EVALUATION OF LATERAL POSITION FOR MULTI COMBINATION VEHICLES

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Synopsis

Multi-combination vehicles (MCV) are road freight vehicles with a prime mover towing two or more trailers. The proposed research aims to understand how lane width requirements are influenced by the sideways movements of the trailers (lateral displacement or tracking ability), the lateral position of the prime mover and the behavioural characteristics of the drivers of surrounding vehicles. The research includes two full scale testing programs. Firstly, MCV tracking ability will be determined by extending the previous work of Lennie, Haldane and Bunker (2003) on rural lane widths. Secondly, testing on an urban arterial road or motorway will be conducted to yield information on the lateral position and behaviour of surrounding drivers. This paper provides a background to the study and the proposed methodology.

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LITERATURE REVIEW
Figure 1 introduces the factors that affect lane width requirements for MCVs.

Tracking Ability
Tracking ability describes the standard used to measure the amount of lateral displacement that trailers undergo while travelling at high speed. It is used to determine the lane width requirements of roads with the assumption that all wheels of heavy vehicles should remain on the sealed surface. If the lane width is insufficient, there is an increased probability of trailers leaving the lane, causing shoulder damage or encroaching into traffic lanes used by oncoming traffic (NRTC, 2001).

In the late 1970’s, the Alberta Department of Transportation completed research on tracking ability and specified that the rear unit travelling on smooth and level surfaces should not shift more than 80mm to either side when travelling in a straight line (Prem et al., 1999). NAASRA (1978) then stated a figure of 100mm for use in Australia. Prem et al (1999) explained that further work was needed to quantify parameters of speed, smoothness and grade for various types of heavy vehicles.

Prem et al then conducted tests which aimed at estimating the lane width requirements for certain heavy vehicle combinations on straight path travel. They found that cross-slope was the biggest contributor to variations in lateral displacement over all the tests, and furthermore its effect was quite predictable. Speed was another factor that influenced the amount of lateral displacement.

The lane widths were determined for the different vehicles by adding the width of the heavy vehicle (2.5m) to the maximum likely deviations of the trailers in either direction (±3 standard deviations of lateral displacement). This would allow 99% of the displacements to lie within the lane width. Refer to Figure 2. The authors of the report acknowledged that the lane width specified should be verified against a road that is known to have poor tracking characteristics, before the widths are adopted into any guidelines (Prem et al., 1999).

Driver Behaviour
The presence of heavy vehicles impacts the traffic networks due to their large size, the poorer performance capabilities and the psychological effect on other drivers (Lake et al., 2002). Judgement, habits, sensory capabilities, alertness, driving skill and age are factors unique to each driver that affect the outcomes of incidents and accidents (Harris, 1990).

Largely, the existing research has been undertaken through large scale observations, statistical research on accident trends and technical opinion. Further study is needed in this in this area to determine the psychological effects of MCV presence in urban areas.
**Lateral Position**

The lateral position or the lane discipline refers to lateral place within a lane that drivers choose to adopt. Gunay (1999) recognised that traffic that tended not to keep towards the centre of the lane has the potential to cause a safety hazard, reduce speed/volume and reduce the life of lane markings.

Various research has provided correlations between lateral position and
- overtaking vehicles
- lane width
- shoulder width
- effect of line markings
- shoulder type (sealed or unsealed) and
- class of vehicle.

Lee & Garner (1996) found that as the number of axles of vehicles increased, drivers appeared to travel closer to the shoulders. Secondly the data showed that overtaking vehicles will leave more lateral clearance than other vehicles.

No research has been found which presents results for lateral clearance between MCVs and other vehicles.

**Current Practice for Pavement Width**

Primarily, pavement width requirements are determined by assessing the tracking ability (straight sections), the high speed offtracking (corners) and the vehicle width (QDMR & QT, 2002). Pavement widths in rural areas are assessed according to the type of vehicle, the AADT and according to the findings proposed by Prem et al (1999). Refer to Table 1 for a comparison of the national lane width requirements and a case study on B-Doubles.

Urban roads have considerations additional to rural roads, including the use of bicycles and parking (Main Roads Western Australia, 2002; QDMR & QT, 2002; Transport SA, 2002). Therefore, the lane types and widths are specified according to their use. However, the SA guidelines only make such recommendations for the kerbside lane, while all other lanes need to be 3.5m or wider. The NSW guidelines (RTA, 2002) make lane width recommendations purely on the AADTs.

The QLD and SA guidelines suggest that MCVs should only travel on roads with multiple lanes where short sections of single lane may be acceptable.

