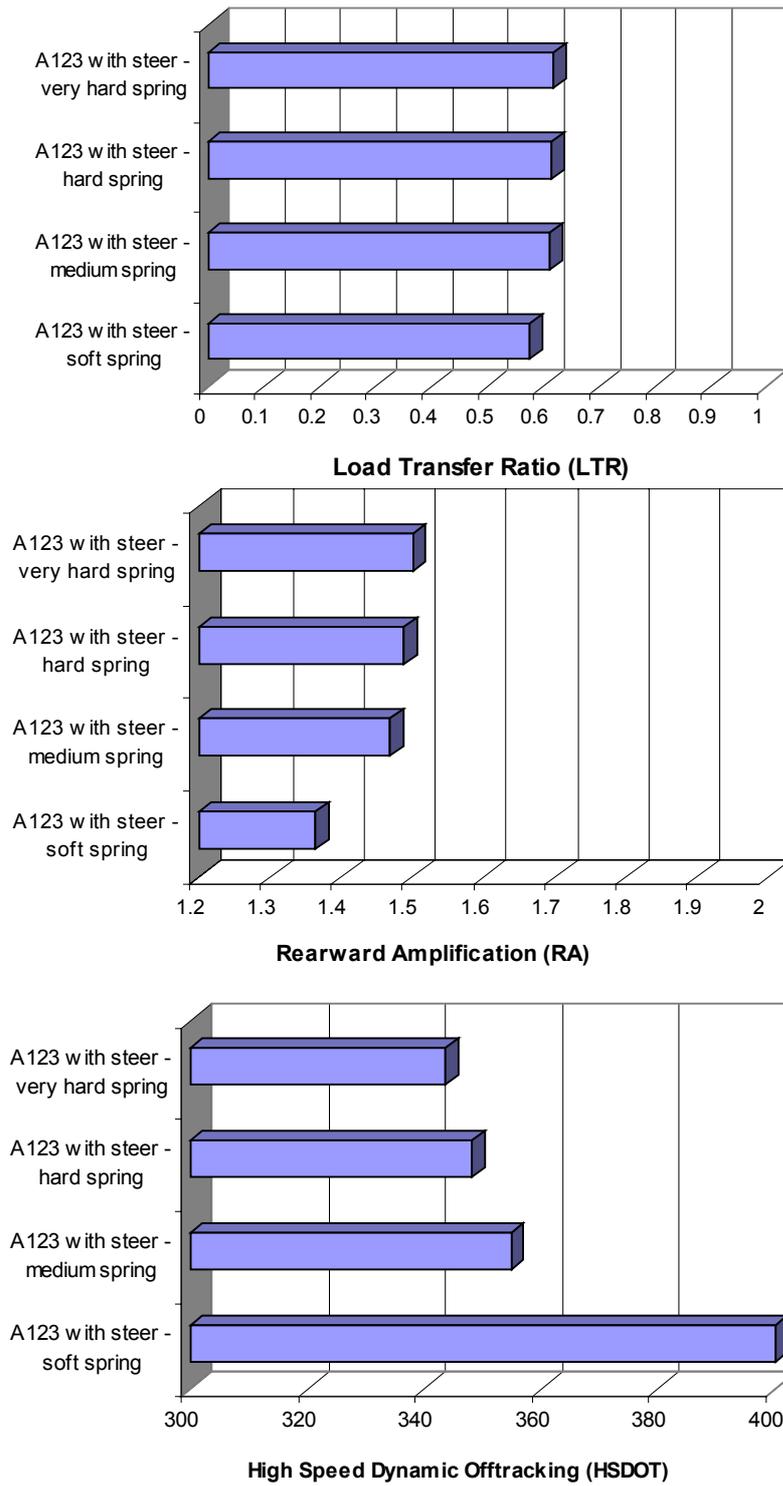


Figure 27 LTR, rearward amplification and HSDOT results for a semi-trailer fitted with a rear mounted steerable trailer axle at 4 different levels of steer axle aligning stiffness

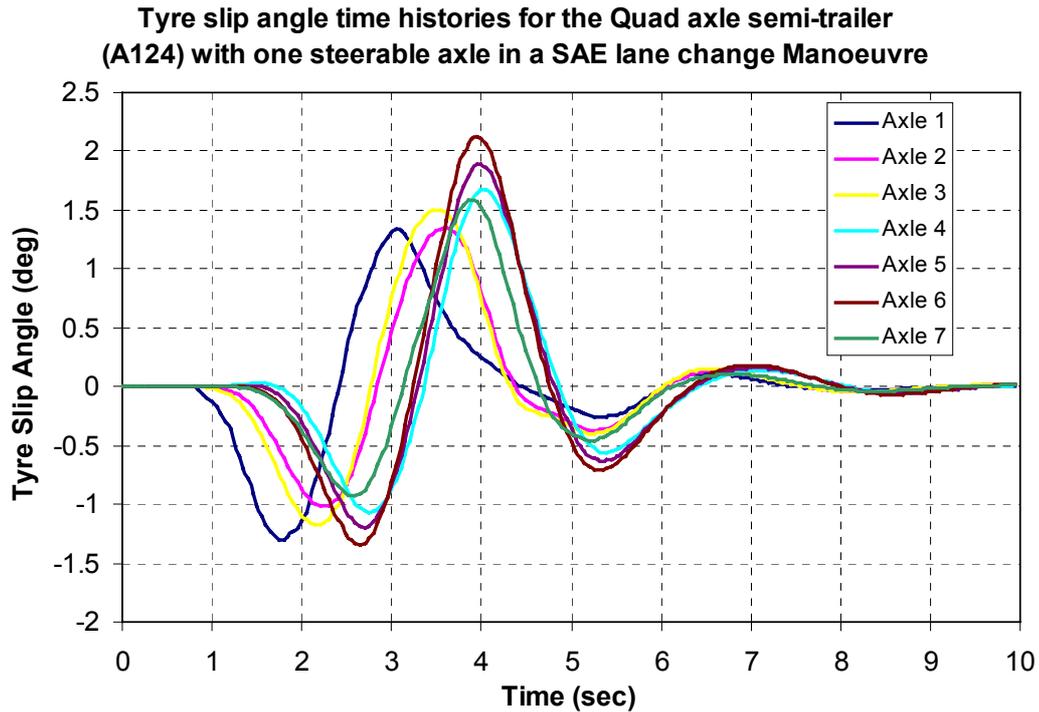


Figure 28 Tyre slip angle time histories for the quad axle tractor-semi-trailer with one automotive type steerable axle

6.2.2 *Linked articulation type steerable trailer axles*

The other steerable axle type modelled in this study was the linked articulation type self-steering semi-trailer axle group. The model developed for this system was based on technical information on an Australian development of such a system (5). The kinematic relationships between the lead and rear trailer axle steer angles, sub-frame rotation and

semi-trailer articulation angle were included as specified in (5). Figure 29 shows some animation clips of the linked articulation type steerable axle model in a low speed turn. This model was only exercised for low-speed turning performance because the mechanism is locked automatically at highway speeds. Therefore this vehicle was simulated with fixed trailer axles in all manoeuvres requiring to be simulated at higher speeds.

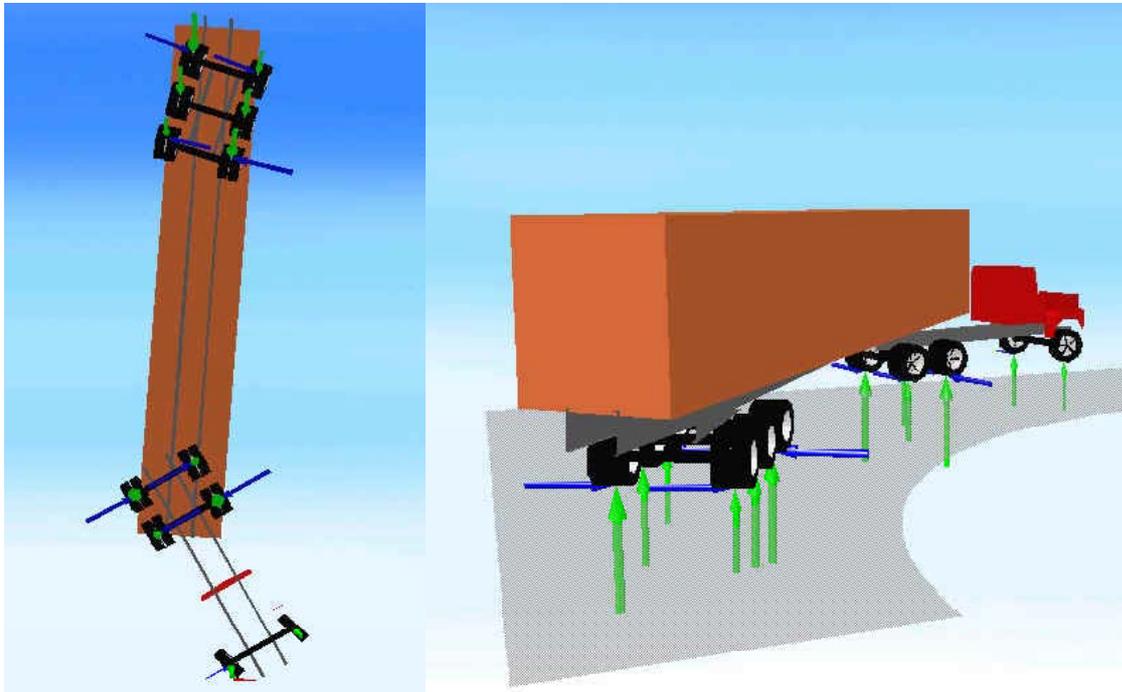


Figure 29 Animation clips of the computer simulation for the (A123) semi-trailer fitted with linked articulation type steerable trailer axles in a low speed turn

6.3 Dynamic performance results for candidate vehicles

This section of the report presents and discusses the computer simulation results for each of the candidate steerable axle vehicles; results are compared with (i) proposed PBS standards and (ii) the performance of baseline vehicles that are currently in operation.

6.3.1 Increased Cube Initiative: semi-trailer (A123) with increased s-dimension and a steerable axle

A maximum cube initiative tractor-semi-trailer with an automotive type steerable trailer axle was developed from the results in Section 3.1.2. This vehicle was simulated with the axle loading and dimensions as described in Figure 30. This vehicle breaches the current 19m overall length regulation for tractor-semi-trailer combinations.

(A123) Tractor Semi-Trailer (Increased cubic capacity - Automotive type steerable axle)

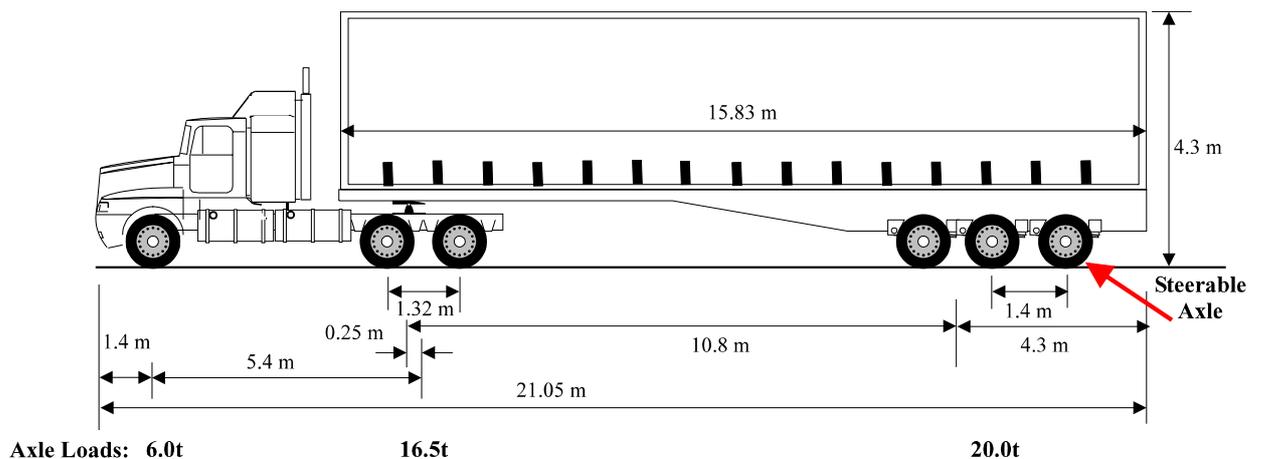


Figure 30 Increased cube initiative tractor-semi-trailer combination with improved load distribution and a steerable axle fitted to the semi-trailer

Static roll stability for the increased cubic capacity semi-trailer (A123) with a steerable axle can be seen in Figure 31. Here the additional steerable axle slightly reduces the static roll stability when compared to the standard general freight tractor-semi-trailer. Both of these vehicles perform below the proposed NRTC standard for heavy vehicle SRS (0.35 g); the absolute performance level depends on the COG height adopted in the simulations.

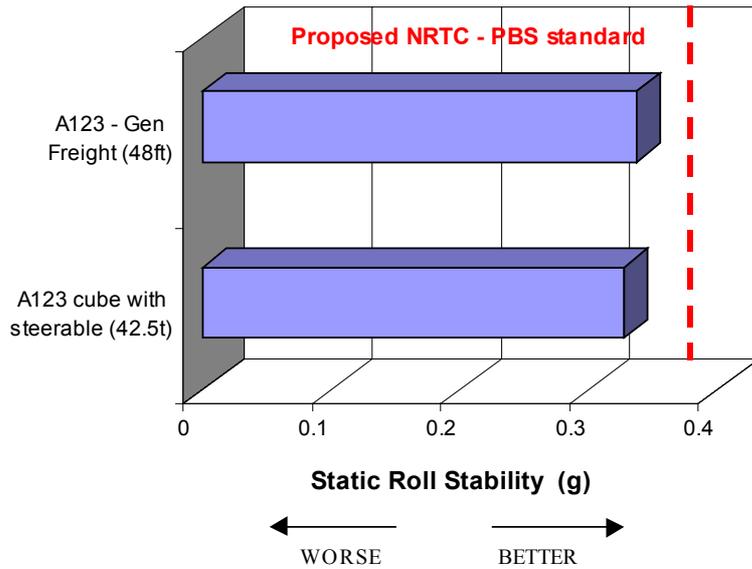
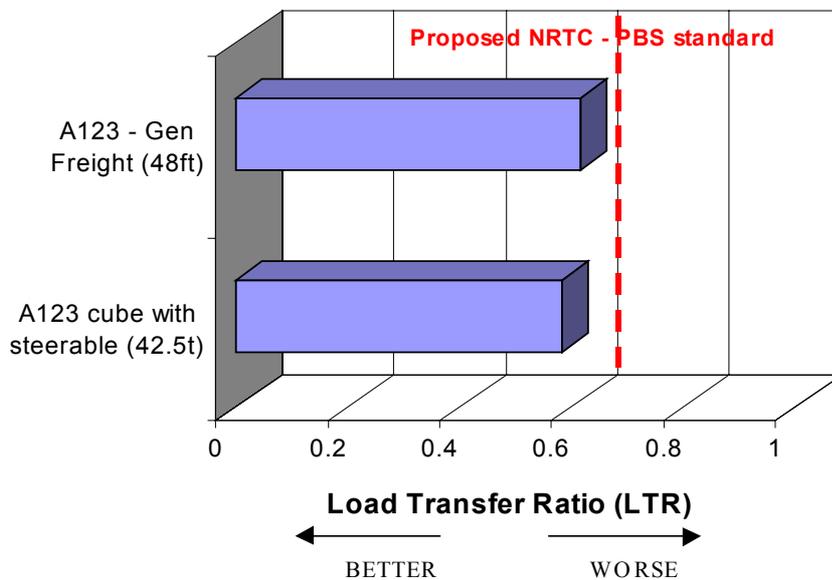


Figure 31 Static roll stability results for the increased cube semi-trailer with a steerable axle

Figure 32 shows the comparison LTR and rearward amplification results for the increased cube semi-trailer with one steerable axle. It can be seen that this semi-trailer with the steerable axle has an improved LTR when compared to a standard general freight semi-trailer. The results show that the addition of steerable trailer axle and improved mass distribution of this vehicle will improve dynamic stability by approximately 6 %. Figure 32 also shows the rearward amplification results for the increased cube semi-trailer with a steerable axle and the baseline general freight tractor-semi-trailer. We can see that both vehicles simulated have rearward amplification well below the proposed NRTC standard of 2.0.



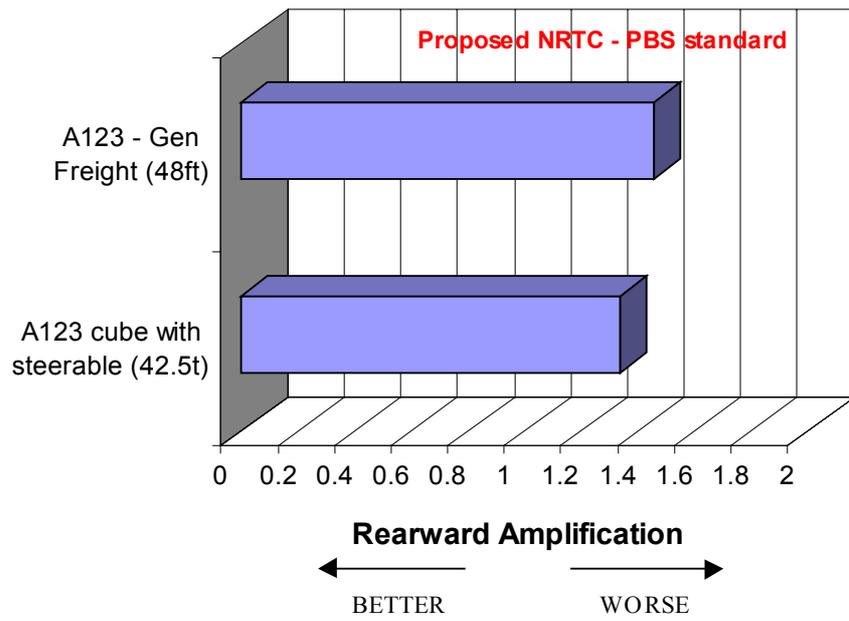


Figure 32 Load transfer ratio and rearward amplification results for the increased cube semi-trailer with a steerable axle

Figure 33 shows that increased cubic capacity for this tractor-semi-trailer and the addition of a steerable trailer axle will increase high-speed dynamic offtracking. Both semi-trailer combinations have high-speed dynamic offtracking well below the proposed NRTC standard of 800mm.

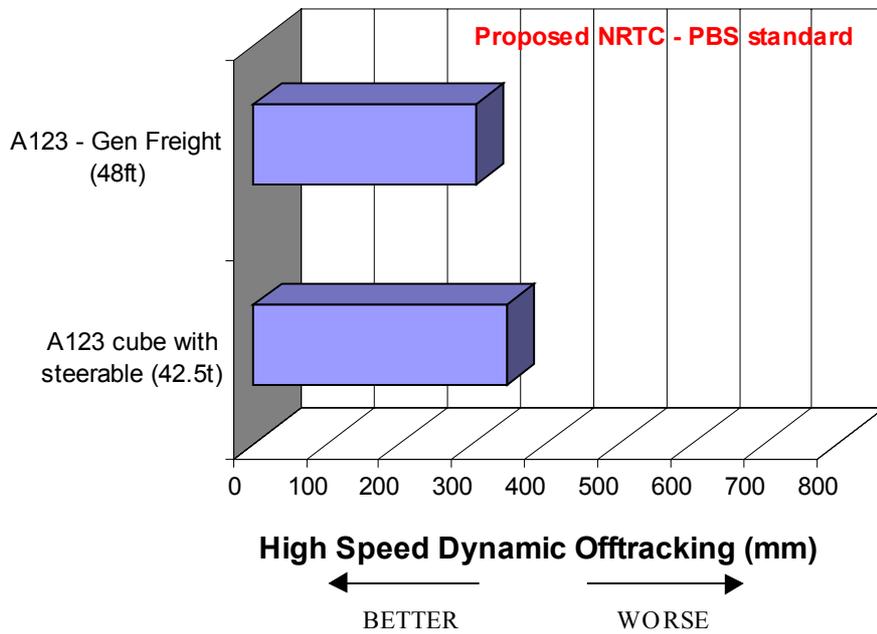


Figure 33 HSDOT results for the increased cube semi-trailer with a steerable axle

Figure 34 shows results for the increased cube semi-trailer combination in a low speed offtracking manoeuvre. Here we can see that the additional trailer length in combination with the steerable axle will result in the total swept path width just below than the proposed standard of 7.4m. Tail swing is shown to be much worse for increased cube semi-trailer than the standard general freight semi, but still below the proposed standard of 500mm. Frontal swing results did not change significantly, as this measure is dependent on prime mover characteristics.

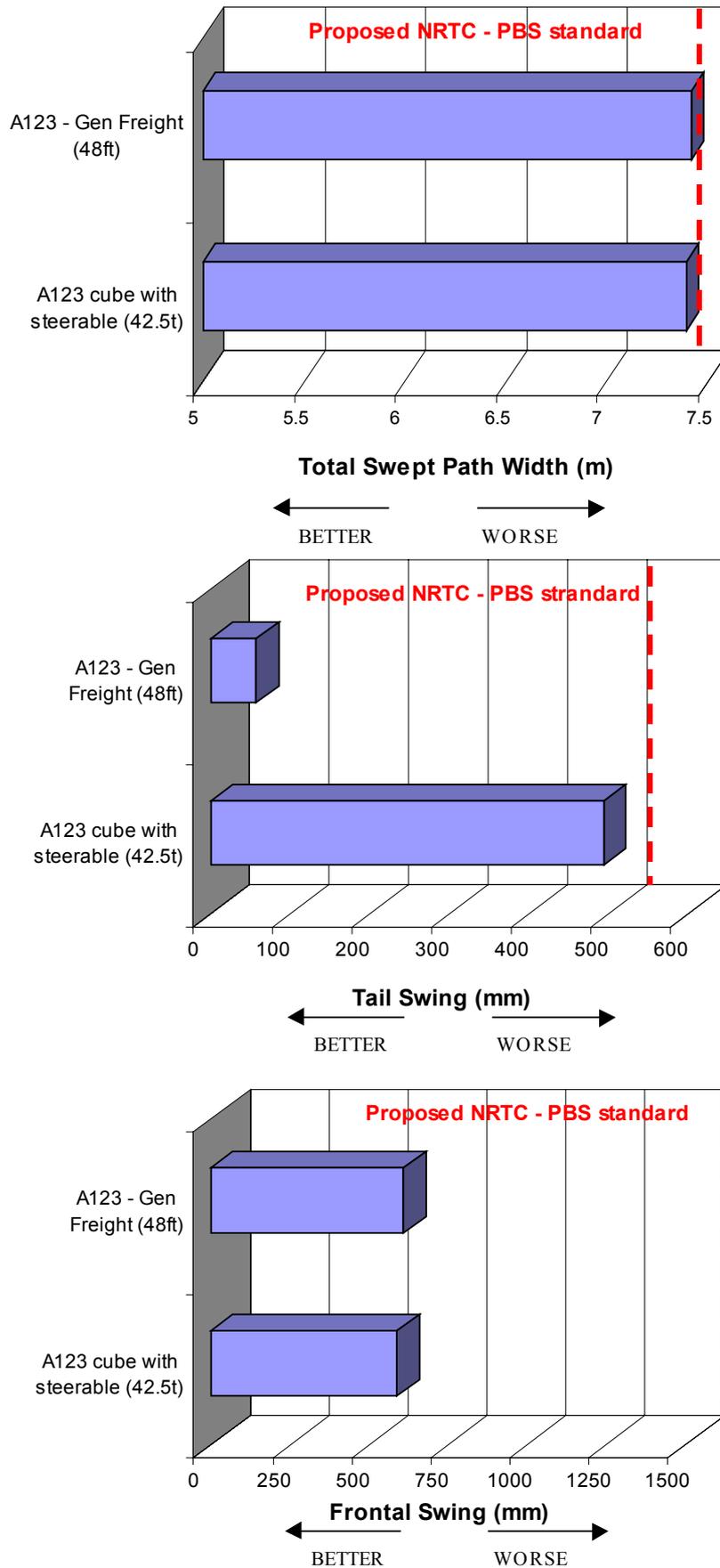


Figure 34 Total swept path width, tail swing and frontal swing results for increased cube semi-trailer with a steerable axle fitted

Figure 35 shows high-speed offtracking and yaw damping results for the increased cube semi-trailer and a standard general freight tractor-semi-trailer. It can be seen that the increased trailer s-dimension and length along with the steerable trailer axle causes a marginal increase to the high-speed offtracking. It can also be seen that a semi-trailer fitted an additional steerable trailer axle has considerably less yaw damping than the general freight tractor-semi-trailer.

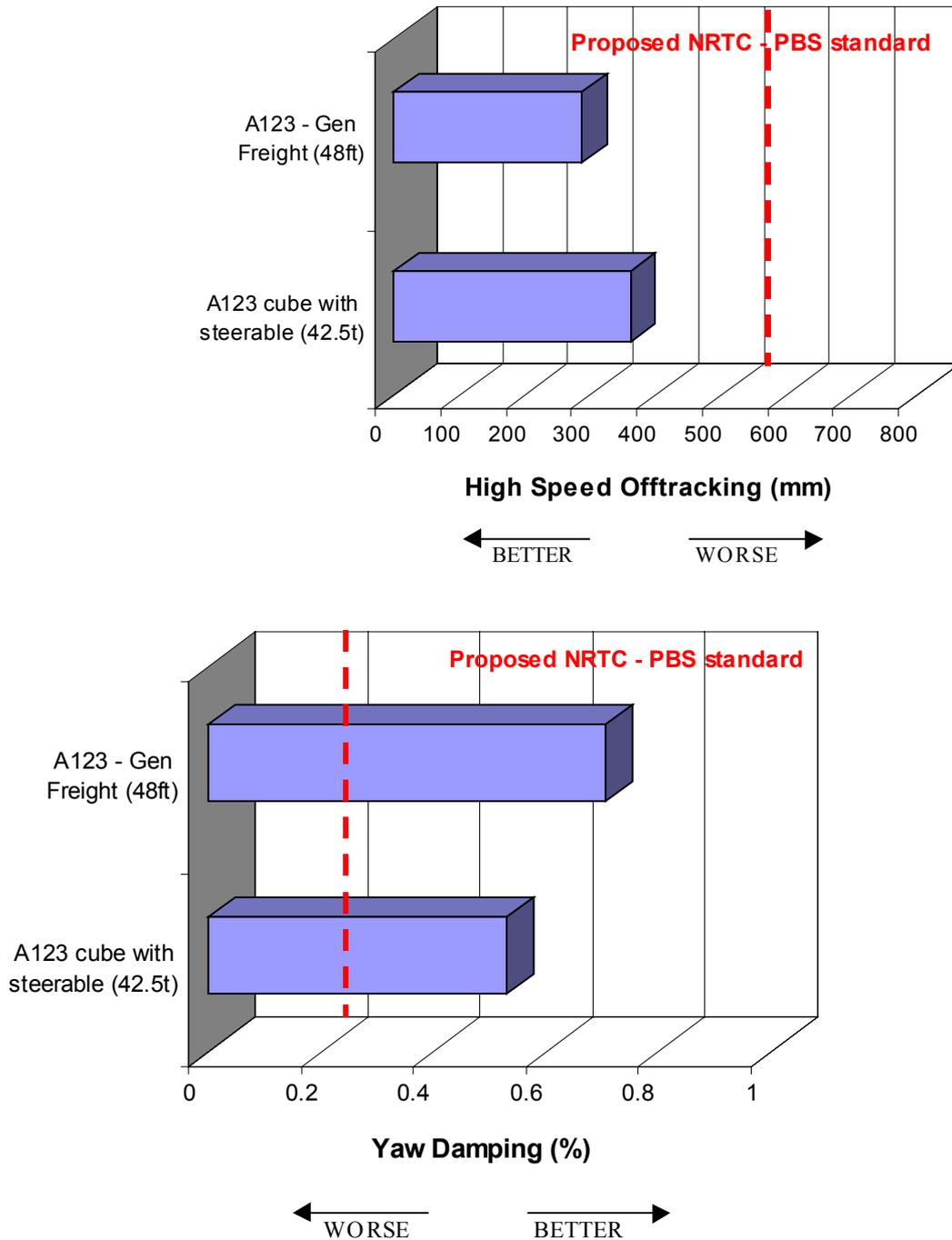


Figure 35 High-speed offtracking and yaw damping results for the increased cube semi-trailer with a steerable axle fitted

All of the performance measures for the increased cube semi-trailer combination have values within the proposed PBS standards, with the exception of SRS. This candidate vehicle is not considered to have safety performance deficiencies. Operators of this vehicle would need to take into account the significant increase in tail swing.

6.3.2 Increased Cube Initiative: semi-trailer (A123) with increased s-dimension and a linked articulation type steerable axle group

A maximum cube initiative tractor-semi-trailer with linked articulation steerable trailer axles was developed from the results of Section 3.1.3. This vehicle was simulated with the load conditions and vehicle dimensions as described in Figure 36; the rear trailer height was increased to allow for the increased chassis height of the axle group steering system. This vehicle breaches the current 19m overall length regulation for tractor-semi-trailer combinations.

(A123) Tractor Semi-Trailer (Increased cubic capacity - Linked Articulation type steerable axle group)

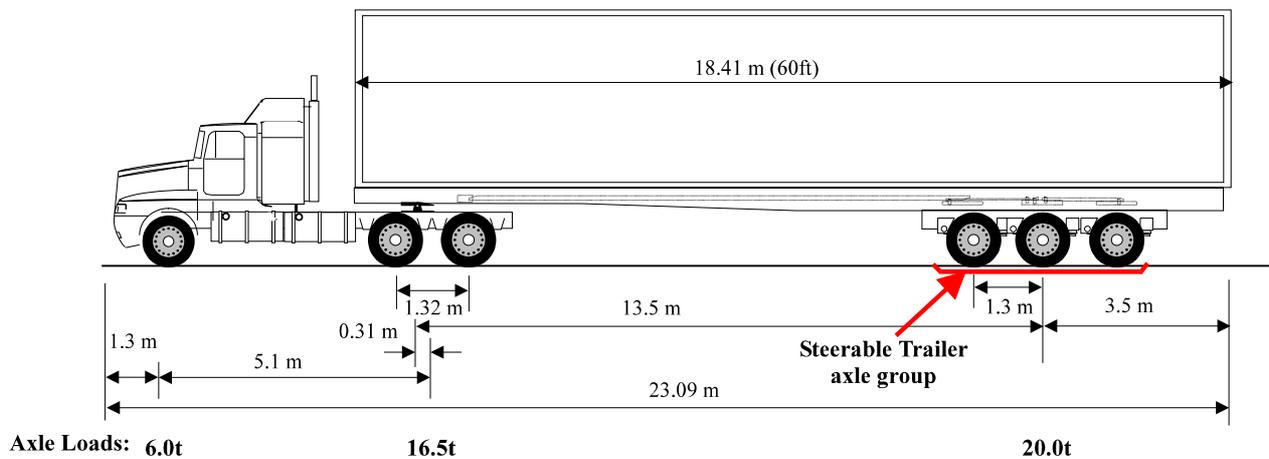


Figure 36 Increased cube initiative tractor-semi-trailer with linked articulation type steerable trailer axles on the trailer

Static roll stability results for the increased cubic capacity semi-trailer (A123) with a linked articulation type steerable axle group can be seen in Figure 37. Here the increased cubic volume trailer and slightly higher trailer COG due to the linked articulation steering system have a small effect in reducing static roll stability when compared to the standard general freight semi-trailer. Both of these vehicles perform below the proposed acceptable minimum for heavy vehicle SRS, which is 0.35g.

