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PUTTING THE DRIVER IN THE VEHICLE PERFORMANCE EQUATION WITH ON-ROAD TESTING

Peter Sweatman Roaduser Systems Pty Ltd, 76 – 80 Vella Drive, Sunshine, VIC, Australia

ABSTRACT

The engineering performance of heavy vehicles is a critical element in their access to road systems. Increasingly, vehicle performance must be assessed before permits are granted, or regulations are changed, to allow more productive vehicles to operate on public roads. This is especially true for the larger and heavier vehicle combinations.

Heavy vehicle performance is usually assessed in open-loop manoeuvres under certain sets of conditions. Extensive use of computer simulation has been made for this purpose. However, in order to adequately assess larger vehicle combinations, or problem vehicles, it is often necessary to carry out dynamic testing under typical on-road operating conditions. This allows measurement of vehicle performance plus certain aspects of driver steering performance.

This paper will present the results of several recent studies carried out by Roaduser Systems where both vehicle and driver performance have been measured under actual on-road operating conditions. Results are presented for a range of vehicle configurations from tractor-semi-trailers through double trailer combinations (including B-doubles) to multi-trailer combinations.

The test results are presented in such a way as to encourage benchmarking of on-road vehicle performance and to encourage the use of some common measures for comparing vehicles from around the world.

1 INTRODUCTION

The productivity and safety of heavy vehicle operations, and the way in which they are regulated, depend on their engineering performance. Engineering performance describes vehicle behaviour in terms of its ability to start, stop and turn and its impacts on infrastructure including pavements and bridges.

Vehicle performance assessment has become a useful tool in a world where creep in vehicle limits, albeit based on rational periodic review, has run its course. Performance assessment has become essential in the issue of permits for larger and/or unusual vehicle combinations. Specialisation in road freight vehicles is also creating a myriad of vehicle configurations which defy prescriptive regulation because prescriptive limits rely in part on knowing the vehicle configuration in advance.

Heavy vehicle safety and community acceptance is a major public policy issue. While vehicle engineering performance directly affects a small but significant number of truck accidents (typically 10 % or less), it also has a pervasive effect on many other truck accidents which are currently attributed to "driver error"; mass accident investigation data currently offers poor insight into accident causation and countermeasures, but we do know that truck accidents are highly multi-factor, especially in urban areas. This means driver-vehicle-environment interactions often come into play.

Depending on whether we need a screening tool prior to letting a vehicle on the road, an alternative to prescriptive limits (performance-based standards) or means of investigating truck safety issues after they are manifested we require different types of performance measures. Some measures pertain to the vehicle only and some to the driver-vehicle and driver-vehicle-road interaction. It is prudent to avoid permitting or proliferating the worst-performing vehicles (according to vehicle-based measures) and it is equally prudent to minimise the potential for poor driver-vehicle-environment performance.

The latter is more difficult to measure. While a range of vehicle measures and road measures have been developed, driver measures are few and far between. The current Australian project to develop performance-based standards (PBS), as an alternative form of regulation to prescriptive standards, has collected and refined available performance measures (1). Recent major Australian safety investigations (2,3) have attempted to apply performance measures to the identification of systemic safety issues related to truck on-road behaviour.

This paper presents stability and control performance measures which select from and go beyond the current "PBS" measures and have provided insight into on-road safety and acceptability issues. This is necessary because remarkably little physical testing of the PBS measures has been carried out.

2 ON-ROAD PERFORMANCE MEASUREMENT

On-road performance measurements have been carried out for a range of vehicle configurations from tractor-semi-trailers through doubles combinations (including B-doubles) to multi-trailer roadtrains. The performance measurements vary in scope and intent and include:

- Vehicle parameters – measures which are properties of vehicle sub-systems (such as suspensions) and are not affected by the manoeuvre or operating environment
- Vehicle performance measures – measures which are a property of the entire vehicle system, apply to a particular manoeuvre and are not intended to be affected by the operating environment
- Driver-vehicle performance/interaction measures – measures which are a property of the driver-vehicle interaction and reflect the operating environment.

2.1 Tractor-Semi-Trailers

Tractor-semi-trailers were tested (2) in response to complaints about unsafe handling. All testing was carried out under typical on-road operating conditions and the range of performance measures included:

- Vehicle parameters (steering ratio, suspension roll steer coefficient, front axle bump steer coefficient)
- Vehicle performance measures (understeer coefficient, roll gradient, response transfer functions)
- Driver-vehicle performance measures (rms steering angle, dominant steering frequency, rms responses (yaw and lateral acceleration)).