**Testing**

For all traffic environments (urban and rural), the lane width requirements as presented in the various route assessment guidelines (Table 1) differ quite dramatically from the national report by Austroads (Prem et al., 1999) and between states. The following two testing programs will endeavour to extend this understanding of lane widths.
1. Tracking Ability on Straight Paths at High speed: The previous work published by Lennie, Haldane and Bunker (2003) on lane widths required by MCVs in rural areas will be extended to incorporate the effects of steer angle and lateral position. This will determine the tracking ability of various MCVs on straight path travel.

2. Lane requirements in multi lane traffic: Further testing on an urban arterial road or motorway will yield information on the behaviour of drivers around MCVs and assist in determining suitable lane widths on MCV routes.

**TRACKING ABILITY ON STRAIGHT PATHS AT HIGH SPEED**

Tests were undertaken (Haldane, 2002) to measure the lateral movements of the trailers and a manual data collection technique was employed to gather the lateral displacement information from video footage.

**Aim**

The aim was to determine the lane width requirements and identify factors that influence tracking ability for MCVs on straight path travel.

The objectives of this project flow from that preliminary review of tracking ability testing as follows:

1. To determine the lane width requirements for heavy vehicles and quantify variations in tracking ability of different combinations by including the effects of the steer angle.
2. To compare the results with the previous works of Prem et al (2000) and the national route assessment guidelines.

**Method**

This section provides a summary of the lateral displacement testing methodology including the test vehicles, locations and procedure.

**Test Vehicles**

The following vehicle combinations were used in the tracking ability test:

- B-Double;
- Double Road Train (Type I Road Train) and
- Triple Road Train (Type II Road Train-air suspension), Refer to Figure 3;

Details of all the MCV tested are provided in Table 2.

**Test Site and Procedure**

Six vehicles (of which three are reported in this paper) were tested on Toowoomba-Cecil Plains Road between the chainages of 49300 and 53510, the test being 4.21km long. The alignment is generally straight, but there is one sweeping corner towards end of the section. The speed limit along this section of road is 100km/h; however the MCVs travelled at approximately 80km/h. It has an average crossfall of 3% from the
crown of the road according to construction plans and a flexible granular pavement. The average annual daily traffic for the section of road is 162 vehicles (Haldane, 2003).

Special access permission was granted by QDMR to test the A-Triple and other larger combinations on this road. Roughness data was collected at 20m intervals for both the inner and outer wheel paths. The range varied between 50 and 100 counts/km (NAASRA), with occasional spikes of up to 150 counts/km, and one spike of 230 counts/km. It was considered to be typical for a rural road of its age and function.

To measure lateral displacement a video camera was attached to the centre of the roof of the prime mover and zeroed by aiming at the centre of the rear trailer after the vehicle had been straightened on level pavement. Tracking ability boards as illustrated in Figure 4 were mounted high on the rear of each trailer to measure lateral displacement during travel. These boards were painted with a centre vertical strip of 100mm width and vertical strips of 250mm width either side.

An onboard computer was used to record distance from a roto-pulse mounted on one of the prime mover wheels against a time stamp, and to place cross hairs on the video screen. The cross hairs allowed the lateral positions of the tracking ability boards to be measured relative to the prime mover, in order to determine lateral displacement. A second camera was mounted on the prime mover to observe the front right hand wheel and the pavement beneath it. This image was displayed on screen beneath the image displaying the overhead view to the tracking ability boards, so that they could be recorded and later viewed simultaneously.

Winds in the area were low during the tests and weather conditions were dry (Lennie et al., 2003).

**Data Processing**

The video footage was viewed at 1/5 real time to facilitate the manual data collection process. The lateral displacement data was then recorded and analysed to determine the lane width requirements.

Some errors were inherent in the data as reported in Lennie et al (2003). The main inaccuracy was quite significant and would require further calibration of steer angle plots. This occurred due to the location of the video camera on the prime mover. Any lateral displacement information collected from the video was always relative to the direction of the prime mover, rather than to the road.

**Steer Angle Data Processing**

The results from this steer angle analysis are yet to be finalised; however the planned method is reported in this section.

