Connecting Australia with modular B-Triples

Matthieu Bereni[a], Rob Di Cristoforo[b]

[a] National Transport Commission (NTC), Australia
[b] Advantia Transport Consulting Pty Ltd, Australia (**Enquiries**: rob@advantia.com.au)

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Abstract

The National Transport Commission (NTC) has proposed a national framework for B-triple operations that includes basic vehicle specifications and operating conditions. The Commission anticipates that the national framework will replace the inconsistent state-by-state approaches currently adopted for B-triples, which largely discourage the use of B-triples for interstate operation. This paper presents a productivity analysis, a safety analysis and an infrastructure impact analysis (pavements and bridges). It also presents a cost-benefit analysis that includes the monetised safety and environmental benefits of national B-triple operation.

1. INTRODUCTION

B-triples are vehicle combinations comprising a prime mover towing three semi-trailers. They are a basic extension of the already common B-double, and have mass and dimensions similar to those of the existing A-double, or 'double road train' (FIGURE 1). The articulation points between the three trailer units each feature a fifth-wheel coupling (or ‘B’ coupling, hence the name ‘B-triple’). Such a coupling supports the front of the following trailer and allows free relative rotation between adjacent vehicle units about the vertical axis (when turning) and the transverse axis (when travelling over crests and through dips), but strongly resists relative rotation about the longitudinal axis. The resistance to relative rotation about the longitudinal axis is commonly referred to as ‘roll-coupling’. It is widely accepted that vehicle combinations featuring ‘B’ couplings exhibit far greater dynamic rollover stability than those with non-roll-coupled ‘A’ couplings (i.e. standard converter dollies).

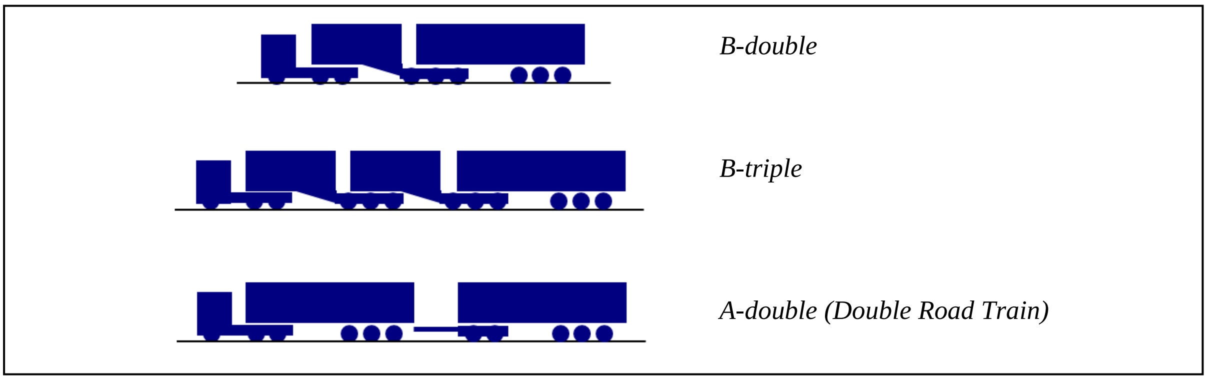


FIGURE 1 B-double, B-triple and A-double combinations.

The purpose of this paper is to present the methodology that has been used to arrive at a national framework for B-triple operations in Australia, to replace or augment existing state-by-state arrangements. Section 2 provides some information regarding the context in which B-triples currently operate in Australia.

Section 3 describes the policy proposal and the modular B-triple specifications developed as part of it. Section 4 explains in detail how the corresponding impact analysis was performed, while section 5 presents conclusions.

2. B-TRIPLES IN AUSTRALIA

As a result of the B-double's productivity and safety success story in Australia, there has been growing support throughout Australia, from industry and governments alike, for higher productivity vehicles that use B-double component vehicles (i.e. trailers coupled by fifth wheels). Aware of this, the NTC has launched a study with the aim of designing a policy, which would ultimately provide wider and more consistent B-triple access across Australia. Differences between each state and territory effectively discourage B-triple use for interstate operation. The ultimate goal of this reform is to enable B-triples to operate nationally wherever double and triple road trains currently operate and also on suitable non-road-train routes of strategic importance. The Bureau of Infrastructure, Transport & Regional Economics (BITRE) projects that B-triple road freight share could reach one-fifth of total if B-triples are allowed access to the right set of inter-capital routes (1).

The mass and dimensions of the B-triple are similar to those of the double road train, with productivity being slightly better for B-triples. B-triples are therefore expected to replace some double road train operations on road train routes, but the rate of substitution could be significantly augmented because B-triples offer a distinct advantage when they are disassembled for travel on non-road-train routes. The suggested initial network for modular B-triple operations is the same as the double road train network (FIGURE 2), which is confined to areas of low population density. It is planned to expand this network over time to incorporate at least the key inter-capital transport corridors.

