

Pages 357-376

ROAD NETWORK ACCESS STANDARDS FOR HEAVY COMMERCIAL VEHICLES

*Rod George, Matt Elischer and Hans Prem
ARRB Transport Research Ltd*

ABSTRACT

Regulators, vehicle manufacturers and operators of articulated vehicles require information which can be used to assess the extent to which these vehicle types should have access to the road system.

When the hauling unit of an articulated vehicle travels in a straight line over an uneven surface, the trailers do not necessarily follow exactly the same path. This trailer tracking behaviour means that articulated vehicles require more road width when travelling at highway-speeds than when they are stationary.

With the increasing use of articulated vehicles in various configurations there is a need for regulators, vehicle manufacturers and operators of articulated vehicles to determine which vehicle types should be permitted to access various sections of the road system without compromising safety.

A research program was undertaken to measure the trailer tracking fidelity of a number of vehicle types. This performance information was used to develop further understanding and knowledge of the road space requirements for these vehicles and to validate a computer simulation system to predict the road space requirements for other vehicle types and combinations.

A number of full-scale tests were conducted to obtain dynamic performance for a range of vehicle types as they travelled over a number of different road profiles at three nominal speeds. Both wheel track road profiles were measured on the test roads from which the spectral and cross-slope characteristics were computed. These profile data were used as vehicle inputs in computer simulations to estimate the vehicle road space requirements.

This study demonstrated two methods of estimating vehicle lateral motion during normal in-service operation; one is video-camera based, the other uses an accelerometer whose output has been corrected for vehicle roll and road cross-fall. It was established that driver steering activity, road cross-fall, road unevenness, and travel speed are key parameters influencing trailer tracking, and must be considered in computer modelling of vehicle on-road dynamic performance. The major output from this work is a validated computer simulation system that allows road space requirements for combination vehicles to be predicted.

Information from this study has provided preliminary input to the development of a suite of performance-based measures and target values that have been proposed for National endorsement to be used when assessing candidate vehicle for access to the road network. Further work on the development of profile indices specific to heavy vehicles is recommended as it has been shown that vehicle lateral motion behaviour is not consistent with the road roughness classification system based on the traditional roughness indices of NAASRA roughness or IRI.

INTRODUCTION

Transport efficiencies could be improved if heavy commercial vehicles (HCV) were allowed greater access to the road network; this of course would only be acceptable if safety is not compromised. With the development and introduction of purpose-built and innovative, new vehicle types, permits are being sought for a more diverse range of vehicle configurations. Regulators and government agencies lack information and the means to assess the suitability of these different vehicle types to access the most appropriate parts of the road network.

The existing methods for defining HCV routes or issuing permits for routes is based on subjective judgements, and experience with the current vehicle fleet, and these methods make no allowance for new or different vehicle types or configurations.

When articulated-vehicles travel at highway speeds in a straight line, the trailers do not necessarily follow exactly the same path as the prime-mover. Road space is the total envelope that a vehicle sweeps laterally as it travels at highway speed – it is the sum of the vehicle width at the rear plus the lateral deviation of the rear unit. This phenomena is referred to as vehicle **Road Space Requirement** and means that dynamically such vehicles tend to occupy a greater road width than when they are stationary.

A performance-based scheme to determine route access for HCVs is presented that considers the effect of road surface characteristics (roughness and cross-slope) on the vehicle's road space requirement performance and hence attempts to match the vehicle to the road network. This system can be used to assess the suitability of a specific vehicle to use specified roads or assess the road characteristics that are required to allow a specific vehicle to access that route.

In general, the concept of defining performance criteria for a vehicle using a specific road has potential to improve efficiency and productivity in the road transport system and provide information to determine the safety or risk to other road users.

This paper outlines the method, and its development, for determining route access for heavy commercial vehicles using a performance-based scheme.

METHOD

A number of field tests were conducted to study develop and understanding of the lateral behaviour of heavy vehicles as they travel at highway speeds on roads of varying roughness. These tests also provided information that enabled the validation of computer simulations to predict the road space requirements for a range of existing or proposed vehicle types, or combinations.

