THE USE OF PERFORMANCE-BASED STANDARDS FOR LONG VEHICLE CONBINATIONS
- A NEW APPROACH IN VEHICLE REGULATIONS

1. INTRODUCTION

Queensland Transport encourages and facilitates continuous improvement in the efficiency and competitiveness of the transport sector with flow-on benefit to Queensland's international competitiveness. A number of projects is being undertaken for the introduction of more productive vehicles in the transport industry. These productivity improvements, however are always balanced by safety considerations and the new combinations must demonstrate high levels of dynamic performance and safety.

Queensland is also at the forefront of reform in the road use management, particularly implementing a performance-based regulatory system for the transport industry. The introduction of higher productivity vehicles is supported by Queensland Transport provided that increased safety standards are demonstrated and achieved.

To progress these initiatives, Queensland Transport is conducting trials on new, innovative vehicles configurations such as B-triples and AB-triples. The trials are designed to

- investigate the actual on-road performance of the new combinations;
- investigate the use of performance measures rather than dimensional requirements;
- gather data on the vehicle dynamic performance that will assist development of future directions of the road transport in the national arena.

This paper highlights the initial results of vehicle trials, in particular, the B-Triple project, and considers the potential use of performance-based standards that may be suitable for regulating of new, innovative vehicle combinations.

2. CURRENT REGULATORY REGIMES IN QUEENSLAND

There are two broad classes of heavy vehicles using the Australian road system:

- General Access Vehicles, which have unrestricted road access are allowed to operate throughout the road network, or wherever they can fit.
- Restricted Access Vehicles, which include Large Combination Vehicles or road trains and Medium Combination Vehicles (mainly B-Doubles) and are subject to specific controls on dimensional limits and restrictions on routes or operating times.

Within these broad categories, there are four classes of vehicle combinations most commonly used in heavy vehicle operations. These categories are listed and differentiated in Table 1.

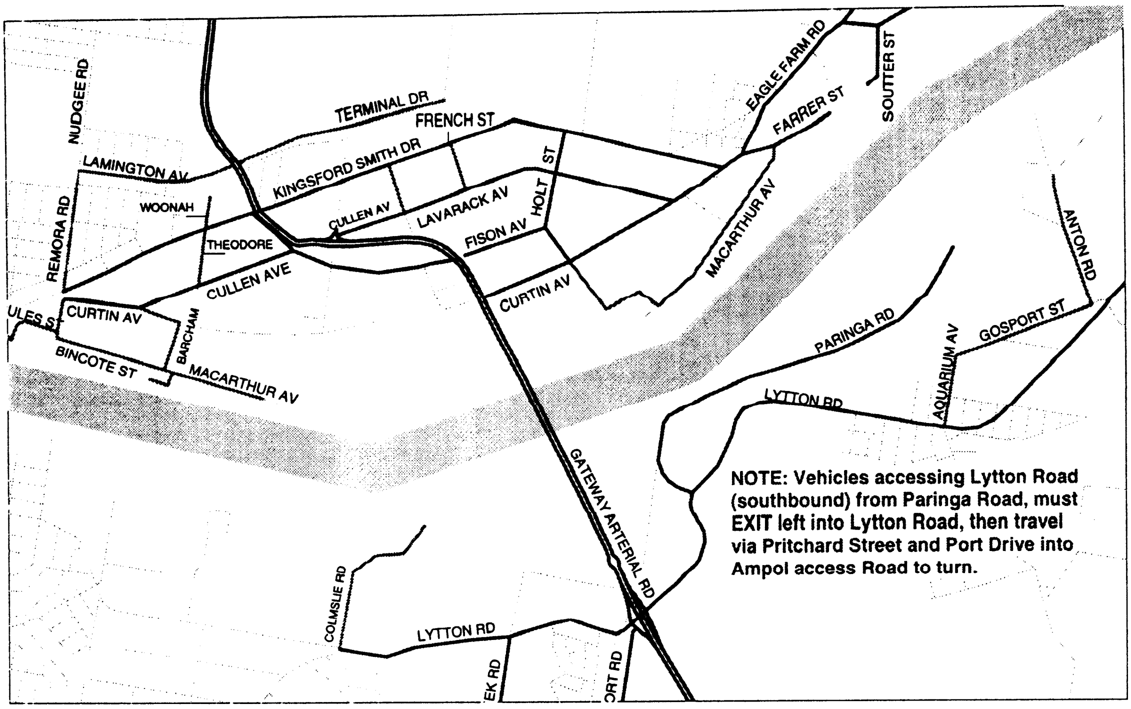
In addition, the Australian Design Rules (ADRs) cover the construction standards of all new vehicle units used in these combinations, controlling length, width, braking performance, couplings and tyres.

VEHICLE TYPE	MAXIMUM LENGTH (m)	MAXIMUM GCM (Tonnes)
General Access Vehicles	Up to 19 metres long	42.5 Tonnes
B-Doubles	Up to 25 metres long	62.5 Tonnes
Type 1 Road Trains	Up to 36.5 metres long	79 Tonnes
Type 2 Road Trains	Up to 53.5 metres long	115.5 Tonnes

Table 1. Heavy Vehicle Categories

In Queensland, B-doubles and Road Trains are allowed to operate on approved routes without specified permits. These operations are managed under a Gazettal system, in which a set of performance guidelines are issued to cover routes, vehicle dimensions, vehicle standards, speed restrictions and travel times. It also includes a route mapping system of the state showing the permitted routes. These approved Road Train and B-Double routes are based on vehicle combination length. An example of the mapping system is shown in Fig 1.

Road Trains and B-Doubles which meet performance guidelines no longer require permits to operate on Queensland's approved route system. The "As Of Right" movement for road trains came into effect on 2 Dec 1994 and for B-Doubles, operations commenced on 30 June 1995.



NOTE: Vehicles accessing Lytton Road (southbound) from Paringa Road, must EXIT left into Lytton Road, then travel via Pritchard Street and Port Drive into Ampol access Road to turn.