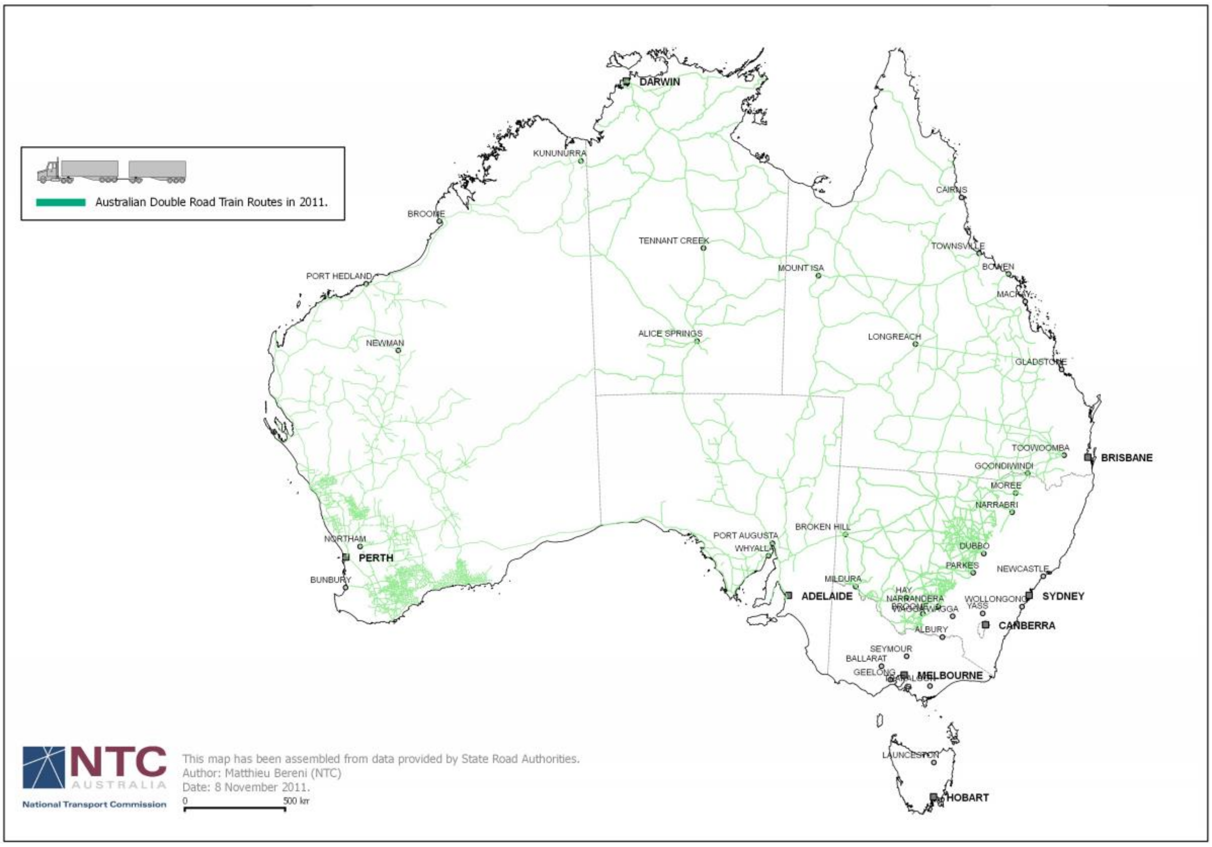


FIGURE 2 Australian double road train network

3. PROPOSED MODULAR B-TRIPLE SPECIFICATION

3.1. Principle

The proposed prescriptive modular B-triple specification is constructed on the principle that the B-triple combination must be able to be broken down into a complying 26-metre B-double, and that this must be the case regardless of which of the two lead trailers is removed from the combination. This is referred to as “B-double compatibility.” This approach effectively imposes by extension the existing 26-metre B-double requirements, including additional prime mover safety features, on the vehicle components used in a prescriptive modular B-triple. Double road trains are not required to have some of these features, such as anti-lock braking systems (ABS) on prime movers, so this presents an increase in safety.

Compared with double road trains, B-triples appear to offer improved safety in all key aspects of safety performance except swept path width, which, for a given overall length, is generally greater for B-triples than for double road trains (the results of the safety performance of B-triples are presented in section 4 of this paper). By specifying a maximum overall length for modular B-triples, the proposed B-triple policy guarantees that the swept path width of modular B-triples will remain within the accepted road design envelope of 10.6 metres, as required by the Performance Based Standards Level 3 (2), if not comparable with that of a double road train.

3.2. Key requirements

The modular B-triple specification is concerned primarily with ensuring that combinations operated under the proposed policy have acceptable safety and infrastructure impacts and that the risk of non-compliance with B-double requirements when one trailer is removed is mitigated to the extent that is practical. The five key requirements of the modular B-triple specification are:

- **Configuration:** modular B-triples must be constructed from a prime mover having a single steer axle and a tandem drive axle group towing three triaxle semi-trailers all connected by fifth-wheel couplings.
- **B-double compatibility:** modular B-triples must form a compliant 26-metre B-double when one lead trailer is removed, regardless of which one is removed (see FIGURE 3 below).