Three variables have been introduced to summarise the angles between the road, prime mover and trailers as shown in Figure 5. The variable $\psi$ represents the angle...
between the direction of prime mover and the rear trailer. This information was collected from the video footage. Variable $\theta$ represents the angle between the direction of the prime mover and the road, to be determined from the steer angle data. Variable $\beta$ represents the angle between the direction of the trailers and the road. This variable may be calculated using Equation 1.

$$\beta = \theta - \psi$$  \hspace{1cm} \text{Equation 1}

The lateral displacements of the prime mover and trailers will be calculated by manipulating the angles with trigonometry as shown in Equation 2 and Equation 3. Variable $X_{pm}$ indicates the lateral displacement due to the direction of the prime mover and variable $X_t$ indicates the lateral displacement due to the orientation of the trailers (both with respect to the direction of the road).

$$X_t' = L_t \sin \beta$$  \hspace{1cm} \text{Equation 2}

$$X_{pm} = L_{pm} \sin \theta$$  \hspace{1cm} \text{Equation 3}

In the case presented in Figure 5, where the prime mover and trailers are pointed in the same direction Equation 4 will be used to find the total lateral envelope. Where the prime mover and trailers are pointed in opposite directions, Equation 5 will be used. Refer to Figure 5 for other notation.

$$\text{Lateral Envelope} = X_{pm} + X_t'$$  \hspace{1cm} \text{Equation 4}

$$\text{Lateral Envelope} = \max(X_{pm}, X_t')$$  \hspace{1cm} \text{Equation 5}

Finally, once the lateral envelope is known for each vehicle along the length of the road, the method used by Prem et al (1999) will be applied to determine the 99%ile envelope.

**LANE REQUIREMENTS IN MULTI LANE TRAFFIC**

**Aim**
This testing program intends to determine the tracking ability of the MCV, and the lateral position and driver behaviour of both the MCV and other surrounding vehicles along a short length of road. Refer to Figure 6.

This figure and the list below show the distance measurements that are desired from the testing.

1. Lateral position of the MCV prime mover in the lane
2. Lateral position of the rear MCV trailer in the lane;
3. Lateral placement of adjacent vehicle within their lane.

Together points 1 and 2 will help to determine the overall lateral envelope (tracking ability) of the combination within the short study section by determining the difference between the lateral positions of the prime mover and the rear trailer at any point in
time or space. It is recognised that this does not provide a representative tacking ability profile for the overall road section.

Point 3 will be used to help determine the psychological impact of MCV presence on surrounding vehicles. A statistical analysis on the lateral placement will be used to determine whether drivers operate differently around MCVs compared with other vehicle types including, passenger cars, rigid trucks and general access articulated vehicles.

**Data Collection Equipment**

The information may be collected by several technologies including laser beams, axle/vehicle detectors and video image processing. The technology was selected on the following basis:

1. Data collection methods were firstly assessed according to cost and availability. Therefore, providing either the initial purchase price was low or the equipment was already available at Queensland University of Technology or at Queensland Department of Main Roads, the technology was considered. Further consideration was given to the traffic management and specialist costs associated with installation and calibration.

2. Following cost, the options were appraised against accuracy. For the study to be valid, the resulting data should be representative of the objectives and have an acceptable level of accuracy.

3. The level of manual data processing was considered as a further indication of accuracy for two reasons.
   a. High levels of manual data processing are likely to increase human error
   b. The project is restricted by time; so a high rate of data processing per vehicle will reduce the overall testing duration, consequently reducing the statistical sample.

The proposed technology to be used is video image processing (VIP) because it satisfies the above three criteria. The following paragraphs provide a general description of VIP technologies and some of the errors/problems that (in the past) have known to cause inaccuracies. VideoTrak-900 by Peek is the intended VIP technology.

**VIP Description**

Essentially, lane position information will be processed by prerecording vehicles on a roadway in a digital format and activating software with specifically designed algorithms to perform the computations.

**Common Algorithms of VIP Equipment**

Methods of analysing images differ between the various VIP equipment; so some common algorithms are shown below. Each of the following techniques identifies patterns in the brightness of image pixels and manipulates them to detect vehicles.
• **Edge Detection:** Edges in the image are detected by identifying pixels where the brightness intensity changes suddenly. This is useful for identifying the edges of vehicles on the roadway; however it can miss detections if the vehicle brightness is similar to the roadway or it can reveal edges of non importance such as line marking.

• **Motion Detection:** Motion detection analyses several image frames to detect changes in the brightness of pixels (Chatziioanou, 1994).

### Common Limitations of VIP Equipment

Even though the automation of the VIP eliminates human error occurring from manual data processing, the software algorithms have certain inaccuracies resulting from the computer capability or other natural imperfections (Chatziioanou, 1994).