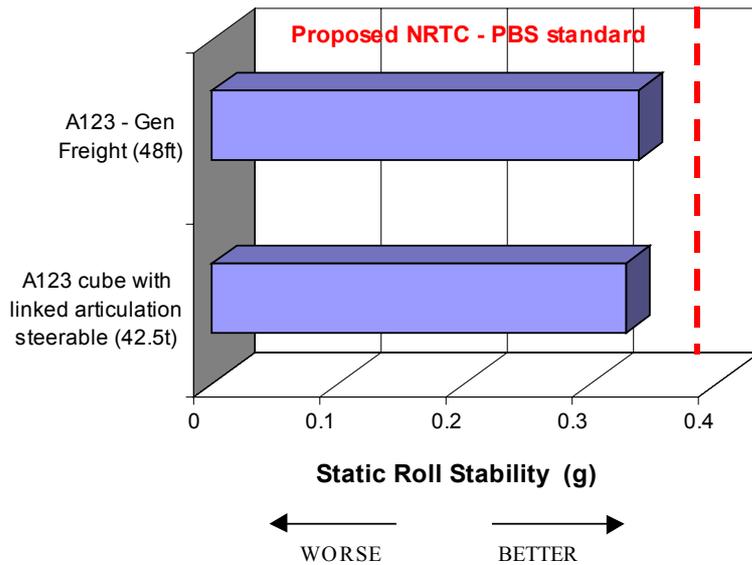


Figure 37 Static roll stability results for the increased cube semi-trailer with a linked articulation type steerable axle group

Figure 38 shows the LTR results for the increased cube semi-trailer with linked articulation steerable axles. The results show that this semi-trailer has improved LTR when compared to a standard general freight tractor-semi-trailer (due to its increased wheelbase); dynamic stability is improved by approximately 16%.

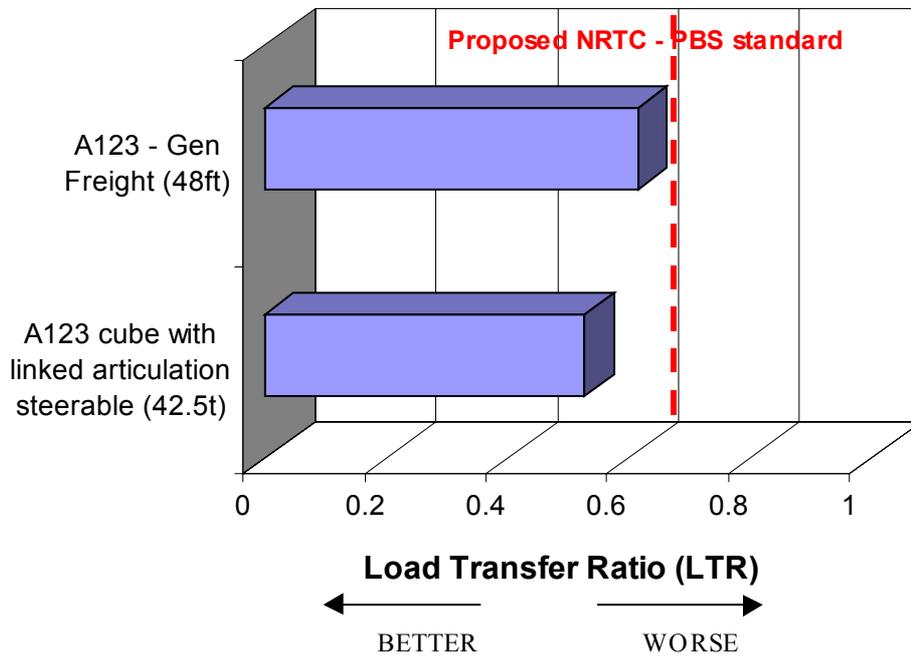


Figure 38 LTR results for the increased cube semi-trailer with linked articulation type steerable axle group

Figure 39 shows the rearward amplification and high-speed dynamic offtracking results for the increased cube semi-trailer with linked articulation type steerable axles and the baseline general freight semi-trailer. We can see that both vehicles simulated have rearward amplification well below the proposed NRTC standard of 2. The results also show that the increased cubic capacity vehicle has reduced rearward amplification by almost 26% compared to the general freight tractor-semi-trailer.

The chart shows that these tractor-semi-trailer combinations have a high-speed dynamic offtracking well below the proposed NRTC standard of 800mm.

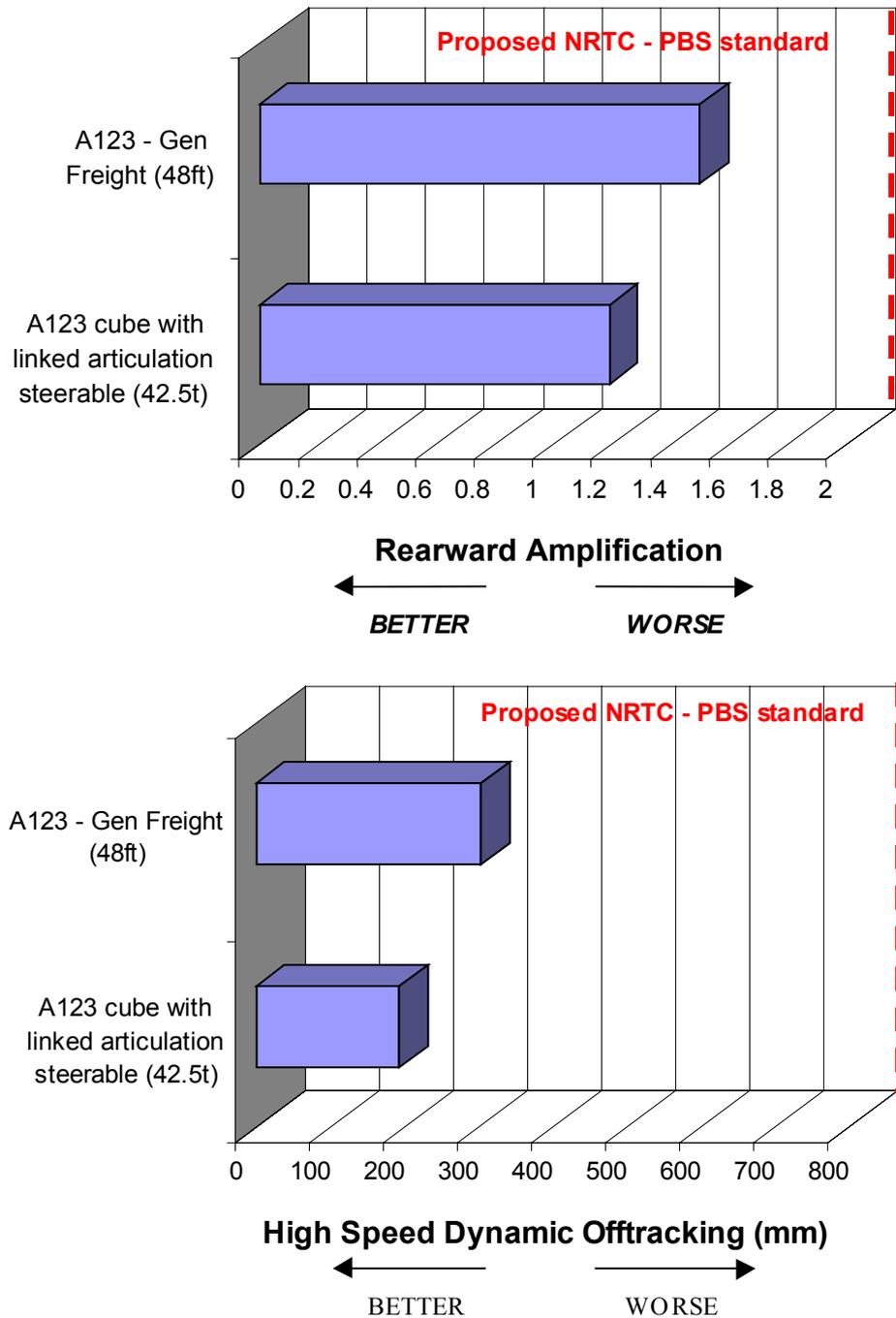


Figure 39 Rearward amplification and high speed dynamic offtracking results for the increased cube semi-trailer with a linked articulation type steerable axle group

Figure 40 shows the comparison of results for the increased cube semi-trailer combination in a low speed offtracking manoeuvre. Here we can see that the additional trailer length in combination with the linked articulation type steerable axle group will result in the total swept path width well below the proposed standard of 7.4m. Tail swing was shown to be worse for increased cube semi-trailer than the standard general freight vehicle, but meets the proposed standard of 500mm. Frontal swing results did not change significantly with the addition of the steerable trailer axles, as this measure is mainly dependent upon the prime mover geometry.

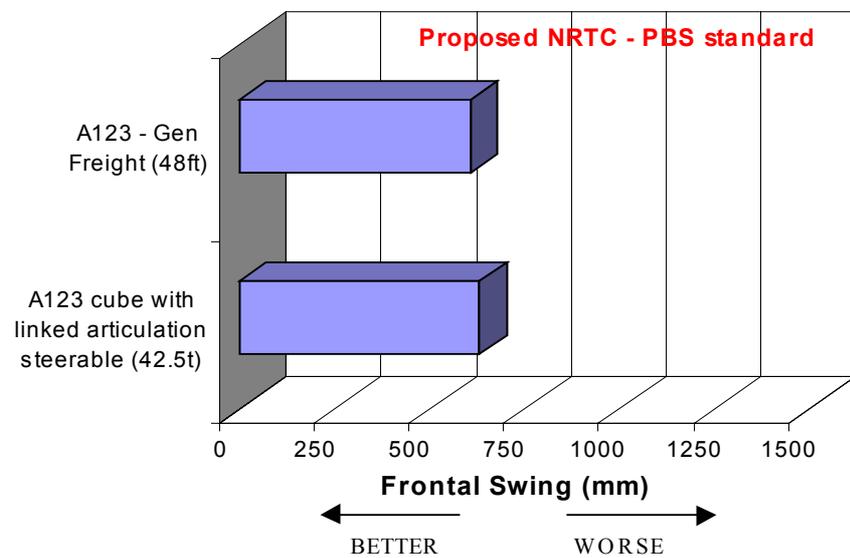
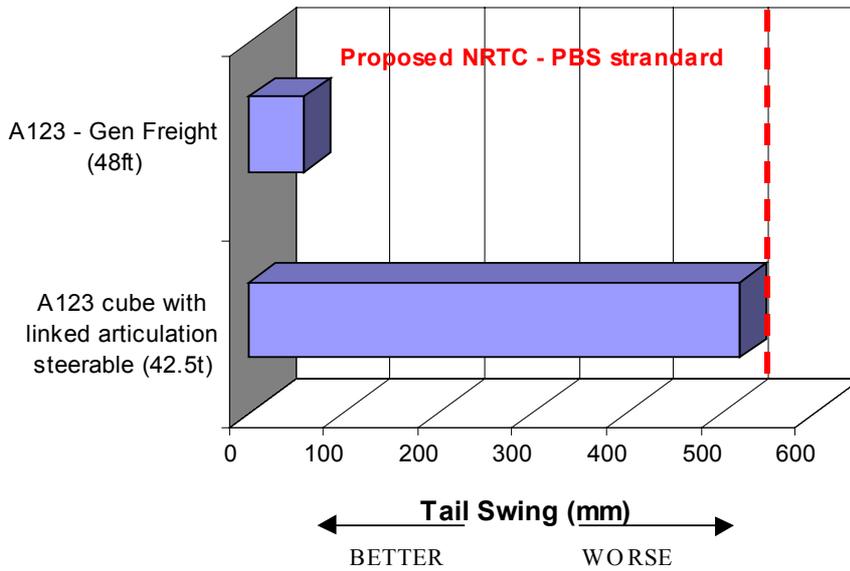
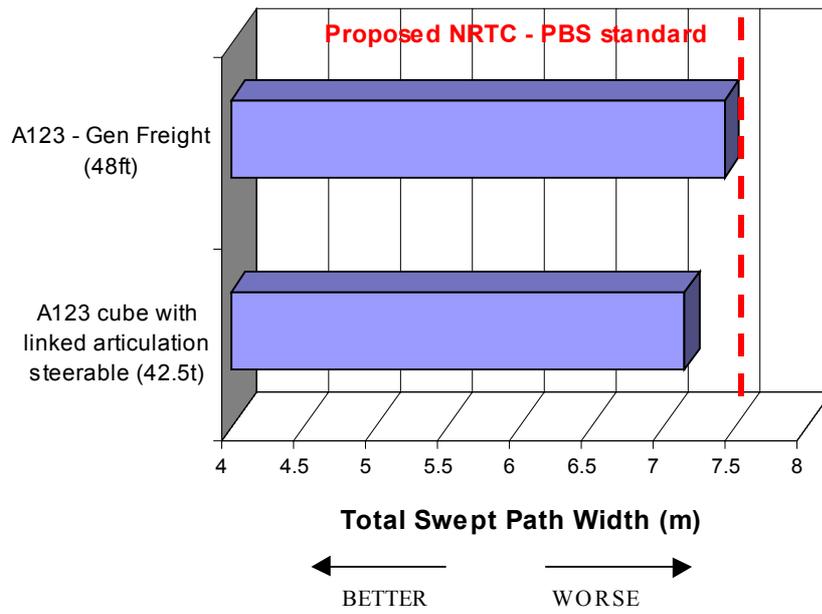


Figure 40 Total swept path width, tail swing and frontal swing results for increased cube semi-trailer with a linked articulation type steerable axes

High speed offtracking and yaw damping results for the increased cube semi-trailer with linked articulation type steerable axes and the general freight tractor-semi-trailer are shown in Figure 41. It is apparent that the high-speed offtracking of this increased cube semi-trailer is slightly improved and still below the proposed standard of 500mm. Yaw damping is well above the NRTC standard of 0.15.

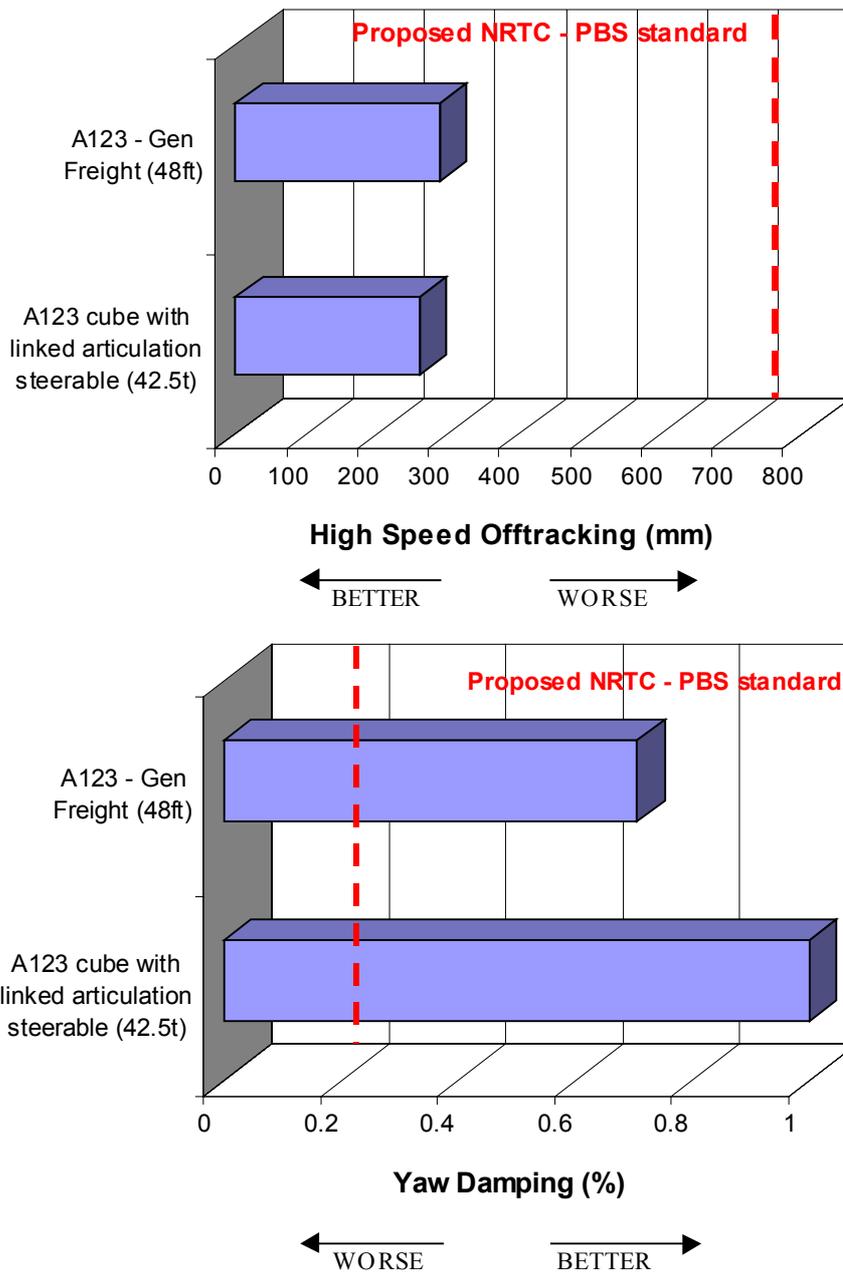


Figure 41 High speed offtracking and yaw damping results for the increased cube semi-trailer with a linked articulation type steerable axle group

All of the performance measures for the increased cube semi-trailer with linked-articulation type steerable axle group have values within the proposed PBS standards, with the exception of SRS. This candidate vehicle is not considered to have safety performance

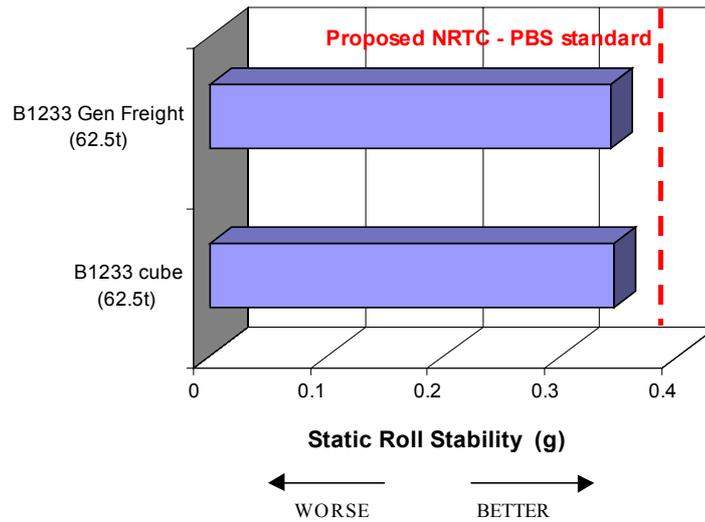
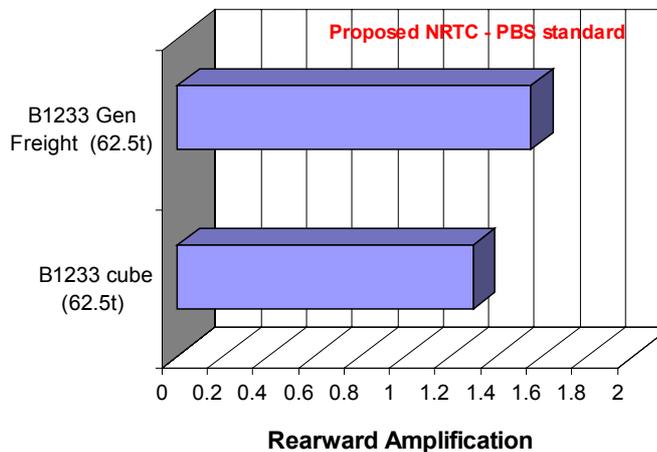
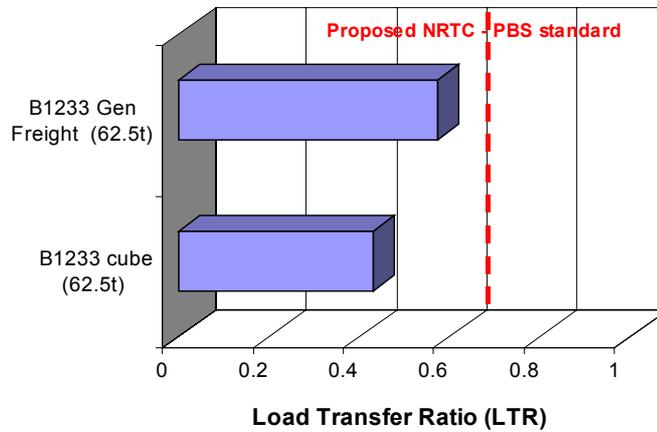


Figure 43 Static roll stability results for the increased cube B-double (B1233) with 2 steerable axles

Figure 44 shows the LTR, rearward amplification and high-speed dynamic offtracking results for the increased cube B-double with 2 steerable axles and the baseline general freight B-double. Dynamic stability is improved by approximately 22%. Both vehicles have rearward amplification below the proposed NRTC standard of 2.0. Both of these B-double combinations have high-speed dynamic offtracking well below the proposed NRTC standard of 800mm.



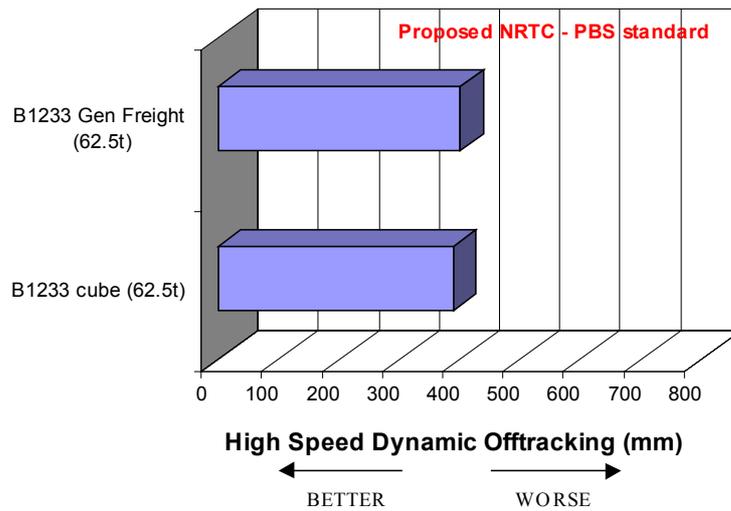
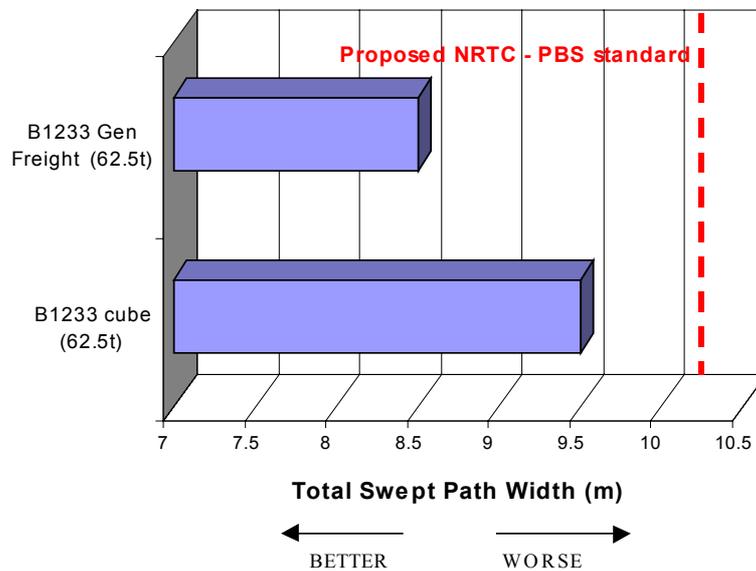


Figure 44 Rearward amplification and high speed dynamic offtracking results for the increased cube B-double with 2 steerable axles.

Figure 45 shows the results for the increased cube B-double in a low speed offtracking manoeuvre. The additional trailer length in combination with the steerable axles results in the total swept path width well below than the proposed standard of 10.1m, but significantly higher than the benchmark B-double. Tail swing is shown to be almost double for high cube B-double than the standard general freight B-double. Frontal swing results did not change significantly with the addition of the steerable trailer axle to this vehicle, as this measure is mainly dependent on prime mover characteristics.



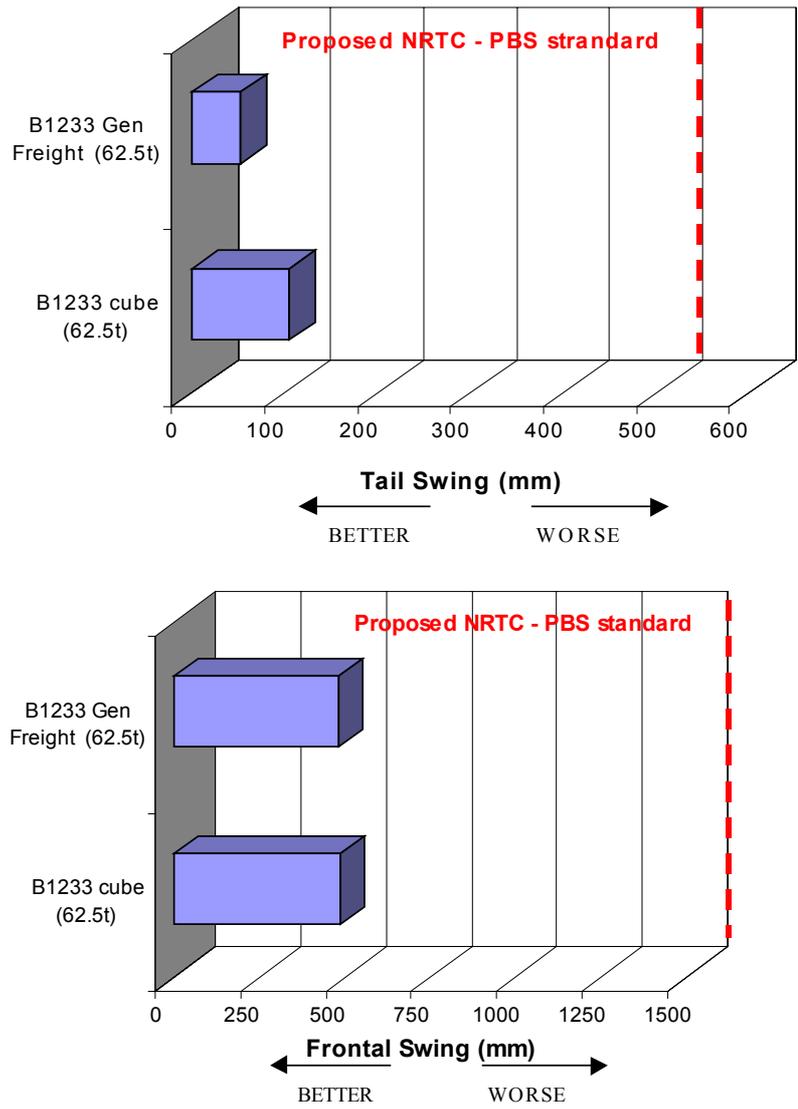


Figure 45 Total swept path width, tail swing and frontal swing results for increased cube B-double with 2 steerable axles

High-speed offtracking and yaw damping results for the increased cube B-double with 2 steerable axles and a standard general freight B-double are shown in Figure 46. It is apparent that yaw damping is not an issue and high-speed offtracking of this increased cube B-double is within the proposed standard of 500mm.

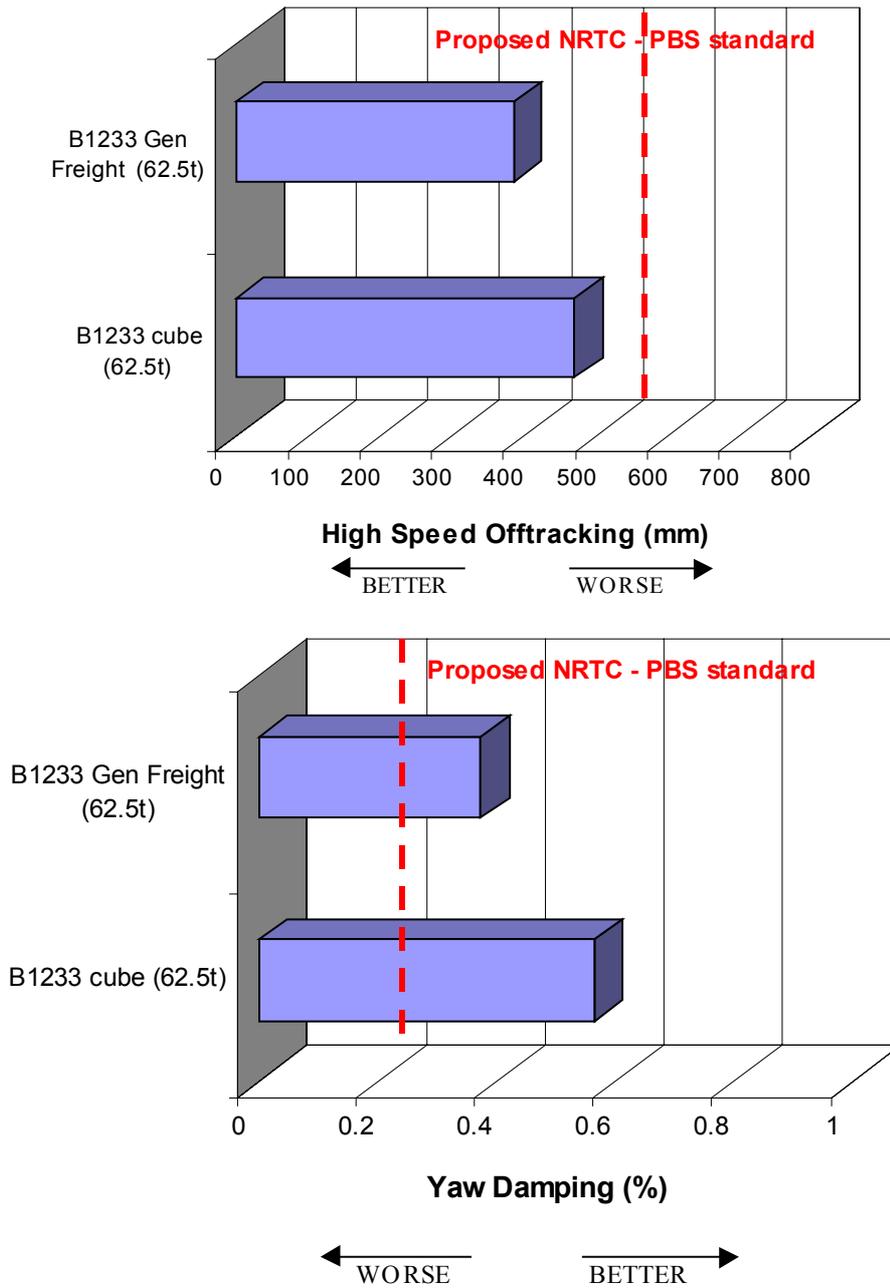


Figure 46 High-speed offtracking and yaw damping results for the increased cube B-double with 2 steerable axles

All of the performance measures for the increased cube B-double with two steerable axles have values within the proposed PBS standards, with the exception of SRS. This candidate vehicle is not considered to have safety performance deficiencies. Agencies would need to consider the significant increase in swept path. Operators of this vehicle would need to take into account the increase in high-speed offtracking.

6.3.4 Increased Mass Initiative: rigid truck with a steerable tag axle (R13 steerable)

The static roll stability for the rigid truck (R13) with a steerable tag (as shown in Section 3.2.1, Figure 15) can be seen in Figure 47. It is apparent that the additional steerable axle improves vehicle static roll stability by approximately 12% when compared to the standard rigid truck (R12) with fixed axles.