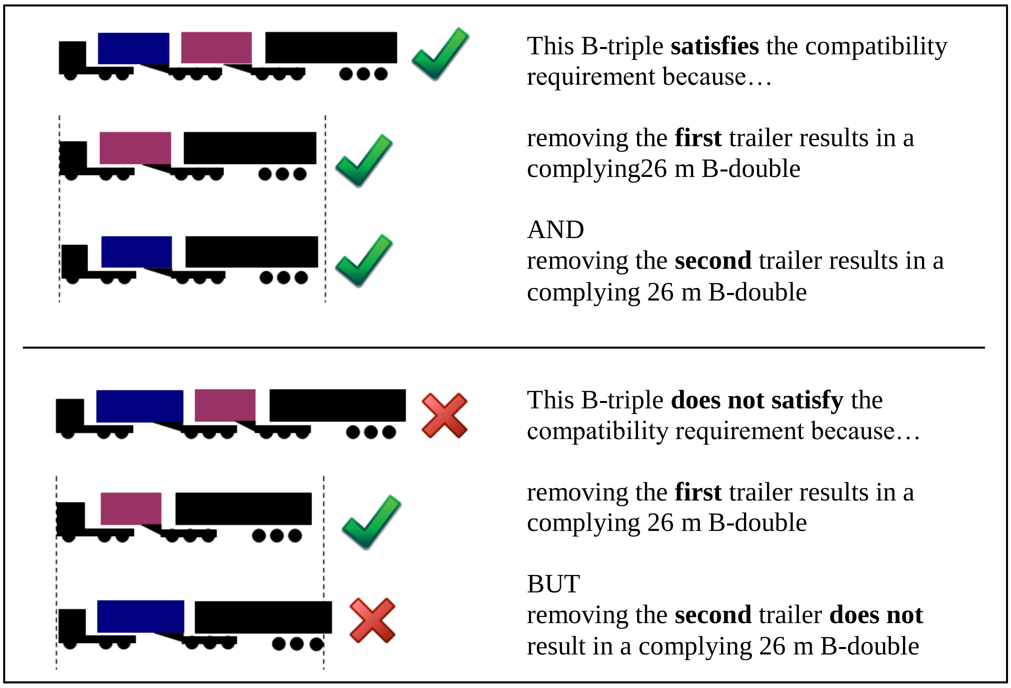


FIGURE 3 Demonstration of the B-double compatibility requirement.

- **Overall length:** must not exceed 35 metres, including any bull bar and other after-market fittings. This is 9.0 metres longer than a 26-metre B-double, and allows the addition of most existing standard lead trailers to form a B-triple from a 26-metre B-double. The choice of 35 metres, and not 36.5 metres as for double road trains, is a necessary control to aid compliance and enforcement of the B-double compatibility requirement. It also ensures that low-speed swept path width is within acceptable limits.
- **Kingpin to rear dimension:** must not exceed 29.6 metres. This is 9.0 metres longer than the equivalent dimension for a 26-metre B-double, and ensures that prime mover wheelbases remain within acceptable limits from a driver health perspective (as per the 26 m B-double) when operating at maximum length.
- **Mass limits:** General Mass Limits or Concessional Mass Limits (not 'Higher Mass Limits') (3). General Mass Limits are as follows : 6.0 t for single axles with single tyres, 9.0 t for single axles with dual tyres, 16.5t for tandem axles with dual tyres and 20.0 t for triaxles with dual tyres or wide single tyres.

4. IMPACT STUDY OF MODULAR B-TRIPLES

4.1. Productivity analysis

Overview

National adoption of modular B-triples under this policy is expected to have the following benefits:

- **For operation on road train routes,** B-triples offer a modest productivity increase and a significant safety increase in comparison with conventional double road trains.
- **For operation on B-double routes**, B-triples can be broken down into B-double combinations, providing a significant increase in productivity and safety in comparison with the single semi-trailers that would be formed from breaking down conventional double road trains. The crash statistics published by National Transport Insurance's National Truck Accident Research Centre (4) demonstrated the safety benefits convincingly; while B-doubles are responsible for 46% of articulated vehicle freight tonne-kilometres they are involved in only 29% of major articulated vehicle crashes.

The following quantitative analysis shows that for mass-constrained freight and volume-constrained freight, the productivity benefits of B-triples for all freight densities are compelling.

Mass-constrained freight

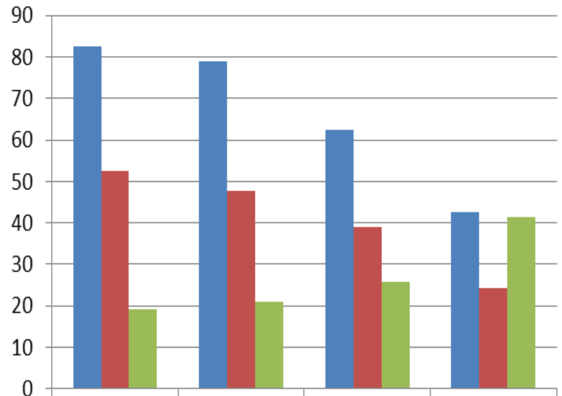
Mass-constrained freight is freight of such high density that it can bring a vehicle up to its maximum permitted mass without completely filling the volume available for freight. Examples of mass-constrained freight include bulk liquids and mined resources. When analysing vehicle productivity for mass-constrained freight the important parameters are the maximum permitted mass of the vehicle and the tare mass of the vehicle. TABLE 1 presents the results of a mass-constrained productivity analysis for the four vehicle configurations discussed. The analysis shows that for operation on road train routes, B-triples offer a 10% payload mass increase over double road trains, resulting in 9% fewer trips for the same freight task. For operation on B-double routes, B-doubles offer a 61% payload mass increase over semi-trailers, resulting in 38% fewer trips for the same freight task.