Fig 1. B-Double routes in Eagle Farm, Brisbane

These combinations, Road Trains and B-Doubles, grew out of economic necessity and have provided significant economic benefits to various industry groups. Road Trains have been providing affordable transport to and from remote areas, and B-doubles have established a very good safety record during the eight years they have been operating. At the present time (end of April 1996) there are

B-Doubles	516
Type 1 Road Trains	817 and
Type 2 Road Trains	609

operated under Queensland registration.

Based on the experience with these heavy vehicle combinations it has been recognised that the use of medium and large truck combinations can enhance the efficiency of freight haulage, the efficiency and safety of the road system, and reduce negative environmental effect.

2.1 Use of Performance-based standards in evaluating new vehicle combinations

In Queensland, the new approach to vehicle management is the use of performance-based standards, which are based on performance outcomes. While prescriptive standards are still necessary, industry has demonstrated compliance with performance standards.

In recent years, there has been an increased development, by government and industry consulting engineers, in computer simulation programs to predict the dynamic performance of new and innovative vehicle combinations. To evaluate the accuracy of predictions, practical on-road trials are necessary before committing large number of new vehicle types to the road network. During these vehicle trials, specific issues are identified such as:

- examination of network capacity with respect to dimensions, mass and vehicle dynamic performance,
- matching vehicles and roads for the larger heavier road train combinations by computer simulations,

- development of future "target" performance measures for vehicles and also for infrastructure planning to ensure safety operation.

2.2 Vehicle configurations

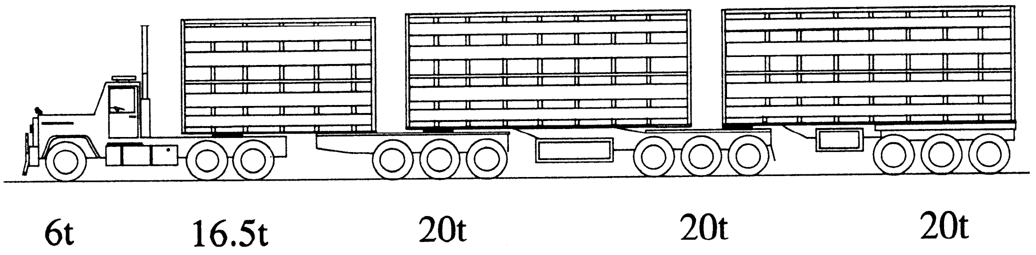
The vehicle configurations under considerations are:

- AB-Triples, consisting of a 6-axle prime-mover-semi-trailer towing an 8 or 9-axle B-Double, with Gross Combination Mass up to 102.5t and an overall length of 36.5m

- B-Triples, consisting of a prime-mover hauling three semi-trailers, with a GCM of 82.5t and overall length of 36.5m.

These configurations are illustrated in Fig 2 showing the layout and the maximum permitted axle loads.

B-Triple



AB-Triple

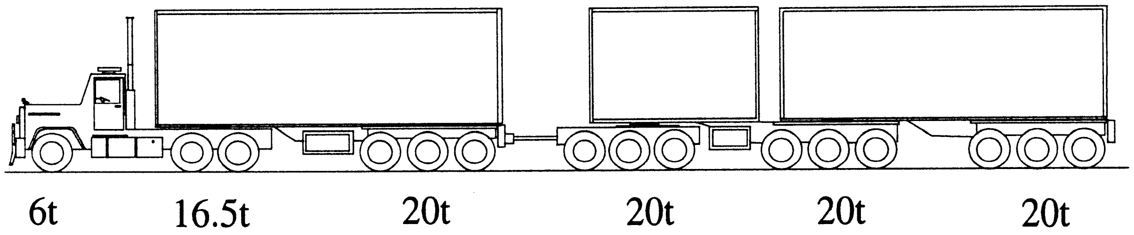


Fig 2. New vehicle configurations trialed

These new vehicle combinations may be permitted to operate outside gazetted guidelines based on the findings of the trials a permit may be used to specify operating conditions.

The performance of AB-Triples has already been examined and approved by Queensland Transport, following a detailed computer analysis, instrumentation and dynamic testing program. As they are not covered under the performance guidelines for road trains, they operate under a permit issued from Queensland Transport. There are three AB-Triple combinations on the road and they can be operated on all Road Train routes. This paper concentrates on the evaluation of the B-Triple trial vehicle combination.

3. THE B-TRIPLE TRIAL

It has been widely recognised by the transport industry that the B-Triple concept would result in a better performing combination than many current road trains. The B-Triple combination is shown in Fig 2. In general terms, the B-Triple has good stability, efficient load carrying capacity for a given length, and the use of triaxle groups on the trailers is more productive and induces less road wear than tandem axle groups.

A number of requests had been received from industry to operate B-Triples in Queensland. Expressions of interest to take part in the B-triple trial were called by Queensland Transport in November 1995 and eight transport operators have expressed interest in using B-Triple combinations to transport to Brisbane and different regions of Queensland.

Minimum combination standards have been set up for the B-Triples:

- the maximum Gross Combination Mass permitted is 82.5 tonnes;
- the maximum permitted length of the combination is 36.5 metres;
- the maximum speed of the B-Triple combination is limited to 100km/h;
- Antilock Braking System (ABS) is required on the prime movers of all combinations, and on trailers transporting bulk dangerous goods.

Discussions have commenced with local councils, Police, industry representatives, manufacturers and officers of Queensland Transport on the proposed operations. The trial will also be monitored by the group.

The applications are evaluated by Queensland Transport based on the computer simulation of the proposed combinations, performance standards, and considering heavy vehicle dynamics and safety. The safety issues are addressed through:

- dynamic performance characteristics of the combinations;
- road characteristics where the combinations operate;
- impact on other road users and
- environmental impact of the proposed B-Triple operations.

Based on the outcomes of the evaluation process, four B-triples will be selected to take part in the trial which will run for 15 months.

4. ASSESSMENT OF PERFORMANCE OF THE B-TRIPLE CONFIGURATIONS

4.1 Computer simulation

The dynamic performance of the proposed B-Triples was assessed in a similar manner to the analysis carried out in a report prepared for the National Road Transport Commission (1). The simulations in the B-Triple trial are carried out using the following software packages:

- University of Michigan Transport Research Institute (UMTRI) Simplified Models,
- YAW/ROLL program and
- AUTOSIM B-Triple model, which was provided by RoadUser Research for evaluation purposes.