Field tests were conducted on two separate occasions. The first, under contract to the Roads and Traffic Authority of NSW, in May/June 1995 when 6 HCV types were tested on roads roughness characteristics were measured with a highway-speed laser-based roughness measuring system, and the second in September 1996 using 2 HCV types over the same roads used in the first series of tests. Table I summarises test vehicles used for both the field experiments, their length and gross combination mass.

Table I: Test vehicle details

Vehicle Code	Description	Length (m)	GVM (t)	Series 1	Series 2
A123	Semi-trailer	18.5	42	√	-
A123-T23	A-double	33	80	√	√
A123-T23-T23	A-triple	49	110	√ √	-
B1223	B-double	23	58	√	-
B1233	B-double	25	62	√	-
R12-T12	Truck/trailer	16.8	43	-	√

ROAD CHARACTERISATION

Prior to the second series of tests the road characteristics in each travelled wheel path were measured using ARRB TR walking profiler (ARRB TR (1995)). This device was used to measure the absolute left and right track wheel paths on each test section.

Figure 1 is a plot of the raw profile data for the driver and passenger side wheel paths for the 'medium' roughness test section taken in the east bound direction. Both profiles have the same initial starting reference point and have not been corrected for cross-slope.

In order to ensure the wheel path profiles taken with the walking profiler contained the correct cross-slope information, additional measurements were taken every 100 m and were used to make adjustments as required.

Figure 2 shows the same profile information as presented in Figure 1 corrected for the measured cross-slope.

Table II lists two measures of road roughness, namely, International Roughness Index (IRI) and the mean square value of profile height. The mean square of profile height is simply the average value of all the profile height data after they have been squared. While both measures are useful, the second, the profile mean square, covers the full wavelength range and is considered a better measure of total energy in the profile producing vibrations in the vehicle. It can be seen from Table II that for the medium roughness test section the driver-side wheel path profile mean square is one third more that of the passenger-side wheel path. This difference is believed to be significant with respect to induced lateral motions of the vehicle units and its effect will be discussed later. The average cross-slope for the medium test section is also larger than the other test sections, this could also contribute to the lateral behaviour of the vehicle over this section.

It is important to note that classification of the road by roughness - smooth, medium and rough - is based on IRI. IRI by definition is a measure of pavement rideability as perceived by a person travelling on the road in a passenger car. IRI does not cover the full range of roughness wavelengths (only 1 to 30m) and therefore may be excluding some important features of the road profile affecting lateral motion of HCVs on the road network. Further work is required to develop road roughness indices which are sensitive to road profile features likely to cause large lateral motions in HCVs. The possible application of such indices could be a much wider and include ride comfort for example.

Table II: Measure road characteristics

Test Section	Length (m)	Roughness (IRI)		Profile elevation mean square		Cross-slope (average) (%)
		Passenger (mm/m)	Driver (mm/m)	Passenger ($m^2 \times 10^{-3}$)	Driver ($m^2 \times 10^{-3}$)	
Smooth	1,200	2.94	3.01	1.8	1.7	-3.2
Medium	1,000	4.36	3.85	1.8	2.4	-4.5
Rough	998	4.38	4.53	3.8	4.1	-4.0

Roads and test speeds

Throughout this report the road roughness levels and travel speed have been coded as follows:

- S, M, R 60 smooth, medium and rough roads at 60 km/h;
- S, M, R 75 smooth, medium and rough roads at 75 km/h;
- S, M, R 90 smooth, medium and rough roads at 90 km/h.

The following test roads were selected to represent the three levels of road roughness for this work:

- Smooth SAE (Smooth section ‘A’ east bound)
- Medium MBE (Medium section ‘B’ east bound)
- Rough RCW (Rough section ‘C’ west bound)

FIELD RESULTS

Data obtained from the second field test series were processed to obtain vehicle performance information. Both lane change and road space data were measured for the A-double whereas only road space data for the truck/trailer combination were taken. Lane change data were collected for a range of truck/trailer combinations during the recent study conducted by George et al (1996).

Lane change tests

Lane change tests were conducted with the A-double as outlined in SAE (1993), however, the data were processed using the lateral acceleration peak values rather than the RMS method from the SAE draft procedure. Results from the lane change tests are summarised in Table III. These data show that the mean rearward amplification for the A-double taking the maximum positive values was found to be 1.6, and 1.3 using the maximum negative values. The main purpose of obtaining lane change data for this vehicle was to provide data to validate the computer simulation, it also contributes to the general body of knowledge in this area.