The following vehicle parameters were able to differentiate problem vehicles from benchmark vehicles:

- Suspension roll steer coefficient
- Suspension roll stiffness and roll centre height
- Front axle bump steer coefficient.

The following vehicle performance measures were able to differentiate problem vehicles from benchmark vehicles:

- Understeer coefficient
- Roll gradient.

The following driver-vehicle performance measures were able to differentiate problem vehicles from benchmark vehicles:

- Rms steering wheel angle
- Dominant steering frequency
- Rms tractor yaw rate.

This work showed that poor values of certain vehicle parameters (suspension and steering) flowed through to poor performance measures for the vehicle system (handling and stability) and these in turn caused the driver to apply more steering corrections at a higher frequency but the net result was still poorer control of the tractor (yaw rate).

2.2 Doubles Combinations

A range of doubles (see Figure 1) was tested on-road in response to regulatory agency concerns about stability and control for some configurations (3). Certain standard test manoeuvres were also carried out (lane-change and yaw damping).

The following vehicle performance measures were able to differentiate poor combinations from the other combinations:

- Roll gradient
- Response transfer functions
- Rear amplification ratio
- Yaw damping
- Rearward amplification.

The following driver-vehicle performance measures were able to differentiate poor combinations from the other combinations:

- Rms suspension roll angle
- Rms lateral acceleration of rear trailer.

This work showed that there are three key indicators of poor performance in doubles combinations:

- Suspension roll angles developed by all units (expressed as rms values); these are affected by suspension roll characteristics (represented in the roll gradient)
- Various measures of rear amplification
- Yaw damping.

Of these measures, suspension roll angle characteristics and rear amplification can be measured in normal travel or in stylised lane-change manoeuvres. Yaw damping can only be measured in a pulse steer manoeuvre, but this is readily carried out during normal on-road operation.

It should be noted that several measures of "rear amplification" were obtained:

- What was termed rear amplification (rms lateral acceleration of rear trailer divided by rms lateral acceleration of tractor, obtained during normal travel) – this can also be measured using yaw rates
- Rearward amplification as measured in the well-defined SAE lane-change manoeuvre
- Transfer functions between the lateral acceleration (or yaw rate) of the rear trailer and that of the tractor.

The latter transfer functions provide valuable insight into "resonances" in the response of multi-combination vehicles. Figure 2 shows the lateral acceleration transfer function for the B-double. It is apparent that the peak gain of 2.85 occurs at a frequency of 0.8 Hz; by comparison, the standard lane-change test of rearward amplification returns a gain of 1.11 at a frequency of 0.4 Hz. It was found that the standard test missed the peak gain for all doubles tested. Does this matter? Driver steering input has a dominant frequency in the range 0.2 – 0.6 Hz (2) and therefore high gains occurring above this frequency are of lesser concern (unless they coincide with suspension frequencies).

Extensive US research (4) also measured rearward amplification of multi-combinations under actual operating conditions. Measures which were found to be useful in relation to quantifying the stability-enhancing characteristics of improved trailer coupling arrangements included:

- The lateral acceleration transfer function gain described above
- The peak rearward amplification obtained from the transfer function gain
- Comparison of front and rear histograms of lateral acceleration (percent of time spent above a certain lateral acceleration, front versus rear)
- A measure termed the lateral acceleration experience of trailers relative to the experience of tractors; this was computed as the ratio of the percent of time spent above a certain lateral acceleration value (trailer over tractor) plotted against lateral acceleration.

2.3 Roadtrains

Candidate innovative roadtrains of GCM in excess of 100 t have been tested on-route alongside currently-permitted triple roadtrains to provide performance data to guide permitting procedures. Certain standard test manoeuvres have also been carried out (lane-change and yaw damping).

The following vehicle performance measures were able to differentiate poor combinations from the other combinations:

- Response transfer functions
- Rear amplification ratio
- Yaw damping
- Rearward amplification

The following driver-vehicle performance measures were able to differentiate poor combinations from the other combinations:

- Rms suspension roll angle of rear trailer
- Rms lateral acceleration of rear trailer.