Additionally, the V/PATH program was used to evaluate low speed offtracking and the AUTOMAN3 package to evaluate intersection clearance times.

4.2 Performance characteristics

The following safety-related dynamic performance characteristics of the B-Triple combinations were analysed:

- Steady-State Rollover
- Rearward Amplification
- Load Transfer Ratio
- High-Speed Offtracking
- Low-Speed Offtracking.

STEADY-STATE ROLLOVER

Steady-state rollover performance is expressed in terms of the lateral acceleration required to produce rollover of the combination of the vehicle travelling at constant speed in a steady turn, and is expressed as a proportion of gravitational acceleration (g). The rollover limit is reached when the load on all wheels on the inside of the turn reduces to zero.

REARWARD AMPLIFICATION

Rearward amplification is a frequency-dependent measure, defined as the ratio of the peak value of lateral acceleration achieved at the centre of gravity of the rearmost unit to that developed at the hauling unit in a dynamic manoeuvre of a particular frequency. Rearward amplification expresses the tendency of the vehicle combination to develop higher lateral accelerations in the rear unit when undergoing avoidance manoeuvres.

LOAD TRANSFER RATIO

The load transfer ratio is defined as the ratio of the absolute value of difference between the sum of the right wheel loads and the sum of the left wheel loads, to the sum of all wheel loads - when the vehicle is in an evasive manoeuvre. When the load transfer ratio reaches a value of 1, rollover occurs.

HIGH-SPEED OFFTRACKING

High-speed offtracking is defined as the degree to which the rear unit of a combination vehicle tracks outboard of the hauling unit in high-speed turns of moderate severity. The high-speed offtracking measure is obtained when the vehicle is operated in a shallow turn of radius 318 metres at a speed of 90 km/h, attaining a lateral acceleration level of 0.2g.

LOW-SPEED OFFTRACKING

Low-speed offtracking is defined as offtracking of the rearmost axle with respect to the path of the steering axle. Low-speed offtracking is evaluated using a set of low-speed turning specifications produced by AUSTROADS.

4.3 Performance requirements

Performance requirements have also been developed considering the current performance of the Australian fleet, best practice in Australia and overseas and future performance targets. The performance characteristics and the performance requirements are shown in Table 2.

Performance characteristics	Requirements
Roll Stability	> 0.35 (g)
Load Transfer Ratio	< 0.6
Rearward Amplification	< 2.0
High-speed Offtracking	< 0.5 m
Low-speed Offtracking	AUSTROADS turning templates

Table 2. Performance requirements

Field testing of each combination will be required to validate the computer simulations and to allow valid judgements to be made on what the results of the computer simulations mean when related to real world situations.

5. MATCHING A DESIGN TO THE CURRENT ROAD SYSTEM

5.1 Low-speed offtracking

The low-speed offtracking performance of multicombination vehicles affects the road space requirements at intersections and also manoeuvrability and tendency for encroachment in other traffic lanes. For operations outside of the current road train areas, the routes need to be assessed for their suitability to accommodate B-Triples. Structural and geometric adequacy of the routes must be assessed for their suitability to cater for heavy vehicles.

In order to verify the computer model for low-speed offtracking, field tests were carried out with the B-Triple combination. The offtracking performance was assessed and evaluated in accordance with the current AUSTROADS swept path envelopes for Road Train areas and Major Arterial Roads. In these templates, a left-hand turn was chosen as it is the most difficult to negotiate with a large vehicle. The results of the computer simulations are shown in Fig 3 and Fig 4.

The figures show that this B-Triple would easily comply with the AUSTROADS swept path template for road trains and its turning performance is comparable with B-Doubles.