Volume-constrained freight

Volume-constrained freight is freight of such low density that it can completely fill the volume available for freight without the vehicle reaching its maximum permitted mass. Examples of volume-constrained freight include consumer products such as whitegoods and electronics. When analysing vehicle productivity for volume-constrained freight the important parameter is the available volume of the vehicle. TABLE 1 presents the results of a volume-constrained productivity analysis for the four vehicle configurations discussed. The analysis shows that for operation on road train routes, B-triples offer a 5% payload volume increase over double road trains, resulting in 4% fewer trips for the same freight task. For operation on B-double routes, B-doubles offer a 55% payload volume increase over semi-trailers, resulting in 35% fewer trips for the same freight task.

TABLE 1 Mass-Constrained and Volume-Constrained Productivity Analyses

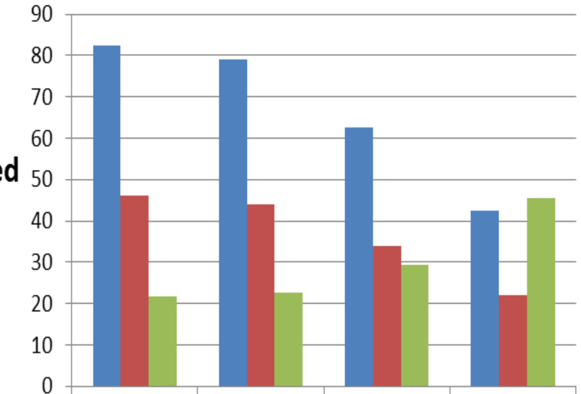
Mass-Constrained Analysis



	B-triple	Double Road Train	B-double	Semi-trailer
Gross Combination Mass at General Mass Limits (tonnes)	82.5	79	62.5	42.5
Payload mass (tonnes)*	52.44	47.77	38.93	24.13
Number of trips required to transport 1000 tonnes	19.1	20.9	25.7	41.4

* Payload mass values are industry averages (Australian Trucking Association 2010)

Volume-Constrained Analysis



	B-triple	Double Road Train	B-double	Semi-trailer
Gross Combination Mass at General Mass Limits (tonnes)	82.5	79	62.5	42.5
Payload volume (pallets)**	46	44	34	22
Number of trips required to transport 1000 tonnes	21.7	22.7	29.4	45.5

** The analysis is based on palletised freight for ease of calculation. It assumes standard 12-pallet lead trailers and standard 22-pallet tag trailers. Modular B-triples may in fact be able to use at least one 14-pallet lead trailer for further increased productivity.

4.2. Safety analysis

Overview

B-triples are generally safer than conventional double road trains because of their improved on-road dynamics, which is largely a product of their fully roll-coupled trailer configuration. The safety analysis presented in this paper used well-established assessment techniques based on computer simulation of on-road vehicle dynamics (2). The modelling technique used to model the performance of modular B-triples has been validated in numerous field tests and comparative studies over the last 12 years and is largely used in Australia as part of the National Performance Based Standards (PBS) scheme. The objective was to examine the safety performance of a wide range of modular B-triple configurations that could be assembled from B-double equipment by comparing their performance in a range of PBS tests with two independent benchmarks:

- The performance levels defined in each of the PBS standards, where Level 3 corresponds with the double road train network and Level 2 corresponds with the B-double network;
- The performance of a conventional double road train subjected to the same PBS tests.

The safety analysis was conducted by ARRB Group Ltd (Germanchev, A. et al.) and was documented in a detailed report (5).

Commodity and body types

The analysis considered B-triples designed for the following commodity or trailer body types, considered to be representative of the vast majority of potential B-triple operations:

- General freight;
- Refrigerated freight;
- Bulk commodities;
- Liquid commodities (road tankers);
- Livestock.

In consultation with the Australian Trucking Association, the Truck Industry Council and major prime mover and trailer manufacturers, the NTC compiled dimension specifications of representative prime movers, lead trailers and tag trailers that are currently in use and being sold in Australia for B-double operation, and that would also be potentially suitable for B-triple operation according to the modular approach. The many vehicle units considered by this study were hypothetically assembled into an exhaustive list of 79,656 potential B-triple combinations and checked against the modular B-triple dimensional requirements to determine which combinations were in fact complying modular B-triples. Of those combinations that did satisfy all of the requirements, a worst-case subset was then selected for analysis in the PBS tests, as it was neither feasible nor particularly informative to test every remaining combination.

