B-TRAIN TRACTOR WHEELBASE LENGTH—WHAT SHOULD IT BE?

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ABSTRACT

B-trains have been operating in Australia since the early 1980s, but they are called B-doubles in Australia. The length limits for B-doubles do not regulate trailer (or box) length, only overall length. This paper reports on an investigation to assess claims by the transport industry that regulations of this type favour the use of short wheelbase prime movers and lead to a range of design and operational problems.

The review of B-double length was undertaken in a performance based assessment framework. For the project, which relates to prime mover wheelbase issues and overall length, the performance measures selected for consideration were:

- ride quality
- vehicle handling quality
- load transfer ratio (dynamic stability)
- rearward amplification
- high speed offtracking
- low speed offtracking
- overtaking time
- intersection clearance time

Some of the work on vehicle dynamics used in the project was undertaken in Canada in the early 1990s. However, four full-vehicle computer models of B-doubles were created for evaluating ride quality. Each model featured a combined seat and driver model. Simulations were performed that required each B-double to travel at 100 km/h along a 3-dimensional uneven road surface.
1. INTRODUCTION

1.1 Background

The B-train concept originated in Canada in the 1970s and was introduced into Australia during the 1980s where it became known as a B-double. The maximum allowable length of 23 metres adopted in Australia was the same as was permitted in Canada at that time. No separate internal dimension limits were introduced except for minimum axle spacing requirements.

In 1994, 25 metre B-doubles were permitted because of:

⇒ interest in improving productivity using triaxles on both trailers, a configuration which until then had been prohibited;
⇒ the need to increase length to accommodate the 62.5 tonnes of tri-tri B-doubles under a revised axle spacing mass schedule proposed by Austroads; and
⇒ to allow the use of bonneted prime movers.

It was expected that the 2 metre length increase would result in the use of 32 pallet trailers (an additional 1.2 metres) and the other 0.8 metres would be used to accommodate longer wheelbase prime movers. Because trailer (or box) length is not regulated, the result was that 34 pallet trailers became common and industry chose to reduce the prime mover wheelbase by 0.4 metres for B-doubles to accommodate 34 pallet trailers. Dimensions of a typical 34 pallet Australian B-double are given in Figure 1.

More recently B-doubles with a 36 pallet capacity have been constructed with an even shorter wheelbase prime mover and shorter cabin.

Concerns had long been expressed that current regulations, which generally control overall length only, favour the use of short wheelbase prime movers and lead to a range of design and operational problems. In particular, it was claimed by sections of industry that:

• short wheelbase prime movers may compromise the handling and dynamic stability of B-doubles; and
• poor ride with short wheelbase prime movers with set forward steer axle and short springs lead to greater driver fatigue and back injuries.

A review of the length limits of B-doubles was instigated to examine these concerns. Other issues raised during initial consultation included:

• there was a possibility of the trailers steering the prime mover;
• driver safety may be greater in a cab over engine (COE) prime mover because he is positioned above the engine rather than behind it; and
• there is a lack of effective enforcement of current requirements.

A range of other operational problems including lack of fuel tank capacity were also raised.
1.2 Present Australian Regulations

The legislated dimension limits are illustrated in Figure 2. These limits apply throughout Australia (apart from Western Australia which allow up to 27.5 metres with some conditions). In addition, the axle spacing mass schedule acts as a de-facto set of dimension limits as it affects the positioning of axle groups. It should be noted, however, that there is some evidence that a significant number of B-doubles exceed the allowable length.

1.3 Performance Based Assessments

The review of B-double length was undertaken in a performance based assessment framework. For this project, which relates to prime mover wheelbase issues and overall length, the performance measures selected for consideration were:

- ride quality
- load transfer ratio (dynamic stability)
- high speed offtracking
- overtaking time
- vehicle handling quality
- rearward amplification
- low speed offtracking
- intersection clearance time

ARRB undertook original research into the ride quality issues and that research is the main focus of this paper. Other PBS assessments were taken from previous research apart from low speed offtracking.