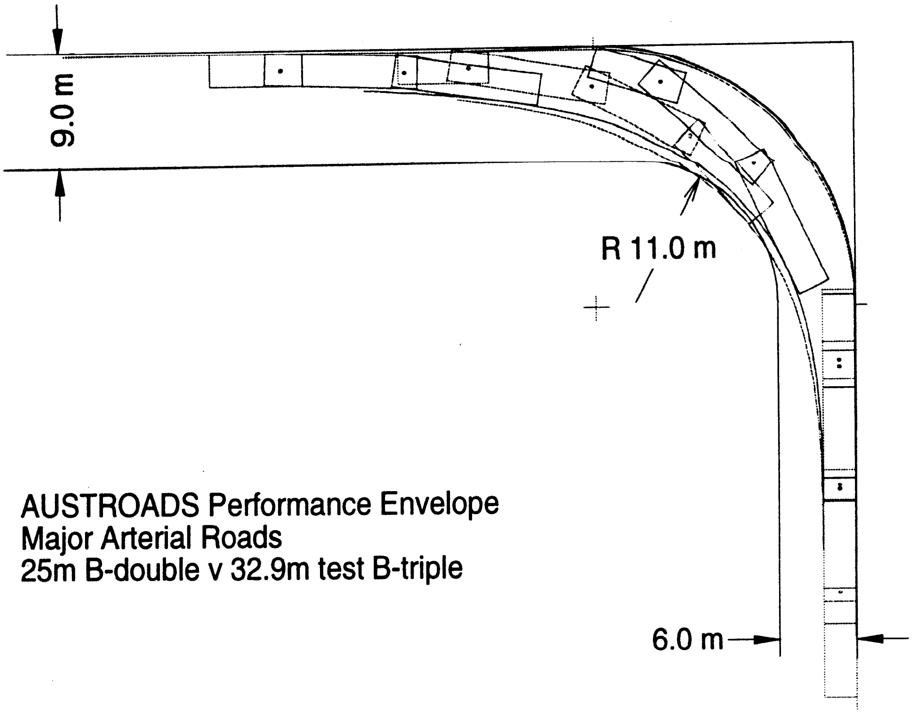


Fig 3. Low-speed offtracking result of 25m B-Double versus 32.9m B-Triple

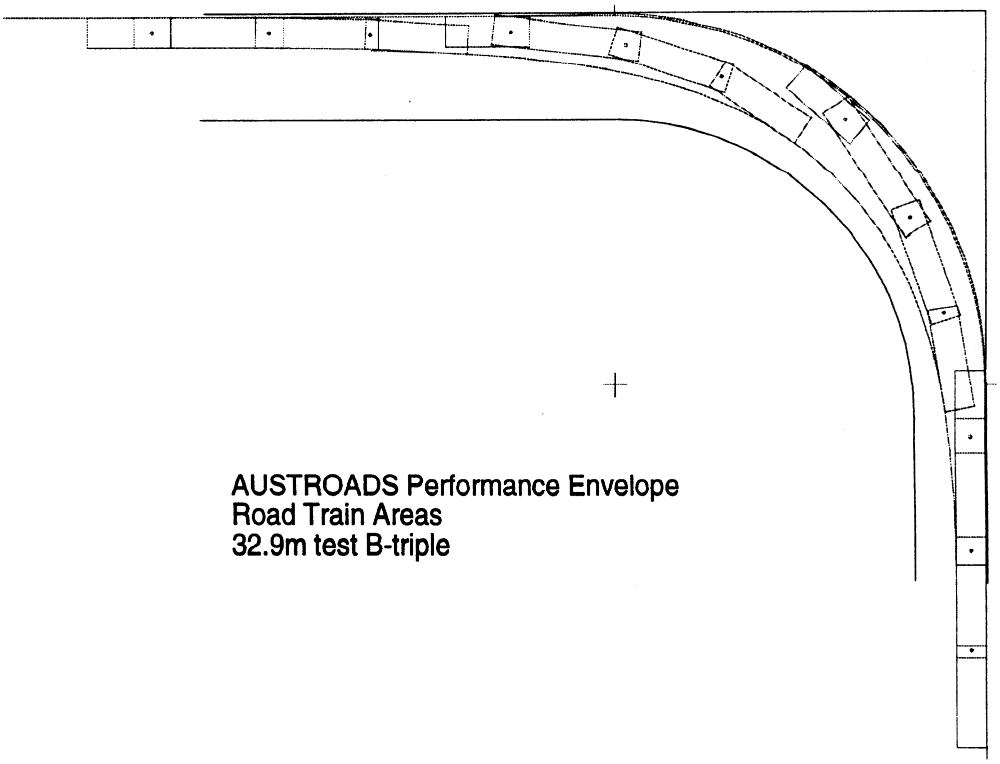


Fig 4. Low-speed offtracking of a test B-Triple (road train envelope)

5.2 Assessment of the operating performance of a test B-triple

According to the Australian Design Rules ADR (44) the vehicle must have sufficient hauling capacity to safely draw the maximum load proposed. As a part of the evaluation process, several test runs have been conducted with test B-Triples. During these runs, the performance of the test B-Triples on the road was monitored and recorded. Route specific analysis and computer simulation have been carried out to consider the following performance attributes of the test B-Triple:

- gradability
- minimum and average speed
- starting capability on grade
- trip time
- fuel consumption.

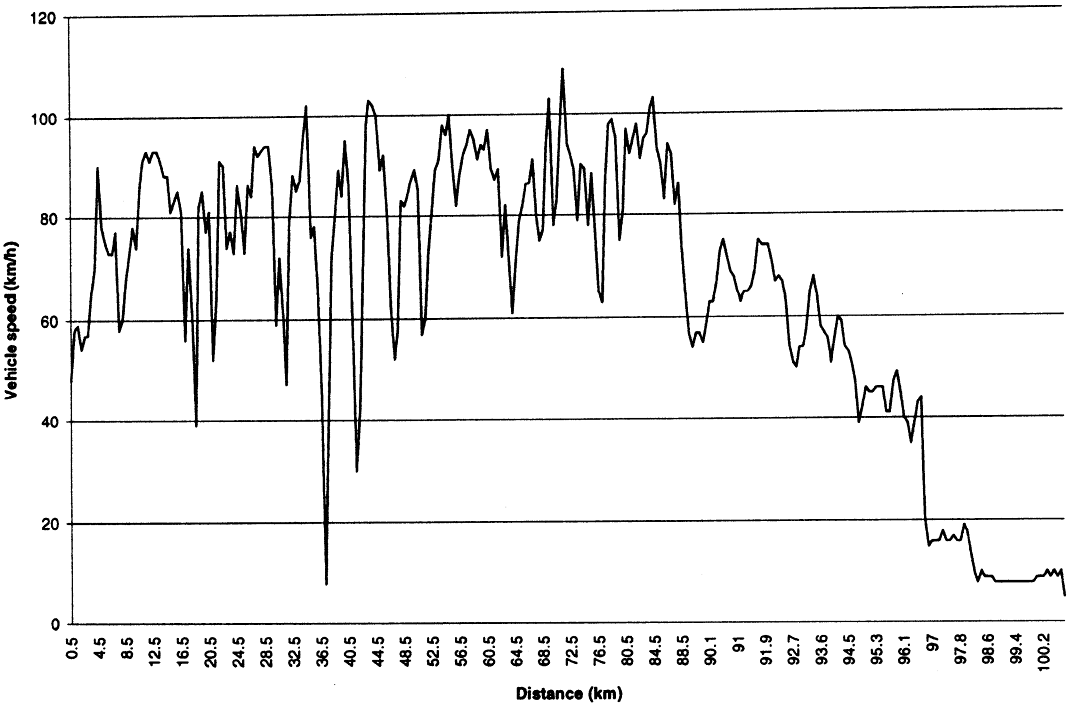


Fig 5. Speed performance of the test B-Triple (Brisbane-Toowoomba)

As several operators requested the Toowoomba - Brisbane route to be included in the B-Triple trial, the performance of the test B-Triple on this road section was more carefully observed, modelled and analysed. The distance of this leg was 100.7 km and the trip time was 1.35 hrs. This represents an average speed of 74 km/h for the whole trip.

Figure 5 shows the recorded speed of the test B-Triple for the entire Toowoomba-Brisbane section of the test run. The effects of an increasing vertical slope can be seen in Fig 6 that resulted a significant drop in the vehicle speed on the Toowoomba Range.