B-triple combinations selected for safety analysis

The B-triple combinations selected for the safety analysis are:

- **Generic:** Those combinations having typical dimensions and considered to be most suitable within the pool of potential combinations;
- **Short prime mover:** Same as the generic but with a short prime mover;
- **Long prime mover:** Same as the generic but with a long prime mover;
- **Trailer axle groups forward and aft:** Same as the generic but with varied longitudinal placement of axle groups relative to coupling points;
- **Shortest combination:** Shortest combination that could be constructed from the range of individual vehicle units for each commodity or body type;
- **Longest combination:** Longest combination that could be constructed from the range of individual vehicle units for each commodity or body type.

The selected subset of combinations captures the extremes of both high-speed and low-speed dynamic performance within the scope of the safety analysis. In addition to the previous B-triple combinations, a benchmark double road train was constructed for each commodity or body type from a prime mover and two semi-trailers, and a tandem axle converter dolly with 5-metre drawbar length connecting the two trailers.

Analysis method

The B-triple vehicles and the benchmark double road trains were all submitted to PBS tests to determine their performance against the measures presented in the following table. These tests, recognised internationally as a vehicle safety analysis method, are defined by the NTC. More details on each of the standards described in Table 3 may be obtained in NTC (2).

TABLE 2 Performance Assessment Of Modular B-Triples

Driveline-related performance	**Low-speed dynamic performance**	**High-speed dynamic performance**
- Startability - Gradeability - Acceleration Capability	- Low-Speed Swept Path - Frontal Swing - Tail Swing - Steer Tyre Friction Demand	- Tracking Ability on a Straight Path - Static Rollover Threshold - Rearward Amplification - High-Speed Transient Offtracking - Yaw Damping Coefficient.

Results

The performance of the modular B-triples of all freight types was considerably better than that of the corresponding reference double road train, no doubt because of trailer roll-coupling. However, two sets of results deserve particular attention. First, due to the geometry of modular B-triples, the low speed swept path width of the modular B-triples was approximately 0.5 to 1.2 metres greater than that of the reference double road train, but still within the PBS Level 3 envelope of 10.6 metres. The low-speed swept path assessment is essential as it determines whether a vehicle will be able to make a turn at an intersection without the rear trailer cutting in too much. The corresponding results are presented in FIGURE 4.

Second, high-speed dynamic performance of the modular B-triples was found to be excellent on all measures except Static Rollover Threshold in the case of livestock transport. Still, the modular B-triples had a Static Rollover Threshold around 0.01 to 0.02 g better (up to 5% better) than the double road trains across the board (FIGURE 5). Modular B-triples therefore offer a significant improvement in Static Rollover Threshold and a corresponding reduction in the risk of rollovers.

The safety analysis demonstrated that, in general, modular B-triples significantly exceed the safety benchmarks set by the PBS levels and the conventional double road train’s performance. Modular B-triple performance is in some aspects up to the benchmarks for Level 2 (corresponding with B-double routes) and Level 1 (corresponding with General Access).

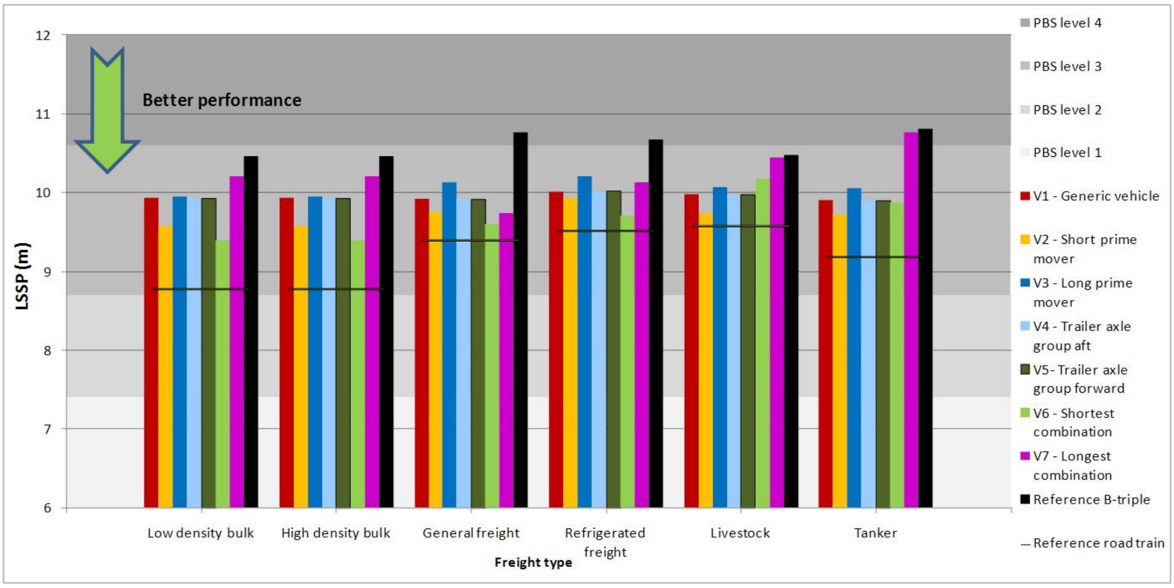


FIGURE 4 Results for low-speed swept path.