2. RIDE QUALITY EVALUATION

2.1 Computer Models

Four full-vehicle computer models of B-doubles were created using the ADAMS multi-body dynamics simulation software package (Mechanical Dynamics Inc., 1999). The models are based on those created and validated in previous work undertaken by ARRB TR (Prem et al, 1999a; Prem et al, 1999b). The models include a combined seat and driver model. Key dimensions for the baseline B-double are shown in Figure 3. This vehicle has an overall length of 24.7m and features a short wheelbase (3.8m) prime mover. A second version of the model was also created that features a 4.8m wheelbase prime mover giving an overall vehicle length of 25.7m.

A baseline B-double and three variants were considered in the ride study, comprising two wheel-bases for the prime mover, two separate values for steer axle spring stiffness and two separate seat locations. Long soft springs with characteristics typical of those normally found on bonneted prime movers were used on the baseline vehicle and Variants #2 and #3, and a short stiff spring designed to fit within the space restrictions of the shorter COE prime movers was used on Variant #1. A seat was located directly over the steer axle for simulations involving the COE prime mover configurations (Baseline, Variants #1 and #2), whereas for the bonneted prime movers the seat was located some distance aft of the steer axle and slightly lower (Variant #3) than for the COE configurations. The combinations of
seat location, prime mover wheelbase and steer axle spring stiffness are summarised in Table 1.

For the simulations the trailers were loaded to their maximum legal limits at maximum volume by assuming a uniform density payload, a payload box 2.5m wide and an overall trailer height of 4.3m. All axle loads and group loads were at their respective maximum legal limits of 6t on the steer, 16.5t on the tandem drive group, and 20t on each tri-axle group. Trailer dimensions and other trailer parameters (masses, suspensions, etc) were not varied from the baseline for all the ride simulations.

Parameters for the combined seat and driver model were taken directly from Prem et al (1998). A travel speed of 100km/h was chosen for all the ride simulations and the 3-dimensional surface (road file) corresponding to Test Section B created in the study described in Prem et al (1999a) was used in the work. Test Section B is 1000m long and its outer and inner wheelpath unevenness, expressed in IRI, is 4.36 and 3.85m/km, respectively. This unevenness level corresponds to a NAASRA roughness of about 110 counts/km, a moderately rough road.

2.2 Simulations and Analysis of Ride Quality

Simulations were performed that required each B-double computer model to travel at 100 km/h along the 3-dimensional uneven road surface. At the conclusion of each simulation the vertical acceleration of the reference point on the seat (seat-to-buttocks interface) was taken and the frequency weighting described in BS 6841 was applied. The root mean square (rms) of the frequency weighted vertical acceleration was calculated for each run. On this basis a single number was determined from each run, that is a measure of ride quality, for each vehicle and the corresponding test conditions considered.

The International Standard ISO 2631 is the most widely used and accepted whole-body vibration standard. The frequency weighting for vertical vibration defined in BS 6841 are similar overall to ISO 2631. However, BS 6841 decreases the importance of frequencies between 0.9 and 4 Hz and increases the importance of frequencies below 1 Hz and above 8 Hz. Long wavelength road unevenness is considered a key factor in truck ride and is more likely to be emphasised by the frequency weighting proposed in BS 6841. Therefore, the vibration acceleration frequency weighting defined in BS 6841 is considered more appropriate for evaluation of heavy vehicle ride, and a performance measure for ride quality based on this standard has been adopted in this study.

It is important to note that ride quality estimates from the simulations may not correspond to actual values taken on any particular real vehicle because the computer models are generic and because of other issues including:

- tyre size, pressure, construction and brand;
- shock absorber damping rate and condition;
- seat type and setting and spring damping rates;
- 5th wheel setting (fore-aft and height);
- trailer specifications (tyres, suspension, etc).