Table III: Lane change results for the A-double

Run	Lateral acceleration				Rearward Amplification		Speed (km/h)
	Prime mover		Rear trailer		Positive	Negative	
	Max	Min	Max	Min			
1	0.15	-0.13	0.22	-0.15	1.48	1.13	88
2	0.14	-0.12	0.23	-0.15	1.73	1.32	92
3	0.10	-0.09	0.14	-0.12	1.37	1.32	89
4	0.11	-0.10	0.17	-0.15	1.54	1.45	89
5	0.09	-0.11	0.18	-0.15	1.92	1.34	-
				Mean	1.61	1.31	89.5
				SD	0.22	0.12	1.80

Figure 3 shows a typical lateral acceleration time history for the A-double. The peak on the prime-mover signal occurring at approximately 6 sec is the initial lateral vehicle movement on the course and the larger peak at approximately 7.3 sec is the acceleration that the vehicle experienced as it manoeuvred onto a line parallel to the forward direction of travel.

Lateral position measuring system

A video-based system was developed to estimate the lateral movement of the rear of the vehicle during the second field tests. This system incorporated a pavement marking system which operated by spraying a jet of water onto the pavement from a nozzle secured to the front of the vehicle. The jet of water would leave a water trace on the pavement of the vehicle’s path and a video camera mounted on the rear of the vehicle aimed at the pavement would record an image of the pavement showing the water trace. The location of the water trace in the video recording was used to estimate the lateral position of the rear of the vehicle relative to the towing unit. These video recordings were processed in the laboratory to extract the vehicle lateral position from each video frame.

Figure 4 shows the lateral position of the rear of the A-double, measured relative to the water trace left by the lead unit, when travelling over the medium roughness road at 75 km/h.

The video data were analysed and lateral position determined. These have been summarised in Tables IV and V for the two vehicles used in the second field test series, involving the A-double and truck/trailer, respectively. These data are the average of the repeat test runs.

Table IV: Measured relative lateral movement for the A-double

	Total lateral movement (mm)		
	Speed (km/h)		
	60	75	90
Smooth	159	170	178
Medium	256	323	371
Rough	229	248	321

The data shown in Table IV indicate that over the medium roughness road at 90 km/h the rear of this trailer has moved laterally a total of approximately 370 mm with reference to the prime mover. It is important to note that this does not consider the lateral movement of the hauling unit relative to the road, which has been assumed here to be small.

Table V: Measured relative lateral movement for the truck/trailer

	Total lateral movement (mm)		
	Speed (km/h)		
	60	75	90
Smooth	124	138	165
Medium	197	226	278
Rough	183	214	227

The effect of vehicle speed and road roughness on the lateral motion behaviour of the A-double is shown in **Figure 5a**, where it can be seen that there is equal or greater lateral movement on the medium road (MBE) compared to the rough road (RCW).

Figure 5b shows the effect of vehicle speed and road type on the lateral behaviour of the truck/trailer. A similar vehicle lateral response was measured for this vehicle as on the A-double - equal or greater lateral movement over the medium road (MBE) than the rough road (RCW).

Estimate of lateral movements

Lateral motion of the vehicle units was also estimated from the measured lateral acceleration signals by using a double integration scheme to calculate lateral displacement. The integration was performed numerically using a digital filter similar to that successfully employed in the ARRB TR highway-speed profilometer (Prem 1989). The lateral acceleration signal was corrected for vehicle roll angle, and the component of gravity was removed that is sensed by the accelerometer when its axis of measurement moves away from the vertical with vehicle roll angle. **Figure 6** compares the two independent estimates of lateral for the A-double travelling on the medium road at 75 km/h. It can be seen that the lateral acceleration based estimate compares well with the video based measurements and could be considered for future trials. It is a much simpler system to install and data processing requirements are very modest. This technique was later used to estimate lateral motion of the hauling unit.

Driver steering activity

Table VI summaries the lateral movement based on lateral acceleration measured on A-double for the three test speeds over the test sections, and it can be seen that driver steering activity increases with vehicle speed and road roughness consistent with the fact that task demand increases with both speed and roughness.