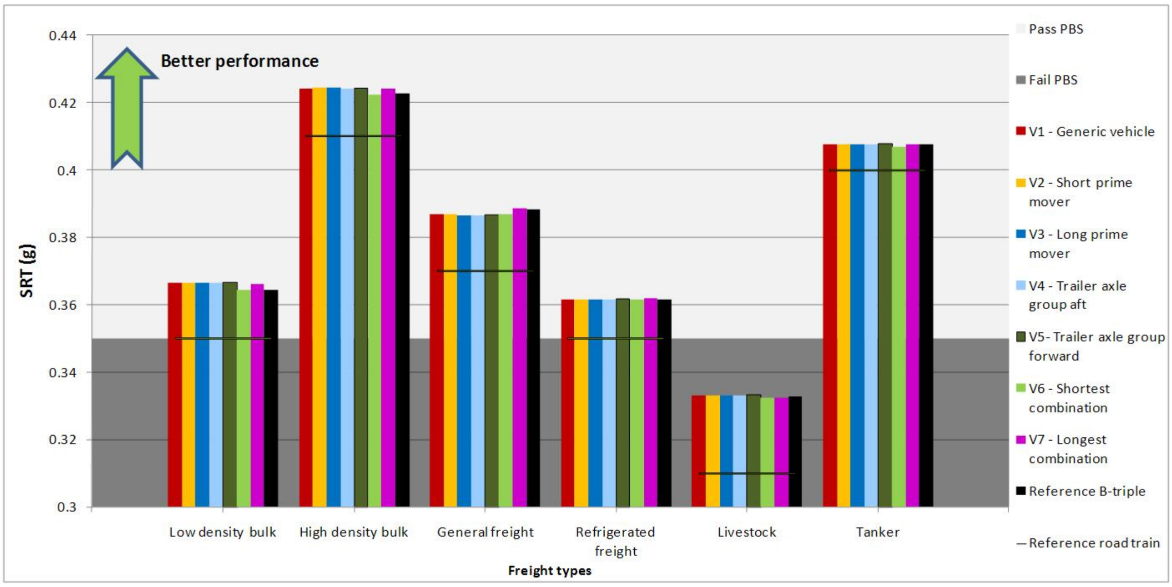


FIGURE 5 Results for static rollover threshold.

4.3. Infrastructure impact analysis

Pavement loading analysis

Pavements have been empirically proven to progressively wear out over time due to the repeated passing of laden heavy vehicles. The amount of wear that develops can be estimated using the Standard Axle Repetition (SAR) approach. The SAR approach considers that one unit of pavement wear is the amount of wear caused by one pass of a standard axle, being a single axle with dual tyres that is laden to 80 kN (8.16 tonnes). According to Austroads (6) (7) the amount of wear caused by one pass of a vehicle with various axle group types laden to various axle group loads is equal to the wear caused by an equivalent number of passes of a standard axle (i.e. standard axle repetitions, or SAR) using the formula:

$$SAR = \sum_{i=1}^{i=m} (L_i / SL_i)^n \qquad \text{(Equation 1)}$$

where:
L_i = load carried by axle group type i in tonnes
SL_i = standard load for axle group type i in tonnes
n = pavement wear exponent, which may vary from 4 to 12 depending on the pavement distress type
m = number of axle groups on the vehicle.

TABLE 3 presents the results of a pavement wear analysis using the SAR approach.

TABLE 3 Pavement Wear Analysis

Loading	B-triple	A-double	B-double	Semi-trailer
	Equivalent Standard Axles (ESAs) per vehicle pass			
Laden	7.72	8.40	6.34	4.96
Unladen	1.15	1.19	1.13	1.14
	ESAs per 1,000 tonnes by proportion of distance travelled fully laden			
Full one way, empty the other (50%)	169	201	192	253
Always full (100%)	147	176	163	206

It can be determined from the analysis results that for operation on road train routes, B-triples produce 16% less pavement wear than double road trains for the same freight task. For operation on B-double routes, B-doubles formed from B-triples produce 21% less pavement wear than semi-trailers formed from double road trains for the same freight task.

Bridge loading analysis

Road authorities have suggested that some double road train routes may not be suitable for modular B-triples because of insufficient bridge capacity. This section presents a bridge loading analysis that characterises the effects of B-triples on a wide range of bridges. The assessment draws from the methodology proposed by Woodrooffe et al. (8).

The assessment of bridge loading due to heavy vehicle use is a complex matter that can be addressed using various approaches. One approach, known as the capacity approach, compares the calculated effects due to the passing of a given vehicle over a given bridge with the known capacities of that bridge. When conducting network-level analyses for common freight vehicles to access hundreds or thousands of bridges it is not feasible to use such a data-intensive method. In such cases the preferred approach, known as the reference vehicle approach, compares the calculated effects due to the passing of a given vehicle over a given bridge with the calculated effects due to the passing of another vehicle for which the bridge has previously been approved as suitable.

In 1997 the Austroads Bridge Assessment Group (ABAG) issued *Guidelines for Bridge Load Capacity Assessment* (9). These guidelines proposed typical live loads to be used as reference vehicles. These included a six-axle articulated vehicle, a nine-axle B-double and a double road train. The ABAG double road train loaded to General Mass Limits (Gross Combination Mass of 79.0 tonnes) and represented in FIGURE 6 served as the reference vehicle for this analysis.