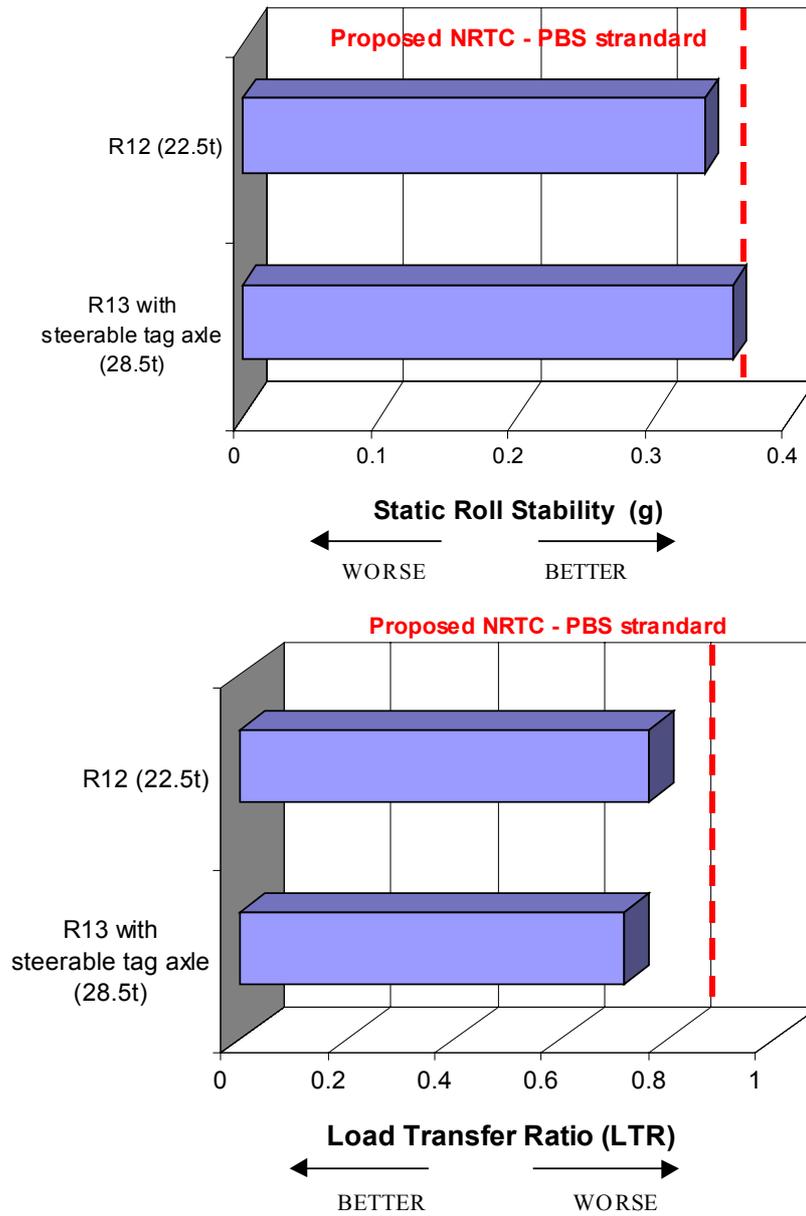


Figure 47 Static roll stability and load transfer ratio results for rigid trucks

The dynamic stability of the rigid truck with an additional steerable axle is good, improving the load transfer ratio by approximately 5%. From the results in Figure 47 it is apparent that the dynamic stability of this vehicle is not compromised by the addition of a steerable axle, even when the gross vehicle mass (GVM) increases by 27%.

Figure 48 shows the low speed directional performance for the rigid truck with and without an extra steerable axle. The additional steerable axle improves vehicle total swept path width by approximately 8% when compared to the standard fixed axle rigid truck. The use of the steerable axle improves the vehicle total swept path width so that it does not breach the proposed NRTC total swept path width standard for local roads. This proposed NRTC standard is 5m.

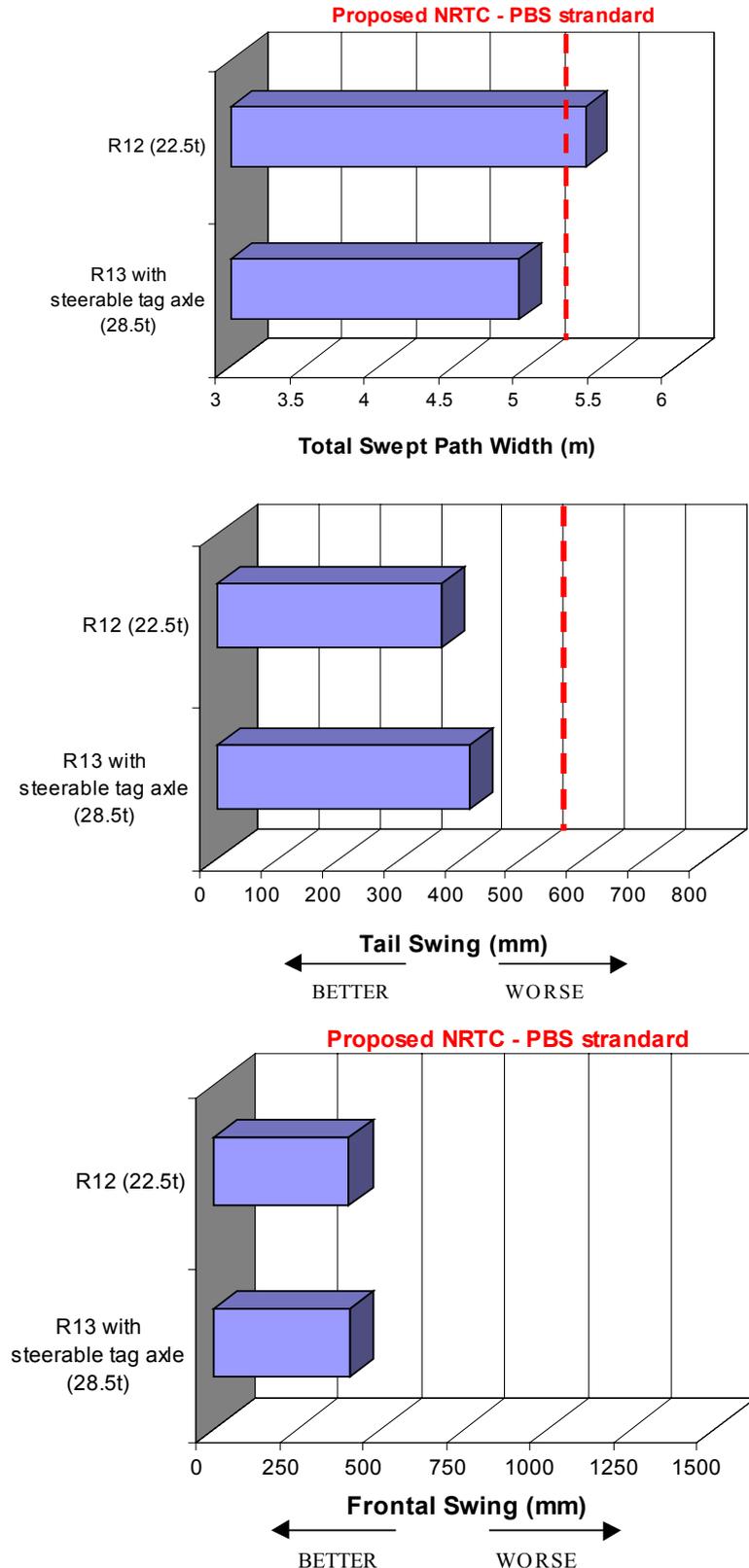


Figure 48 Total swept path width results for rigid trucks

All of the performance measures for the R13 with steerable axle have values within the proposed PBS standards. This candidate vehicle is not considered to have safety performance deficiencies.

6.3.5 Increased Mass Initiative: twin steer rigid truck with a steerable tag axle

The static roll stability and load transfer ratio results for the twin steer rigid truck (R23) with a steerable axle (as shown in Section 3.2.1, Figure 15) can be seen in Figure 49. It is apparent that the additional steer axle improves vehicle static roll stability by approximately 15%, to a value greater than the NRTC standard of 0.35g.

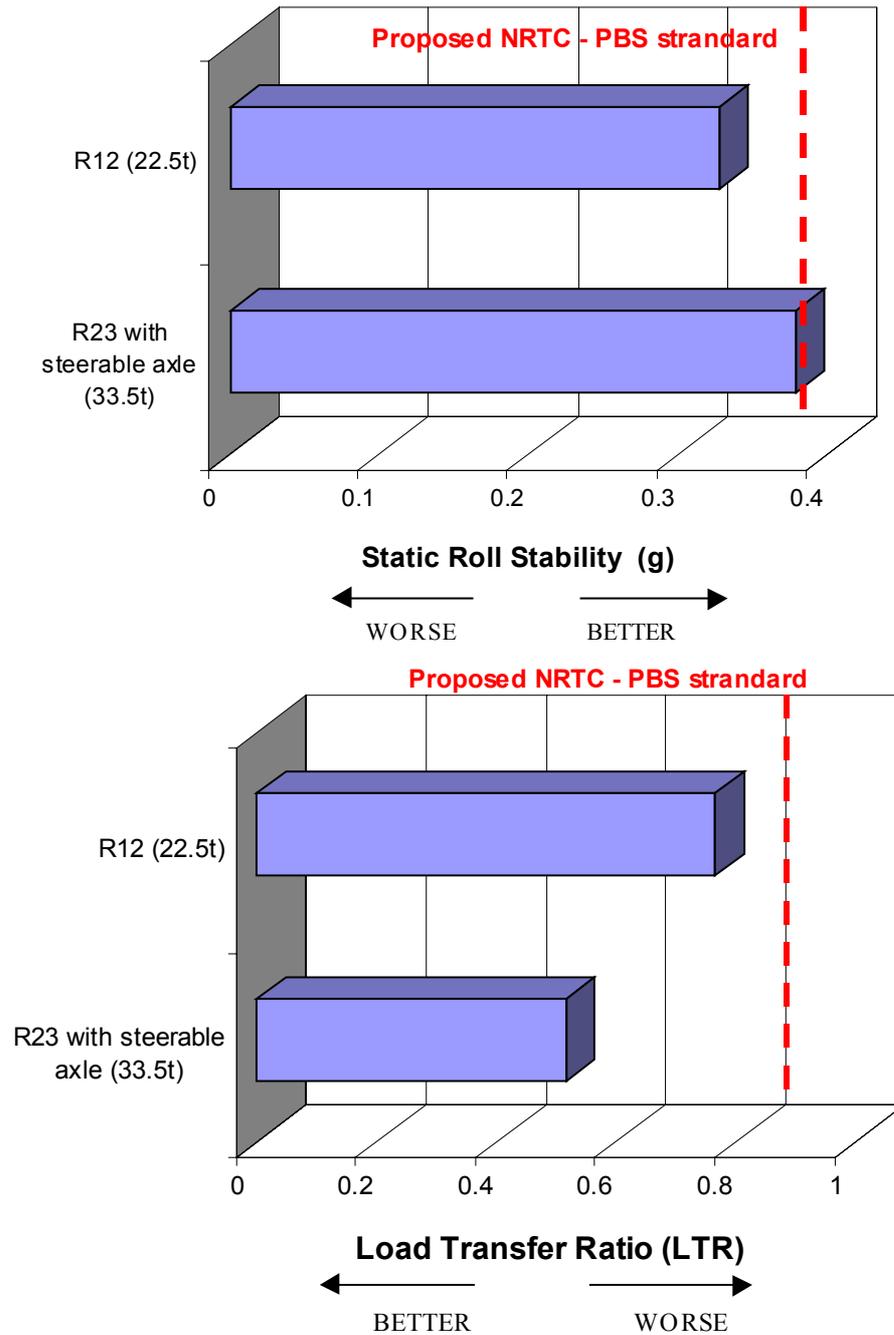


Figure 49 Static roll stability and load transfer ratio results for twin steer rigid trucks

From the results shown in Figure 49 we can see that the dynamic stability is positively influenced by the steerable axle on the R23 vehicle, even when the vehicle mass increased by almost 18%.

The results for low speed geometric performance of the rigid truck (R23) with a steerable tag axle are as shown in Figure 50. The use of the steerable axle improves the total swept path width enough so that this vehicle does not breach the proposed NRTC total swept path width standard of 5m for local roads. The results also show that this vehicle will have increased tail swing with a steerable axle.

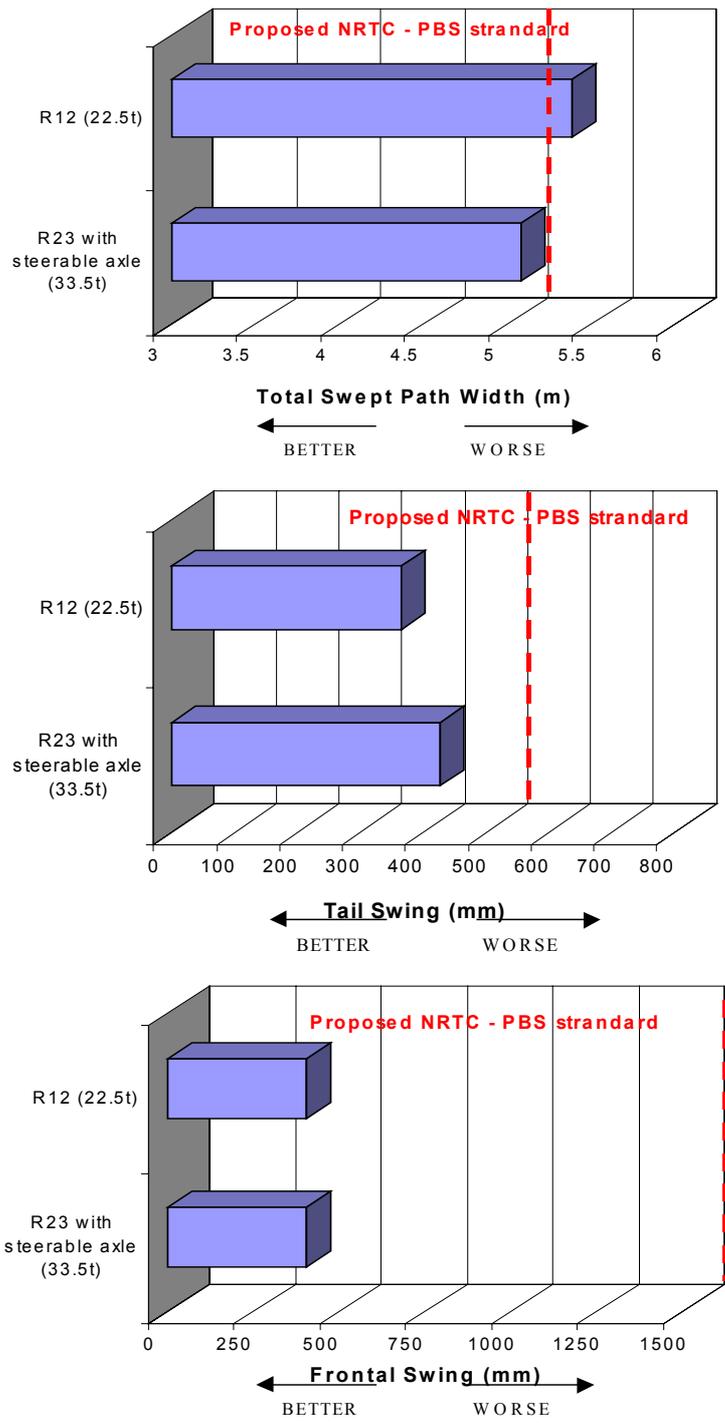


Figure 50 Total swept path width, tail swing and frontal swing results for twin steer rigid truck

All of the performance measures for the R23 with steerable axle have values within the proposed PBS standards. This candidate vehicle is not considered to have safety performance deficiencies.

6.3.6 Increased Mass Initiative: semi-trailer (A123) with increased s-dimension and a steerable axle

An improved mass distribution initiative for 14.6m (48ft) semi-trailers with an automotive type steerable trailer axle was developed from the results of Section 3.2.2. This vehicle was simulated with the axle loading and dimensions as described in Figure 51. This vehicle breached the Australian vehicle standards rules, part 7, division 2, rule 68-1(a), length of single trailers: the 9.5m limit on trailer s-dimension is breached (6).

(A123) Tractor Semi-Trailer - (Improved mass distribution with steerable axle fitted)

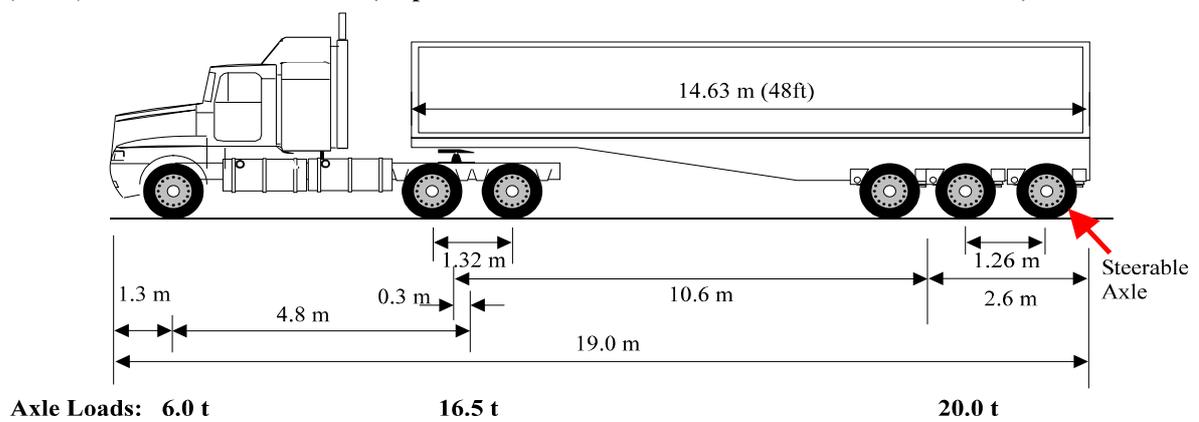


Figure 51 Improved mass distribution: semi-trailer (A123) with increased s-dimension and a steerable axle

The static roll stability results for the increased s-dimension semi-trailer with a steerable tag axle can be seen in Figure 52. Here the results show that the improved mass distribution and additional steerable axle have no effect on static roll stability, when compared with the standard 14.6m long semi-trailer combination.

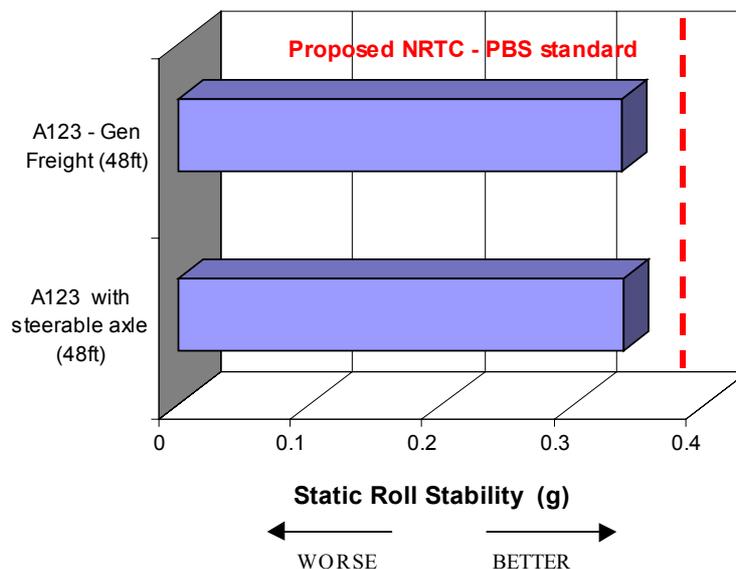


Figure 52 Static roll stability results for improved mass distribution 14.6 m (48 ft) semi-trailer (A123) with a steerable axle

The results shown in Figure 53 show that the dynamic stability of this semi-trailer combination is not adversely influenced by the addition of a steerable axle to this vehicle. The steerable axle improved the LTR value of this vehicle and the dynamic stability of the semi-trailer with a steerable axle in the standard SAE lane change manoeuvre was improved by approximately 6%.

Rearward amplification shows an improvement of 11% with the addition of a steerable axle. While high-speed dynamic offtracking worsened by approximately 4%. Both performance measures are still within the recommended NRTC standards.

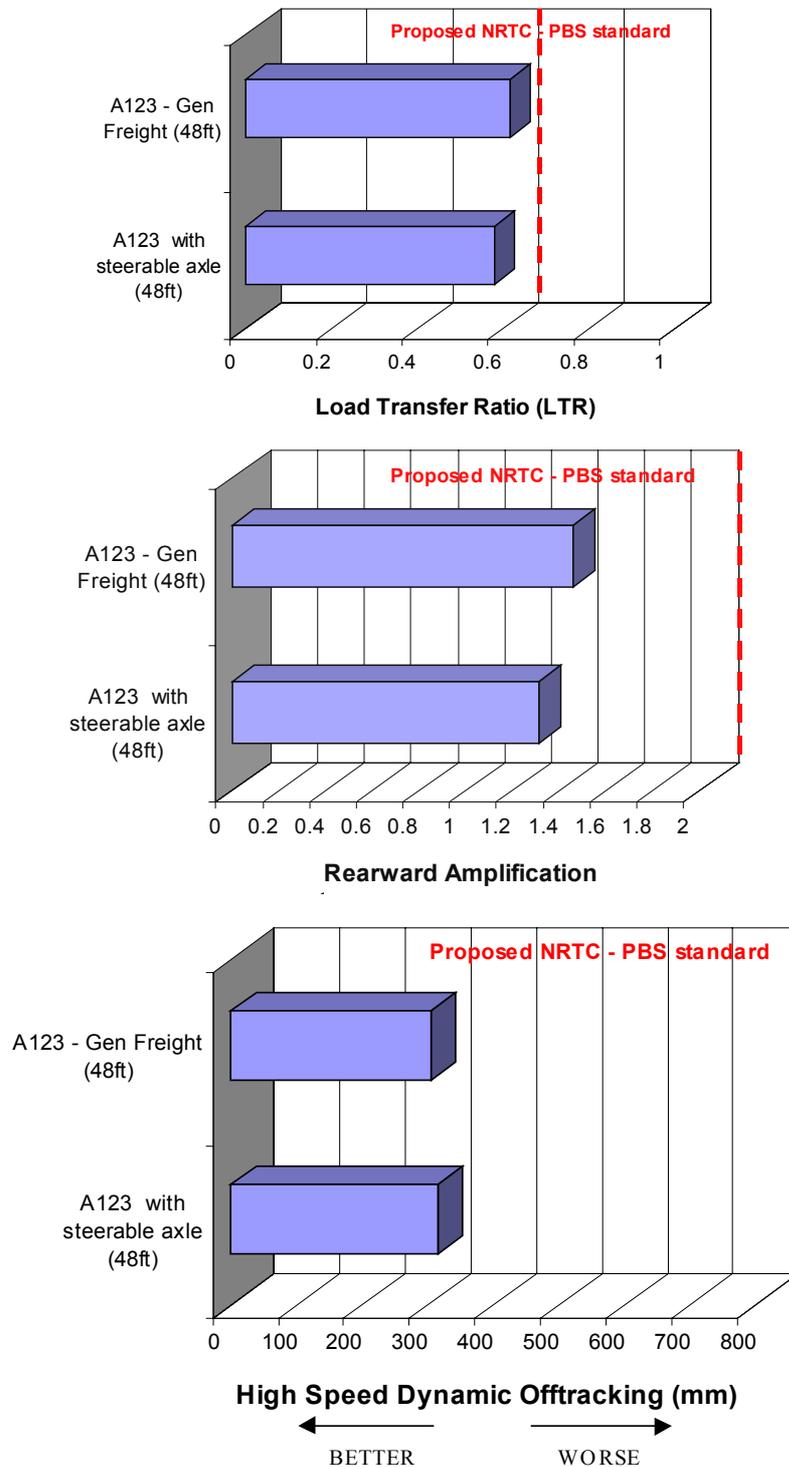


Figure 53 LTR, rearward amplification and HSDOT results for improved mass distribution 48ft semi-trailer (A123) with a steerable axle

Figure 54 shows the low-speed geometric performance results for the semi-trailer vehicle in a low speed offtracking manoeuvre. Here we see that the additional steerable axle improves vehicle total swept path width by approximately 14% enough so that it does not breach the proposed NRTC total swept path width standard of 7.4m for arterial roads. The results for Tail swing have been shown to marginally increase while frontal swing was shown to increase by approximately 177mm. Both vehicles perform well below the proposed NRTC standard for frontal swing of 1500mm.

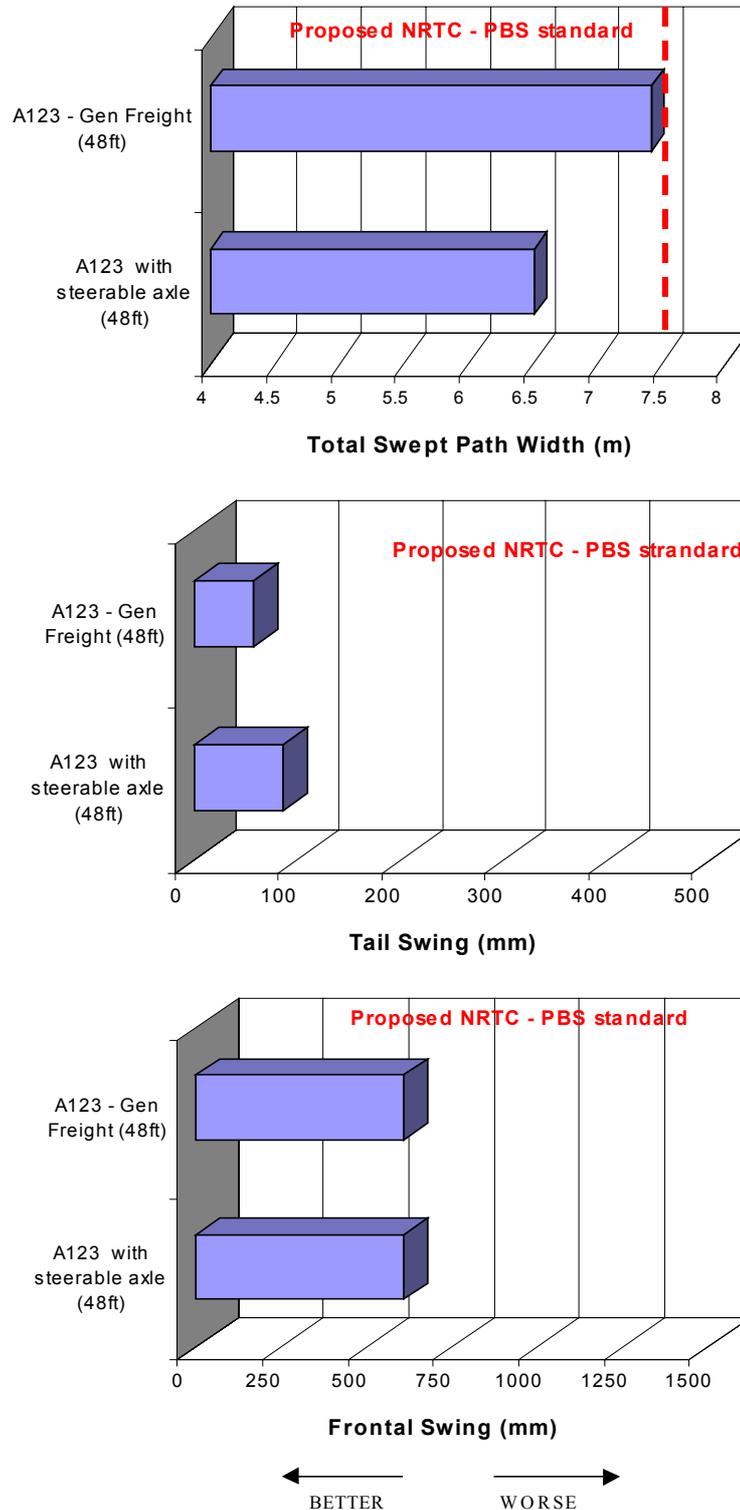


Figure 54 Total swept path width, frontal swing and tail swing results for 48ft semi-trailers

Figure 55 shows the high-speed offtracking and yaw damping results for the comparison semi-trailer vehicle combinations. It can be seen that the steerable trailer axle marginally increases the high-speed offtracking. It can also be seen that a semi-trailer fitted a steerable trailer axle will have marginally less yaw damping than a standard 14.6m (48ft) long general freight tractor-semi-trailer, but both vehicles perform well within the proposed NRTC standards.

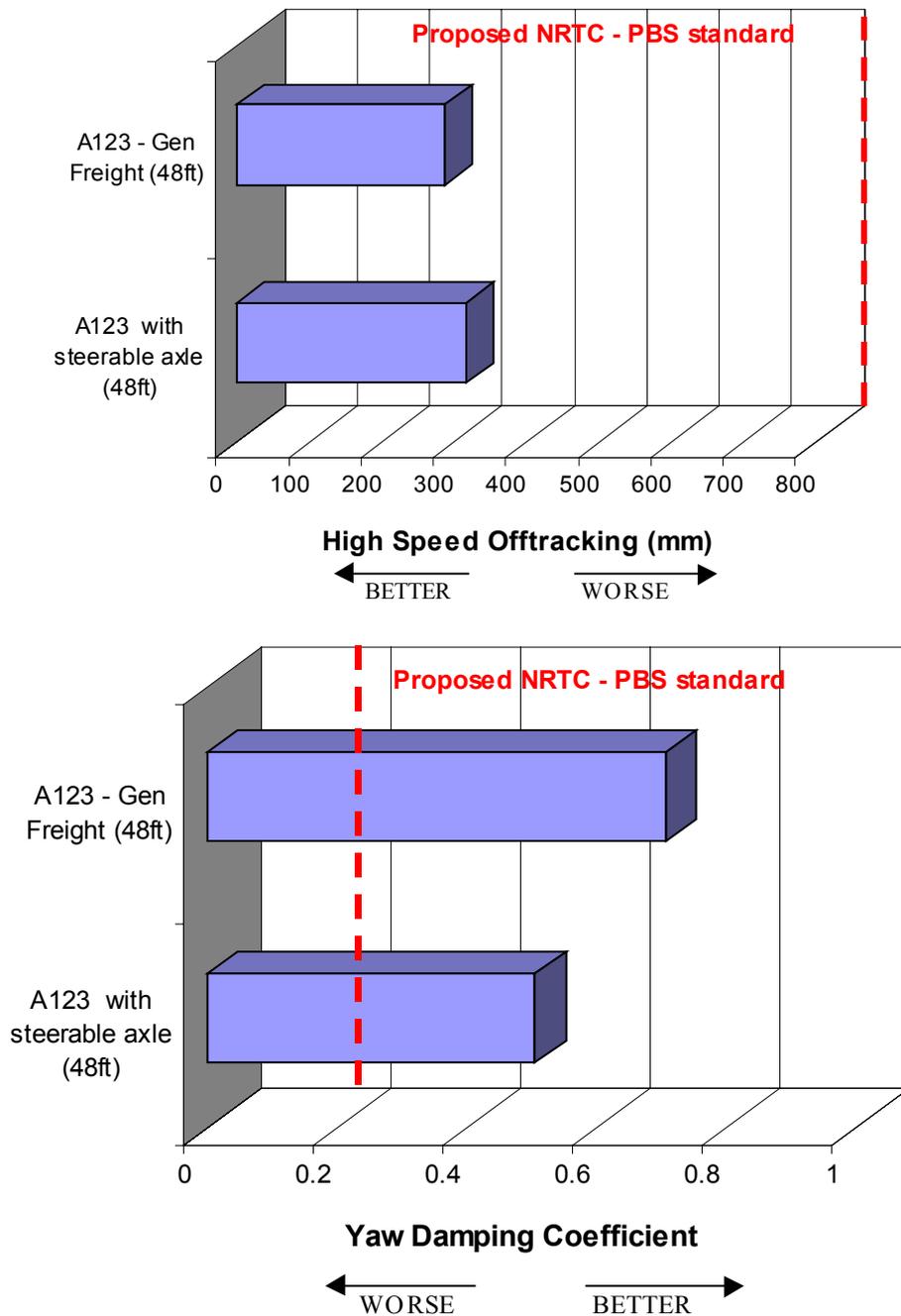


Figure 55 High-speed offtracking and yaw damping results for 14.6 m (48 ft) semi-trailers

All of the performance measures (except SRS) for the A123 with improved mass distribution and steerable axle have values within the proposed PBS standards. This candidate vehicle is not considered to have safety performance deficiencies.