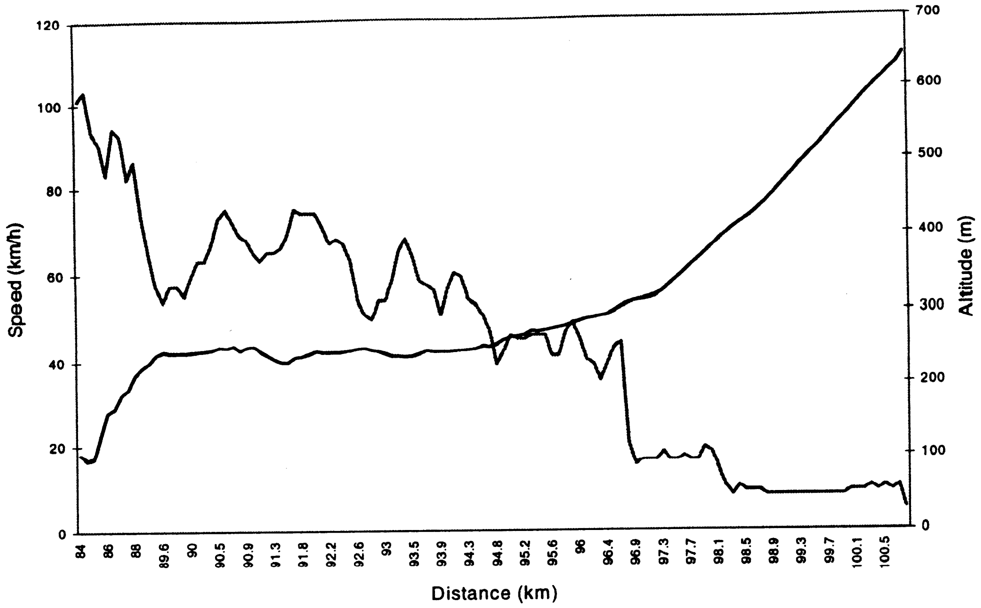


Fig 6. Effects of terrain on vehicle speed performance

6. INITIAL FINDINGS OF THE STUDY

6.1 Rollover Stability

Fig 7 provides an overview of roll stability for different vehicle configurations and also shows the current range of the roll stability performance of B-Double and Type 1 Road Trains. It can be seen that B-Triples generally have superior roll stability and are less sensitive to rollover than other configurations. In the B-Triple design the roll-coupled length is maximised which increases the dynamic stability.