• **Frame Capture Rate:** an error related to the limitation of the video equipment capture rate (25 frames per second). Therefore the detector zones will be positioned sufficiently wide so that vehicles will travel through the zone over a few frames. Refer to Figure 8.

• **Reflections and Shadows:** Can cause missed or false detections. Shadows across many lanes, slow moving shadows from roadside objects and shadows from clouds typically cause errors. The VideoTrak developers assert that special algorithms now overcome these sources of error.

• **Occlusion:** Obstruction of view, which can be improved by correcting the camera orientation, i.e. the camera should be positioned high above the centre line of the lane. See Figure 8.

• **Perspective:** Representing a 3D reality on a 2D surface.
  - **Parallax Phenomenon:** caused by varying heights of vehicles and the camera position (Figure 7) (Chatziioanou, 1994).

Even though these errors have been reduced or eliminated by the VideoTrak software designers, a manual data collection process will be employed to verify a portion of the results and determine the accuracy. This process will be undertaken by viewing the video footage and manually recording data of interest.

### Testing Locations

A test location for this project was chosen to satisfy the objectives of the testing and the requirements of the testing equipment.

Characteristics for choosing a site are identified below (in order of importance)

1. **MCV traffic (B-Doubles):** The road must carry MCVs.
2. **Two lanes in the target direction:** An objective is to find behaviour patterns in the vehicles travelling in adjacent lanes to MCVs. Sites were restricted to two lanes to control the testing. Behaviour of drivers travelling on roads with three or more lanes will be more complex then drivers on two lane roads.
3. **Overpass:** To reduce vertical occlusion, the video camera is to be mounted on an overpass.
4. **No on/off ramps within 500m of overpass:** To the reduce the external influences of merging traffic, a site should be chosen away from on/off ramps. The HCM (2000) indicates that the area of influence of a ramp is 500m.
5. Motorway Facility: To consistently analyse high speed operation in uninterrupted flow, a motorway facility should be chosen.

6. High AADT: A site with a high AADT should be chosen to increase the probability of vehicles being present in both lanes on any section of road; however data sampling will only occur in uncongested conditions.

7. Straight section of road: Chosen to reduce the effect of external influences.

8. Level to slight grade: Chosen to reduce the effect of external influences.

9. Good Pedestrian Access on overpass: This will enable the camera to be installed without disruption to traffic on the overpass.

The test section is the Gateway Motorway northbound viewed from the Meadowlands Road overpass at Carindale. The Gateway Mwy provides access to 25m B-Doubles and has two lanes in each direction. 100km/h speed limit is posted.

Pedestrian access is available on Meadowlands Road (on the overpass) and nearby parking is available.

The traffic counts, (QDMR, 2001) show that the Gateway Motorway carried 29 000 AADT northbound in May 1998. It is expected that traffic volumes have grown during this time. It will be important to ensure that testing is conducted during uncongested operation.

CONCLUSIONS

Current trends show that more freight efficient vehicles such as MCVs are becoming more prevalent on Australian roads. The two proposed testing programs will endeavour to expand the current knowledge on impacts of MCVs on other drivers including the standard passenger car driver. Shy distances in the lateral direction are measurable data that can be used to determine the driver’s lateral comfort. The first testing program is expected determine the lateral displacements or lateral envelope of three regular MCVs. The second test on the urban motorway will attempt to capture the driver impacts by employing video imaging processing. The site was chosen by identifying the important characteristics and finding a location that satisfied.

Comments on this paper and on the project in general are welcomed by the authors.

REFERENCES


AUTHOR BIOGRAPHIES

**Sandra Lennie**

Sandra completed her Bachelor of Engineering (Civil) (Hons) at Queensland University of Technology (QUT) in 2002 as a Queensland Department of Main Roads (QDMR) scholarship holder. Her fourth year projects included an investigation into the effect of roundabout entry metering on traffic performance in the Brisbane area, and analysis of tracking ability of multi-combination vehicles. Sandra is now undertaking her Master of Engineering degree at QUT investigating impacts of multi-combination vehicles in urban areas and works on a part time basis at QDMR in the heavy vehicle management section.