6.3.7 Increased Mass Initiative: quad axle semi-trailer (A124) with a steerable axle

The static roll stability results for the quad axle semi-trailer (A124) (simulated as shown in Figure 16) with a steerable axle can be seen in Figure 56. Here we can see that the steerable axle vehicle has slightly better static roll stability. Both of these vehicles perform below the proposed standard of 0.35g set the NRTC.

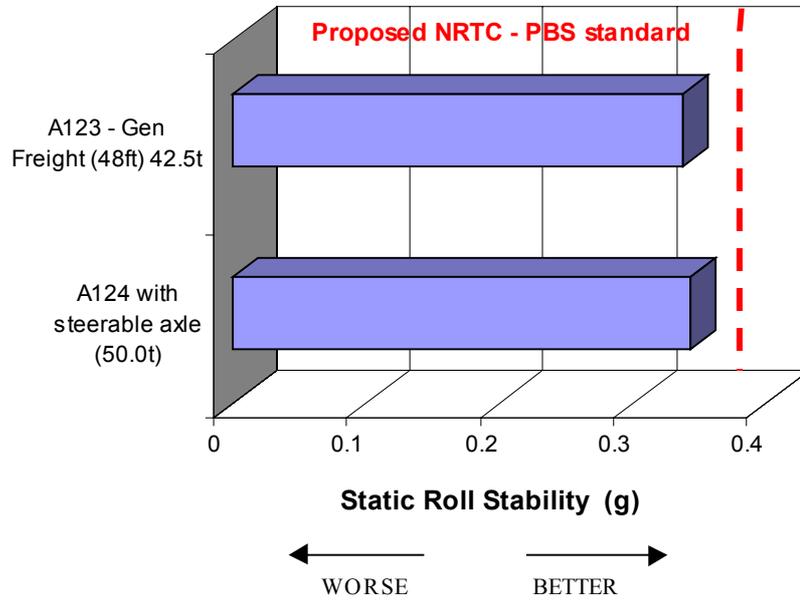


Figure 56 Static roll stability results for quad axle semi-trailers

Figure 57 shows results for the quad axle semi-trailer with steerable axle in a standard SAE lane change manoeuvre. Dynamic stability is improved by approximately 9% when compared to the standard general freight semi-trailer. Rearward amplification is shown to be 8.5% better for the quad axle semi-trailer than the standard general freight tractor-semi-trailer. While the high-speed dynamic offtracking results showed a marginal increase with the addition of the steerable trailer axle and increased GCM, but remained well within the proposed NRTC standards.

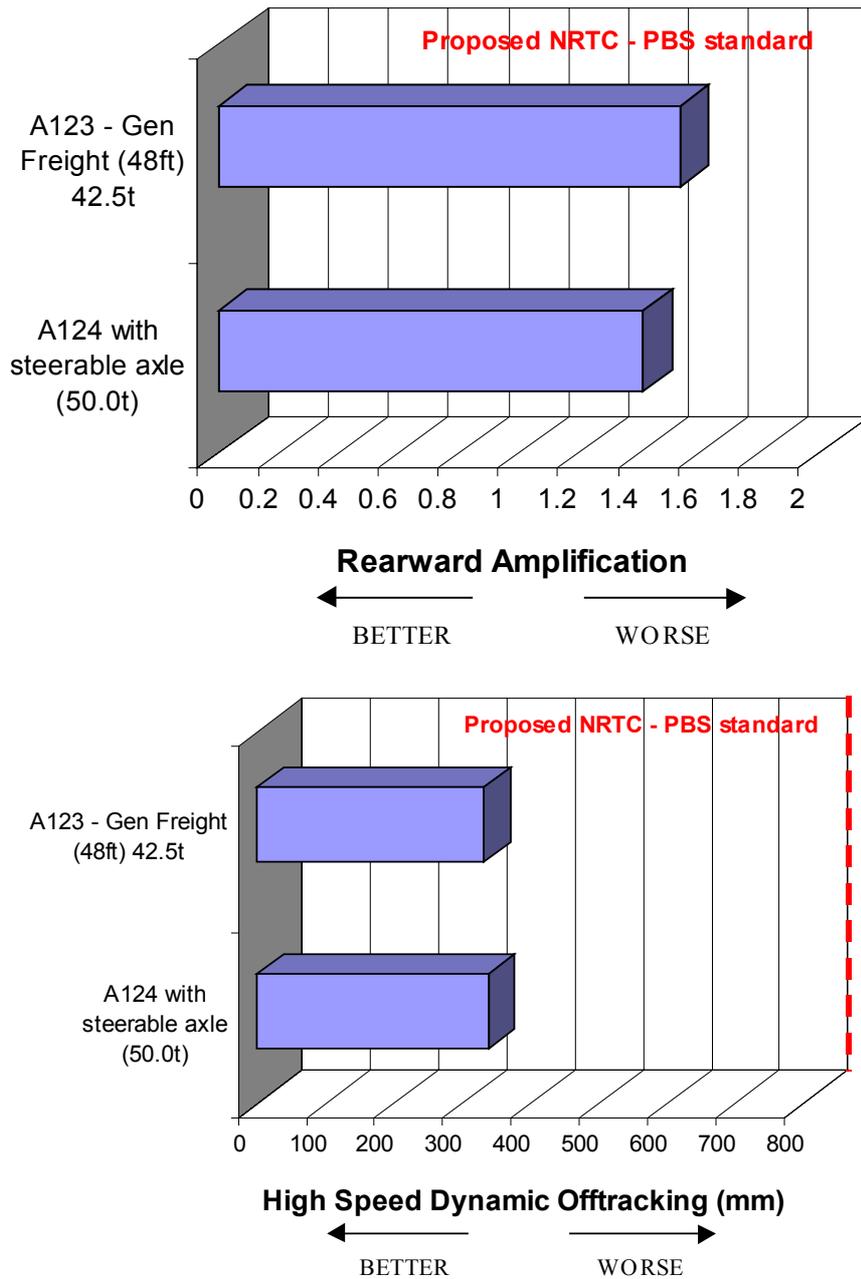


Figure 57 Quad axle semi-trailer results comparison for LTR, rearward amplification and high-speed dynamic offtracking

Results for the quad axle tractor-semi-trailer combination with a steerable axle in a low speed turn are shown in Figure 58. It is apparent that the additional steerable axle improves total swept path width by approximately 8%. Tail swing is shown to be significantly higher for the quad axle vehicle, but still well below the proposed standard of 500mm. The frontal swing barely changed with the addition of the steerable trailer axle, as this performance measure is mainly dependent on the prime mover geometry.

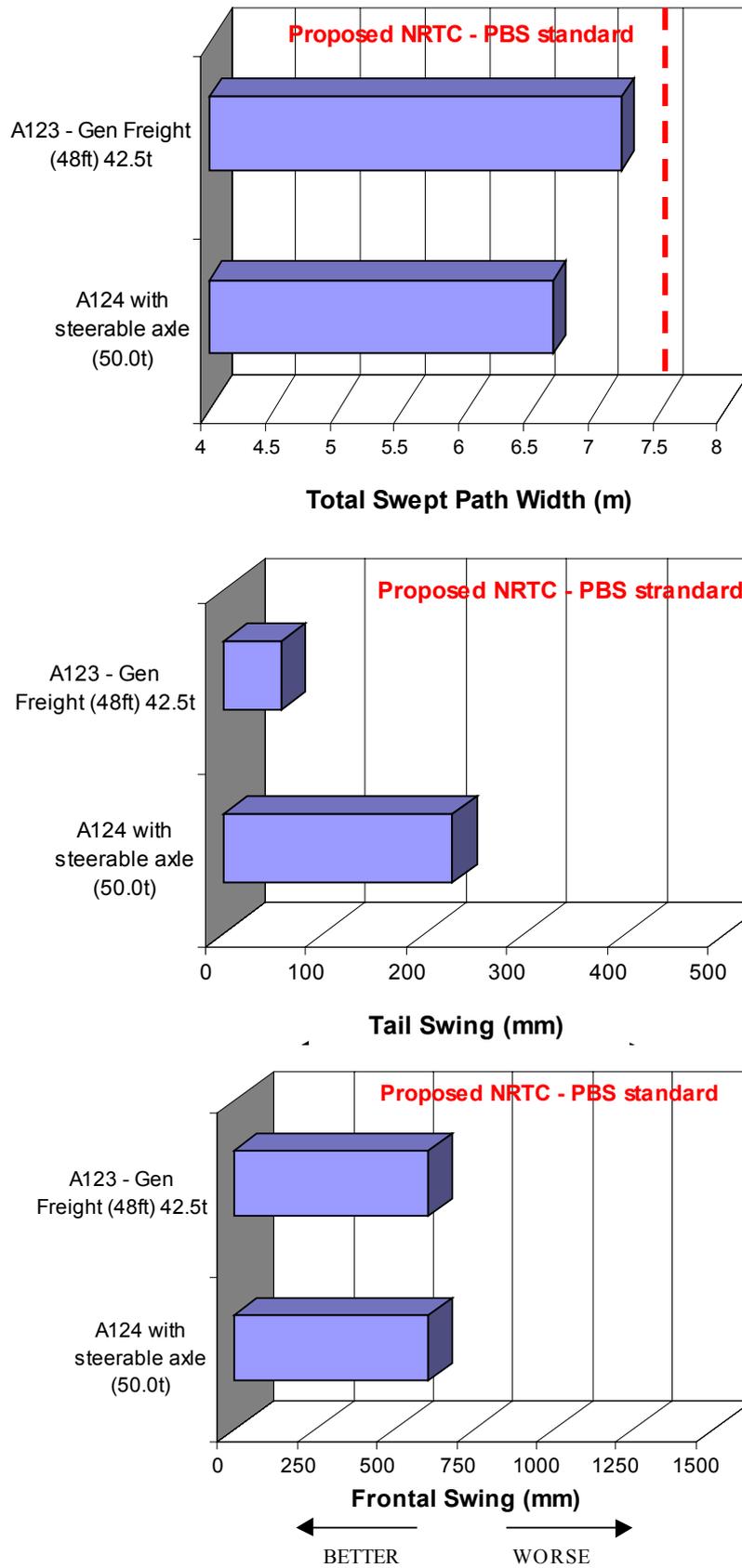


Figure 58 Quad axle semi-trailer results comparison for total swept path width, tail swing and frontal swing

Figure 59 shows the high-speed offtracking and yaw damping results for the 50t quad axle tractor-semi-trailer and standard general freight semi-trailer. It can be seen that the application of the steerable axle causes a marginal increase to the high-speed offtracking. It can also be seen that an additional steerable trailer axle will reduce the yaw damping when compared to a standard 14.6m (48ft) long general freight semi-trailer.

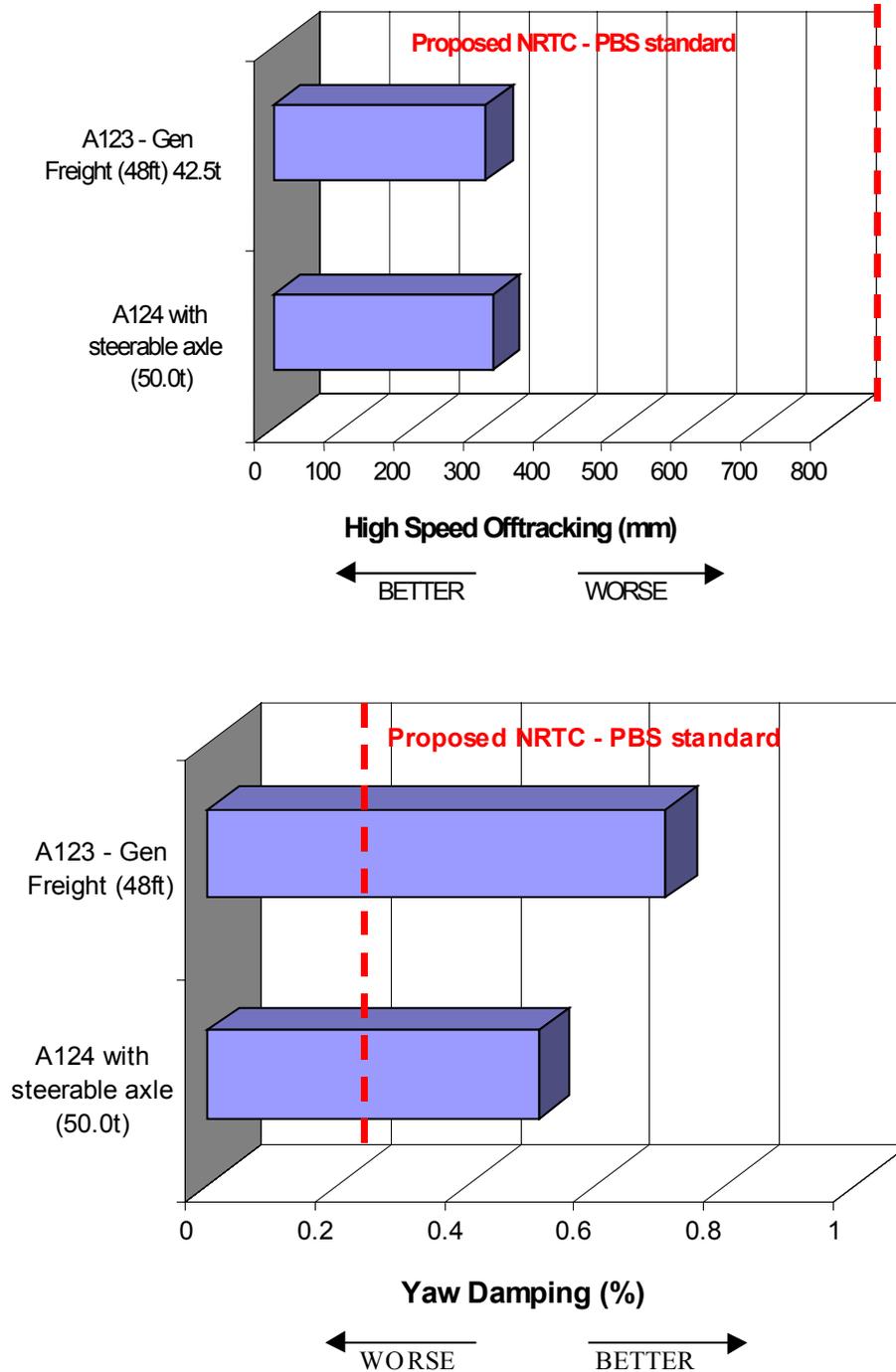


Figure 59 Comparison high-speed offtracking and yaw damping results for quad axle semi-trailer fitted with a steerable axle

All of the performance measures (except SRS) for the A124 with steerable axle have values within the proposed PBS standards. This candidate vehicle is not considered to have any safety performance deficiencies.

6.3.8 Increased Mass Initiative: super B-double (B1244) with 2 steerable axles

The static roll stability results for the super B-double (B1244) shown in Figure 17 with two steerable axles can be seen in Figure 60. It is apparent that the additional steerable axles improve static roll stability when compared to the general freight B-double. The additional axle and increased mass have increased SRS for this candidate vehicle to above the proposed PBS minimum standard.

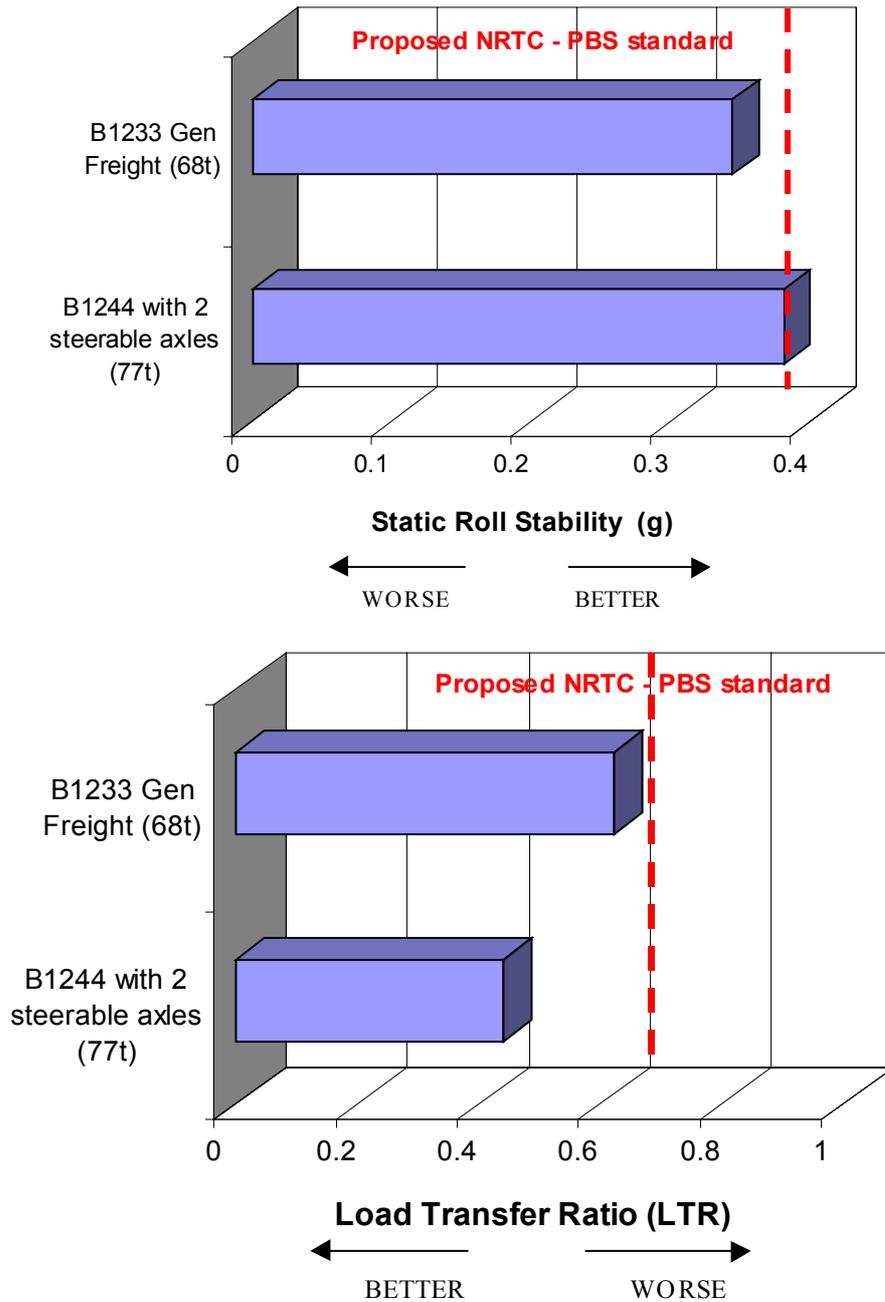


Figure 60 Static roll stability and load transfer ratio results for super B-double combination (B1244) with 2 steerable axles

Figure 60 also shows the LTR results for the super B-double (B1244) combination. It is apparent that the addition of the steerable trailer axles to this vehicle combination will significantly improve dynamic stability. We can see that both vehicles simulated perform below the proposed NRTC load transfer ratio standard of 0.6.

Figure 61 shows the rearward amplification and high-speed dynamic offtracking results for the super B-double combination (B1244). We can see that both vehicles perform well within the proposed NRTC rearward amplification standard of 2.0. The results also show that the addition of steerable trailer axles to this vehicle combination will improve rearward amplification by almost 18%. High-speed dynamic offtracking results are worse for the super B-double than the standard general freight B-double, however both results are well below the proposed standard of 800mm.

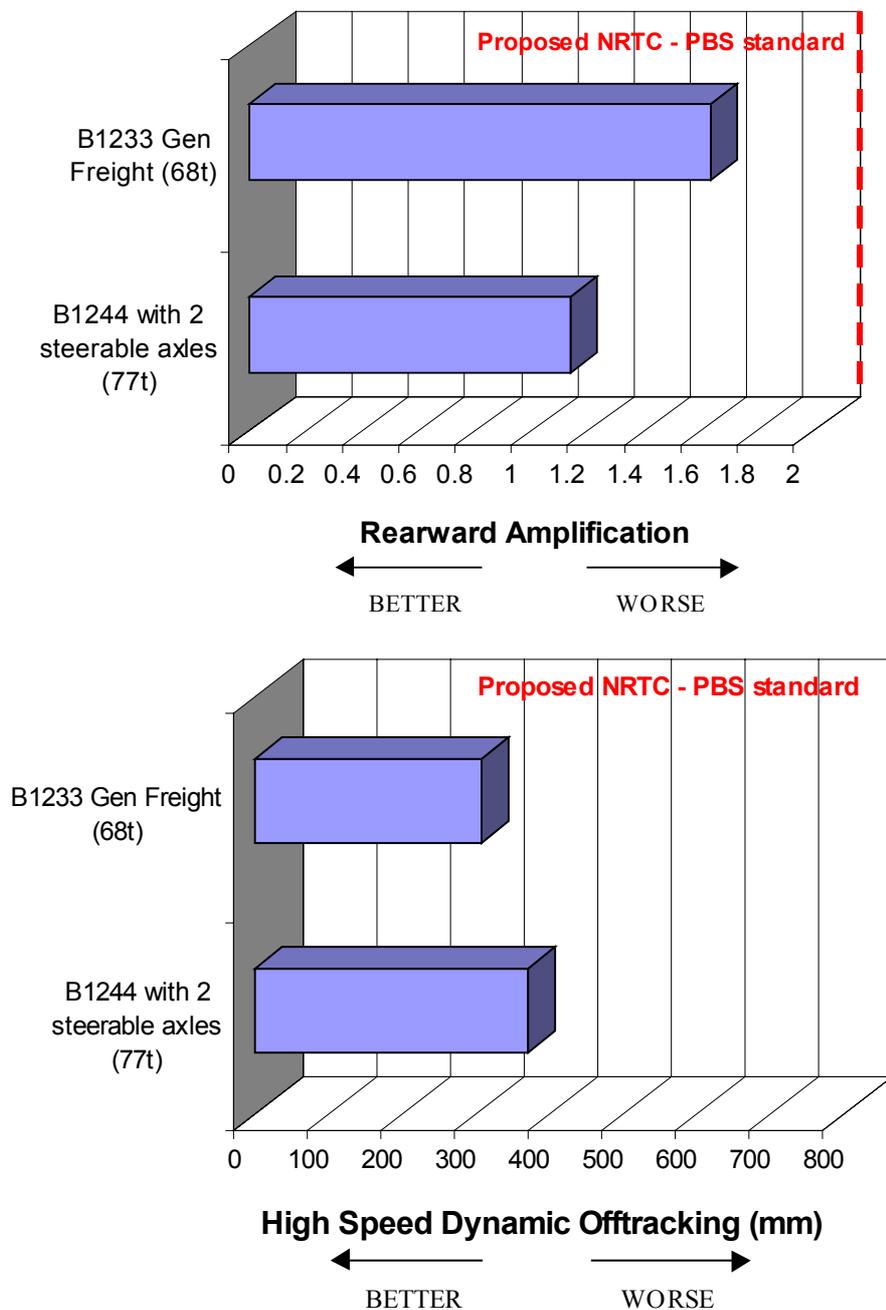


Figure 61 Rearward amplification and load transfer ratio results for super B-double (B1244) combination with 2 steerable axles

Figure 62 shows the low speed geometric results for the super B-double (B1244) with two steerable axles in a low speed offtracking manoeuvre. Here we can see that, despite the benefits of the steerable axles, the increased vehicle length leads to increased total swept path width barely within the proposed PBS standard of 10.1m. Tail swing also increased for the super B-double, but is still well within the proposed PBS standard of 500mm. Frontal swing results were found to be little affected by the addition of the steerable trailer axles.

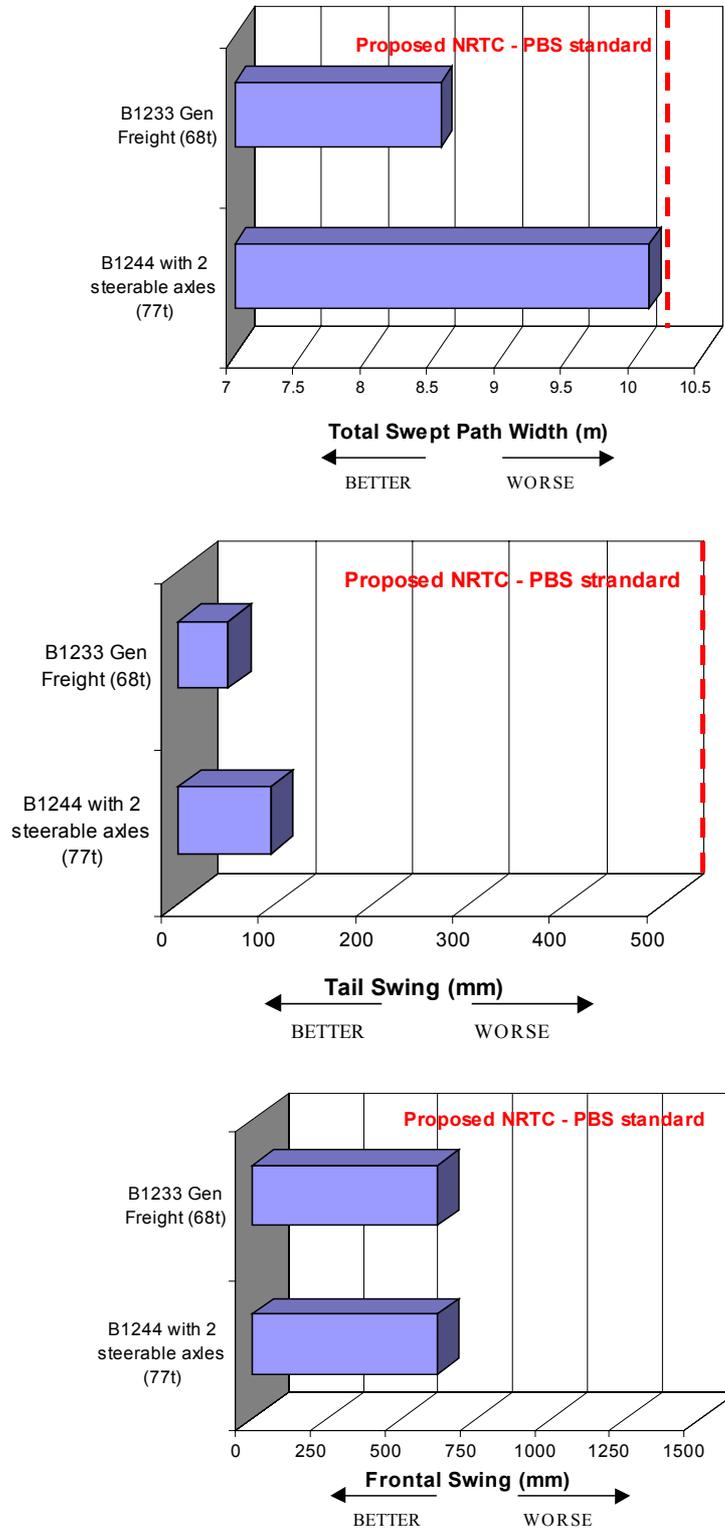


Figure 62 Total swept path width, tail swing and frontal swing results for super B-double (B1244) combination with 2 steerable axles

Figure 63 shows the comparison high-speed offtracking and yaw damping results for the super B-double (B1244) combination. The increased vehicle mass and use of the steerable axles cause a marginal increase to the high-speed offtracking results. It can also be seen that a B-double fitted with additional steerable trailer axles will have better yaw damping than a standard general freight B-double; this would most likely be due to the action of the additional axle in each trailer axle group and the increased s-dimension of each trailer.

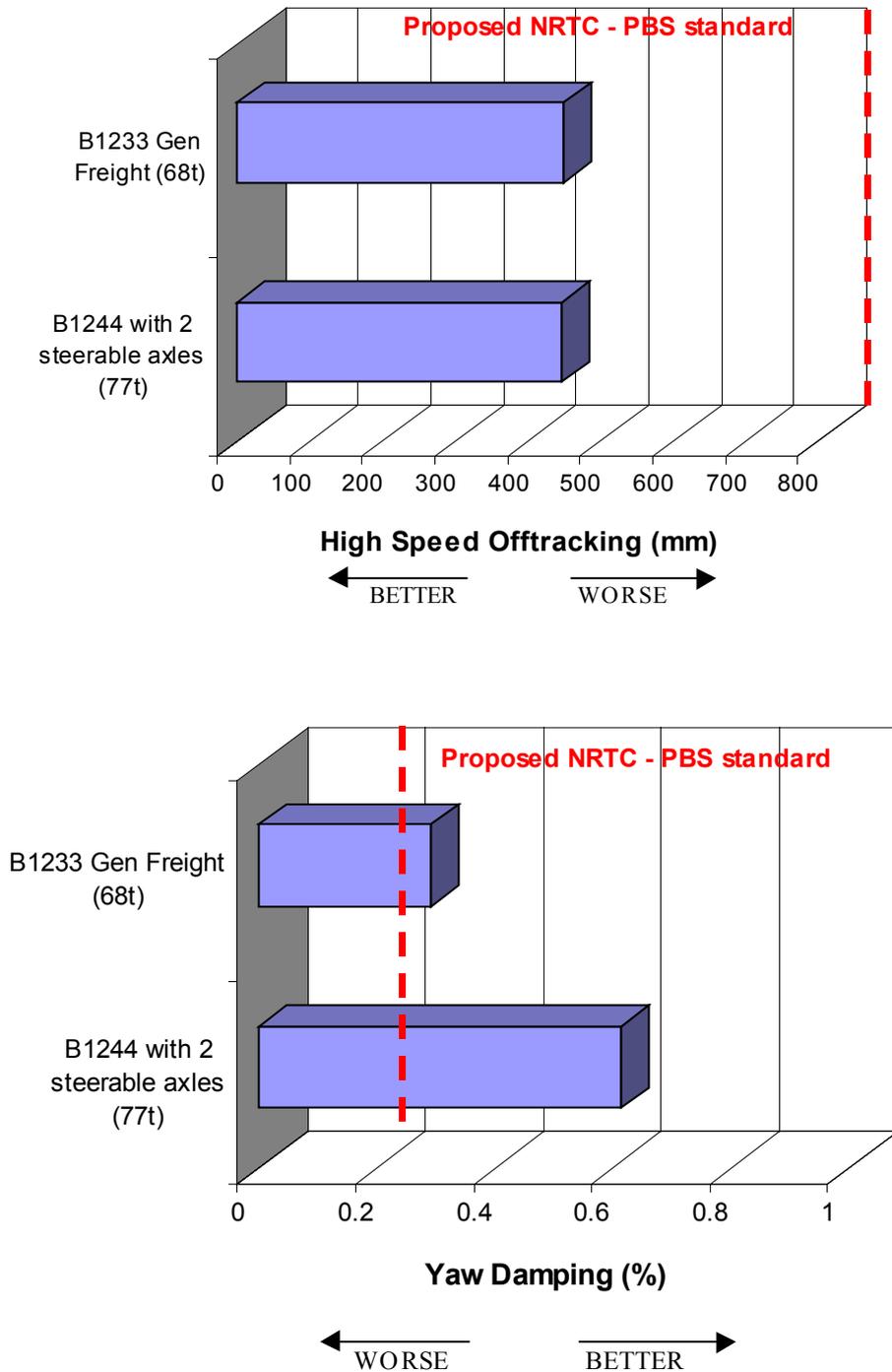


Figure 63 Comparison high-speed offtracking and yaw damping results for super B-double (B1244) combination with 2 steerable axles

All of the performance measures (except SRS) for the B1244 with steerable axles have values within the proposed PBS standards. This candidate vehicle is not considered to have

safety performance deficiencies. Agencies and operators would need to carefully consider the increased swept path of this vehicle.