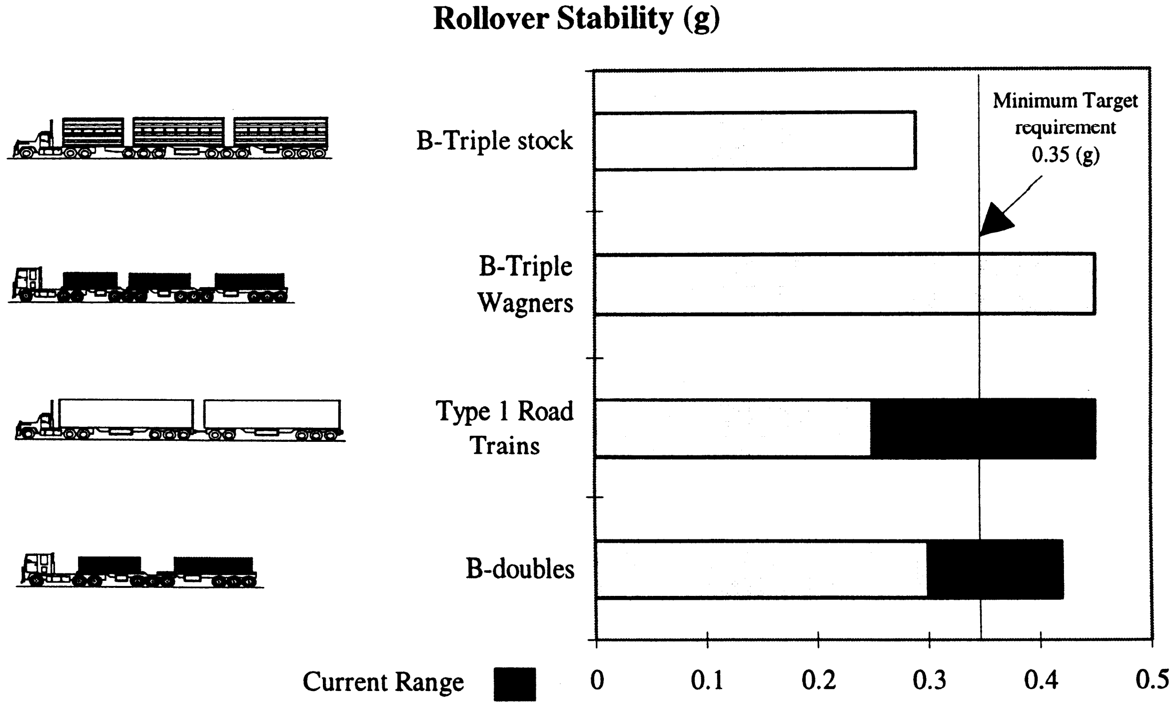


Fig 7. Roll Threshold of vehicle configurations

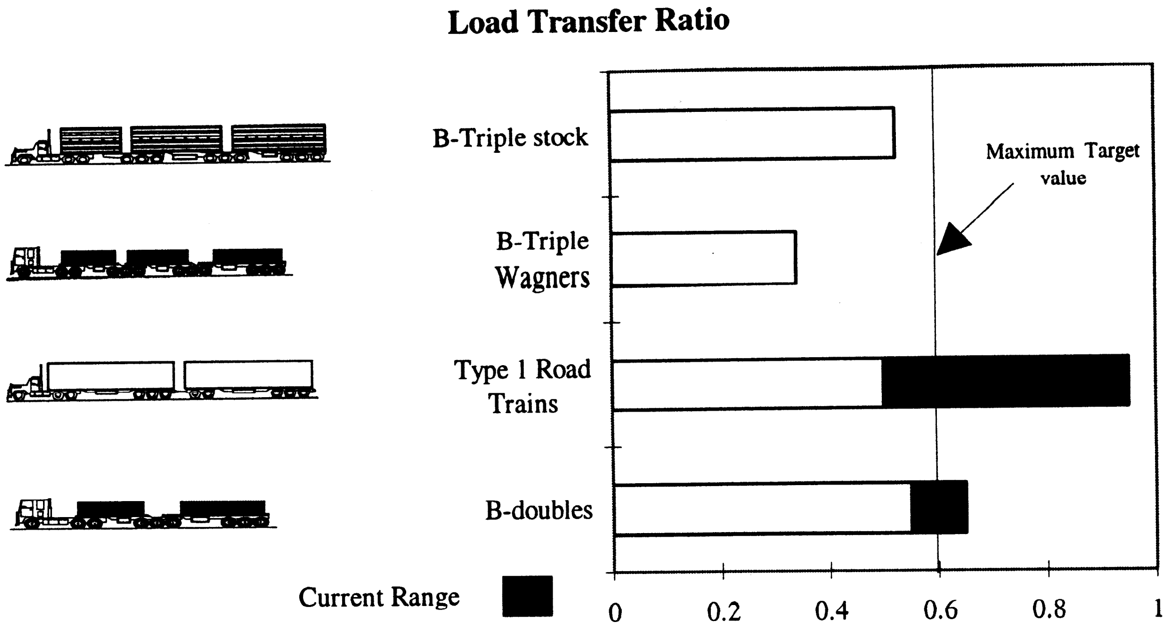


Fig 8. Load Transfer Ratio of vehicle configurations

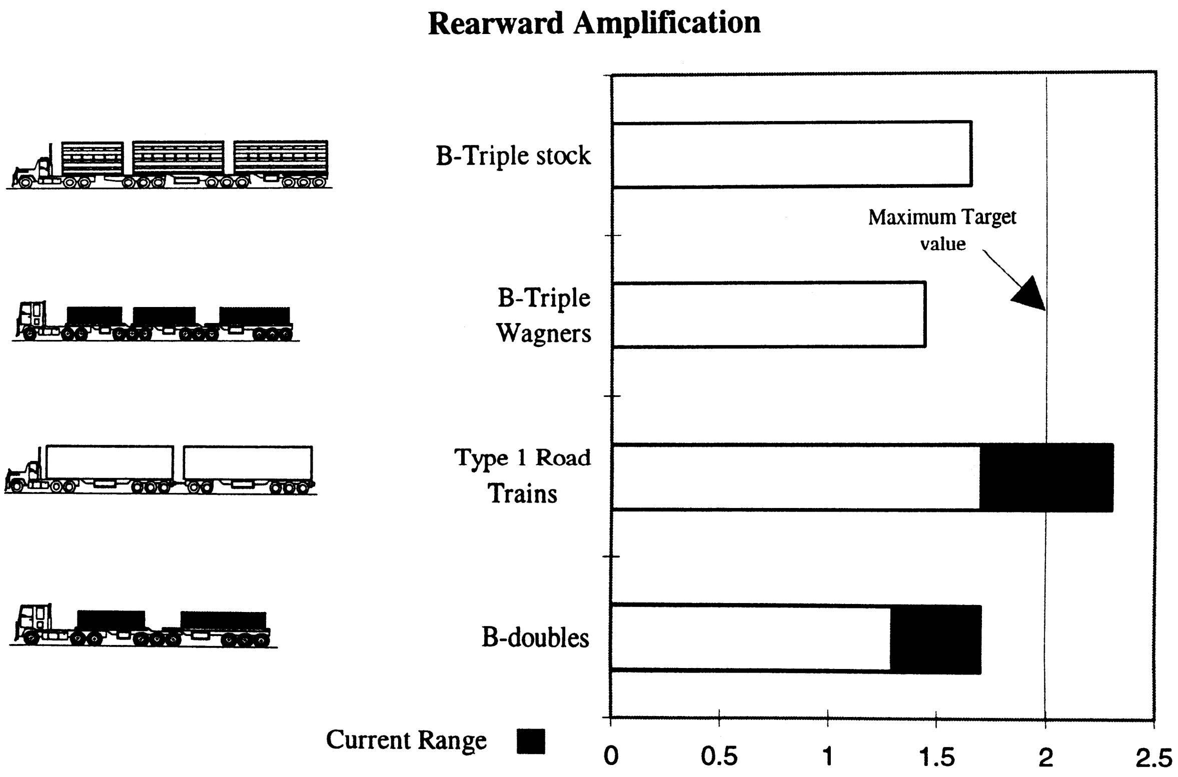


Fig 9. Rearward Amplification of vehicle configurations

6.2 Load Transfer Ratio

The results in Fig 8 show that the dynamic stability of the B-Triple is much better than most current Type 1 Road Trains.

6.3 Rearward Amplification

Rearward amplification is a useful performance measure for quantifying obstacle-avoidance capability. The rearward amplification of B-Triples is simulated at a speed of 90 km/h as has been proposed by the Society of Automotive

Engineers USA (SAE) (1993) (2). The lateral displacement to be used in testing will be 1.8 m. The computer results in Fig 9 show that the dynamic stability of the B-Triple is also much better than most current Type 1 Road Trains.

7. OPERATIONAL ECONOMICS

The economics of the majority of regional districts in Australia and particularly in Queensland are dependant on primary production. Road freight transport is a very important input into many of Queensland's major industries, including mining, agriculture, manufacturing and trade. It is also expected that the demand for road freight transport is going to increase in line with economic and population growth. The expectation of road freight transport operators are for solid rates of growth of 5-6% for the 5 years (3). Increased local, intrastate and interstate freight movements are expected, particularly for wholesale and agricultural produce.