Table VI: A-double: Estimated lateral movement at the prime-mover

Speed (km/h)	Lateral movement (mm)		
	Smooth	Medium	Rough
60	106	101	106
75	100	125	155
90	132	120	171

COMPUTER SIMULATIONS

The A-double vehicle that was used for the second series field trials was modelled using the ADAMS1 multi-body dynamics package (MDI, 1997) and a validation study using the measured lane change manoeuvre data was conducted, and reported by Elischer and Prem (1997).

Further validation of the computer simulations were performed and comparisons were made against the video-based lateral movement estimates from measurements taken on the road test sections. [Figure 7](#) shows data from three repeat runs over the same section of road (medium roughness) at a speed of 90 km/h. While there is a general underlying trend, the variation between the runs is clearly apparent and this would be due to differences in driver tracking from one run to the next, small speed variations between runs, and inaccuracies in converting the video screen coordinates to lateral position, for example.

[Figure 8](#) shows a time history comparison between the measured and the simulated lateral movement for the A-double travelling over the rough road at 90 km/h. The comparisons show there is generally good agreement between the measured and simulated results in terms of both the general range of movement and frequency content, thus confirming the predictive capability of the computer model. As before, differences in driver tracking from one run to the next, small speed variations, and inaccuracies in converting the video screen coordinates to lateral position, would introduce run-to-run variations in the real data accounting for some of the observed differences. In the simulations both driver tracking and speed can be controlled very precisely.

Table VII: A-double: lateral movements at 90 km/h

	Measured	Simulated
	SD (mm)	
Smooth	48	73
Medium	59	76
Rough	73	69

Table VII shows a comparison between the measured and simulated lateral movements standard deviations for the A-double travelling over the medium roughness road at 90 km/h. Overall, the predictions are considered reasonable given the size of the lateral movements, approximately 50 to 80mm, and the various sources of possible variation and error previously identified

A number of vehicle models were created using dimensions for 85th percentile vehicles from Austroads (1995). Simulations were conducted with these models on the medium measured road profile at 90 km/h to predict the lateral movement and estimate the total vehicle road space requirements.

Road space requirements

Given that the lateral movement of the rear trailer is broadly normally distributed, then the vehicle road space requirements can be conservatively estimated using ± 3 standard deviations from the mean.

**Table VIII: Estimates of lateral movements
90 km/h on medium roughness road**

Vehicle	Standard deviation (mm)	Total Movement	Road space (m)
A123	35	211	2.71
A-double	76	456	2.96
A-triple	154	923	3.42
B-double	38	231	2.73
B-triple	37	223	2.72

Table VIII shows the estimated total movement for the modelled vehicles travelling on the medium roughness road at 90 km/h. This Table also shows estimates for the road space requirements for these vehicles using a vehicle width of 2.5 m. The difference between the measured lateral movement of 371 mm for the A-double (from Table III) and the estimated 456 mm from Table VIII could be attributed to the difference in the shape of the discrete probability density functions and the difference in sample size due to the sampling frequencies.

It is important to note that the road space estimates in Table VIII assume that the vehicle is travelling in a straight line and some tolerance will need to be added to allow driver behaviour when negotiating horizontal curves.

ROUTE SELECTION CRITERIA

Information from this study allows route selection criteria to be set using estimated vehicle lateral movements together with road geometry information on the desired route.

Possible criteria

The proposed route assessment scheme is based on the road space requirements of the candidate vehicle. Specifically, the lane encroachment could be classified in terms of the magnitude and duration that the vehicle exceeds the lane width, as it travels over the proposed route giving consideration to questions such as:

- (a) Does the vehicle encroach into adjacent lanes ?
if so:
- (b) What are the magnitudes of the encroachments ?
- (c) What is the duration of the encroachments over the journey ?

With road geometry information maintained by the jurisdictions, these proposed criteria could be used to assess a candidate vehicle's suitability to use a specific route.

CONCLUSIONS

This paper has shown that it is possible to both directly measure and predict road space requirements for heavy commercial vehicles, and that measurements of road space requirements can be made during normal in-service operation with fairly modest acceleration-based equipment.

The creation of computer vehicle models and the application of simulation techniques provides a viable means of making both vehicle or road based assessments of road space requirements. This enables assessments to be made of the suitability of specific vehicle types to access a road network, or, alternatively, make assessments of a road network and identify vehicle types that can access that network.