6.3.9 Increased Mass Initiative: higher mass B-double (B1234) with 2 steerable axles

An increased mass initiative B-double (B1234) with two automotive type steerable trailer axles was simulated at the loading and dimensions shown in Figure 18. Figure 64 shows that the additional steerable axles (at increased mass) improve static roll stability.

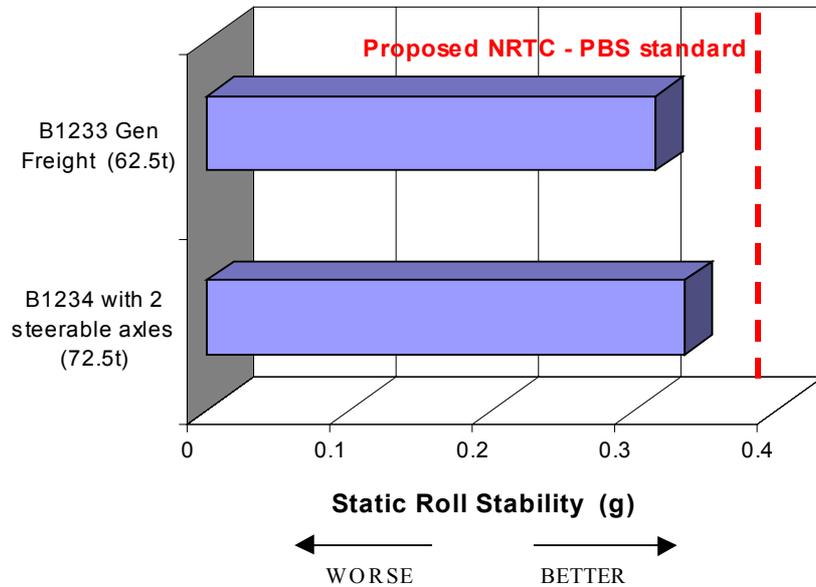


Figure 64 Static roll stability for higher mass B-double (B1234) with 2 steerable trailer axles

Figure 65 shows the LTR, RA and HSDOT results for the candidate higher mass B-double (B1234) combination. The results show that the addition of the steerable trailer axles to this vehicle combination improves dynamic stability. It is apparent that both vehicles perform within the proposed NRTC standards of 0.6 for load transfer ratio, 2.0 for rearward amplification and 800mm for high-speed dynamic offtracking.

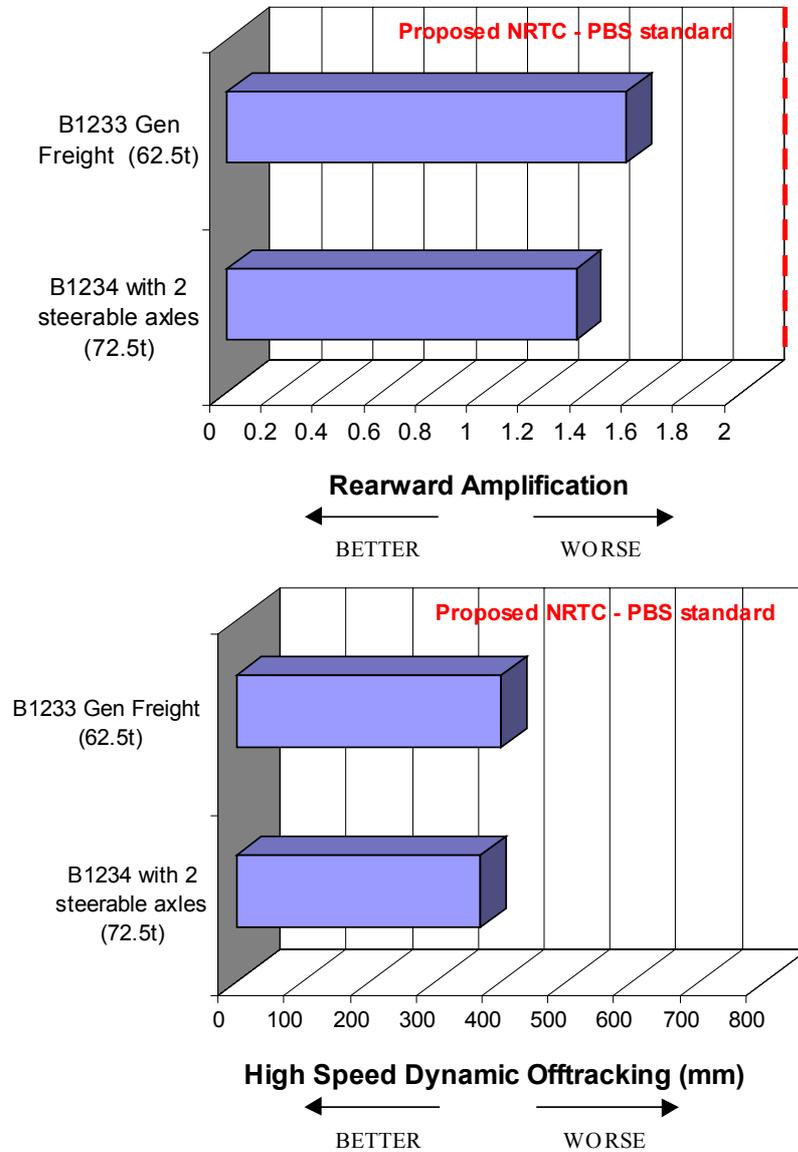


Figure 65 Comparison LTR, RA and HSDOT results for the higher mass super B-double (B1234) with two steerable axles

Figure 66 shows the low speed geometric results for the higher mass B-double (B1234) combination. The addition of the steerable trailer axles to the longer vehicle results in both vehicles simulated having the same total swept path width of almost 8.5m. The tail swing on the high mass B-double (B1234) was shown to be increased, but still well below the proposed NRTC standard of 500mm. Frontal swing did not change significantly for the candidate higher mass B-double (B1234).

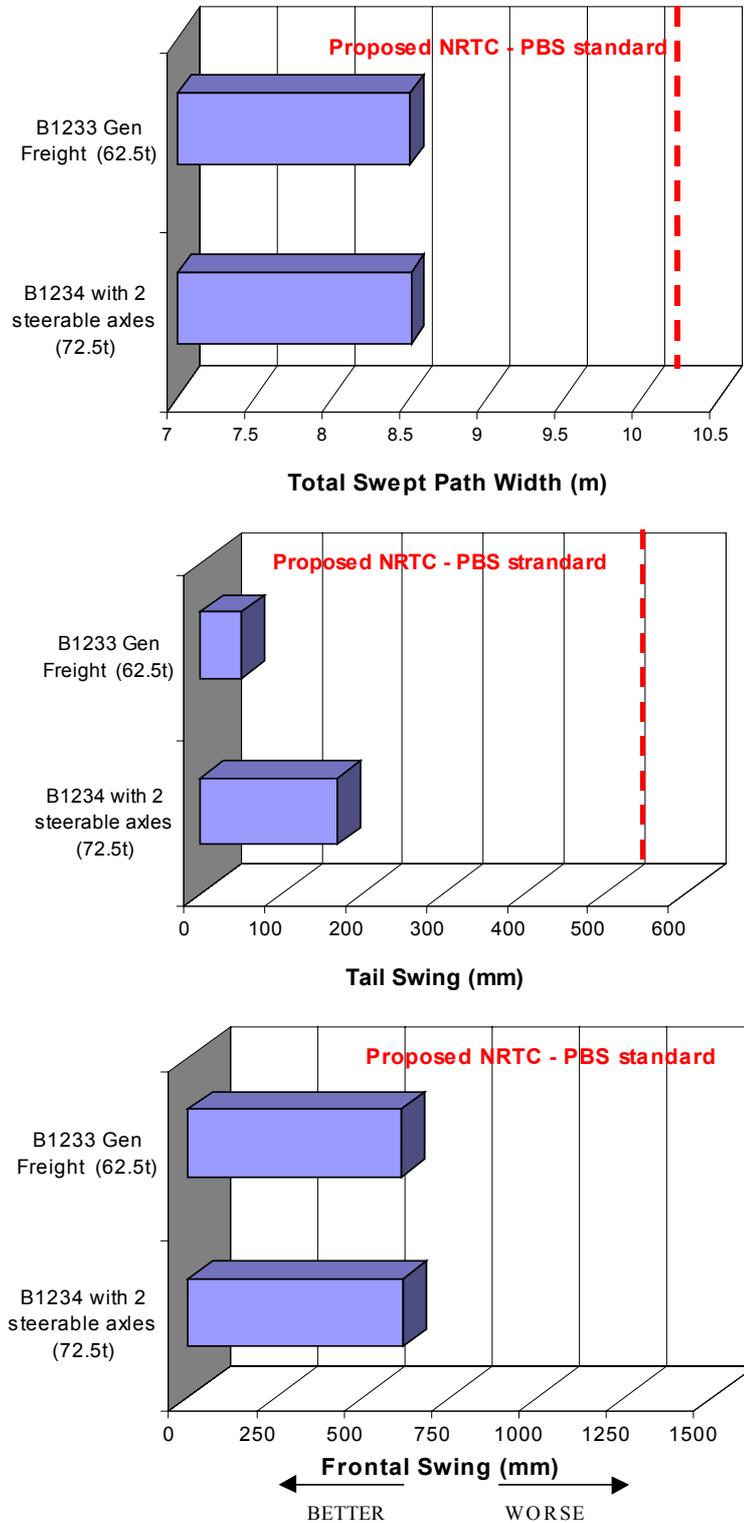


Figure 66 Comparison low speed swept path results for the higher mass B-double (B1234) with two steerable axles

Figure 67 shows the comparison high-speed offtracking and yaw damping results for the candidate B-double (B1234). The increased vehicle mass and use of steerable axles causes a marginal increase to the high-speed offtracking results. It can also be seen that a B-double fitted with additional steerable trailer axles has better yaw damping than a standard general freight B-double; this would most likely be due to the combined effect of the steerable axles and the increased s-dimension of the trailer.

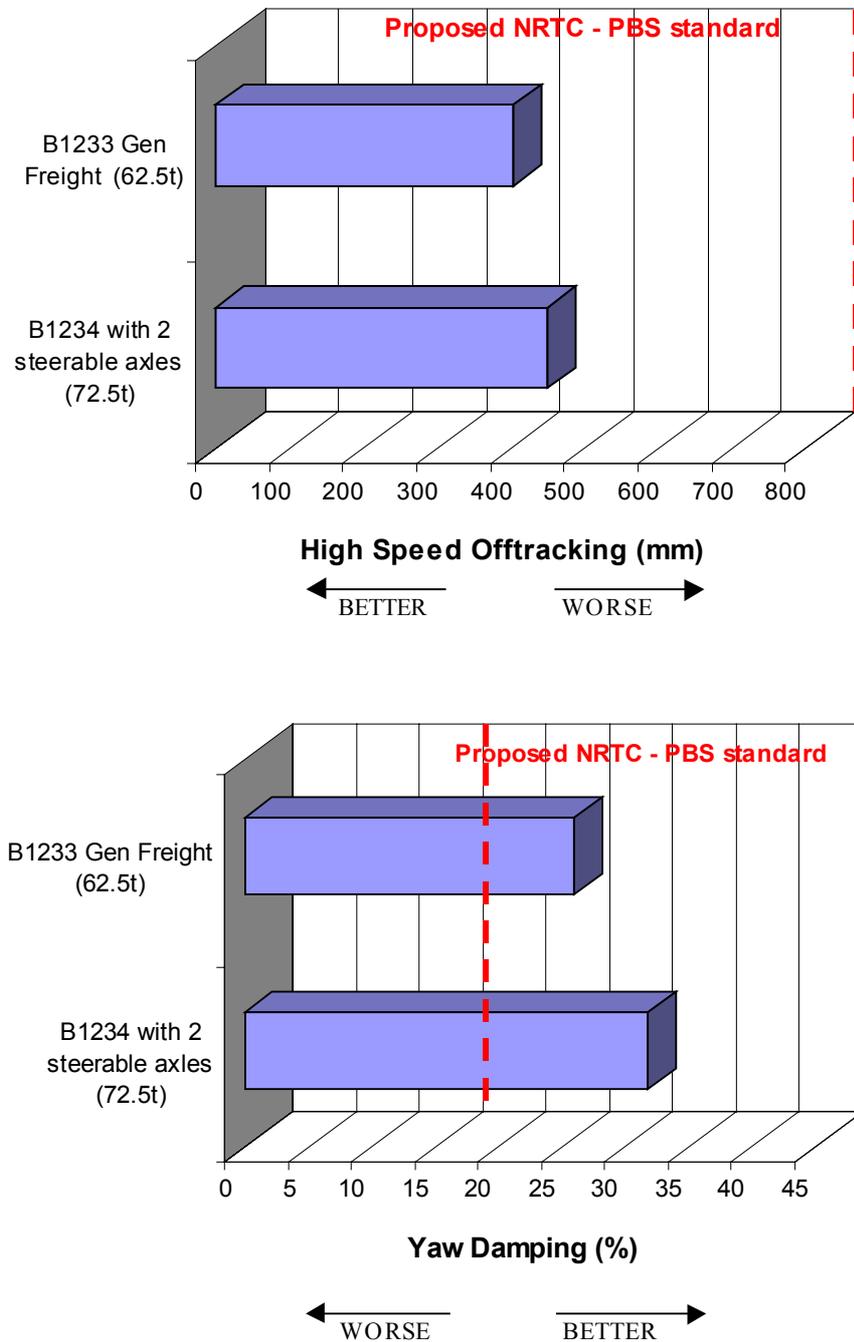


Figure 67 High-speed offtracking and yaw damping results for higher mass B-double (B1234) fitted with 2 steerable axles

All of the performance measures (except SRS) for the higher mass B1234 with steerable axles have values within the proposed PBS standards. This candidate vehicle is not considered to have safety performance deficiencies.

6.3.10 Increased Mass Initiative: triple road train with steerable axles (A124T34T34)

The increased mass initiative triple roadtrain was simulated at the axle loading and dimensional configuration as specified in Figure 19. Static roll stability for the increased mass initiative triple roadtrain (A124T34T34) with steerable axles can be seen in Figure 68. It is apparent that the increased mass and additional steerable axles improve static roll stability by approximately 9% when compared to the standard higher mass triple roadtrain (A123T33T33). Both of these vehicles perform well above the proposed PBS SRS minimum.

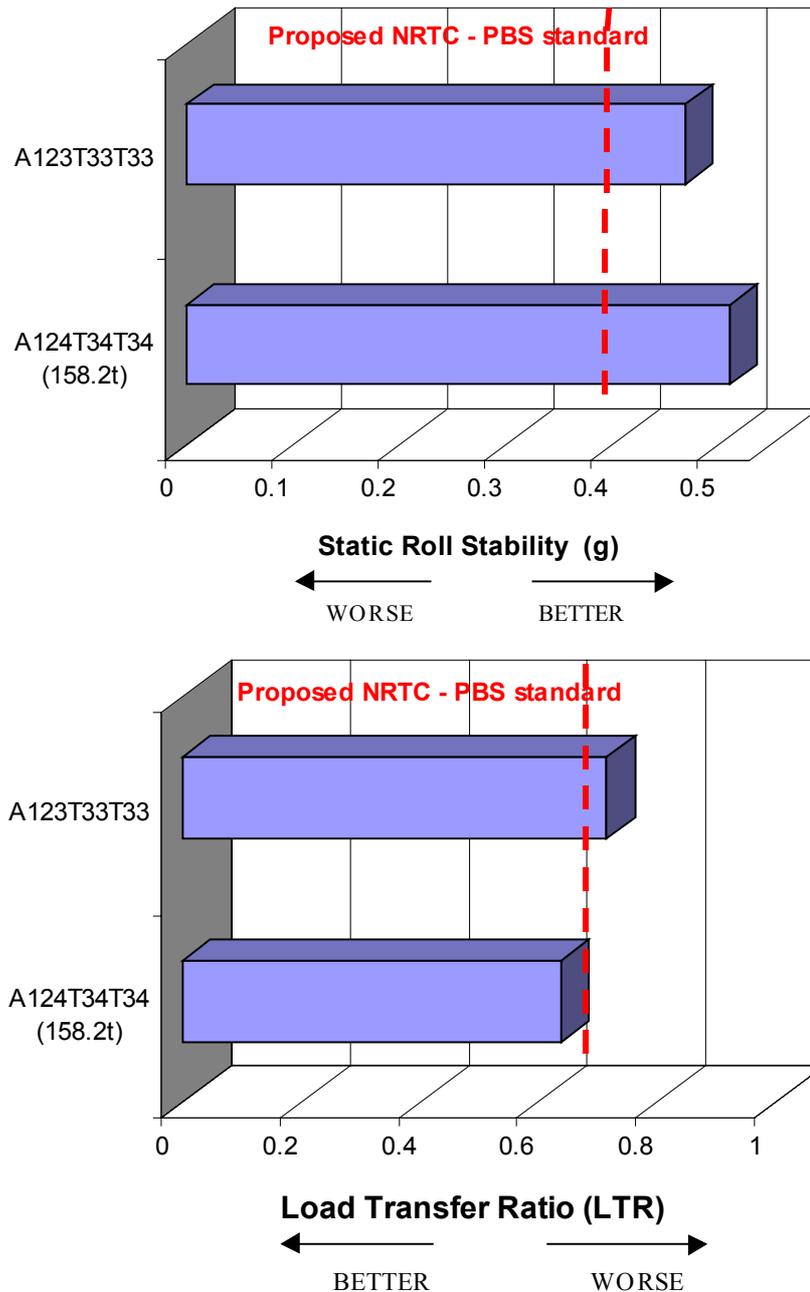


Figure 68 Static roll stability and load transfer ratio results for triple roadtrain combination with steerable axles (reduced lane change manoeuvre)

Figure 68 also shows the LTR results for the triple roadtrain with steerable axles. It can be seen that this roadtrain with steerable axles has improved LTR.

Figure 69 shows the comparison rearward amplification and high-speed dynamic offtracking results for the triple roadtrain with steerable axles. It is apparent that both vehicles have worse rearward amplification than the proposed NRTC standard of 2.0. The results also show that the increased payload for this vehicle combined with the addition of the steerable trailer axles will marginally increase high speed dynamic offtracking to lie outside the proposed NRTC standard of 800mm.

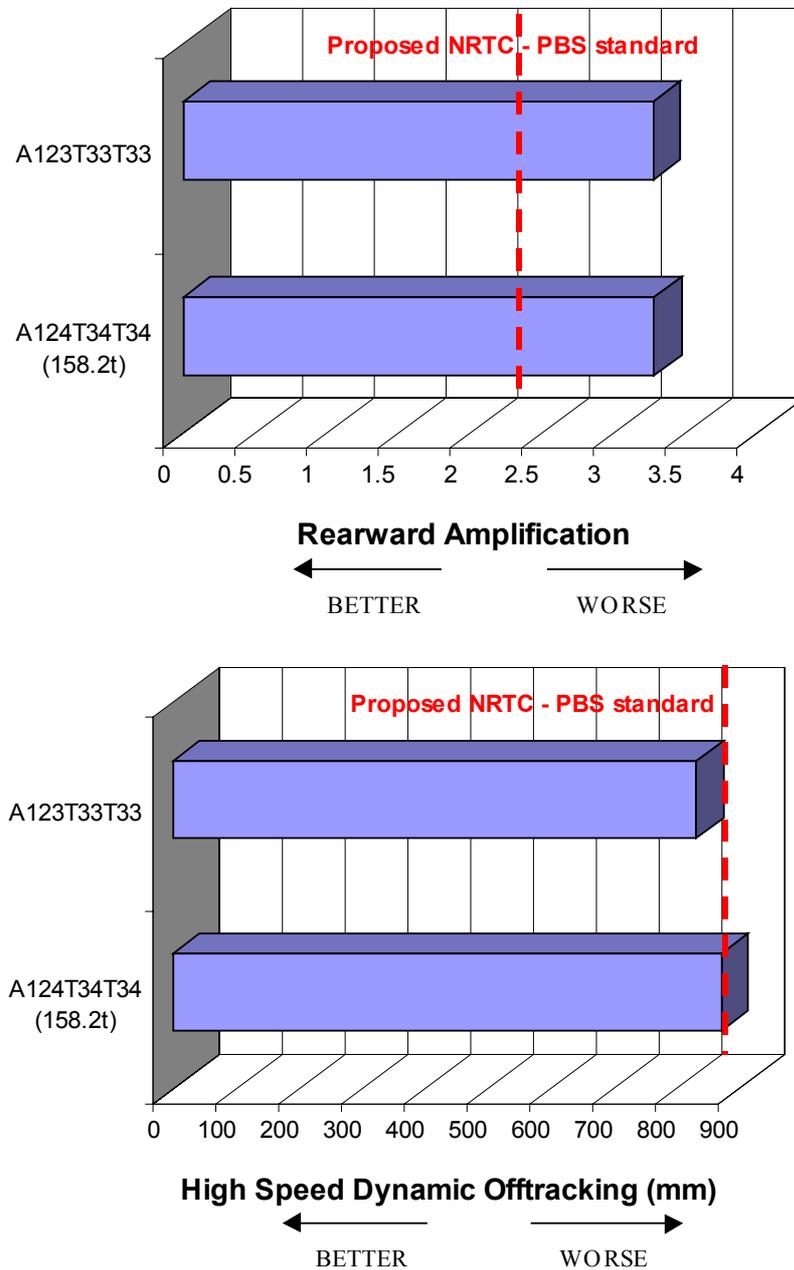


Figure 69 Rearward amplification and high-speed dynamic offtracking results for candidate triple roadtrain with steerable axles

Comparison high-speed offtracking and yaw damping results for the candidate triple roadtrain with steerable axles are shown in Figure 70. It is apparent that the addition of the steerable trailer axles and increased GCM resulted in increased high-speed offtracking. Both roadtrains had greater HSOT than the proposed PBS standard of 700mm. Although the yaw damping behaviour of this triple roadtrain combination was shown to worsen with the addition of steerable axles and increased mass, both road trains perform within the proposed PBS yaw-damping standard.

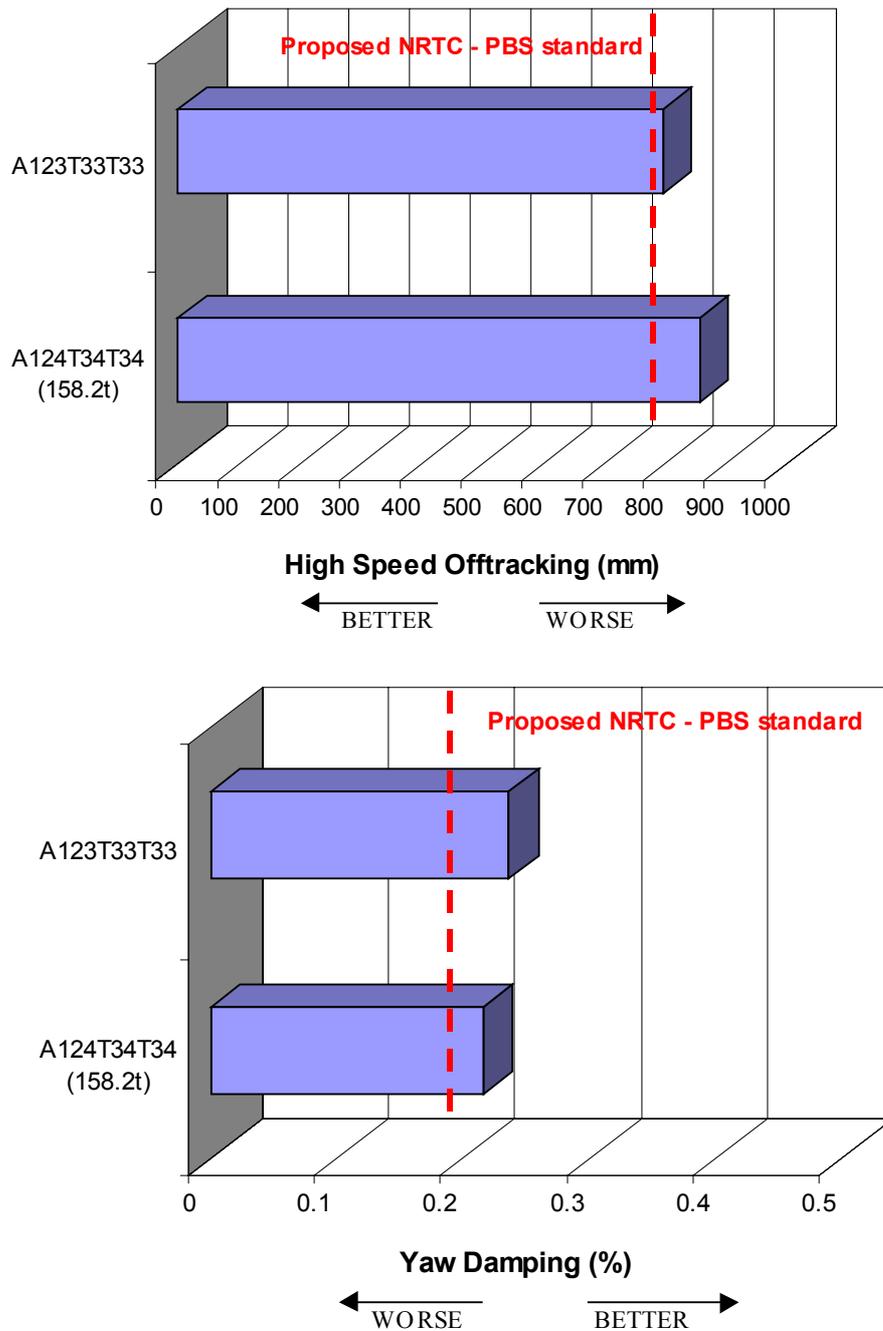


Figure 70 High-speed offtracking and yaw damping results for the candidate triple roadtrain with steerable axles

Most of the performance measures for the A124T34T34 roadtrain with steerable axles have values within the proposed PBS standards. However, this candidate vehicle is considered to have a potential safety performance deficiency in the area of high-speed dynamic offtracking.

6.3.11 Increased Flexibility Initiative: semi-trailer (A123) with longer wheelbase prime mover and steerable axle

An increased flexibility initiative tractor-semi-trailer with an automotive type steerable trailer axle was developed from the results of Section 5. This vehicle was simulated with

the axle loadings and dimensions as described by Figure 71. This vehicle breaches the 19m overall length limit for tractor-semi-trailer combinations.

(A123) Tractor Semi-Trailer - (Increased flexibility with steerable axle, longer Primemovers)

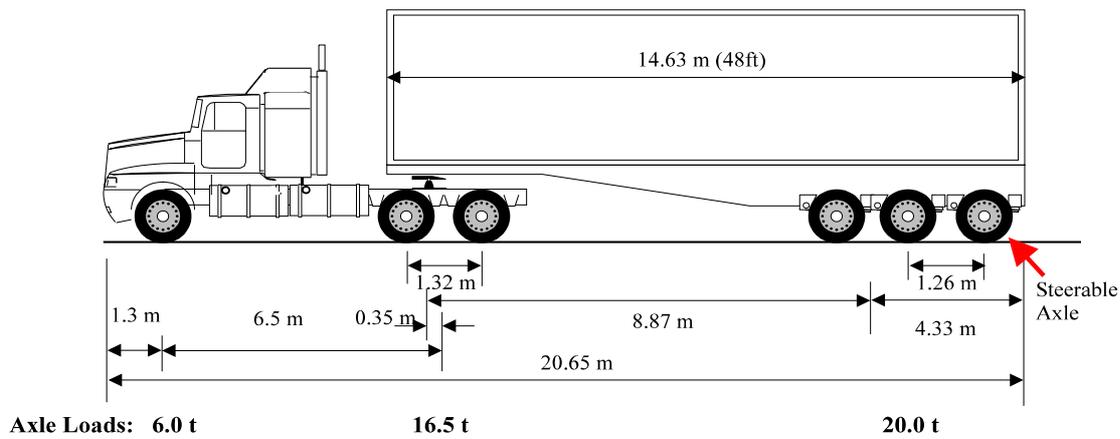


Figure 71 Increased flexibility initiative longer wheelbase tractor-semi-trailer with a steerable axle

Static roll stability results for the increased flexibility semi-trailer (A123) with a steerable axle can be seen in Figure 72. Here we can see that the increased flexibility prime mover and steerable axle have a minor effect on static roll stability when compared to the general freight semi-trailer. Both of these vehicles perform below the proposed PBS standard.

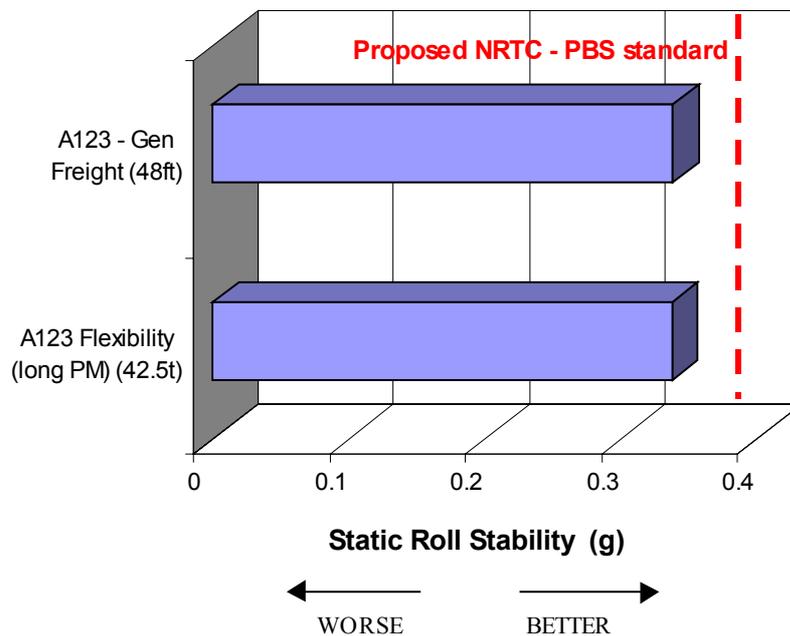


Figure 72 Static roll stability results for the increased flexibility semi-trailer with steerable axle fitted

Figure 73 shows that the increased flexibility semi-trailer with a steerable axle has an improved LTR. Both vehicles have a rearward amplification below the proposed NRTC maximum of 2.0. However the high-speed dynamic offtracking worsens with a steerable axle, but remains well within the proposed PBS standard.