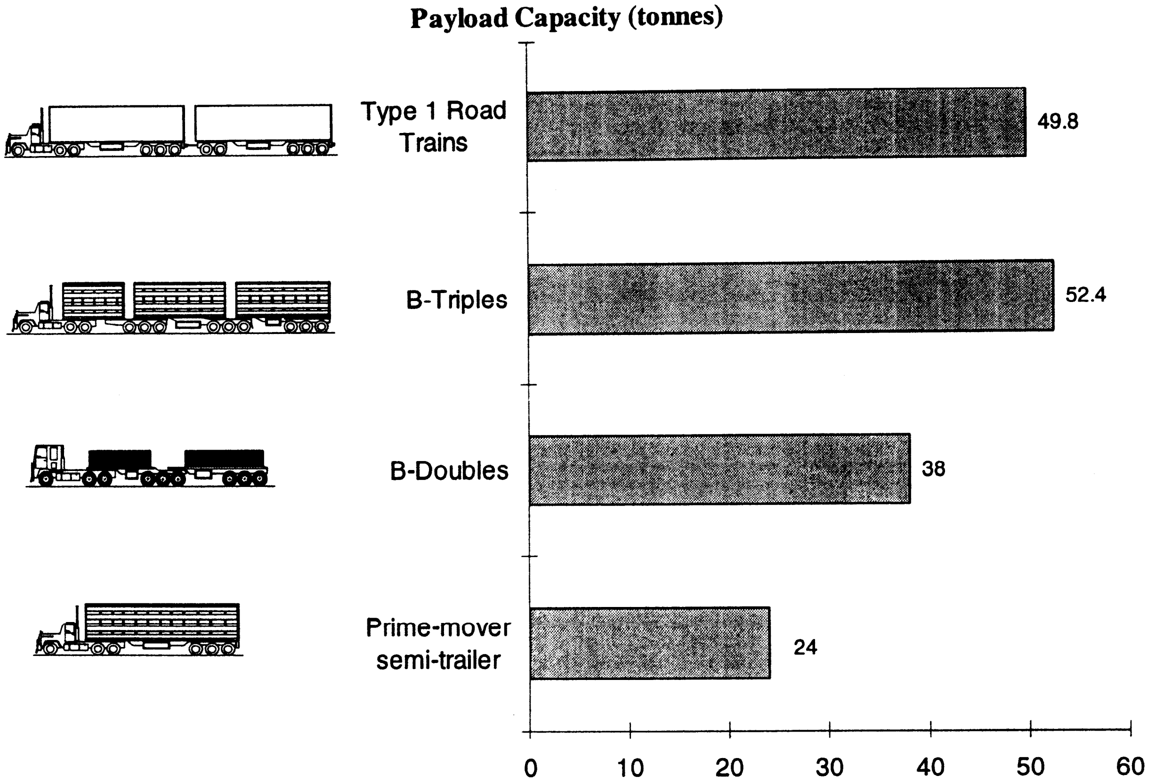


Fig 10. Load capacity of vehicle configurations

7.1 Payload

Productivity is strongly related to the payload which heavy vehicles are able to carry. The importance of new innovative vehicle combinations and their higher efficiency therefore offers the potential to lower freight costs to the benefit of producers and regional economies. It is estimated, that on a per vehicle basis B-doubles and Road Trains undertake between 2 and 6 times as many tonne kilometres per year as semi-trailers or rigid vehicles. The main reason for this is because road trains and B-doubles are predominantly long haul vehicles carrying significantly larger loads on a per vehicle basis. Fig 10 illustrates the payload capacity of different configurations. An increase in the productivity of the haul vehicles would lead to a direct benefit to the community and a reduction in the number of vehicles on the road, and the number of trips required for the freight task.

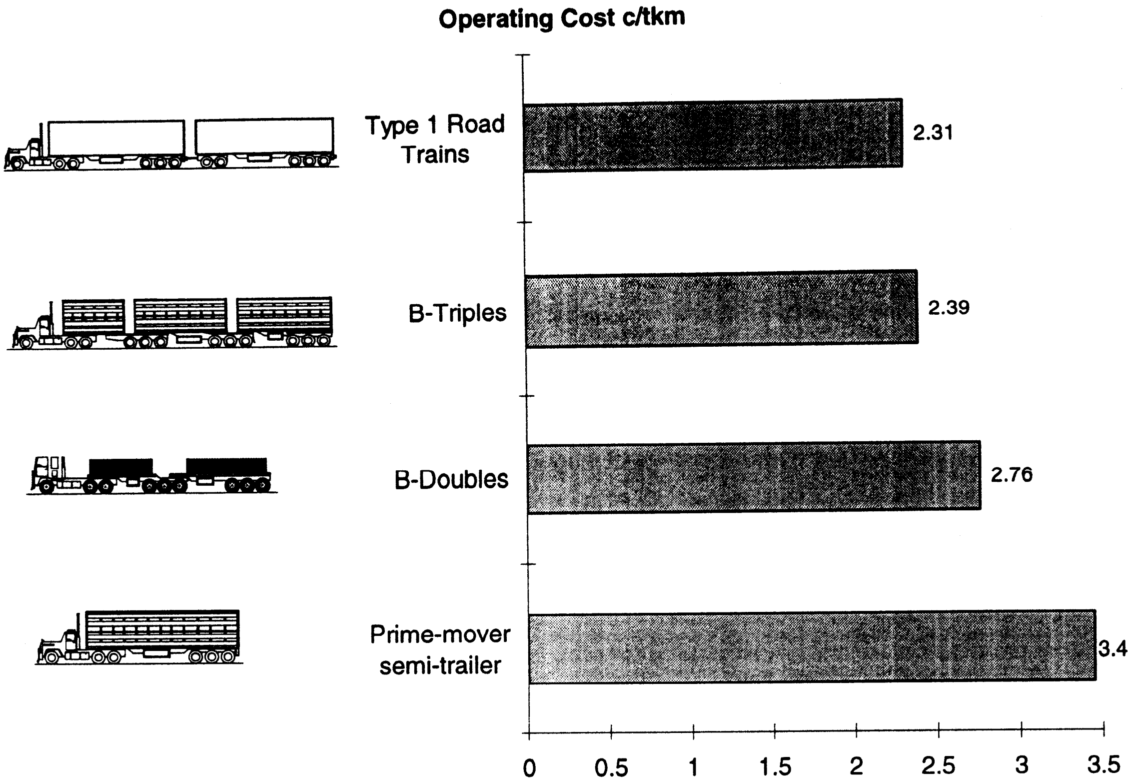


Fig 11. Operating cost of vehicle configurations

7.2 Operating cost

The possible future of the freight industry has been surveyed within transport operators (3). The study found that more than 30% of the responses suggested that there is a need to provide more B-double and Road-train routes and a greater access to the road network would make the businesses more effective. In the study it was also suggested that converting to a road train would reduce the operating costs by 50%. The comparison of operating cost of various configurations is shown in Fig 11.