A key finding for some roadtrains is that the response transfer functions may have more than one peak. Multi-trailer combinations tend to have a response peak in the lower-frequency range (0.2 – 0.5 Hz) plus a peak in the higher-frequency range (0.8 – 1.2 Hz). Figure 3 shows a typical example for a conventional Australian triple roadtrain. These transfer functions have important implications for performance measurement because:

- The lower-frequency peak may or may not coincide with the standard lane-change test (0.4 Hz)
- The rear amplification may vary rapidly at frequencies varying from 0.4 Hz (adversely affecting the accuracy of rearward amplification measurement)
- The higher-frequency peak tends to be higher for B-coupled combinations
- In some cases, the higher-frequency peak may coincide with the suspension bounce frequency, causing dramatic yaw oscillations under some road conditions.

It is also important to consider the effect of driver steering behaviour on vehicle behaviour, as well as the reverse: the effect of vehicle behaviour on driver steering behaviour. Driver behaviour is evidenced in the power spectrum of steering wheel angle or front wheel angle movements. Drivers normally have a dominant steering frequency of 0.2 – 0.3 Hz. Under demanding conditions or emergency manoeuvres, the dominant frequency increases to 0.5 – 0.6 Hz. It is therefore possible that the driver's emergency mode would excite an undesirable yaw resonance. However, observation of roadtrain drivers suggests that they are well aware of vehicle resonant frequencies and modify their steering behaviour to avoid these frequencies.

3 VOCATIONAL USE OF PERFORMANCE MEASURES

Performance measures which have proven vital in the make-up of problem vehicles, and which may be used to screen vehicles in a type approval sense are the following *vehicle parameters*: suspension roll stiffness and roll centre height, suspension roll steer coefficient and front axle bump steer coefficient.

Performance measures which have a proven track record in the identification of problem vehicles, and which may be used for pre-qualification regulatory purposes under a PBS regime include:

- The following *vehicle parameters*: suspension roll stiffness and roll centre height, suspension roll steer coefficient and front axle bump steer coefficient
- The following *vehicle performance measures*: Static Roll Stability, understeer coefficient, roll gradient, yaw damping, rearward amplification (in various forms including rearward amplification in the lane-change, response transfer function using lateral acceleration or yaw rate, peak response gain and peak frequencies).

Performance measures which have a proven track record in the benchmarking and comparison of vehicles, and which may be used for post-compliance regulatory purposes under a PBS regime include:

- The following *vehicle performance measures*: Static Roll Stability, understeer coefficient, roll gradient, yaw damping, rearward amplification (in various forms including rearward amplification in the lane-change, response transfer function using lateral acceleration or yaw rate, peak response gain and peak frequencies)
- The following *driver-vehicle performance measures*: rms roll angle of each unit, rms lateral acceleration of each unit.

Performance measures which have been able to pinpoint vehicles with stability-and-control safety deficiencies are the following *driver-vehicle interaction measures*: rms steering wheel angle, dominant steering frequency(ies), rms tractor yaw rate.

4 INTERNATIONAL BENCHMARKING OF PERFORMANCE MEASURES

With some important exceptions, relatively little research is available to link performance measures with actual safety outcomes on a statistical basis. One useful and practical way of assessing vehicle performance is to compare the various countries' performance measures applicable to various common categories of vehicle, which could be represented by:

- Most common vehicle configurations which have been generally acceptable over a period of time
- Innovative or special designs which are believed to have superior safety performance
- "Black sheep" configurations which are suspected to be inferior
- Larger and heavier configurations which are permitted for productivity reasons on selected routes or at reduced operating speeds.

With regard to commonly-accepted vehicle configurations, it would be useful to compare the tractor-semi-trailers which are in wide use in many countries with the truck-trailer combinations used widely in some European countries and to a lesser extent elsewhere. While vehicle performance measures for these two configurations may diverge, driver and environmental factors may lead to a convergence in driver-vehicle performance measures.

Important measures for comparison would include:

- Rms trailer lateral acceleration
- Rms trailer suspension roll angle
- Response transfer function
- Yaw damping
- Rms steering wheel angle, dominant frequency(ies)
- Rms truck/tractor yaw rate
- Truck/tractor understeer coefficient
- Roll gradient
- Average operating speed.

All of these measures may be obtained cost-effectively during on-highway operation with a realistic level of instrumentation, and with little risk.

By way of example, Australian data shows the following rms lateral acceleration of tractors:

- In the range 0.05 – 0.10 g in tractor-semi-trailer combinations
- In the range 0.02 – 0.04 g in multi-combinations (indicating greater driver caution).

The rms lateral acceleration of trailers has been found to be:

- In the range 0.03 – 0.04 g for B-doubles
- In the range 0.04 – 0.07 g for other doubles
- In the range 0.05 – 0.07 g for roadtrains (where speeds are somewhat lower).