- front suspension geometry;
- cab suspension (type, damping rates etc)
- 5th wheel type (fixed/ballrace);
- trailer type (i.e. tanker, flat top); and

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In addition, the computer models are robust but no data has been collected to validate the models against actual ride measurements on B-doubles under Australian conditions. This was considered to be beyond the scope of this study but would be necessary to undertake in the future if ride quality is to become a performance standard. Therefore, greater emphasis should be placed on the relative comparisons, and where the simulations predict a decrease or increase in ride vibrations with prime mover wheelbase, for example, the same trend should occur in practice.

1.3 Results and discussion

The results from the ride simulations are summarised in Table 2, which shows the following measures of ride quality:

- unweighted rms vertical acceleration;
- frequency weighted rms vertical acceleration - determined by applying the frequency weighting given in British Standard BS6841, and scaled so the value for the baseline vehicle is consistent with subjective ratings of ride provided by industry. The process of frequency weighting retains vibrations that occur at frequencies that humans are sensitive to and lessens the intensity of vibrations at other frequencies;
- frequency weighted rms vertical acceleration expressed as a percentage of the value for the baseline vehicle.

Table 2 shows that when compared to the baseline B-double an increase in steer axle spring stiffness of 250% will produce an increase in ride vibrations of 27%. That is, a suspension change on the steer axle from a long soft spring to a short stiff spring would be enough to degrade ride quality by almost 30%.

The effect of wheelbase is somewhat less dramatic but still significant. When compared to the baseline B-double, an increase in wheelbase from 3.8m to 4.8m reduces ride vibrations by almost 10%. The effect of seat location on ride quality for the long wheelbase prime mover with the soft steer axle suspension is small. In other words, no difference was found between a COE and a conventional bonneted prime mover.

3. OTHER PERFORMANCE BASED ASSESSMENTS

Details on the other performance measures have been examined in a range of publications, and the data in this paper were obtained from:

- Canadian research undertaken by El-Gindy and Woodroffe in the early 1990s;
- a report to the South Australian Road Transport Association (Blanksby et al 1998); and
- an assessment in Queensland (Bruzsa and Hurnall, 1999).

3.1 Vehicle Handling Quality

The draft report on the Field of Performance Measures (NRTC 1999a) defines handling quality as the ratio of the response to steering (change of vehicle direction) to the steering wheel input and its dependence on vehicle speed and severity of manoeuvre. The prime
mover wheelbase and the king pin lead of the front trailer are the primary aspects of dimensions impacting on B-double handling quality.

Canadian analyses of handling quality were undertaken on a 23 metre B-double with a 20 metre box length and Canadian mass limits (El-Gindy and Woodrooffe 1990). As the aspects of the handling quality of interest are prime mover wheelbase and fifth wheel lead, the conclusions of the analyses would be expected to be broadly applicable to Australian conditions. The prime mover wheelbases tested were 3.76 metres, 4.83 metres and 5.67 metres.

The conclusions of the Canadian research were that:

- prime mover wheelbase variations have a first order effect on the handling of a B-double;
- increasing the wheelbase improves the general handling of the vehicle;
- the sensitivity of handling response increases as the wheelbase diminishes, particularly in the range of 4.83 metres to 3.76 metres (the lowest in the simulations); and
- a wheelbase in the range of 4.4 metres to 5.07 metres produces acceptable vehicle dynamic performance.

Blanksby et al (1998) reported these results from an earlier publication (Woodrooffe and El-Gindy 1990) but then stated:

A similar handling analysis . . has verified these findings for Australian B-doubles. However, we conclude that an acceptable range for prime mover wheelbase is 3.8 m to 5.3 m.

Unfortunately the report did not provide the details of that similar handling analysis, or explain the reasons for the variation from the earlier Canadian work in regard to the acceptable range of prime mover wheelbase.