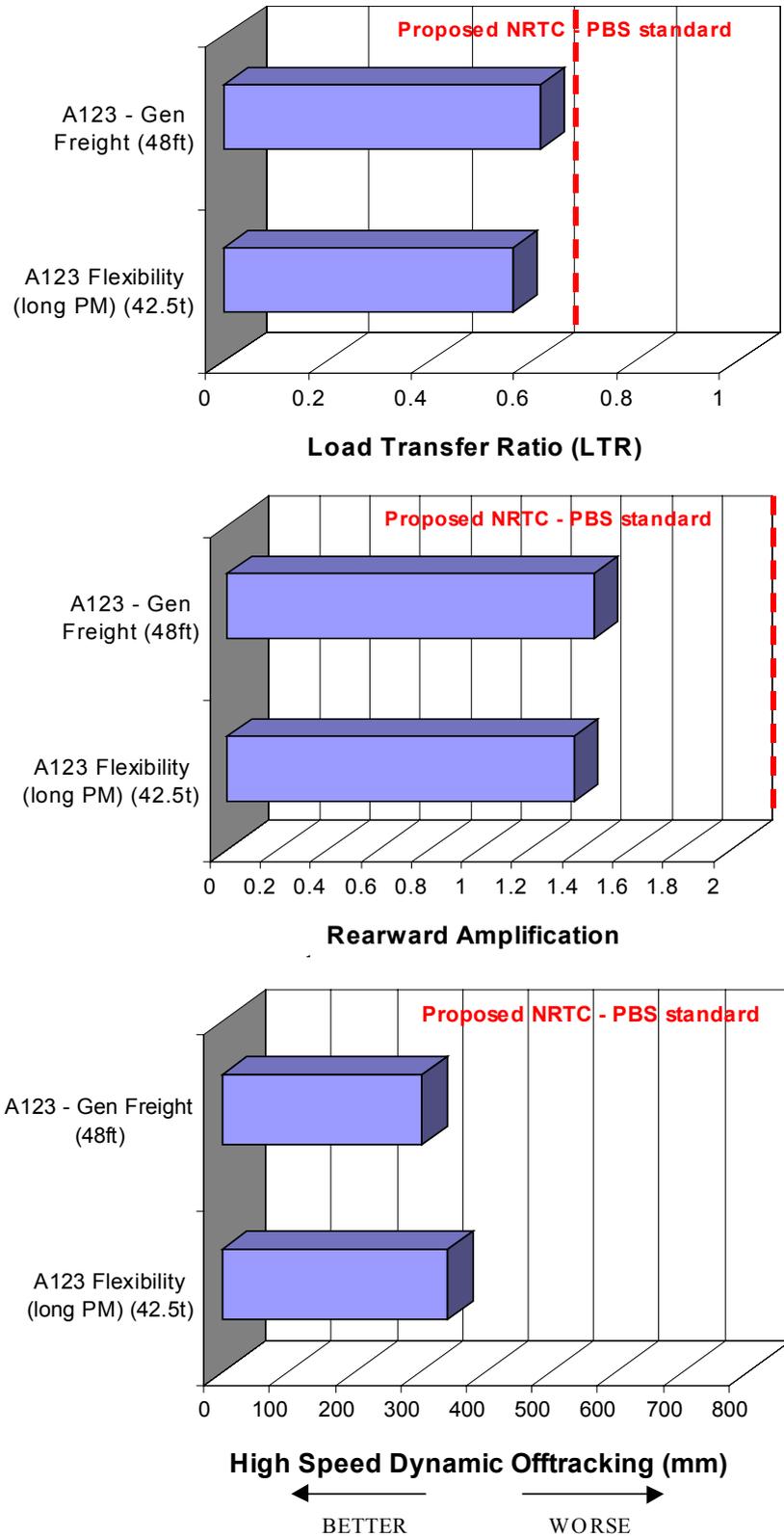


Figure 73 LTR results for the increased flexibility semi-trailer with steerable axle fitted

Figure 74 shows low speed geometric performance results for the increased flexibility semi-trailer combination. The additional prime mover length in combination with the steerable trailer axle will result in the total swept path width just remaining within the proposed PBS standard. Again tail swing and frontal swing are only marginally affected.

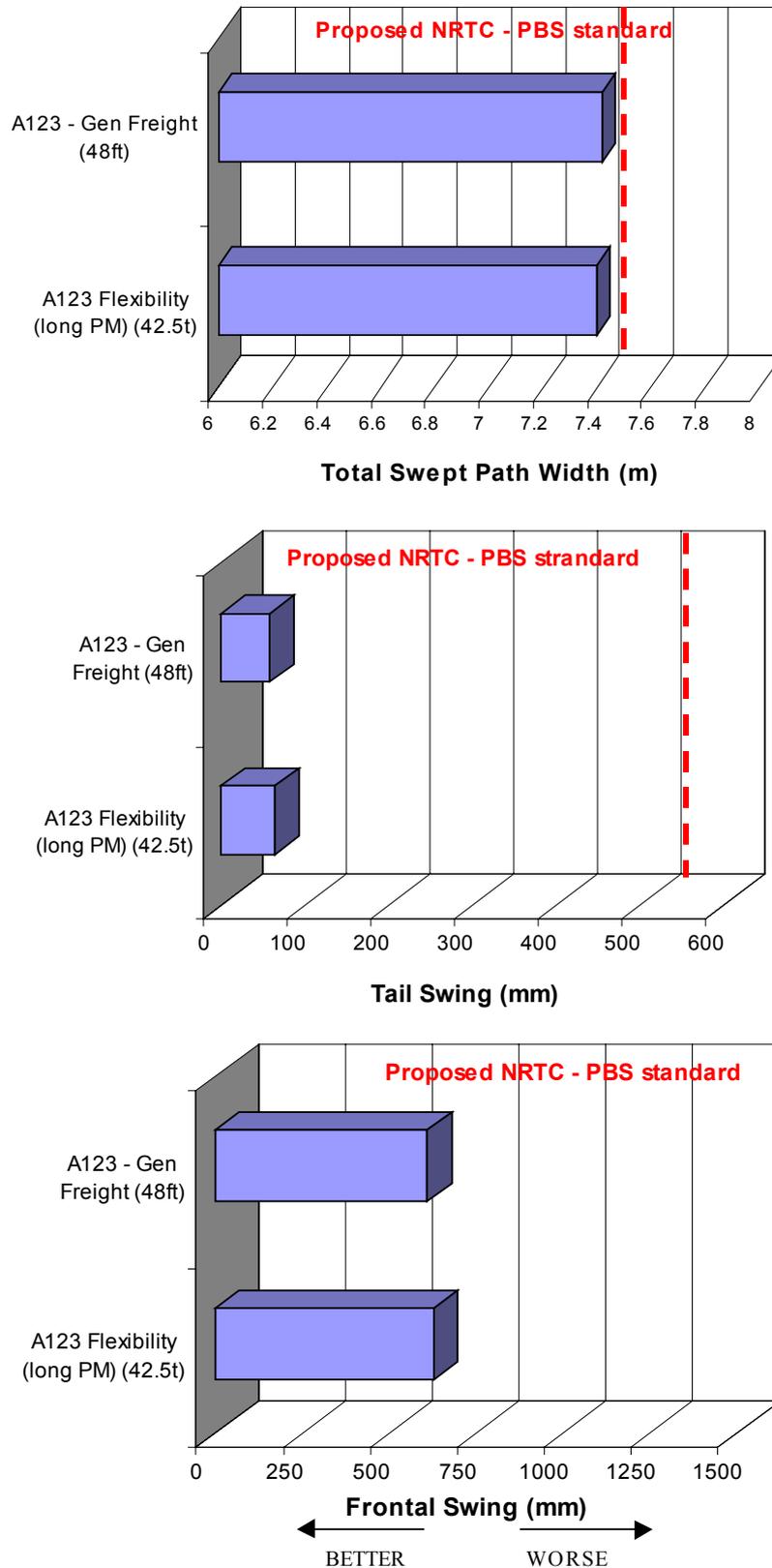


Figure 74 Total swept path width, tail swing and frontal swing results for increased flexibility semi-trailer with a steerable axle

High-speed offtracking and yaw damping results for the increased flexibility semi-trailer with one steerable axle and a standard general freight semi-trailer are shown in Figure 75. It is apparent that this semi-trailer will have increased high-speed offtracking with a steerable axle but still within the proposed standard of 800mm. This vehicle also has less yaw damping than the benchmark semi-trailer. However, both vehicles displayed better performance than the proposed PBS yaw damping standard of 0.15.

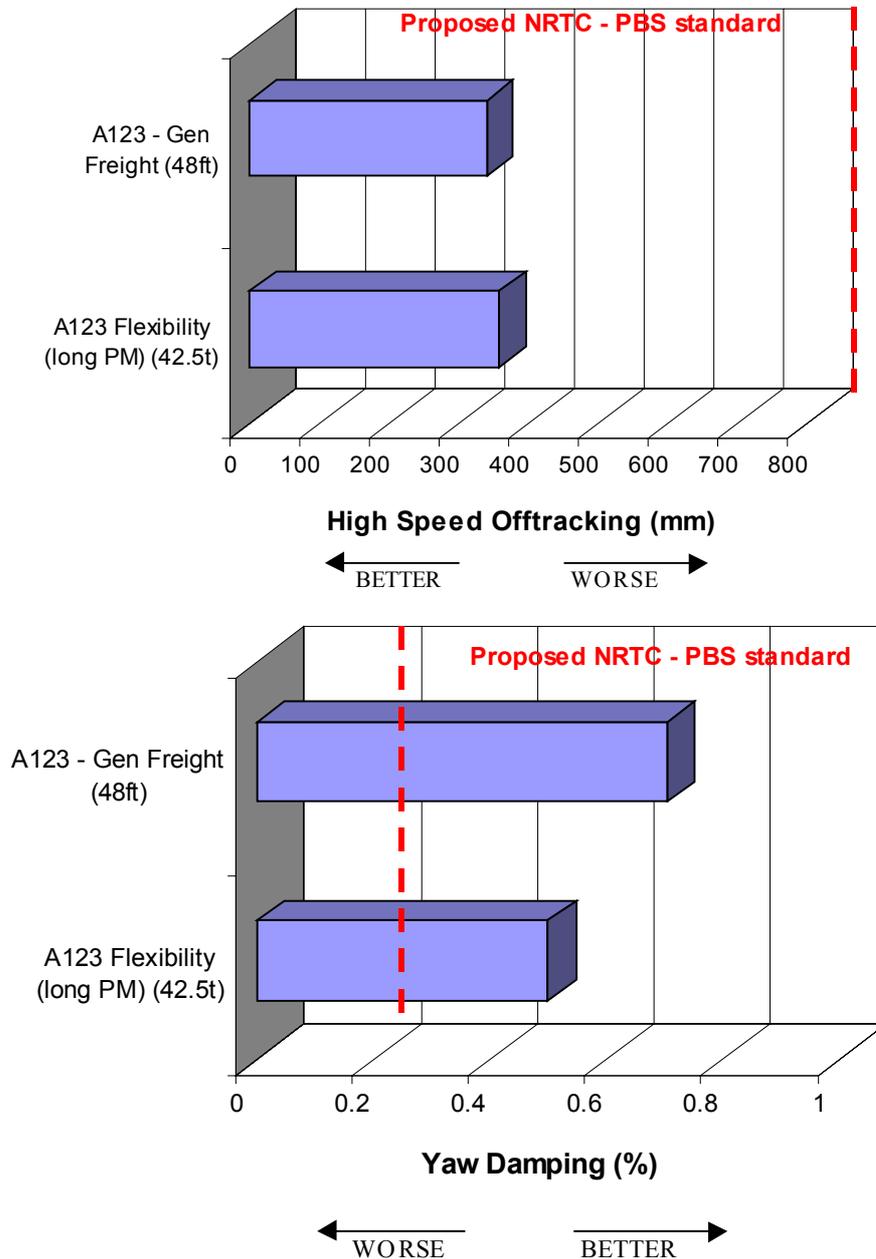


Figure 75 High-speed offtracking and yaw damping results for the increased flexibility semi-trailer with a steerable axle

All of the performance measures (except SRS) for the increased flexibility tractor-semi-trailer (A123) with a steerable axle are within the proposed PBS standards. This candidate vehicle is not considered to have safety performance deficiencies.

6.3.12 Increased Flexibility Initiative: B-double (B1233) with longer wheelbase prime mover and 2 steerable axles

An increased flexibility initiative B-double with a longer prime mover wheelbase and two automotive type steerable trailer axles was developed from the work done Section 5. This vehicle was simulated at the dimensions and axle loading as shown in Figure 76. This vehicle also breaches the 25m maximum overall length rule for restricted access B-doubles.

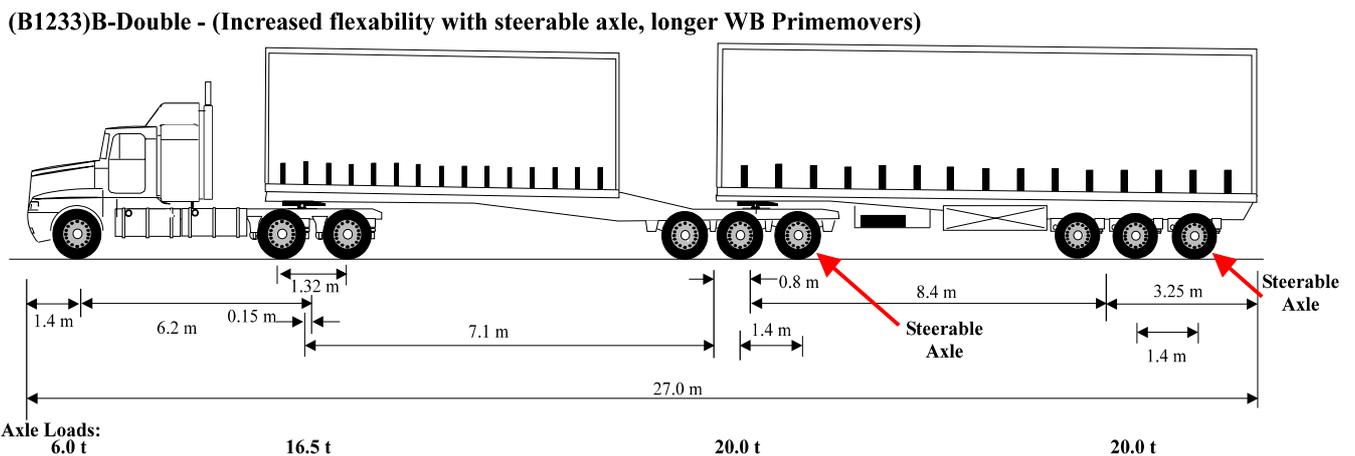


Figure 76 Increased flexibility initiative: B-double with 2 steerable axles, allowing longer prime mover wheelbase

SRS results for the increased flexibility B-double (B1233) with longer wheelbase prime mover and steerable axle can be seen in Figure 77. The results show that the increased wheelbase and steerable axles have no significant effect on SRS when compared to the general freight B-double. Both vehicles perform just below the proposed PBS standard, which is 0.35g.

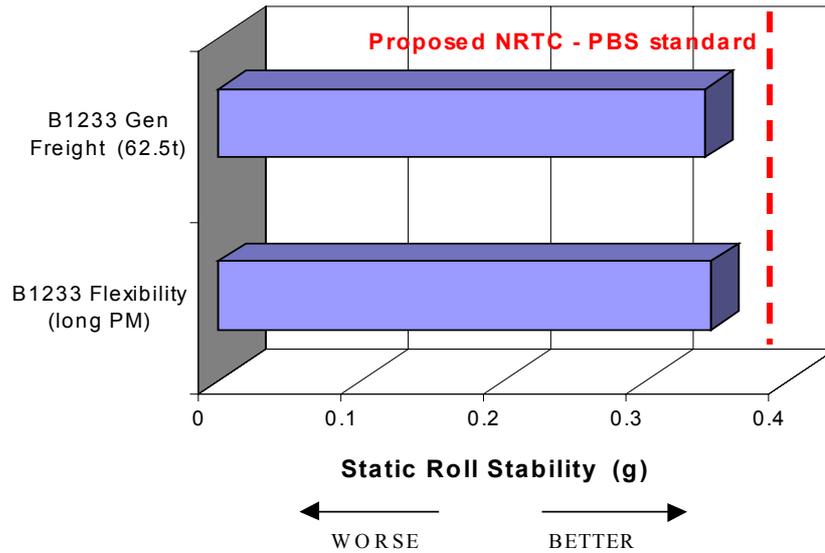
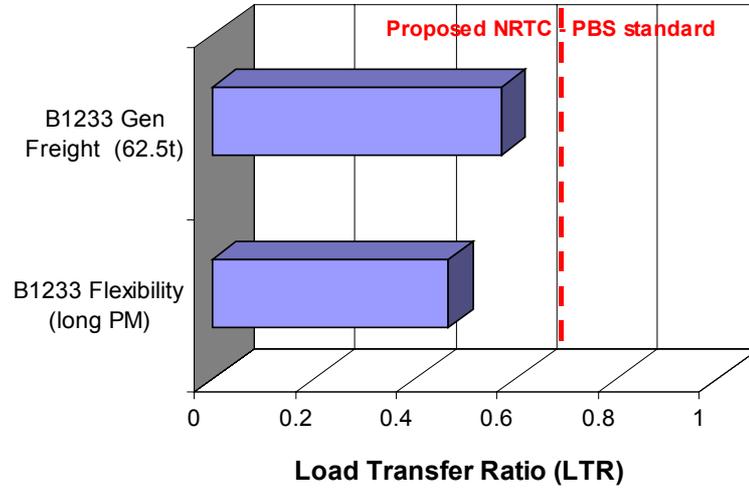


Figure 77 Static roll stability results for the increased flexibility B-double (B1233) with 2 steerable axles

Figure 78 shows comparison LTR, rearward amplification and HSDOT results for the increased flexibility (longer wheelbase) B-double with 2 steerable axles. It can be seen that this vehicle has an 18% better LTR than the benchmark B-double. Both B-doubles have rearward amplification and HSDOT within the proposed PBS standards, even though HSDOT was made worse with the addition of two steerable trailer axles.



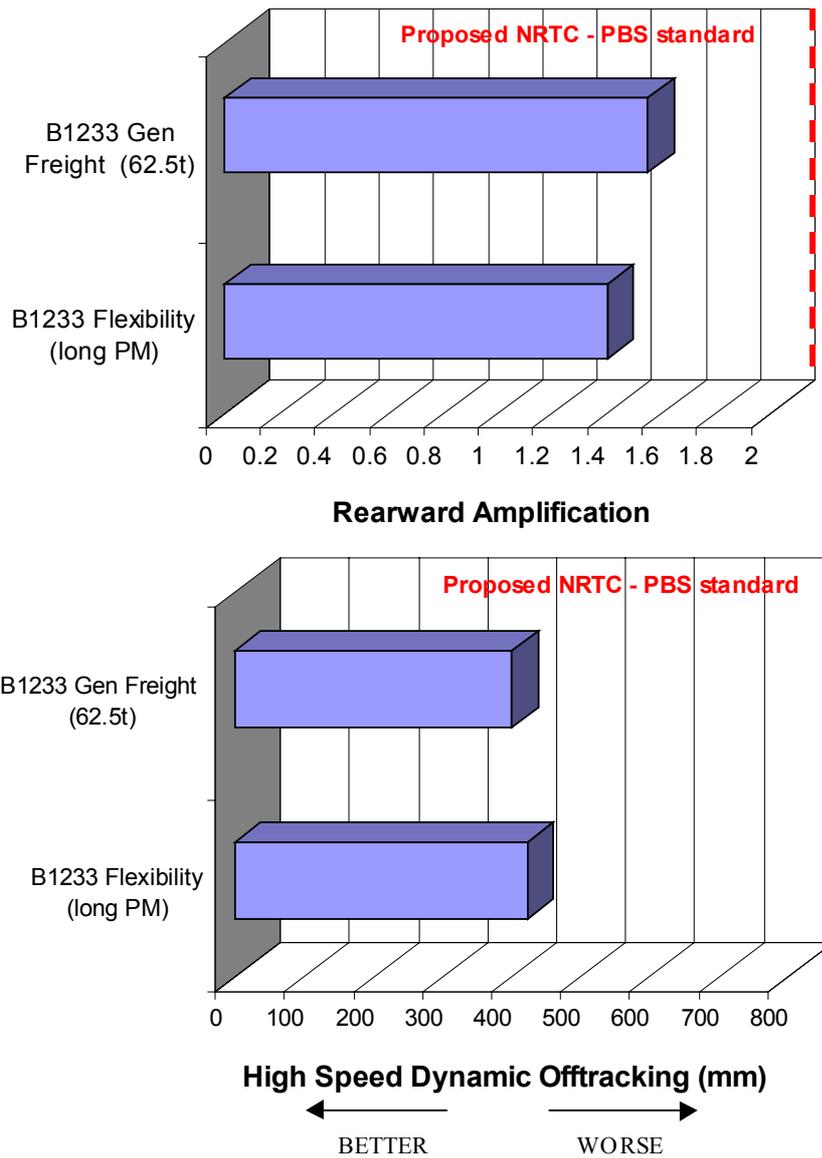


Figure 78 LTR, rearward amplification and HSDOT results for the increased flexibility B-double (B1233) (longer prime mover) with 2 steerable axles

High-speed offtracking and yaw damping results for the increased flexibility (longer prime mover) B-double with 2 steerable axles are shown in Figure 79. Yaw damping is well within the proposed PBS standard. While the high-speed offtracking of this candidate B-double increased by almost 100mm, the performance of both these B-doubles is still below the proposed PBS standard of 800mm

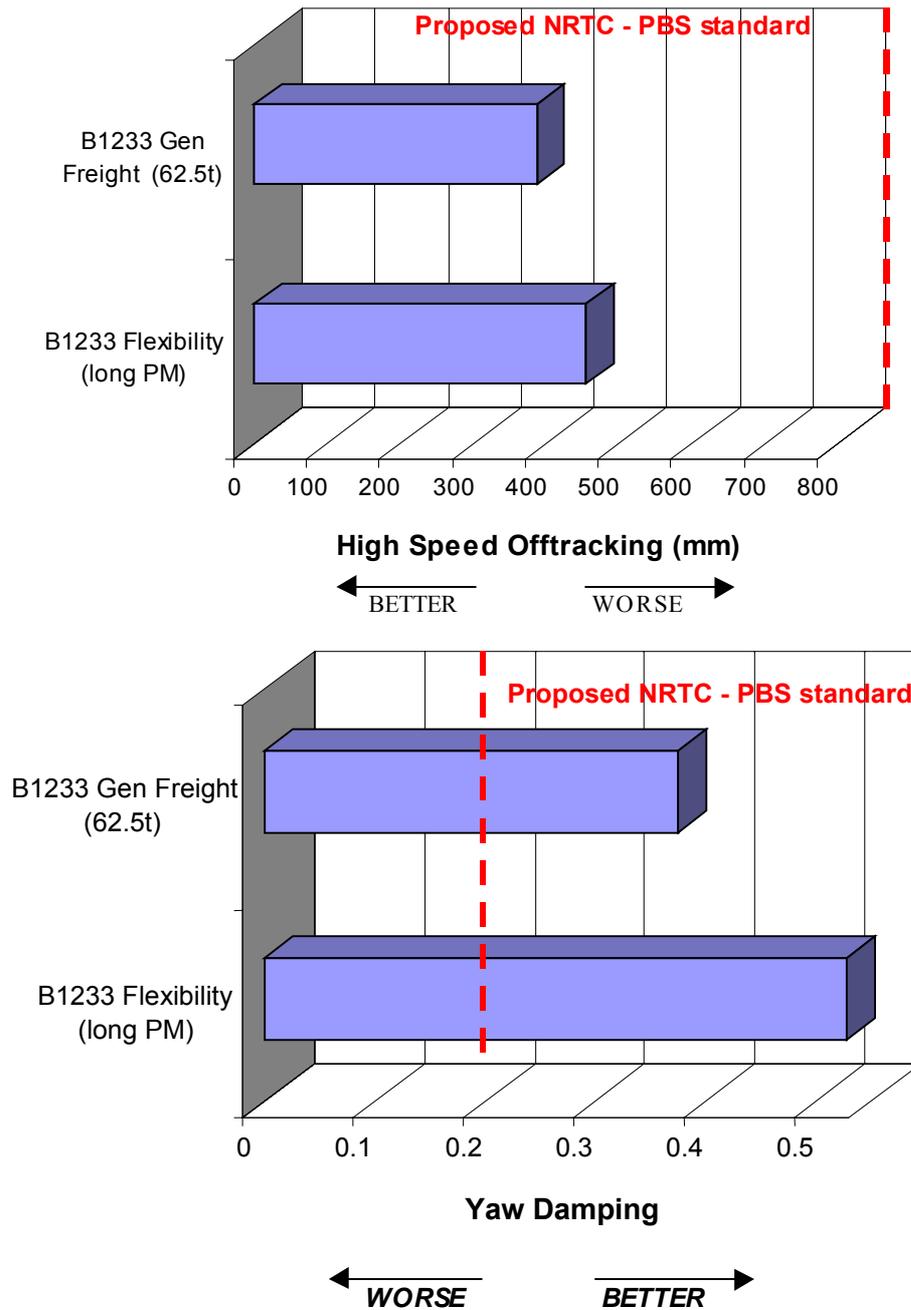


Figure 79 High-speed offtracking and yaw damping results for the increased flexibility (longer prime mover) B-double with 2 steerable axles

All of the performance measures (except SRS) for the increased flexibility B-double (B1233) with a longer prime mover are within the proposed PBS standards. This candidate vehicle is not considered to have safety performance deficiencies.

6.3.13 Increased Flexibility Initiative: B-double (B1233) with 14.6 m (48ft) semi-trailer and 2 steerable axles

An increased flexibility initiative B-double with a standard 14.6m (48ft) long second trailer and two automotive type steerable trailer axles was developed from the results of Section 5. The vehicle was simulated with dimensions and at the axle loading shown in Figure 80. This B-double also breaches the 25m maximum overall length rule for restricted access B-doubles.

(B1233) B-Double - (Increased flexibility - Use a standard 48ft second trailer with 2 steerable axles)

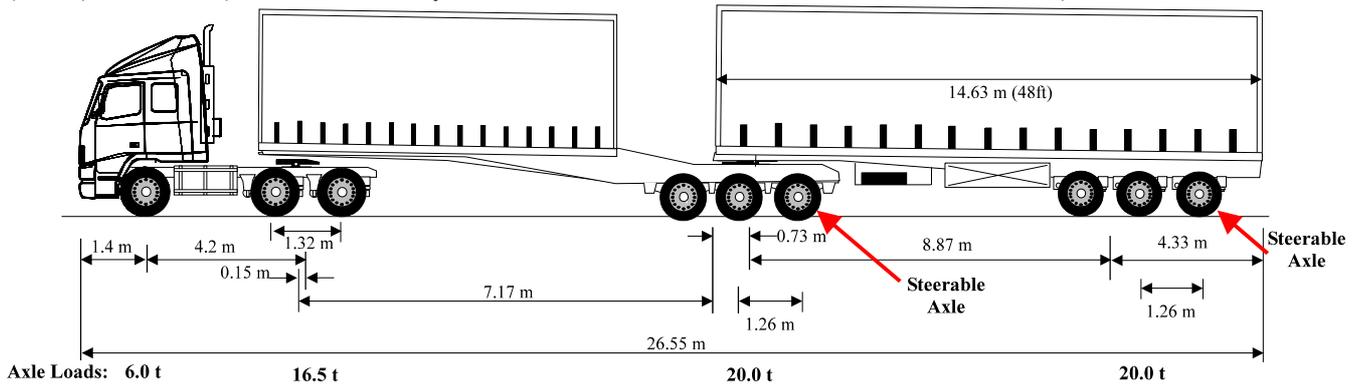


Figure 80 Increased flexibility initiative B-double with 2 steerable axles, allowing longer standard 14.6 m (48 ft) second trailer

Static roll stability results for the increased flexibility B-double with a 14.6m (48ft) long rear trailer and 2 steerable trailer axles are shown in Figure 81. It is apparent that the increased trailer s-dimension and steerable axles have a minor effect on static roll stability when compared to the general freight B-double. Both of these vehicles perform below the proposed PBS standard, which is 0.35g.

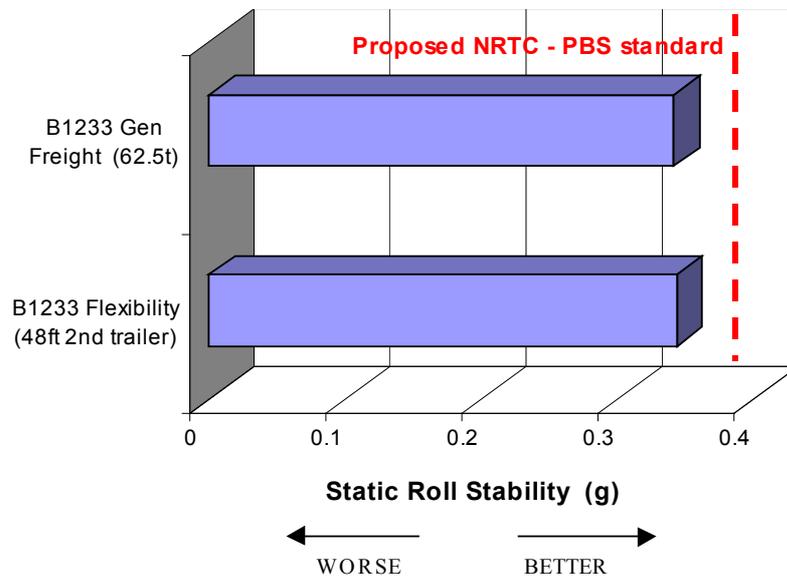
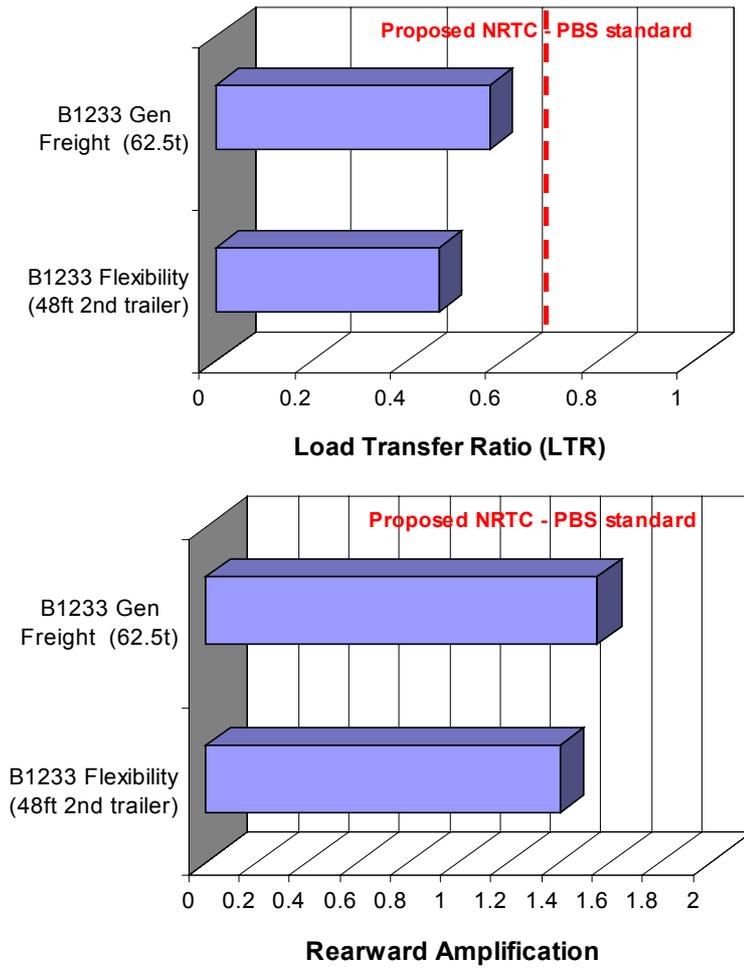


Figure 81 Static roll stability results for the increased flexibility B-double 14.6 m (48 ft) second trailer with 2 steerable axles

Figure 82 shows comparison LTR, rearward amplification and HSDOT results. It is apparent that the increased flexibility vehicle with two steerable axles has improved dynamic stability by approximately 18%. Both vehicles have rearward amplification and HSDOT well within the proposed PBS standards. The increased flexibility B-double displayed almost 12% less rearward amplification and even though the steerable axle vehicle had a marginally worse HSDOT, it remained within the proposed PBS standard.