7 CONCLUSIONS

The safety significance of heavy vehicle stability and control performance exists not only in relation to "good" and "bad" vehicles but also to the ability of the driver to interact with, and compensate for, aspects of vehicle performance.

Certain performance measures have been shown through extensive on-road testing to provide practical differentiation of vehicle quality. These measures include vehicle parameters, vehicle performance measures and driver-vehicle performance/interaction measures.

Consideration has been given to the most suitable of these practical measures for the following purposes:

- Type approval screening
- Pre-qualification in a PBS regulatory regime
- Post-compliance in a PBS regulatory regime
- Pinpointing stability-and-control safety deficiencies.

As definitive research linking vehicle performance to safety outcomes is scarce, more effort should be devoted to international benchmarking of practical performance measures.

8 REFERENCES

1. Prem, H et al (2002) Performance characteristics of the Australian heavy vehicle fleet. NRTC Working Paper.
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3. McFarlane, S et al (2000) On-road dynamic performance testing of MAD and MAP vehicle combinations. Roaduser International report to Transport South Australia.
4. Winkler, CB et al (1995) An operational field test of long combination vehicles using ABS and C-dollies – Volume 1 Final Technical Report.

TABLES & FIGURES

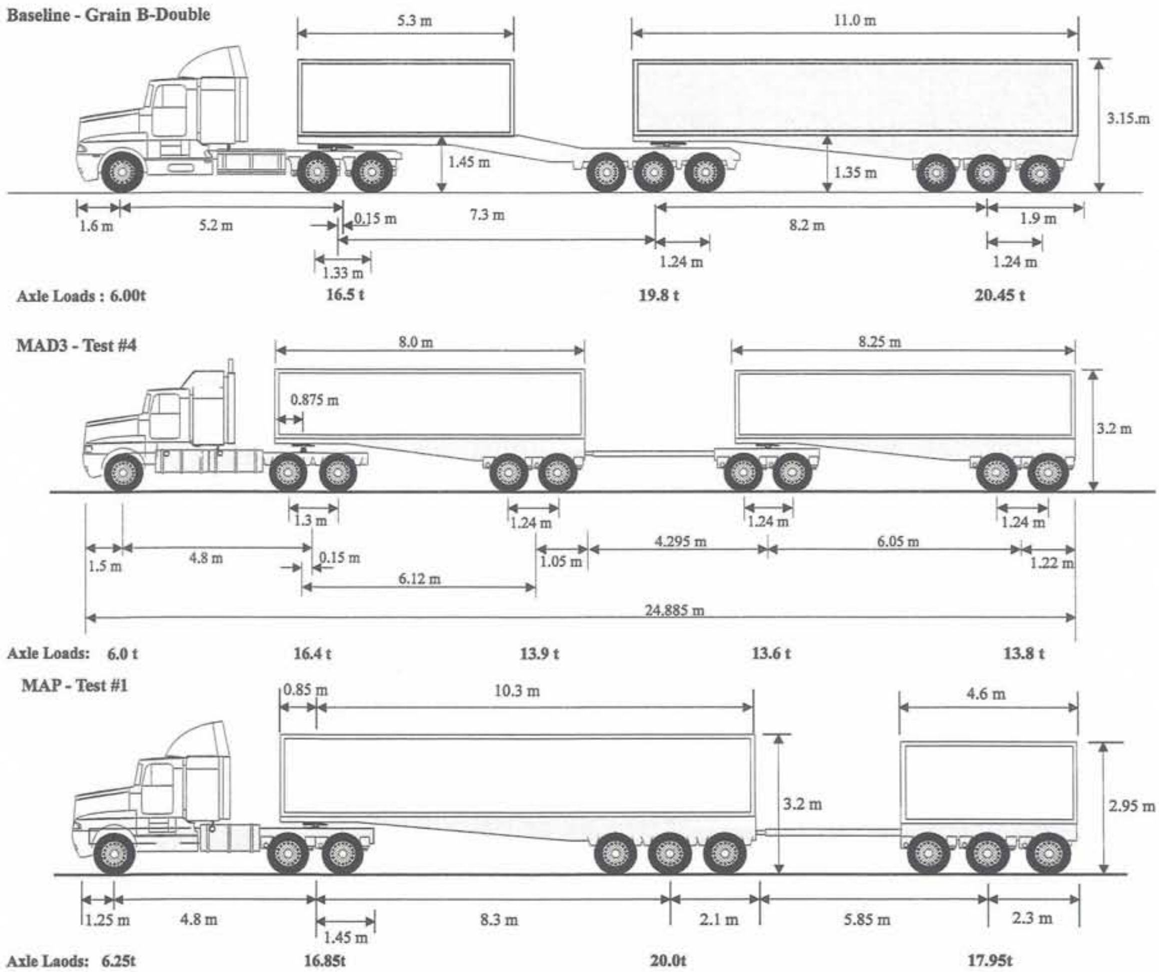

Figure 1 – Examples of doubles combinations tested under typical on-road conditions