**Jonathan Bunker**

Jon completed his Bachelor of Engineering (Civil) (Hons) in 1991, and Doctor of Philosophy on Microscopic Modelling of Freeway Operations in 1995, both at QUT. For five years he practiced as a consulting transport engineer with Kittelson & Associates, Inc. in Portland, Oregon, and sister firm Eppell Olsen & Partners in Brisbane, undertaking development transport planning, urban and regional integrated transport planning, road hierarchy and network analysis studies, design of transport facilities, and public engagement activities. He contributed with Kittelson & Associates to the development of Roundabouts, An Information Guide for the US FHWA. Jon is now Lecturer in Transport Engineering in the School of Civil Engineering, QUT. He teaches and coordinates transport engineering/planning and professional studies courses at undergraduate and postgraduate levels. Jon is currently active on numerous research projects including pavement asset management, heavy vehicle management, freeway operation, and freight logistics, and in-vehicle technologies.
FIGURES

Figure 1: Influencing Factors for Lane Width Requirements

Figure 2: Lane Width Requirements for Heavy Vehicles (Prem et al., 1999)

Figure 3: Triple Road Train Photograph, (Haldane, 2003)

Figure 4: Output from Video Recordings
Figure 5: Illustration of Notation

Legend

- $L_{pm}$: Length of the Prime Mover
- $L_t$: Length of Trailers
- $\theta$: Angle between the direction of the Prime Mover and the Road
- $X_{pm}$: Lateral Distance between the front centre of the Prime Mover and the road
- $\psi$: Angle between the Direction of the Prime Mover and the direction of the trailers
- $X_t$: Lateral Distance between the centre of the rear trailer and the projected direction of the prime mover
- $\beta$: Angle between the direction of the trailers and the road
- $X_t'$: Lateral Distance between the centre of the rear trailer and the road
- Basic Representation of Vehicle
- Centre of Lane

NB: All angles shown in this figure are positive with respect to the road direction.

\[ \beta = \theta - \psi \]
\[ X_t' = L_t \sin \beta \]
\[ X_{pm} = L_{pm} \sin \theta \]

Lateral Envelope = $X_{pm} + X_t'$

or

Lateral Envelope = max($X_{pm}, X_t'$)
Figure 6: Lateral Position Measurements

Legend

- MCV Unit
- Other Vehicle

1. Lateral Position of the Trailers
2. Lateral Position of the Trailers
3. Lateral Position of surrounding drivers

Figure 7: Parallax error, the truck appears to travel across a detection zone first (Chatziioanou, 1994)

Figure 8: Intended Horizontal Camera Orientation

Site: North bound lanes on the Gateway Motorway

Table 1: Comparison of Lane Width Requirements

1
2
<table>
<thead>
<tr>
<th>State</th>
<th>Comparison of National Lane Width Requirements</th>
<th>Case Study of B-Doubles</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rural</td>
<td>Urban</td>
</tr>
<tr>
<td>SA</td>
<td>Lane Widths have been adopted from an ARRB Report (Prem et al., 1999) however both the gazettal and permit routes require larger lane widths</td>
<td>3.5m is suggested for all lane widths however, the kerbside lanes have considerations of cyclists and parking and are wider</td>
</tr>
<tr>
<td>QLD &amp; WA</td>
<td>For AADTs above 150, seal widths are up to 3m greater than recommended by Prem et al.</td>
<td>Various lane widths are suggested, depending on the type of cross section (divided/undivided), and these widths are larger than recommended by Prem et al</td>
</tr>
<tr>
<td>NSW</td>
<td>Regardless of the speed, in some cases lane widths for B-Doubles are more conservative than Prem et al. Some Road Train lane widths are less conservative than Prem et al.</td>
<td>Urban Roads are considered separately and should be assessed based on traffic, gradient, sight distance etc.</td>
</tr>
</tbody>
</table>

2. Comparison of National Lane Width Requirements and recommendations by Prem et al (Figure 2) and Case Study of B-Doubles (25-27.5m) on 2-way undivided carriageways at 80-100km/h. Sources: (Main Roads Western Australia, 2002; Prem et al., 1999; QDMR & QT, 2002; RTA, 2002; Transport SA, 2002)

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### Table 2: Details of Test Vehicles (Haldane, 2003)

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Trailers</th>
<th>Length (m)</th>
<th>Laden Test Mass (t)</th>
<th>Coupling Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>B-Double</td>
<td>2 Trailers</td>
<td>22.84</td>
<td>52.54</td>
<td>B-coupled</td>
</tr>
<tr>
<td>Double Road Train</td>
<td>2 Side Tippers</td>
<td>27.43</td>
<td>79.88</td>
<td>Converter Dollies</td>
</tr>
<tr>
<td>Triple Road Train (air)</td>
<td>3 Side Tippers</td>
<td>40.78</td>
<td>115.83</td>
<td>Converter Dollies</td>
</tr>
</tbody>
</table>