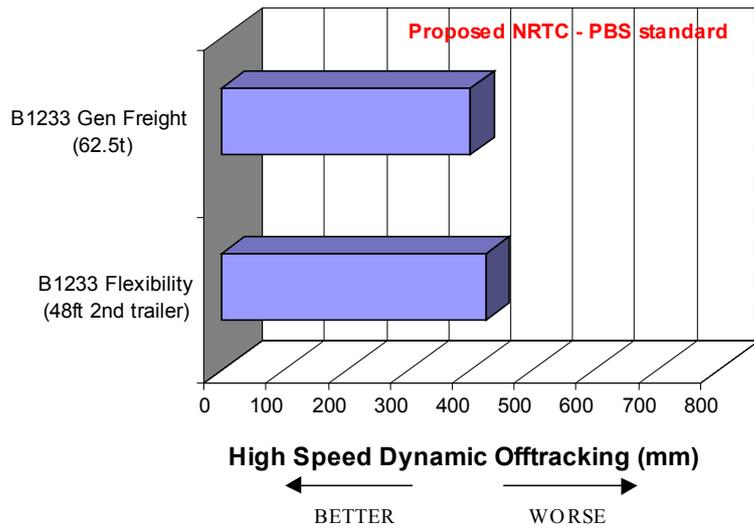
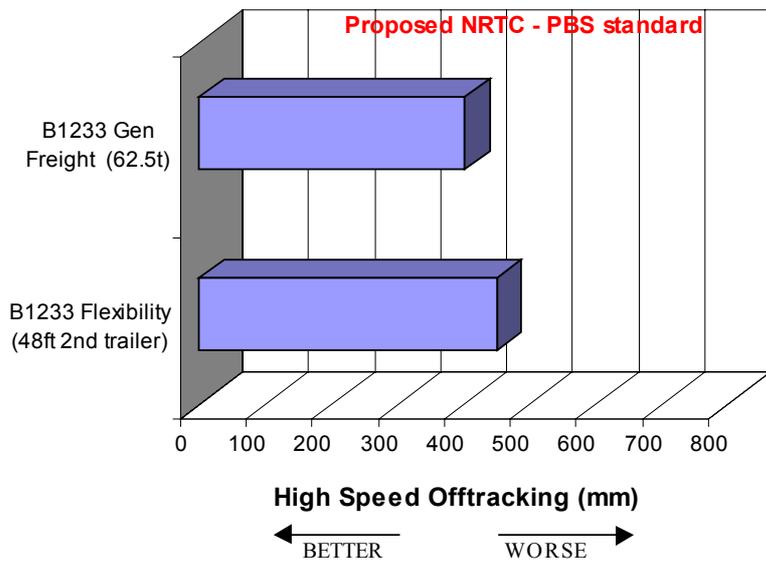


Figure 82 LTR, rearward amplification and HSDOT results for the increased flexibility B-double with a 14.6 m (48ft) long second trailer & 2 steerable axles

High-speed offtracking and yaw damping results for the increased flexibility (longer rear trailer) B-double with two steerable axles and a benchmark B-double are shown in Figure 83. From these charts we can see that the high-speed offtracking behaviour of this B-double was increased marginally to a value still well within the proposed PBS standard of 800mm. The yaw damping of the increased flexibility (longer second trailer) B-double is well above the proposed standard of 0.15.



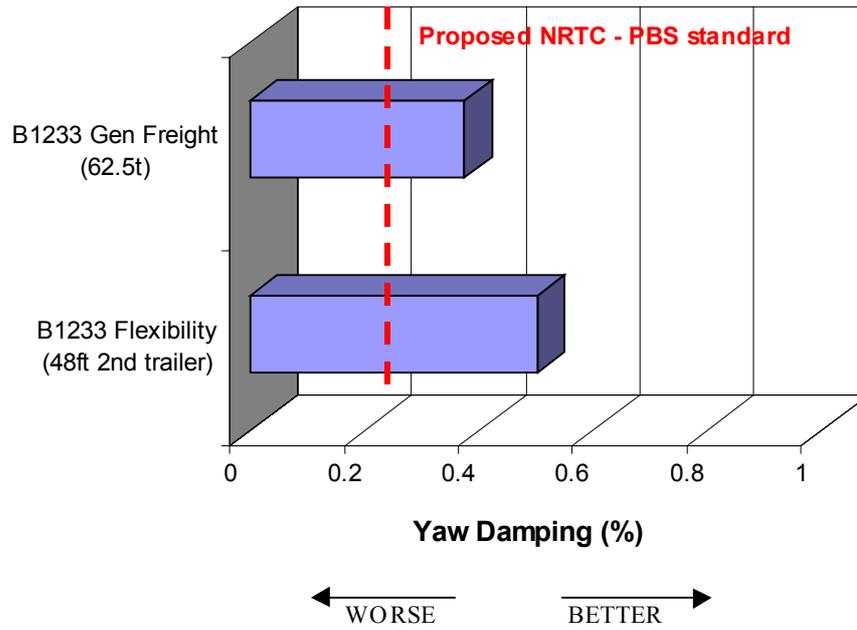


Figure 83 Comparison high-speed offtracking and yaw damping results for the increased flexibility (longer 2nd trailer) B-double with 2 steerable axles

All of the performance measures (except SRS) for the increased flexibility B-double (B1233) with a longer second trailer are within the proposed PBS standards. This candidate vehicle is not considered to have safety performance deficiencies.

6.4 Summary of Geometric and Safety Impacts

Table 3 presents all the simulation results for the candidate steerable axle vehicle combinations and the baseline vehicles. Table 3 also lists the proposed PBS performance measures and initial standards that were considered for each vehicle. The performance values shown in red lie outside the proposed PBS standards.

Table 3 Summary of simulation results for all the baseline and candidate steerable axle vehicles

SIMULATION RESULTS	SRS (g)	LTR	RA	HSDOT (mm)	HSOT (mm)	Total SP Width (m)	Tail Swing (mm)	Frontal Swing (mm)	Yaw Damping
NRTC standards	0.35	0.6	2.0	800	GA: 0.3m MA: 0.5m RTA: 0.7m	LR: 5.0m GA: 7.4m MA: 10.1m RTA:13.7m	500	1500	0.150
Baseline Vehicles									
R12 – Gen F	0.328	0.766	-	-	-	5.39	230	766	-
R13 – Gen F	0.357	0.797	-	-	-	5.40	230	749	-
R22 – Gen F	0.342	0.571	-	-	-	-	-	-	-
A123 – Gen F	0.338	0.617	1.46	304	288	7.42	58	610	0.707
B1233 – (62.5t)	0.342	0.640	1.60	520	387	8.54	51	610	0.375
B1233 – (68t)	0.345	0.624	1.64	508	449	8.54	51	610	0.293

A123T23	0.338	0.980	2.12	1010	715	-	-	-	-
A123T33T33*	0.470	0.716	3.28	835	798	9.51	45	0	0.237
A123 - LA	-	-	-	-	-	6.36	288	698	-
Steerable Axle Vehicles									
Mass									
R13	0.357	0.719	-	-	-	4.94	407	712	-
R23	0.359	0.517	-	-	-	-	-	-	-
A123	0.338	0.580	1.31	315	318	6.514	86	611	0.506
A124	0.344	0.623	1.41	339	316	6.654	228	610	0.510
B1234	0.376	0.478	1.35	370	449	8.54	169	615	
B1244	0.382	0.440	1.14	371	446	10.1	87	620	0.615
A124T34T34*	0.510	0.577	3.28	874	859	9.51	45	600	0.216
Cube									
A123	0.338	0.582	1.34	348	363	-	235	-	0.530
A123 – LA	0.332	0.528	1.19	193	260	7.15	484	634	1.000
B1233	0.344	0.429	1.30	390	471	9.5	105	460	0.566
Flexibility									
A123 – PM	0.338	0.563	1.37	344	359	-	217	-	0.501
B1233 – PM	0.344	0.469	1.40	423	455	-	-	-	0.529
B1233 – Trailer	0.344	0.467	1.40	426	451	-	-	-	0.504

*Vehicle performed a reduced lane change manoeuvre (see Section 7.1.2).

It is apparent that a number of baseline vehicles lie outside current PBS recommendations for SRS and LTR, and this issue is outside the scope of the present study.

With regard to the candidate vehicles, all perform adequately except the A124T34T34 road train, where high-speed dynamic offtracking and high-speed offtracking are outside the proposed PBS standards and are worse than the baseline road train. Note that the slight tail swing exceedance for the A123-LA is considered trivial in the context of this study.

7. REGULATORY STATUS OF CANDIDATE STEERABLE AXLE VEHICLES

Table 4 specifies the current regulations which prevent the operation of each of the candidate steerable axle vehicles. The aspects of the current regulatory regime which impinge on the widest exploitation of steerable axles fall into the following areas:

- exceeding the current prescriptive overall length limits of 19m and 25m for General Access and Restricted Access respectively;
- exceeding current prescriptive limits on the trailer length;
- exceeding or re-defining current prescriptive internal dimensional limits such as kingpin to rear end, kingpin to centre of rear axle group and rear overhang;
- demanding a quad axle group mass limit significantly higher than the current triaxle group limit;
- requiring the treatment of quad groups in the axle spacing mass schedule to be defined;
- requiring the restricted access axle spacing mass schedule to be extended in relation to maximum applicable GCM; and
- requiring the road-friendly allowance for a quad axle group to be defined in relation to the axle spacing mass schedule.

Table 4 Australian Vehicle Standards Rules 1999 preventing the use of candidate steerable axle vehicles

INCREASED CUBE INITIATIVE
A123 - Rear axle converted to non-driven auto-steer type (A123), 1.2m increase in load space length, involves greater than 19m overall length.
<ul style="list-style-type: none"> • Australian vehicle standards rules, Part 7, Division 2 - Dimensions, 68 – 1 – on a semi-trailer, the distance between the point of articulation at the front and the rear overhang line must not be more than 9.5m; in order to provide correct mass distribution and to avoid excessive rear overhang, the s-dimension was increased to 10.1m. • Australian vehicle standards rules, Part 7, Division 2 - Dimensions, 69 – 1 – (d) the vehicle combination must not have an overall length greater than 19m. OAL = 21m. • Australian vehicle standards rules, Part 7, Division 2 - Dimensions, 70 – 1 – the rear overhang of a semi-trailer must not exceed the lesser of (a) 60% s-dimension or (b) 3.7m; the rear overhang was increased to 4.3m with the addition of a steerable axle.
A123 – LA - Rear axles all converted to linked articulation type steering axles (A123), 2.8m increase in load space length, Involves greater than 19m overall length.
<ul style="list-style-type: none"> • Australian vehicle standards rules, Part 7, Division 2 - Dimensions, 68 – 1 – on a semi-trailer, the distance between the point of articulation at the front and the rear overhang line must not be more than 9.5m; in order to provide correct mass distribution the s-dimension was increased to 13.5m. • Australian vehicle standards rules, Part 7, Division 2 - Dimensions, 69 – 1 – (d) the vehicle combination must not have an overall length greater than 19m; the overall length was increased to 23.1m.
B1233 - Rear axles of each non driven group converted to non-driven auto-steer type (A123), 2.8m increase in load space length, Involves greater than 25m overall B-double length.
<ul style="list-style-type: none"> • Australian vehicle standards rules, Part 7, Division 2 - Dimensions, 69 – 1 – (b) the B-double combination must not have an overall length greater than 25m; the overall length was increased to 28.6m.
INCREASED MASS INITIATIVE
R13 - No regulation breaches .
R23 - No regulation breaches.

<p>A123 - Rear axle converted to non-driven auto-steer type (A123), increase trailer s-dimension to improve the trailer payload distribution, and avoid overloading the axles.</p>
<ul style="list-style-type: none"> • Australian vehicle standards rules, Part 7, Division 2 - Dimensions, 68 – 1 – on a semi-trailer, the distance between the point of articulation at the front and the rear overhang line must not be more than 9.5m; in order to provide correct mass distribution the s-dimension was increased to 10.6m.
<p>A124 - A non-driven auto-steer type axle added to rear of quad axle group (A124) to increase overall GCM.</p>
<ul style="list-style-type: none"> • Australian vehicle standards rules, Part 7, Division 2 - Dimensions, 70 – 1 – the rear overhang of a semi-trailer must not exceed the lesser of (a) 60% s-dim or (b) 3.7m; the rear overhang was increased to 4.35m to allow for the steerable axle. • Road Transport Reform (Mass and loading) Regulations, Statutory Rules 1995 No.56 - 1.2 (6) – the sum of the mass on the axle groups on a vehicle combination (A123) must not exceed 42.5t (note that dual-tyred quad axle groups are not specifically mentioned with regard to axle group mass).
<p>B1234 - A non-driven auto-steer type axle added to rear of each trailer group (B1234) to increase overall GCM.</p>
<ul style="list-style-type: none"> • Australian vehicle standards rules, Part 7, Division 2 - Dimensions, 69 – 1 – (b) the B-double combination must not have an overall length greater than 25m; the overall length was increased to 31.7m in order to meet the bridge formula. • Axle Mass Spacing Schedule applicable to B-double routes – this formula does not extend to GCM's greater than 62.5t this vehicle's GCM was increased to 77t. • Road Transport Reform (Mass and loading) Regulations, Statutory Rules 1995 No.56 - 1.2 (6) – the sum of the mass on the axle groups on a vehicle combination (B1233) must not exceed 62.5t (note that dual-tyred quad axle groups are not specifically mentioned with regard to axle group mass).
<p>B1244 - A non-driven auto-steer type axle added to rear of each trailer group (B1244) to increase overall GCM.</p>
<ul style="list-style-type: none"> • Australian vehicle standards rules, Part 7, Division 2 - Dimensions, 69 – 1 – (b) the B-double combination must not have an overall length greater than 25m; the overall length was increased to 31.7m in order to meet the bridge formula. • Axle Mass Spacing Schedule applicable to B-double routes – this formula does not extend to GCM's greater than 62.5t; this vehicle's GCM was increased to 77t. • Road Transport Reform (Mass and loading) Regulations, Statutory Rules 1995 No.56 - 1.2 (6) – the sum of the mass on the axle groups on a vehicle combination (B1233) must not exceed 62.5t (note that dual-tyred quad axle groups are not specifically mentioned with regard to axle group mass).
<p>A124T34T34 - A non-driven auto-steer type axle added to rear of each trailer group (A124T34T34) to increase overall GCM.</p>
<ul style="list-style-type: none"> • Road Transport Reform (Mass and loading) Regulations, Statutory Rules 1995 No.56 - 1.2 (6) – there is currently no specific dual-tyred quad axle group mass limit (Mass and loading regulations 1.2 (3)).
<p>INCREASED FLEXIBILITY INITIATIVE</p>
<p>A123 – PM - Rear axle converted to non-driven auto-steer type (A123), increase in prime mover wheelbase, Involves greater than 19m overall length.</p>
<ul style="list-style-type: none"> • Australian vehicle standards rules, Part 7, Division 2 - Dimensions, 69 – 1 – (d) the vehicle combination must not have an overall length greater than 19m; the overall length increased to 20.7m. • Australian vehicle standards rules, Part 7, Division 2 - Dimensions, 70 – 1 – the rear overhang of a semi-trailer must not exceed the lesser of (a) 60% s-dimension or (b) 3.7m; the rear overhang was increased to 4.3m with the presence of a steerable axle.
<p>B1233 – PM - Rear axle of each trailer group converted to non-driven auto-steer type (B1233), increase in prime mover wheelbase, Involves greater than 25 m overall length.</p>
<ul style="list-style-type: none"> • Australian vehicle standards rules, Part 7, Division 2 - Dimensions, 69 – 1 – (b) the B-double combination must not have an overall length greater than 25m. OAL = 27m.
<p>B1233 – Trailer - Rear axle of each trailer group converted to non-driven auto-steer type (B1233), increase in second trailer length to standard 48ft, involves greater than 25m overall length.</p>
<ul style="list-style-type: none"> • Australian vehicle standards rules, Part 7, Division 2 - Dimensions, 69 – 1 – (b) the B-double combination must not have an overall length greater than 25m. OAL = 26.55m.

8. ECONOMIC IMPACTS OF STEERABLE AXLE VEHICLES

Analysis of the potential benefits and costs of implementing the candidate steerable axle vehicles identified in Section 5 was carried out. The scenarios of increased productivity considered were (i) vehicles with increased payload mass, (ii) vehicles with increased payload volume (or cube) and (iii) semi-trailers with marginally increased length (and the ability to consistently increase pallet loading volume).

It is important to note that the financial analysis does not explicitly address the issue of the benefits of the options involving increased flexibility of equipment utilisation. This is partly because the industry has shown a strong interest in using overall vehicle dimensions in such a way as to maximise loading and productivity. Consequently it would be expected that the majority of vehicles using any concession in vehicle length or trailer dimensions would use the longer trailer to maximise loading, rather than use shorter trailers with longer prime movers.

8.1 Economic Analysis Scenario

The analysis began with a single vehicle analysis for each vehicle configuration. This phase of the analysis gave a feel for the relative magnitude of the cost and savings parameters. The analysis assumed an operator is looking at new vehicles/combinations for a high utilisation, mass or cube limited service. It was assumed that the potential capital and operating cost productivity benefits will be realised.

The second phase of the analysis looked at the aggregate benefits and costs across the relevant vehicle fleets. In the absence of hard data on likely take-up of steerable axles, an estimated take-up was used to give an indicative figure for the aggregate benefits and costs.

There are potentially a number of reasons why steerable axles are still relatively uncommon:

- effective steerable axles are a relatively new item in the heavy duty market;
- perceived significant capital and maintenance costs, along with uncertainty about the magnitude/reliability of the tyre savings;
- owner/operators may see most of the productivity benefits eroded by rate reductions in the highly competitive general transport market; owner operators with significant contracts might be pressured to take up steerable axle options where the client sees this as a way to reduce costs;
- the productivity gains only apply fully for high utilisation vehicles; partial loading rapidly reduces the effective benefits;
- operators may not own the prime movers (or trailers) and thus do not see the full productivity gains;
- fleet operators might see other options as giving better outcomes eg moving to articulated vehicles from rigid vehicles; and
- the regulatory situation is not clear.

For the purposes of this analysis, the regulatory basis (prescriptive system or PBS) under which the benefits from steerable axles are approved was not considered: the analysis focussed on the productivity benefits available to operators if a range of vehicles using steerable axles were approved under either the PBS regime or the prescriptive regime.

The costs to operators were be considered, but the costs of amending the regulations or establishing PBS were not considered. As a result, the analysis did not allow comparison of the relative costs (to government) of amending regulations or establishing PBS.

In each of the applications considered, the steerable axle was used to allow operators to overcome existing mass or cube load constraints – an additional axle in a group for mass or additional length to allow full utilisation of pallet loads. There will also be situations where operators largely facing cube constraints, but not using standard pallet operations (such as parcel or post deliveries), will see loading benefits from longer trailers and may revise part of their operation to take advantage of this.

This analysis did not specifically consider non pallet operations for cube limited operations. However, the benefit to pallet operators would be indicative of the benefits to non pallet operators.

Estimates were made of the proportion of the relevant fleets that might be mass/cube limited in their operations. These estimates were used to derive an estimate of aggregate productivity benefits offered by steerable axles. In practice, operators would progressively move to the use of steerable axles and the benefits would build up over a period of time.

8.2 Methodology

A traditional productivity analysis was carried out: the higher productivity of a vehicle will translate to both capital and operating cost saving for an operator when considered against a fixed task. The full productivity gains will only be achieved for high utilisation vehicles which are mass or volume limited. Table 5 shows the range of productivity benefits for the vehicles and combinations studied.

Table 5 Productivity increases by vehicle configuration

	Payload Increase	Productivity %
Mass		
R13 (28.5t)	3.80t	28
R23 (31.5t)	3.80	23
A123 (14.6m) (42.5t)	-0.70	-2
A124 (50t)	2.80	10
B1234	2.80	6
B1244 (77t) (30m)	5.60	13
A134T34T34 (158.2t)	14.60	15
A124T34T34 (151.7)	9.60	10
Cube		
A123 (42.5t) (extra 1.2m)	1 pallet	9
A123-LA (42.5t)	3 pallets	27
B1233 (62.5t) (28.5m)	2 pallets	11.7

*This trailer is intended to allow better loading distribution, which is a problem for some loads. There is no productivity gain from increased loading.

There are a range of costs and benefits to offset the productivity gains:

- additional capital cost of the steerable axle. This will vary according to whether the steerable axle substitutes for an existing axle – generally cube limited loads – or whether the axle is an additional axle for mass limited loads;
- additional capital costs for longer/stronger trailers;
- additional maintenance costs for the steerable axle;
- for additional axles, there will be associated tyre costs;
- for replacement axles in a triaxle group, there will be tyre cost savings;
- additional vehicle maintenance costs for heavier loads; and
- additional fuel costs for heavier loads.

It is possible to make order of magnitude estimates of the benefits and costs. For a typical high utilisation cube limited tractor-semi-trailer vehicle, the capital productivity benefit for an additional row of pallets (approx 9%) translate to a potential productivity capital benefit of around \$25,200.

The operating cost productivity benefit per year would be \$18,900 after adjusting for tyre cost savings and additional maintenance costs for the steerable axle. Thus the potential annual operating cost productivity saving in one year far exceeds the cost increase for the steerable axle - \$7200.

For a R13 truck travelling 45000km pa, the capital productivity benefits (assuming capital cost of \$210,000) productivity benefits are quite large at 28%. The potential capital productivity benefit would be around \$58,800, with an additional capital cost of \$15,000 (est) for the steerable axle.

The operating cost productivity benefit, for annual operating costs of \$69,000, would be \$19,320 after allowing for increased tyre costs for the additional axle (with some savings claimed by axle manufacturers) and additional vehicle maintenance and fuel costs. The annual net operating cost productivity benefit would still be significantly greater than the additional cost of the steerable axle.

The estimates for an additional axle for a R13 truck have to be considered against the operation of a R22 truck. These are not a common configuration, but the payload estimates suggest that a steerable axle would be more cost effective and the capital and maintenance costs lower. It may well be that operators find a truck trailer combination the most effective way to increase payload.

The above simplified analysis suggests that steerable axles offer significant productivity benefits. The downside is that the benefits will only accrue in circumstances where the additional capacity is fully utilised. For a transport operator, the benefits will essentially pass on to the client, due to the highly competitive market. A transport operator would still see benefit from being able to tender competitive prices and so gain contracts.

A business which operates transport as an ancillary service to its main business (eg fuel companies) will see the cost savings from the productivity benefit as a significant incentive to use steerable axles to improve productivity. Similarly, a business which sub-contracts its own transport needs under tight control would also see the productivity benefits as direct cost savings.

It is important to note that the productivity benefits from moving to a 15m triaxle trailer for cube loads through the use of a steerable axle can also be gained by simply allowing a

14.94m (49ft) trailer. This is already allowed in one jurisdiction – for refrigerated trailers. The productivity benefits would be slightly higher because a steerable axle is not required. However, the 14.94m trailer is required to operate with a short prime mover to meet the current overall length limit. A 15m trailer with a steerable axle and a longer prime mover, exceeding the current overall length limit, can still meet the PBS performance criteria.. This issue is separately addressed in the estimation of benefits.

8.3 Modelling of Benefits and Costs

The analysis was based on the considerations of an operator investing in capacity to meet a given demand. The model used cost data from the NRTC report “Annual Adjustment Procedure for Heavy Vehicle Charges, Initial Adjustment Regulatory Impact Statement” July 2001 Appendix A and internal estimates to develop the major cost elements for each of the vehicle configurations considered.

The model considered the capital, fixed operating costs and variable operating costs over a ten year cycle to estimate the productivity benefits from the use of steerable axles. A discount rate of 5% was assumed.

The analytical approach considered the situation for an operator considering investing in new equipment for a given contract or for a new contract with a fixed task. A more productive vehicle for the task will result in fewer vehicles required for the task. Fewer vehicles translates to capital and operating cost savings, offset by some additional costs – capital and operating costs. In the competitive transport market, the cost savings translate into transport cost savings and can be considered as community benefits.

Looking at the benefits in another way, the higher productivity for a vehicle will translate into lower unit costs (mass or volume). Lower unit costs translate into lower rates, and in a competitive market, lower rates will translate to lower transport costs and thus a community benefit.

The quite significant productivity gains for these vehicle configurations translate into cost savings, which are significantly larger than the additional cost components for the steerable axle, and some operating cost increases. Consequently, the benefits over a ten year period are significant. In fact, the additional cost of the steerable axle is recovered in cost savings in the first year of operation.

The caveat for this analysis is that the benefits will only be realised in full in a situation where the vehicle(s) is fully utilised at maximum capacity (mass or cube limited). The benefits rapidly decrease for vehicles not fully utilised. For example, an operator who faces a variable workload will not be able to take full advantage of the potential productivity gains.

The fleet benefits were estimated by estimating the number of vehicles of each configuration that might be used, and multiplying the single vehicle estimates by the number of vehicles. A simple average of the estimated 10 year benefit was used to give an indication of annual potential benefits.

8.3.1 Vehicle numbers

The following sets out the basis for the vehicle numbers used in the fleet productivity analysis:

Rigid trucks	Assume 5% of the fleet might take up the option.
A124	Difficult to establish numbers. A main use would be tankers. 50% of the fleet would be 1500 vehicles. Assume 1000 vehicles as a conservative estimate.
B1234	This configuration represents operators who might invest in a new rear trailer, but retain the existing lead trailer configuration. This might be an intermediate stage in the development of the use of steerable axles. For the purposes of analysis, a take-up of 300 vehicles is assumed.
B1244	This is a high mass vehicle useful for major haulage. It may be an attractive option for tankers. Given the high utilisation characteristic of B-doubles, the additional mass capacity may lead to a significant take-up. 400 vehicles represent a rounded 10% of the fleet.
Minerals road trains	These are highly specialised vehicles which would be used in remote areas to move high volumes of ore or concentrates. A figure of 50 is indicative of the possible level of use.
A123	These vehicles would be used in cube limited operations. The analysis considered the estimate of 3250 tautliner trailers built each year, with 1625 estimated as volume limited in operation.. The current ratio of 13.7m to 14.63m trailers is estimated at 85:15. If the 15m trailer was available as an option, it could be considered that the ratio might shift to 60:40 over several years. This would mean a shift from 250 trailers per year to 975 would be 15m, an increase of 725. Ultimately the industry would settle to building to meet the 5 year life cycle assumed for trailers in high utilisation operation. A different approach was used to consider the estimate of 3250 tautliner trailers built per year, servicing an industry which expects a nominal life of 5 years. This suggested a tautliner fleet of around 16,250, with say 50% cube limited. Of the 8000 cube limited trailers, it is estimated that some 20% (1625) are 14.63 m, with the remainder 13.7m. The analysis needs to estimate the number of trailer that might convert to 15 m with steerable axles. A figure of 10% is assumed for the conversion to 15m trailers (650). For the purpose of the analysis, a figure of 700 is assumed.
A123LA	This is a specialised high productivity vehicle. For the purpose of the analysis, a figure of 50 % of the estimate used for A123 vehicles was used.
B1233	For these vehicle, the initial attraction is the use of the longer and more productive trailer for the second trailer. It might be expected that the take-up of the longer lead trailer might be slower. The productivity analysis does not attempt to consider the timing issues and assumes that around 15 % of the B-double fleet (360) will move to the longer trailers. This is based on the fact that B-double operators tend to seek maximum productivity for their vehicles.

A12T34T34T34 This is a high mass specialised vehicle which might be used for major mineral developments. This vehicle configuration did not perform well in the stability analysis and is marginal for the PBS performance requirement. It is included in the analysis as an indication of potential benefits. There are a number of such developments and a figure of 50 vehicles was used to estimate the productivity benefits of using the quad axle group with a steerable axle in this configuration.

The estimates of relevant fleet numbers are set out in Table 6.

Table 6 Estimating vehicle numbers

Vehicle Configuration	Fleet *(1997)	Estimated Number likely to use steerable axles	Comment
R12	24695	1235 vehicles	High utilisation, mass limited
R22	4039	150 vehicles	High utilisation, mass limited
A123	30218	700 vehicles	High utilisation cube
B1233	707	360 vehicles	High utilisation cube
RT 123T33T33	1827	50 vehicles	Special high mass only
B1234	0	300	Mass limited
B1244	0	400 vehicles	Mass limited
A124	0	1000 vehicles	Mass limited
A123 LA	0	350 vehicles	High utilisation cube

Source: Updating Heavy Vehicle Charges Technical Report 1997.

The suggested percentage of the fleet that might use steerable axles if there were no regulatory impediment is indicative only, for the purpose of estimating an overall potential benefit figure for wider use of steerable axles. It is considered that the estimates will be conservative.

8.3.2 Cost components

The major additional cost components arising from the use of a steerable axle are:

- capital costs;
- tyre costs;
- maintenance costs; and
- fuel costs.

The capital cost of the steerable axles were estimated from manufacturers' information and technical advice:

- for an automotive type steerable axle replacing one axle in a triaxle group, \$7200;
- for an additional automotive type steerable axle to form a quad axle group, \$13,000;
- for an additional automotive type steerable axle for R12 and R22 vehicles, \$15,000; and
- for a linked articulation triaxle group, \$30,000.

The tyre cost impact varies depending on the vehicle configuration. For a triaxle group, with one steerable axle, manufacturers' estimates of a 40% tyre cost saving were used. For the linked articulation steerable axle, manufacturers' claimed cost saving of 50% was used.

For an automotive type steerable axle as an additional axle, the tyre costs used are an empirical assessment of the likely cost impact. For triaxle groups the manufacturers claim significant tyre cost savings, but there is little hard data for the effect of an additional (steerable) axle on vehicle tyre wear. In practice, there would be expected to be some reduction in tyre wear from the effect of the steerable axle, but this is counteracted by the additional axle tyre costs. An estimate of additional tyre costs of \$500 per year was assumed for the analysis.

Maintenance costs for a steerable axle were estimated from cost data for vehicle maintenance. For a triaxle group, the additional costs were estimated at \$1,348. For an additional axle, the maintenance costs were estimated at \$2,000.

Fuel cost increases were considered for the mass limited options. The fuel cost increase was assumed to be proportional to half the productivity increase.

8.4 Net Benefits of Mass and Cube Productivity Options

8.4.1 Single vehicles

Table 7 sets out the productivity gains that might be expected for an operator considering the use of steerable axles. While the analysis is in terms of a single vehicle, in practical terms an operator would be looking at a situation involving several vehicles. The analysis assumes that the competitive transport market will ensure that the cost savings are largely passed on in terms of lower transport costs, representing a benefit to the community.

Table 7 Single vehicle productivity benefit over 10 years

Vehicle Configuration	Aggregate Productivity Benefit over 10 yrs \$
Mass Limited	
R13 (28.5t)	209,000
R23 (31.5t)	162,000
A124 (50t)	150,000
B1234 (72.5t)	110,000
B1244 (77t) (30m)	279,000
A134T34T34 (158.2t)	587,000
A124T34T34 (151.7t)	370,000
Cube Limited	
A123 (42.5t) (extra 1.2m)	198,000
A123-LA (42.5t)	248,000
B1233 (62.5t) (28.5m)	256,000

These indicative productivity gains would be expected for a fleet operator whose existing fleet is mass or cube limited in high utilisation operations. In practical terms the benefits form an upper limit of what might be achieved. Where an operator faces a variable workload, the full potential productivity gains will not be realised.