3.2 Load transfer ratio and rearward amplification

Load transfer ratio (LTR) is defined in NRTC 1999a as the proportion of load on one side of a vehicle unit transferred to the other side of the vehicle unit in a transient (evasive) manoeuvre. Where the LTR reaches a value of one, rollover is about to occur. Rearward amplification (RA) is the lateral movement of the rear trailer relative to the hauling unit in a transient (evasive) manoeuvre. The effects of the prime mover wheelbase on LTR and RA are of prime interest. For both LTR and RA, other factors also influence the outcome, including centre of gravity height (COG), axle group loads, coupling types and suspensions. However, these latter factors are not considered in this project.

Work by El-Gindy and Woodrooffe (1990) showed that LTR increases with decreasing wheelbase. In other words, a shorter wheelbase produces a less desirable LTR, and approaches an LTR value of 0.6. Most international researchers and recent work for Austroads (Prem et al 1999b) have suggested the LTR should be 0.6 maximum.
Woodrooffe and El-Gindy (1990) showed that LTR is not significantly affected by fifth wheel location. They also showed that prime mover wheelbase has no significant influence on RA and in all cases the level is below the generally accepted standard upper limit of 2.0 for RA. The variation in LTR and RA for fifth wheel lead, rear trailer overhang, trailer fifth wheel lead and front trailer wheelbase are also insignificant (Blanksby et al 1998).

3.3 High speed transient offtracking

High speed transient offtracking is the tendency of the rear trailer to track outboard in a sudden manoeuvre.

Blanksby et al (1998) concluded:

In terms of high speed offtracking, B-doubles generally perform very well. The effect of changes to dimensions is therefore likely to be small.

This conclusion agrees with the conclusion of Bruzsa and Hurnall (1999). Neither report, however, details the values of high speed offtracking used to reach their conclusion.

3.4 Low speed offtracking

Low speed offtracking is the additional road space occupied by a vehicle in a turn at low speed.

As noted by Bruzsa and Hurnall (1999) the low speed tracking of a combination depends on:

- the steering actions of the driver;
- coupling arrangements;
- vehicle length;
- speed; and
- tyre, suspension and road characteristics.

The influences on low speed offtracking are:

- primary influence - trailer ‘S’ dimensions, front trailer fifth wheel lead and prime mover front overhang;
- secondary influences - prime mover wheelbase; and
- little or no influence - prime mover fifth wheel lead and trailer rear overhang.

The largest potential changes in swept path arise from changes in the trailer wheelbases, and the trailer rear overhang has no effect on swept path. The prime mover front overhang has the greatest influence, but the potential for a large change in swept path is limited by the relatively small possible increase in overhang likely to occur. The effect of prime mover wheelbase on swept path is about half that of trailer wheelbase.

The implications for this project were that any increase in prime mover wheelbase would increase swept path if existing trailer dimensions are retained. The increase in low speed offtracking was shown to be in the order of 250 mm on average.
Low speed offtracking is a critical issue for access to the road network. However, no accepted performance standard exists and low speed offtracking is not well correlated with the present road network.

3.5 Overtaking time

Overtaking time is defined as the time taken for another vehicle to safely overtake the subject vehicle, including pulling out, overtaking and pulling in (NRTC 1999a).

Both Bruzsa and Hurnall (1999) and Blanksby et al (1998) undertook analyses of overtaking time. Bruzsa and Hurnall compared the overtaking time differences between a 23 metre B-double and a 25 metre B-double. Blanksby et al compared the overtaking time for a 27.3 metre B-double to a 25 metre B-double. The results were presented in tabular form with different B-double speeds and overtaking speed differentials, which obviously affect overtaking time.

It can be concluded from this work that an increase of 1 metre in B-double length will increase overtaking time by between 0.6% and 0.8% for a 100 km/h B-double speed. However, there is no accepted performance standard for overtaking time.

3.6 Intersection clearance times

Intersection clearance time is the time taken for the rear of the vehicle to clear an intersection (either straight through or turning) with the vehicle starting from rest (NRTC 1999a).