The calculation considers fuel, labour, tyres, capital cost of equipment, repair and maintenance cost. Due to the additional axle and the different design, an increase in capital cost could be expected to occur. In particular the cost of tyres, fuel and maintenance will likely to be increased. This will be monitored during the trial.

The cost per tonne freight moved in a Type 1 road train configuration is slightly lower than a B-Triple. However, if the transport operators are able to operate B-Triple configurations outside of road train areas, then the B-Triple configuration is more effective and could maximise utilisation of trailers.

8. SAFETY AND TRAFFIC FACTORS

Additional to the dynamic performance of the combination other factors will be assessed such as:

- effect on other road users
- bridge effects
- road and pavement wear.

Using the AUTOMAN3 software, the starting performance of the test B-Triple was modelled, analysed and compared with other vehicle combinations. In the model, the vehicles are assumed to accelerate at maximum throttle, or a throttle setting that produces a tractive effort at the driving wheels limited by the coefficient of friction between the road surface and tyres.

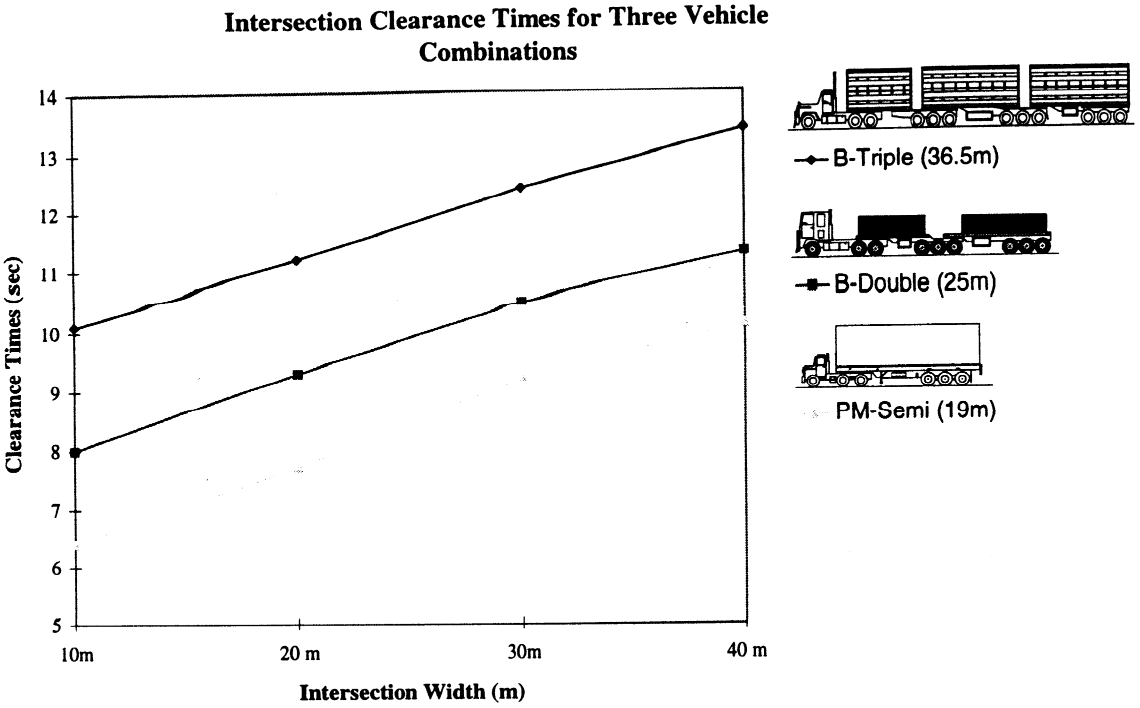


Fig 12. Intersection clearance times of vehicle configurations

The program calculates a tractive effort, and it also estimates the maximum achievable speed, the average speed, average fuel consumption and number of gear changes for a selected road section. The model included the following relevant vehicle characteristics:

- engine data (torque, fuel consumption, rpm limits)
- transmission data (number and ratio of forward gears)
- vehicle mass, load on drive axles
- tyre data (rolling radius, rolling resistance, type)
- aerodynamic properties (frontal area, aerodynamic drag factor)
- drive-line efficiency
- road data.

For the simulations representative engines and transmissions were selected for each combination, e.g. 370 hp engine for the 19 m combination, 460 hp for the B-Double and 525 hp for the B-Triple. The simulations showed that the intersection clearance times were sensitive to these parameters. The results are summarised in Figure 12.

9. SUMMARY

Freight efficient vehicles, B-Doubles, Road Trains and innovative vehicle configurations such as B-Triples in particular, play an important role in the economic development of Queensland and would provide significant productivity and safety benefits to the industry and the community.

Queensland Transport wants to encourage the transport industry to consider improving operations using safer vehicle combinations. New, innovative combination such as B-Triples and AB-Triples are considered desirable to investigate and assess.

For the four B-Triples to be operated under the 12-month trial, the initial computer simulations and field test runs have shown, that the B-Triples have excellent dynamic performance characteristics.

The B-Triple trial will be reviewed and monitored, and extensive consultation will be undertaken to gain public acceptance of the proposed operations.

An important outcome of these trials will be to establish a performance-based philosophy for managing road use. The information and experience gained in this trial will provide a basis for comprehensive route assessment of restricted access vehicles and may result in increased access to the road infrastructure by balancing increased productivity with safety and infrastructure protection.

The success of this project would encourage the trialing of other different configurations if they could be expected to improve transport efficiency.

More diverse fleets could be designed and operated in order to service individual needs and the performance-based standards would assist the development, operation and regulation of more productive vehicle configurations in Australia.

10. REFERENCES

(1) Overview of Dynamic Performance of the Australian Heavy Vehicle Fleet - Technical Working Paper No. 7, by Dr P F Sweatman of RoadUser Research.
(2) A Test for Evaluating the Rearward Amplification of Multi-Articulated Vehicles, SAE J2179 draft 2/27/92.
(3) Queensland Road Freight Industry Study, Symonds Travers Morgan Pty Ltd (1996)

11. ACKNOWLEDGEMENTS

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Les Bruzsa
A/Principal Engineer (Vehicle Standards)

James Hurnall
A/Principal Advisor (Vehicle Operation and Management)