The figures raise some issues in themselves. For instance, the use of an additional steerable axle on mass limited operations seems very attractive. In some instances, there seem to be no regulatory impediments to the use of a steerable axle – for instance a R12 rigid truck. The apparent lack of interest might reflect one or more of the following:

- continuation of existing practices with existing equipment with a relatively long replacement cycle;
- predominance of owner operators with limited resources;
- industrial relations issues;
- recent availability of reliable effective steerable axles;
- perceived benefits only available to high utilisation mass or volume limited operations;
- practical limitations in the use of longer vehicles – loading dock limitations, mismatch with bulk loading equipment; and
- perception that any savings will pass to the client as rate savings.

Given the significant potential benefits, it might be expected that there could be a rapid increase in the use of steerable axles as they become more common and are better understood. The main use of steerable axles to date appears to have been for access benefits rather than productivity benefits.

8.4.2 Estimate of fleet benefits

It is difficult to develop robust estimates of the likely penetration of steerable axles into the fleet. The estimates in Table 8 are believed to be conservative. They are based on fleet composition data and expert advice.

Table 8 Notional annual productivity benefit

Vehicle Configuration	Potential Number of Steerable axle Vehicles*	Productivity Benefit per Vehicle over 10 yrs (\$)	Notional Productivity Benefit per year (\$)
Mass Limited			
R13 (28.5t)	1235	209,000	25,811,500
R23 (31.5t)	150	162,000	2,430,000
A123 (14.6m) (42.5t)			**
A124 (50t)	1000	150,000	15,000,000
B1234 (72.5t)	300	110,000	3,300,000
B1244 (77t) (30m)	400	279,000	11,160,000
A134T34T34 (158.2t)	50	587,000	2,935,000
A124T34T34 (151.7)	50	370,000	1,850,000
Cube Limited			
A123 (42.5t) (extra 1.2m)	700	198,000	13,860,000
A123-LA (42.5t)	350	248,000	8,680,000
B1233 (62.5t) (28.5m)	360	256,000	9,216,000
Total			94,242,500
* indicative empirical estimates			
**mass distribution only, no productivity gains			

It is worth noting that around 25% of the benefits come from mass limited operations of 3 axle rigid trucks where there appears to be no regulatory impediment to the use of steerable axles. This suggests some caution should be used in considering the results. There may be factors outside the scope of this study which act as a constraint on the use of steerable axles in this fleet.

However, there are significant benefits available from other vehicle configurations. If the number of vehicles for R13 and A124 was reduced by 50% the aggregate benefit would reduce by \$25M to \$74M, still a significant gain.

It is also worth noting that the very competitive nature of the transport sector means that the potential benefits from steerable axles would flow through the economy as transport cost reductions.

There are some significant caveats on the notional productivity gains:

- as noted earlier, the productivity gains estimated form an upper bound to what might be achieved. The full gains will only be realised by operators who experience full vehicle utilisation against a stable workload;
- some of the vehicle configurations might be substitutes and care should be taken in aggregating benefits;
- while the productivity gains will diminish if full vehicle utilisation is not achieved, the significant margin of benefits over costs means that there would be opportunities for productivity gains for operators who might not always experience full utilisation of their vehicles;
- operators who only own trailers would see different, but still significant productivity benefits – they would need less tow vehicles and hence see some of the capital and operating cost savings related to the tow vehicle; and
- the high productivity of the A123LA configuration, which offsets the high capital costs, requires a long trailer. There may be physical constraints on the use of such a trailer eg terminal limitations.

8.5 Net Benefits of Marginal Increases in Semi-Trailer Length

The issue of trailer length for articulated vehicles has been contentious for some time. Industry argues that the current 14.63m trailer is just not long enough for an additional pallet if allowance is made for stacking losses. For refrigerated trailers these issues are even more difficult. This situation has led to one jurisdiction allowing 14.94m refrigerated trailers (with short prime movers to meet overall length limits).

Two approaches to this issue were considered:

- allow 14.94m trailers with short prime movers to retain the overall length limit; and
- allow longer vehicles with 15m trailers with a steerable axle (to meet the PBS performance criteria).

The first proposal would lead to some constraint on operators and take-up might be limited due to the limited range of prime movers that would be acceptable. The attraction to operators would be the longer trailer without the additional cost of a steerable axle.

The second proposal would give operators the flexibility of a wider choice of prime movers, but at the expense of the additional cost of a steerable axle on the trailer.

To give some feel for the potential benefits of each option, it is necessary to estimate the number of trailers that might be built at 15m for each option.

For the first option (14.94m trailers with short prime movers), it was assumed that the longer trailers might move from 15% of the fleet to 30% of the fleet, an increase of some 500 vehicles. For the second option, which is assumed to be much more attractive to industry, the 15m trailers were assumed to move to 50% of the fleet, or an increase of around 1200 vehicles. Table 9 shows that the single vehicle productivity estimate for both options is quite similar. The extra cost of the steerable axle is offset to some extent by the tyre cost savings resulting from the steerable axle in the triaxle group.

Table 9 Productivity benefits of marginal semi-trailer length increase (with and without a steerable axle)

Option	Estimated Number of Vehicles	Single Vehicle Productivity Benefit over 10 years (\$)	Aggregate Annual Productivity Benefit Estimate (\$)
14.94m trailer with Current Overall Vehicle Length Limit	500	208,000	10,400,000
Longer Vehicle with 15m trailer with Steerable Axle	1200	198,000	23,760,000

The large difference in aggregate productivity benefit estimate flows directly from the vehicle numbers estimate. In other words, if the second option is more attractive to industry, the productivity benefit will be greater. The point to note is that the steerable axle option will meet all the PBS performance criteria.

8.6 Effects on Vehicle Travel, Exposure and Safety

More productive vehicle configurations should result in less heavy vehicles on the road and consequently less exposure of other road users to heavy vehicles. As a further safeguard, each of the proposed vehicle configurations has been assessed for compliance with proposed PBS standards.

Increases in vehicle length are sometimes raised as a safety issue. There is a general concern regarding overtaking times for longer vehicles. The increases in vehicle length proposed for some vehicle configurations are not likely to lead to significant safety issues. It has to be recognised that the total time required for an overtaking manoeuvre is not directly proportional to the increase in vehicle length. The components of an overtaking manoeuvre are the “*lead in*” to position the overtaking vehicle, the actual passing of the vehicle and the “*cut-in*” to reposition the overtaking vehicle in the traffic stream. Thus, an incremental increase in vehicle length will only have an impact on the time required for the passing of the vehicle and a much lower impact on the time required for the overtaking manoeuvre.

Finally, the NRTC Report “Performance-Based Standards – Policy Framework for Heavy Vehicle Regulation – Regulatory Impact Statement” May 2001 addresses the general issue of road safety impacts of PBS. The report argues that the better stability and “road fit performance” of vehicles required to meet PBS standards is likely to lead to a reduction in heavy vehicle crashes where vehicle stability is a factor. This is estimated to result in a saving of \$13 million to \$25 million per annum. The road safety benefit that might be

attributed to the vehicle configurations considered in this study would be less than this estimate, but still positive.

8.7 Summary of Economic Findings

The economic analysis suggests that significant productivity benefits could flow from a wider use of steerable axles for both mass and volume limited operations. The productivity gains range from a high of 33% for an additional axle on a mass limited rigid R12 truck to a low of just over 8% for a mass limited B-double B1244 vehicle.

There is a range of constraints arising from the regulatory framework which restricts the effective use of some configurations at this time. A number of the constraints appear to result from the lack of consideration of the effective use of steerable axles to achieve increased mass payloads. Other constraints arise from the vehicle dimension limits in the vehicle standards and mass and loading regulations.

It is important to realise that the vehicle configurations considered in this study would all meet the proposed PBS performance standards; one technical exception is the Static Roll Stability measure which probably needs further definition and consideration in the PBS context. Consequently, it can be argued that there would be no significant road safety issues arising from wider use of these vehicle configurations.

The economic analysis was based on the productivity benefits arising from the use of steerable axles to achieve improved payloads for the vehicle configuration. The vehicle configurations address mass limited or volume limited operations where there is a demand for improved vehicle productivity.

The analysis assumed full utilisation of the vehicles and full achievement of the potential productivity gains. In other words, a more productive vehicle will mean fewer vehicles for the task and consequent capital and operating cost savings. In the highly competitive transport market, it is reasonable to assume that the savings will be passed on to clients in terms of cost saving and flow on as general community benefits. However, if vehicles are not fully utilised, the net benefits will erode rapidly.

The major benefit stream (25% of the total) comes from the use of a steerable axle to improve the payload for a rigid R12 truck. There is no regulatory constraint on these vehicles at present. There would therefore have to be other reasons that operators do not seek to take advantage of this option. It may be that operators prefer to use trailers to increase payload.

The second largest benefit stream comes from the use of a 4-axle, or quad, group in an articulated vehicle. One major use of such vehicles would be in tankers. There are regulatory constraints which restrict operators developing such vehicles.

Significant benefit streams also flow from the use of a steerable axle in the triaxle group on volume limited articulated vehicles (A123) and B-doubles (B123).

It should be noted that, while the total scope of net benefits is considerable and indicates great value in facilitating the use of steerable axles on Australian trucks, some of the options are alternatives to each other; totalling of all the benefits calculated would therefore over-represent the total magnitude of economic benefits to the Australian community.

The introduction of PBS provides an avenue which could allow a wider range of vehicle configurations using steerable axles. The PBS system will allow greater certainty to

operators than the existing permit arrangements used to deal with vehicles outside the regulatory envelope.

However, a number of the regulatory constraints arise because the regulations were not framed with steerable axles in mind. There is a case for a review of the regulations to correct these anomalies and recognise the fact that steerable axles now provide a realistic option for transport operators. It may be desirable to develop a special set of parameters for vehicles using steerable axles.

A review of the regulations – noting that there are already moves to review ADR 43 – would provide smaller operators with the opportunity to move to use steerable axles without the need to make a case through the permit system or in time, through the PBS system.

Overall, the analysis demonstrates that significant productivity benefits could flow from the wider use of steerable axles to improve payloads in mass and/or volume limited operations.

9. REGULATORY IMPLICATIONS FOR STEERABLE AXLES

The study has found that, while few current Australian regulations refer directly to steerable axles, there are certain impediments to the use of steerable axles; the study is able to provide recommendations to resolve these issues. Consideration also needs to be given to whether any new regulations may be needed to assist in managing the safe and efficient use of steerable axles.

However, in considering the potential economic benefits of steerable axles, many other aspects of current regulations come into view. To realise the full economic potential of steerable axles, certain aspects of vehicle length and mass regulations would need to be reviewed, or alternative means such as PBS utilised. It is not within the scope of this study to make specific recommendations in these areas; the main regulatory issues are noted for consideration by the NRTC and relevant agencies.

One specific exception is the issue of semi-trailer length: the brief included investigation of the benefits and impacts of marginal increases in semi-trailer overall length; in particular, consideration was given to the wider application of the length increase from 14.6m (48ft) to 14.9m (49ft) recently granted to refrigerated trailers in New South Wales.

9.1 Modified Regulations to Facilitate Steerable Axle Use

ADR No.43/04 - Vehicle Configuration and Dimensions and particularly clause 6, 'Dimensions of Vehicles' provides some restriction to the application of steerable trailer axles on heavy vehicles in Australia. Rules 6.1 Total length and 6.2 Rear Overhang of this subsection specify certain maximum dimension limits measured from the rear overhang line on a semi-trailer (Figure 2). These same requirements are in the Australian Vehicle Standards Rules. General permits for 14.6m (48ft) semi-trailers also include limits, including the rear overhang, measured from the rear overhang line.

Regulatory implications need to be considered for both automotive-type steerable axles and linked-articulation type steerable axle systems.

9.1.1 *Automotive-type steerable axles*

Because the rear overhang line is defined without regard to the presence of any steerable axle, the rear overhang limit of 3.7m would be exceeded with the conversion of the rearmost axle (in a triaxle group) to an automotive-type steerable axle in the cases of:

- certain 13.7m "ADR" semi-trailers which may be built with s-dimension less than the maximum of 9.5m; and
- virtually all 14.6m "general permit" semi-trailers.

Relaxation of the 3.7m rear overhang limit would overcome this problem. As may be seen in Figure 10, rear overhang of a 14.6m semi-trailer may be increased by up to 1.2m and remain within the proposed PBS standard. It is suggested that the rear overhang limit is increased to 4.7m for both 13.7m and 14.6m triaxle semi-trailers.

The benefits of this regulatory change would be transport operators' freedom to opt for improved manoeuvrability, improved access and reduced tyre wear for semi-trailers; the disbenefit would be an increase in tail swing (but within proposed PBS standards). This regulatory change would also contribute to some of the productivity-based initiatives discussed below.

9.1.2 *Linked-articulation type steerable axles*

In this case, the rear overhang line is no longer defined at all. Because the definition of prescriptive rules for linked-articulation systems would become complex, linked-articulation systems are best dealt with under PBS.

9.2 New Regulations for Steerable Axle Management

The regulatory change discussed in Section 9.1.1 would need to be accompanied by certain requirements to ensure that dynamic performance of the vehicle combination is not degraded. As shown in Figure 27, the aligning stiffness of the automotive-type steerable axle should be at least equivalent to the medium stiffness value used in the simulation models.

There should also be a limit of one automotive-type steerable axle per triaxle group, and the steerable axle should be fitted in the rear position.

Consideration should also be given to the need for any specific requirements for load sharing performance of steerable axles when incorporated in an axle group.

9.3 Broader Regulatory Issues

In order to realise the significant productivity-based economic potential of steerable axles, it would be necessary to re-assess and extend certain aspects of the current regulations. Quad axle groups are not currently recognised in the regulations: there is no relevant axle group mass limit for the dual-tyred quad group and the treatment of such axle groups, with road-friendly suspension, in the axle spacing mass schedule is not currently defined.

The deployment of quad axle groups also implies increased GCM for tractor-semi-trailers and B-doubles. In the latter case, the appropriate axle mass schedule for GCM over 68t and up to approximately 77t needs to be considered.

It is suggested that the above issues are examined on a national basis in order that the full economic potential of steerable axles may be established and any recommendations for further regulatory change may be formulated.

Given the substantial economic potential of the A124 tractor-semi-trailer with quad group incorporating a steerable axle, this could become the focus of a national investigation of the regulation of quad axle groups. If the outcome of such an investigation proved positive for a 50t GCM A124 incorporating a steerable axle, the use of such a vehicle could be managed via simple prescriptive regulations, plus performance requirements for the steerable axle as indicated in Section 9.2.

While the issue of B-double overall length regulations is outside the scope of this project, there is substantial economic potential in the use of B-double trailers incorporating one automotive-type steerable axle in the rear position on each trailer. In order to gain increased cubic freight productivity, the overall length would need to increase from 25m to 28.5m. The potential impacts of such an increase in overall length would need to be separately assessed; however, this study has shown no adverse performance impacts in the range of vehicle performance issues considered.

It is suggested that this possibility is examined on a national basis. If such a recommendation were to proceed, simple dimensional regulations in a style similar to those proposed for semi-trailer in Section 9.4 could be formulated to assist in managing the use of such vehicles.

Similarly, the B1234 B-double configuration incorporating a quad axle group with steerable axle on the rear trailer offers certain economic potential. If national investigation of the viability of quad axle groups proved positive, the overall length would need to increase from 25m to 28.5m. The potential impacts of such an increase in overall length would need to be separately assessed; however, this study has shown no adverse performance impacts in the range of vehicle performance issues considered.

9.4 Regulation of Semi-Trailer Length

The current 14.6m (48ft) semi-trailer under general permit is sub-optimal in relation to productivity. A marginal increase in overall length to 15.0m would offer significant economic benefits. While this could be done with a fixed triaxle group, this option has the significant disadvantages of:

- creep in swept path performance, outside the General Arterial swept path specification in some cases; and
- relatively tight restriction on prime mover length dimensions.

The preferred option is to introduce a 15m semi-trailer incorporating a steerable axle in the triaxle group, with the following regulatory requirements:

- the semi-trailer length to be limited to 15m (not including any equipment or items of reduced width in the forward projection area);
- only one steerable axle to be permitted and must be fitted in the rear position;
- the forward projection from the kingpin to be limited by a “swing radius” of 1.9m maximum; taken together with the ADR maximum vehicle width of 2.5m, this equates to a forward dimension limit of 1.43m measured along the side of the trailer;
- the distance from the kingpin to the centre of the axle group (as currently defined, taking into account the presence of the steerable axle) to be limited to 9.35m;
- the rear overhang to be limited to 4.7m;
- the overall length of the combination to be limited to 20m; and
- steerable axle performance criteria as in Section 9.2.

It is noted that the above suggestion is outside the terms of the project brief in that the overall length would increase from 19m to 20m. The potential impacts of such an increase in overall length would need to be separately assessed; however, this study has shown no adverse performance impacts in the range of vehicle performance issues considered.

There is a current demand for a 14.9m semi-trailer in refrigerated transport and there is merit in extending this sectoral general permit throughout Australia. The requirements should be as currently implemented in NSW:

- the length is limited to 14.9m (not including any equipment or items of reduced width in the forward projection area);
- the forward projection from the kingpin is limited by a “swing radius” of 1.9m maximum; taken together with the ADR maximum vehicle width of 2.5m, this equates to a forward dimension limit of 1.43m measured along the side of the trailer;
- the distance from the kingpin to the rear end is limited to 13.6m;
- the distance from the kingpin to the centre of the axle group is limited to 9.9m; and

- the rear overhang is limited to 3.7m.

There is further merit in extending this semi-trailer length regime to all body and commodity types if the 15m semi-trailer concept suggested above is not proceeded with on a national basis.

9.5 Potential Use of PBS

It is suggested that the deployment of linked-articulation steerable axle group systems is best regulated using PBS. Proposed vehicles incorporating linked-articulation steerable axle systems should be subject to PBS assessment. As the potential economic benefits are substantial this should be earmarked as a priority PBS application and perhaps incorporated as a case study or “blueprint” PBS application. Strength requirements for linked-articulation steerable axle group systems should be included in the performance assessment.

A further candidate for PBS blueprint applications is the B1244 B-double incorporating steerable axles. The extended overall length of this vehicle and the significantly reduced swept path performance would make this vehicle subject to PBS assessment.

10. CONCLUSIONS

Current Practices with Steerable Axles

- (1) While steerable axles come in a range of generic types, the most common are “automotive type” steerable axles used on semi-trailers; this type of steerable axle is also available for rigid trucks and prime movers. Other types include linked-articulation axle group steering systems for semi-trailers.
- (2) Steerable axles are not currently in widespread use in Australia. Current users of automotive-type steerable axles on triaxle semi-trailers report improved tyre wear and improved swept path. In certain cases, improved farm access and reduced damage to farm access roads are cited as advantages. Linked-articulation steerable axles are new and are not currently being used in road transport, but offer a large improvement in swept path performance.
- (3) Current Australian regulations mitigate against the use of automotive-type steerable axles on trailers because the rear overhang dimension may be exceeded if the rearmost fixed axle is replaced with a steerable axle.
- (4) There are no current regulatory impediments to the use of steerable axles on rigid trucks, but little use is currently evident on this vehicle type.
- (5) The literature suggests that steerable axles on rigid trucks may in certain cases adversely affect vehicle handling and control; this is much less likely on trailers. Most of the research involving steerable axles and vehicle dynamics has been carried out on potential “problem” areas for steerable axles, such as rigid trucks and “C-dollies” for multi-combination vehicles.

Semi-Trailer Length Limits

- (6) The tractor-semi-trailer – which is a dominant Australian freight vehicle - is the only combination where the trailer unit has a specific length limit. The existence of this limit – and its value at any point in time – are of considerable significance to the productivity, flexibility and re-equipping practices of Australian trucking fleets.
- (7) While there are some subtle differences in the way in which semi-trailer lengths are controlled in national and state regulations, the key points in controlling semi-trailer length are:
 - the forward projection is a key dimension for interchangeability of prime movers and semi-trailers (it can also affect swing-out in low-speed turns);
 - the s-dimension affects low-speed offtracking (as well as the ability to achieve balanced load distribution);
 - the rear overhang affects tail swing in the initiation of low-speed turns; and
 - the distance from the kingpin the rear end affects the overall length of the combination vehicle (although this is limited separately to 19 m in the Australian Vehicle Standards Rules 1999).
- (8) In addition to the 13.7m long semi-trailer defined in the Australian Design Rules, general permits are available for 14.6m (48ft) long semi-trailers and, in NSW, 14.9m (49ft) long refrigerated semi-trailers.

- (9) The longer semi-trailers available under general permit are sub-optimal and remain in the minority of current semi-trailer production in Australia.
- (10) There would be value in extending the 14.9m general permit to other States and Territories and to a wider range of body and commodity types. However, this would be likely to remain a sub-optimal minority semi-trailer with limited overall economic benefits.
- (11) The introduction of a 15m long triaxle semi-trailer incorporating a steerable axle would offer substantial productivity-based economic benefits within current vehicle performance parameters; however, this vehicle would be most effective in vehicle combinations up to 20m in overall length and this issue lies outside the scope of the current study.

Performance Effects of Steerable Axles

- (12) In addition to the known benefits of reduced swept path and reduced tyre wear (see Conclusion 2), steerable axles also affect vehicle dynamic performance. Provided that steerable axles have at least a threshold level of self-centring, their effects on dynamic stability and tracking behaviour of the common Australian freight vehicle configurations are modest. Only in road trains of conventional configuration were dynamic performance impacts found to be of concern.
- (13) In the case of linked-articulation steerable axle group systems, the effects on improving swept path performance can be dramatic. In the case of an automotive-type steerable axle introduced into a triaxle group, there is a modest but worthwhile improvement in low-speed offtracking and swept path.

Steerable Axle Potential Under Current Regulatory Regime

- (14) Steerable axles have the potential to improve access of vehicle combinations in the road network and into sites and depots. This has the greatest potential for B-doubles, where access is often tight and the use of steerable axles could provide substantial gains. Operators should give more consideration to the benefits of fitting steerable axles to B-doubles.
- (15) Steerable axles could also be fitted to rigid trucks, leading to R13 and R23 configurations with increased GVM and productivity for mass-limited loads. Although not currently impeded by regulations, these applications currently find little uptake and there are likely to be useful gains available to some operators.

Steerable Axle Potential Under Minor Regulatory Changes

- (16) It is suggested that the rear overhang limit is increased from 3.7m to 4.7m for both 13.7m and 14.6m triaxle semi-trailers. The benefits of this regulatory change would be transport operators' freedom to opt for improved manoeuvrability, improved access and reduced tyre wear for semi-trailers; the disbenefit would be an increase in tail swing (but within proposed PBS standards). This regulatory change would also contribute to some of the productivity-based initiatives discussed below.
- (17) This regulatory change would need to be accompanied by certain requirements to ensure that dynamic performance of the vehicle combination is not degraded: the aligning stiffness of the automotive-type steerable axle should be at least equivalent to the medium stiffness value used in this report. There should also be a limit of one automotive-type steerable axle per triaxle group, and the steerable axle should be

fitted in the rear position. Consideration should also be given to the need for any specific requirements for load sharing performance of steerable axles when incorporated in an axle group.

Steerable Axle Potential Under National Regulatory Review

- (18) In order to realise the significant productivity-based economic potential of steerable axles, it would be necessary to re-assess and extend certain aspects of the current regulations.
- (19) Quad axle groups are not currently recognised in the regulations: there is no relevant axle group mass limit for the dual-tyred quad group and the treatment of such axle groups, with road-friendly suspension, in the axle spacing mass schedule is not currently defined. It is recommended that these issues are reviewed on a national basis.
- (20) The current axle spacing mass schedule for limited access vehicles is not defined for GCM over 68t. The appropriate axle mass schedule for GCM over 68t and up to approximately 77t needs to be considered
- (21) B-doubles are currently restricted to 25m overall length. Review of this limit for vehicles which meet all current performance parameters including swept path would permit substantial productivity gains to be considered with B-doubles using steerable axles. To encompass the potential productivity gains, an overall length range up to 28.5m should be considered; the issue of B-double overall length limits is outside the scope of the present study.
- (22) Worthwhile productivity initiatives which could be brought to the horizon by the above type of national regulatory review are: (i) 50t A124 tractor-semi-trailer with quad axle incorporating one steerable axle, (ii) 72.5t GCM B1234 B-double with quad axle incorporating one steerable axle on the rear trailer and (iii) 38 pallet B1233 B-double with one steerable axle on each trailer.

Steerable Axle Potential Under PBS

- (23) Linked-articulation steerable axle group systems should be earmarked as a priority PBS application and considered for a case study or “blueprint” PBS application. Strength requirements for linked-articulation steerable axle group systems should be included in the performance assessment.
- (24) A further candidate for PBS blueprint applications is the B1244 B-double incorporating quad axle groups incorporating steerable axles on both trailers. The extended overall length of this vehicle and the significantly reduced swept path performance would make this vehicle subject to PBS assessment.

Potential Economic Role of Steerable Axles

- (25) The wider deployment of steerable axles offers substantial financial and economic benefits in cases where productivity gains are able to be exploited with high-utilisation vehicles. The net benefits to the Australian economy depend on the take-up rate of such initiatives, and take-up can only be estimated.
- (26) The economic benefits of minor regulatory change in relation to improved access and reduced tyre wear are difficult to estimate. However, as the necessary changes

are small and no significant costs to agencies have been identified, such changes are recommended.

- (27) National regulatory review in relation to quad axles, axle spacing mass schedule and B-double length (for B-doubles with steerable axles) would allow a net benefits package in excess of \$20M per year to be addressed.
- (28) National regulatory review in relation to overall length of tractor-semi-trailers and the introduction of a 15m long triaxle semi-trailer incorporating a steerable axle would allow a net benefits package in excess of \$20M per year to be addressed.
- (29) The establishment of PBS blueprint applications for linked-articulation semi-trailers and 77t B1244 B-doubles incorporating steerable axles would allow a net benefits package of approximately \$20M per year to be addressed.

Safety Effects of Facilitating Steerable Axles

- (30) Assessment of the effects of steerable axles on heavy vehicle dynamic performance has shown that, provided certain requirements for the performance and deployment of steerable axles are followed, there are no adverse effects on dynamic performance.
- (31) Wider use of steerable axles under modified regulations would facilitate more productive vehicle configurations which should result in less heavy vehicles on the road and consequently less exposure of other road users to heavy vehicles. As a further safeguard, each of the potential productivity initiatives has been assessed for compliance with proposed PBS standards.

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APPENDIX A – DETAILS OF SURVEY RESPONDENTS

The following Australian transport operators have currently responded to the steerable axle survey conducted by the consultant:

- Australia Post, Manager of Transport (Technical), Barry Degenhardt
- Bunker Freight Lines (Australia) Pty Ltd, National Workshop Manager, Val Gomez
- Cootes Holding Pty Ltd, Fleet Manager, Alan Yates
- FCL Interstate Transport Services Pty Ltd, Peter Killeen.
- JL Pierce Pty Ltd, Mr. Lance Fisher
- K & S Freighters Pty Ltd, General Fleet Manager, Simon Scazlic
- Linfox Pty Ltd, National Line Haul Manager, Mick Best
- McColl's Transport Pty Ltd, Tongala workshop mechanic, Ron Cunningham
- Mobil Oil Australia Pty Ltd, Technical Fleet Adviser, Chris Reid
- Roadmaster Haulage Pty Ltd, Herbert Falgmire
- Sling Shot Haulage Pty Ltd, Transport Manager, Leigh Dehne
- Toll Holdings Pty Ltd, National Linehaul Manager, Steve Granland
- TransWest Haulage Pty Ltd, Marketing and Development Manager, David Lindgren.

The following representatives of Australian steerable axle and heavy vehicle trailer manufacturers and suppliers have responded to the survey conducted by the consultant:

- Barker Trailers Pty Ltd, Mike Bullus
- Colrain Wholesalers Pty Ltd, Original Equipment Manager, Mick Nicholls
- Fibreglass Transport Equipment Pty Ltd, Engineering Manager, Kim Wood
- Gayat Pty Ltd (Trackaxle™), Director, Kerry Atley
- Kennedy Trailers, Director, Gary Kennedy
- Scania (Australia) Pty Ltd, Engineering Support, Peter Louer
- Transpec Ltd (BPW self-steering axles), Manager Trailer Equipment Division, Mario Colosimo
- Volvo (Australia) Pty Ltd, Engineering Manager, Ken Cowell
- York Transport Equipment Pty Ltd, National Sales Manager, John Knight

The following representatives from Australian Regulatory Authorities have responded to the survey conducted by the consultant:

- Vicroads, Senior Freight Consultant, John O'Regan
- Vicroads, Manager Heavy Vehicle Engineering, Grey Scott
- NSW Roads Transport Authority, Phil Leeds
- NSW Roads Transport Authority, Justin Maguire

- Queensland Department of Transport, Les Bruza
- Department of Transport and Works Northern Territory, Ian Phillip
- Department of Transport and Regional Development, Keith Seyer

Industry Associations:

- Australian Trucking Association (ATA), Bob Woodward
- Australian Road Transport Suppliers Association (ARTSA)
- Victorian Transport Association, Phil Level.

APPENDIX B – DETAILS OF EMAIL SENT TO OVERSEAS CONTACTS

The following is an email sent out on to interested parties from overseas on The Roads-Transport Technology email list, for the Vehicle Roads Interaction Network (VRIN) requesting input to the steerable axles project;

National Road Transport Commission – Steerable Axles to Improve Access

Heavy vehicles fitted with steerable axles in Australia are currently used in transport operations but must operate within the restrictions of the legislative system. Steerable axles enable longer vehicles to minimise the amount of road space they require in low-speed turns. Conversely, the length (and therefore cubic load capacity) could be optimised for a fixed geometric capacity in the road system.

The Australian transport industry contends that vehicles with steerable axles offer considerable benefits but to date it has been unable to take full advantage of these benefits. Therefore the industry has approached the National Road Transport Commission (NRTC) to investigate the operational performance of vehicles fitted with steerable axles with a view to enabling improved access and/or higher productivity for those vehicles that meet the required standards.

The NRTC in response to these industry concerns commissioned Roaduser Systems Pty Ltd to carry out a study of the benefits, costs and potential for length increases under Performance Based Standards (PBS) and the overall performance effects of steerable axles. The Performance Based Standards (PBS) regulatory concept under development by the NRTC and Austroads could provide a method of overcoming these regulatory impediments to vehicle productivity. It is intended that the methods developed through the PBS project will be used in the assessment of the steerable axles. Steerable axles appear to have potential for increased application under PBS, and this NRTC study will assess the performance impacts of steerable axles against the currently proposed PBS measures and standards.

This project has the following main objectives;

- define and quantify the benefits of using steerable axles in the transport industry generally and highlight any applications where steerable axles may be particularly beneficial;
- confirm the potential for increased vehicle/trailer length for each configuration when compared to the relevant measures and draft performance values developed under PBS;
- identify the regulatory impediments (if any) that could influence the wider application of vehicles fitted with steerable axles throughout Australia;
- determine the economic impacts on the industry for various vehicle-trailer arrangements including transport fleet owners, vehicle and axle suppliers, local government and regulatory bodies; and
- undertake appropriate modelling (or trials) to determine the geometric and any other safety impacts, including swept path effects against existing standards and any road network issues.

Therefore we would like to request any published research, reports or work that has been done on the vehicle performance benefits for heavy vehicles fitted with self-steering axles. Also we would appreciate advice concerning any work completed with regard to the

regulation of vehicles fitted with steerable axles, particularly regulations which encourage the use of steerable axles.