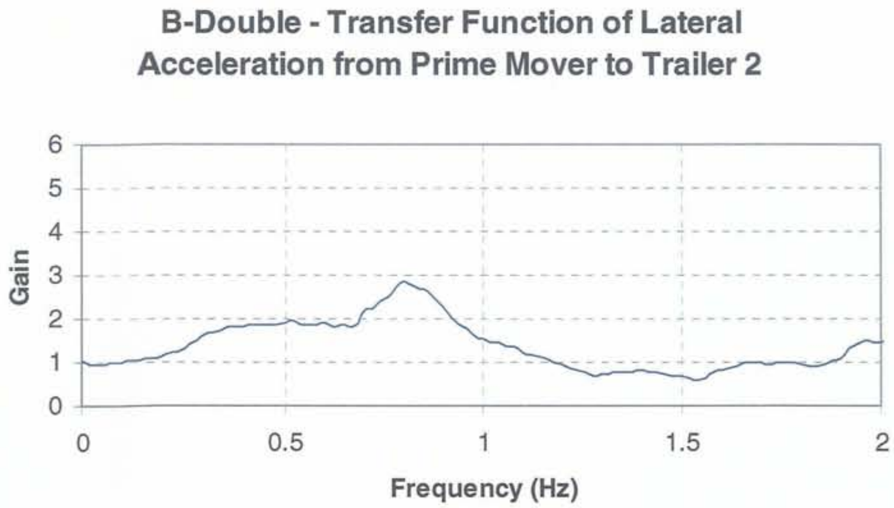

Figure 2 – Transfer function for B-double – obtained under typical on-road conditions

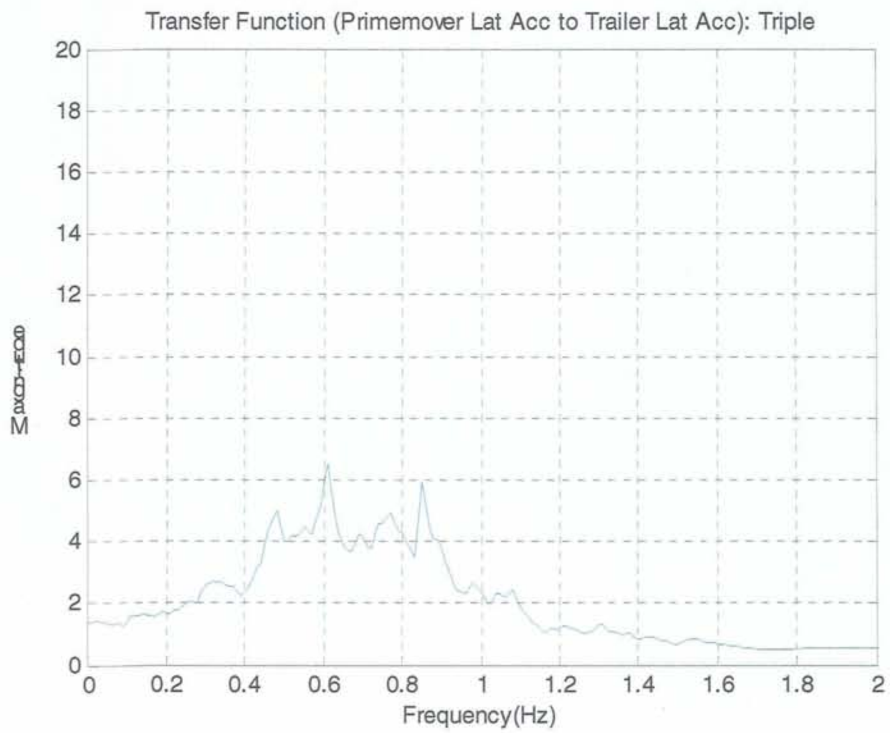

Figure 3 – Transfer function for triple trailer roadtrain – obtained under typical on-road conditions