Bruzsa and Hurnall (1999) assessed the increased times required to clear an intersection when turning through 90 degrees. The increase in overall length from 23 metres to 25 metres increased clearance times in the range 0.4 sec for a 35 metre intersection (1% increase) to 0.5 sec for a 15 metre intersection (3.6% increase). Blanksby et al 1998 also reported differences in intersection clearance times, but did not specify whether it was a turn or straight through, or the size of the intersection. The increase in vehicle length from 25 metres to 27.3 metres was assessed to increase clearance times by 0.4 sec to 0.9 sec or 2% to 4%.

No standard for intersection clearance times has been discussed.

4. CONCLUSIONS

The vehicle dynamics issues show that decreasing the prime mover wheelbase reduces:

- ride quality;
- handling quality; and
- dynamic stability.
However, simply increasing prime mover wheelbase with present trailer lengths will:

- increase low speed offtracking;
- increase overtaking time; and
- increase intersection clearance time.

The results suggest that some justification exists for the concerns expressed about the ride and handling of very short wheelbase prime movers. However, the effects of an increase in prime mover wheelbase on the performance measures is small. Even with low speed offtracking, the prime mover wheelbase is secondary in effect to trailer wheelbase. No agreed performance standards exist against which to measure the case for or against an increase in prime mover wheelbase.

5. ACKNOWLEDGEMENTS

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6. REFERENCES


NRTC (1999a), "Performance Based Standards (PBS) for Heavy Vehicles in Australia, Field of Performance Measures (Draft 02)": Prepared by Roaduser International and ARRB Transport Research for the National Road Transport Commission: Melbourne.

Table 1: Summary of Vehicles for Ride Investigations

<table>
<thead>
<tr>
<th>B-double</th>
<th>Seat Location</th>
<th>Prime Mover Wheelbase (m)</th>
<th>Steer Axle Spring Stiffness (N/mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Height (mm)</td>
<td>Longitudinal Position (mm)</td>
<td></td>
</tr>
<tr>
<td>Baseline</td>
<td>2000</td>
<td>0</td>
<td>3.8</td>
</tr>
<tr>
<td>Variant #1</td>
<td>2000</td>
<td>0</td>
<td>3.8</td>
</tr>
<tr>
<td>Variant #2</td>
<td>2000</td>
<td>0</td>
<td>4.8</td>
</tr>
<tr>
<td>Variant #3</td>
<td>1750</td>
<td>1500</td>
<td>4.8</td>
</tr>
</tbody>
</table>

Note: The reference point on the seat for seat location measurements is taken to be the rear of the seat squab. Height is the vertical distance above the ground plane directly above the steer axle, longitudinal position is the horizontal distance aft of the steer axle.

Table 2: Summary of Results for Ride Investigations

<table>
<thead>
<tr>
<th>B-double</th>
<th>Unweighted RMS Vertical Acceleration (mm/s²)</th>
<th>Frequency Weighted RMS Vertical Acceleration (mm/s²)</th>
<th>Relative to Baseline (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>646</td>
<td>523</td>
<td>100</td>
</tr>
<tr>
<td>Variant #1</td>
<td>803</td>
<td>664</td>
<td>127</td>
</tr>
<tr>
<td>Variant #2</td>
<td>581</td>
<td>474</td>
<td>91</td>
</tr>
<tr>
<td>Variant #3</td>
<td>573</td>
<td>484</td>
<td>92</td>
</tr>
</tbody>
</table>

Note: Frequency weighting for vertical vibrations from BS6841 have been applied and a factor of 2 has been used to scale the frequency weighted values.
Figure 1. Dimensions of a typical 34 pallet 25 metre B-double

Figure 2: Maximum B-double dimensions prescribed in the national Vehicle Standards Rules

Fig. 3 Key dimensions of the baseline B-double for ride investigations.