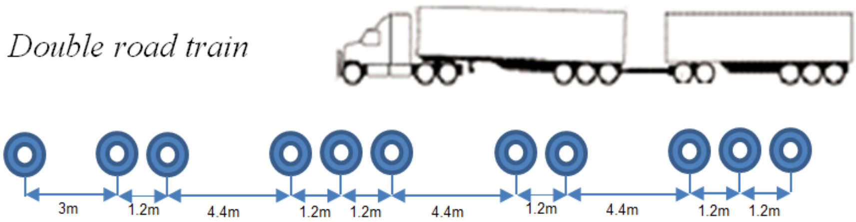


FIGURE 6 ABAG double road train (10).

Following a consultation workshop held at the NTC in May 2011, it was agreed to assess the impact of B-triples on bridges using beam analysis. The structural effects to be included in this assessment were:

- **reaction forces** acting upwards on beams from piers and abutments;
- **shear forces** at various points along a beam;
- **bending moments** at various points along a beam. A bending moment that produces convex bending at the supports of a continuously supported beam is referred to as a negative or hogging bending moment.

It was also agreed that the analysis would consider both 2-span simply-supported bridges with equal span lengths and 2-span continuous bridges with equal span lengths. The span lengths to be examined were 5 metres to 50 metres in increments of 0.5 metres. The vehicles used for the analysis were all loaded to General Mass Limits and included:

- ABAG double road train (the reference vehicle)
- Generic general freight modular B-triple
- Shortest general freight modular B-triple
- Longest general freight modular B-triple.

For each of the examined effects, magnitudes are presented in plots as percentage differences relative to those of the ABAG double road train. The ABAG double road train effects are therefore zero in all cases and do not need to be plotted. Positive percentages indicate that the modular B-triple induces effects that are greater by that percentage, and vice versa.

Results

For 2-span simply supported bridges with equal span lengths, the analysis found that the effects of modular B-triples are in all cases less than or equal to those of the ABAG double road train. For 2-span continuous bridges, the analysis found that the effects of modular B-triples are in most cases much less than those of the ABAG double road train, but in some cases slightly more:

- Maximum hogging moment induced by the modular B-triples is greater than that induced by the ABAG double road train for spans of 20 to 35 metres (FIGURE 7). The difference increases with vehicle length, with the longest modular B-triple inducing effects up to 16% greater. High hogging moments must be treated carefully as they can lead to the cracking of decking slabs.
- Maximum central pier reaction induced by the modular B-triples is greater than that induced by the ABAG double road train for spans exceeding 33 metres (FIGURE 8). The worst B-triple reaction exceeds the ABAG double road train reaction by up to 2.5%. Although increased reaction over central piers needs monitoring, it is less critical than increased bending moments as bridge piers are compression members specifically designed to cope with this type of structural effect.

In the vast majority of cases, the impact of B-triples on bridges is less than that of the ABAG double road train. Unless a specific bridge is considered inadequate by a bridge owner for particular reasons, the calculation of structural effects detailed in this analysis confirms that bridges belonging to double road train network are suitable for modular B-triple operations.

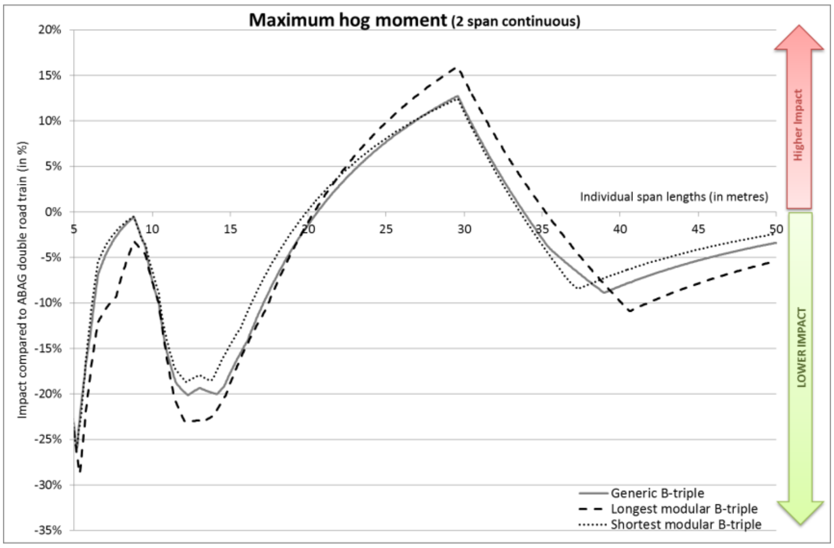


FIGURE 7 Maximum hogging moment for 2-span continuous bridges.

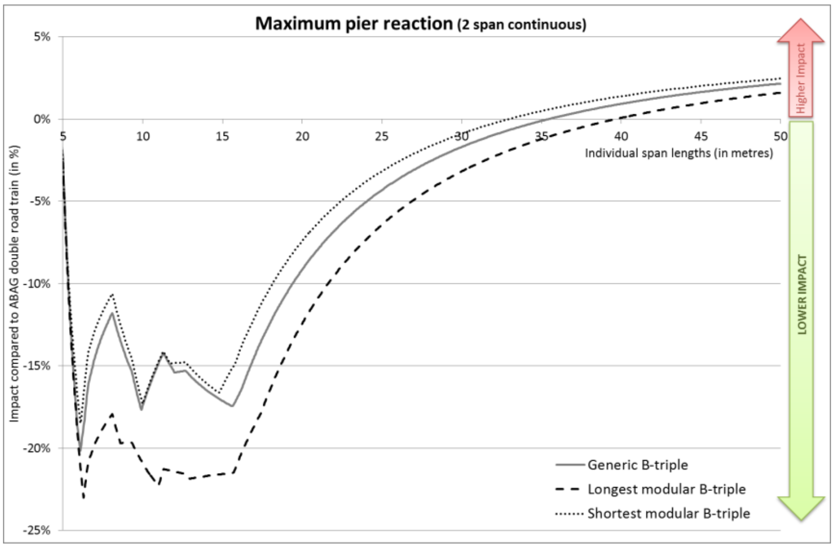


FIGURE 8 Maximum central pier reaction for 2-span continuous bridges.

4.4. Cost-benefit analysis

A cost-benefit analysis was undertaken to estimate the savings that could be gained from national B-triple operation on the double road train network over the period from 2011 to 2030. As well as estimates of the reduction in vehicle numbers and vehicle-kilometres travelled, estimates were made of the reduction in road fatalities and CO_2 emissions. These were then monetised and added to the direct financial savings. The analysis was conducted by the Industrial Logistics Institute (ILI) and was documented in a detailed report (10).

The analysis was based on the assumption that B-triples will be used for some road train network operations that are currently undertaken using double road trains and B-doubles, and that savings would come from not only the improvement in productivity when operating a B-triple on approved B-triple routes, but also the advantages of operating modular B-triple sub-configurations when travelling off approved B-triple routes. The latter is believed to be potentially responsible for the majority of benefits over double road train operation until such time as the approved network is significantly more extensive than existing road train routes (e.g. includes key inter-capital corridors). Three options were modelled in the cost-benefit analysis. These can be considered as the low, median and high adoption scenarios. The level of take-up of B-triples is detailed below:

- Option 1 (Low) – The substitution of B-triples for double road trains was set at a maximum level of 20% with an annual growth rate in the double road train vehicle population of 2.2%, the single semi-trailer predicted growth rate in NTC 2010 (11). This option was considered to be highly feasible and very conservative by existing operators.
- Option 2 (Median) – The substitution of B-triples for double road trains was set at a maximum level of 30% with an annual growth rate for this substitution as being equal to the low B-Double growth rate in NTC 2010 (11). This growth was set at 3.2%.
- Option 3 (High) – The substitution of B-triples for Double road trains was set at a maximum level of 40% with an annual growth rate in B-Triple take- of 4.8%.

Assuming a scenario of median B-triple take-up, over the period from 2011 to 2030 the regulatory proposal based on double road train network access stands to offer total monetised savings of almost $1.1 billion Net Present Value (NPV), of which $1 billion derives from direct financial savings brought about by reduced vehicle numbers and reduced vehicle-kilometres travelled.

The modelling assumes that (a) access will be limited to road train routes and thus there will be no need for major infrastructure upgrades and (b) there will be no additional costs to operators. TABLE 4 sets out the results of the analysis, including figures for low and high take-up scenarios.

TABLE 4 Summary of Findings: B-Triple Operations Between 2011 and 2030

	Take-up scenario		
	Low	**Median**	**High**
Number of B-triples	**1994**	**3665**	**7009**
Reduction in total truck numbers	546	1,028	1,964
Reduction in vehicle-kilometres travelled (million km)	572	1,017	1,785
Reduction in road fatalities	14	25	45
Savings from reduction in road fatalities (NPV)	$36.4M	$64.8M	$114M
Reduction in CO_2 emissions (million tonnes)	0.635	1.131	1.929
Savings from reduction in CO_2 emissions (NPV)	$14.6M	$26.0M	$45.6M
Direct financial savings (NPV)	$561M	$999M	$1,750M
TOTAL SAVINGS (NPV)	**$612M**	**$1,090M**	**$1,909M**

5. CONCLUSION

This paper has outlined the implications of implementing a new policy developed by the National Transport Commission to address the lack of consistency experienced through the current state based arrangements of B-triple operations. This policy offers more flexibility than traditional prescriptive standards without compromising the safety of road users. The safety analysis performed as part of this study has proven that modular B-triples out-perform double road trains, excluding the parameter of low speed swept path width, which does not appear to be a critical issue for B-triple operations on the double road train network. The remaining results presented in this paper (impact on infrastructure and cost-benefit analysis) provide convincing evidence which validates the implementation of this policy. Between prescriptive standards and performance based standards, this policy provides an excellent illustration of the advantages offered by performance based prescriptive regulations that could be successfully implemented in Europe and the United States as a first step forward toward performance based standards.

Acknowledgments

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