Information from this study has provided an input to the development of a suite of performance-based measures and target values (George et al 1998) that have been proposed for National endorsement to be used when assessing candidate vehicle for access to the road network.





REFERENCES

ARRB TR (1995). Walking Profiler Instruction Manual. (ARRB Transport Research: Vermont South, Vic).

AUSTROADS (1995). Design Vehicles and Turning Path Templates. (Austroads: Sydney NSW).

ELISCHER, M.P. and PREM, H. (1997). Validation of heavy vehicle dynamics modelling using ADAMS - Lane change manoeuvre. Contract report OC6053V, restricted circulation. (ARRB Transport Research: Vermont South, Victoria).

GEORGE, R.M., ELISCHER, M.P. and PREM, H. (1998). Exemption guide-lines for non-standard vehicles. Fifth Symposium on Heavy Vehicle Weights and Dimensions, Queensland Australia.

GEORGE, R.M., GLEESON, B.P., ELISCHER, M.P. and RAMSAY, E.D. (1996). Assessment of truck/trailer dynamics, contract report C5535A. (ARRB Transport Research: Vermont South, Victoria).

ISO (1995). Mechanical vibration - Road surface profiles - Reporting of measured data, International Organisation for Standardisation 8608. (ISO: Geneva).

MDI (1997). "www.adams.com", Mechanical Dynamics, Inc. Ann Arbor Michigan, Internet Website.

PREM, H. (1989). The ARRB highway-speed road profiling system: description, technical manual and user's guide. Report to Australian Road Research Board. (Restricted circulation).

SAE (1993). A Test For Evaluating the Rearward of Multi-Articulated Vehicles. Draft J2179, Society of Automobile Engineers. (SAE: Warrendale, PA).





AUTHOR BIOGRAPHIES

Rod George - Senior Research Scientist

Rod George joined ARRB Transport Research in 1977 after serving a traineeship at the Aeronautical Research Laboratories Melbourne. Rod is a member of the heavy research team at ARRB Transport Research and was appointed a Vehicle Design Associate of the International Journal of Vehicle Design. He is currently working on a Masters Degree in Engineering at Swinburne University of Technology. He has been involved in a number of heavy vehicle research programs including: stability, driver comfort, dynamic pavement loading of articulated vehicles, ride, stability and handling of ambulances and the evaluation of truck/trailer combination dynamics with increased mass ratios.

Matt Elischer - Research Engineer

Matt joined ARRB TR in May 1996 after graduating from Royal Melbourne Institute of Technology (RMIT) with a Bachelor of Mechanical Engineering (Hons). He works in the Heavy Vehicles & Mining area, where he is heavily involved in computer modelling and simulation. Matt also investigates heavy vehicle dynamics and performance assessment, a component of this work is data interpretation and analysis.

Dr. Hans Prem - Principal Research Engineer

Hans Prem has a Bachelor's degree and a Ph.D. in Mechanical Engineering from the University of Melbourne, which he received in 1979 and 1984, respectively. His interests are principally in vehicle dynamics and road roughness research. Hans first joined ARRB Transport Research in 1984, and was responsible for development of the prototype version of the ARRB laser profiler. In 1989 Hans left ARRB TR to take up a position in BHP Research, as a specialist in heavy haulage vehicles in mining equipment research, where he played a central role in the design and manufacture of a new and innovative off-highway haulage truck (220t payload capacity). He was also involved in blast-hole drill-rig automation and airborne reconnaissance technology. Hans returned to ARRB TR in 1997, where he is Research Coordinator of the Heavy Vehicles and Mining business area.



ACKNOWLEDGMENT:

The work described in this paper has been carried out under the auspices of Austroads National Strategic Research Program, their funding and support is gratefully acknowledged.

The views expressed are those of the authors and not necessarily those of Austroads.



Introduction



Content

FOOTNOTE

ADAMS (Automatic Dynamic Analysis of Mechanical Systems) is a general purpose multi-body dynamics modelling package, developed at the University of Michigan in the late 1970's. It was enhanced and further developed into a commercial product by Mechanic Dynamics Inc., the first version was released in 1980.



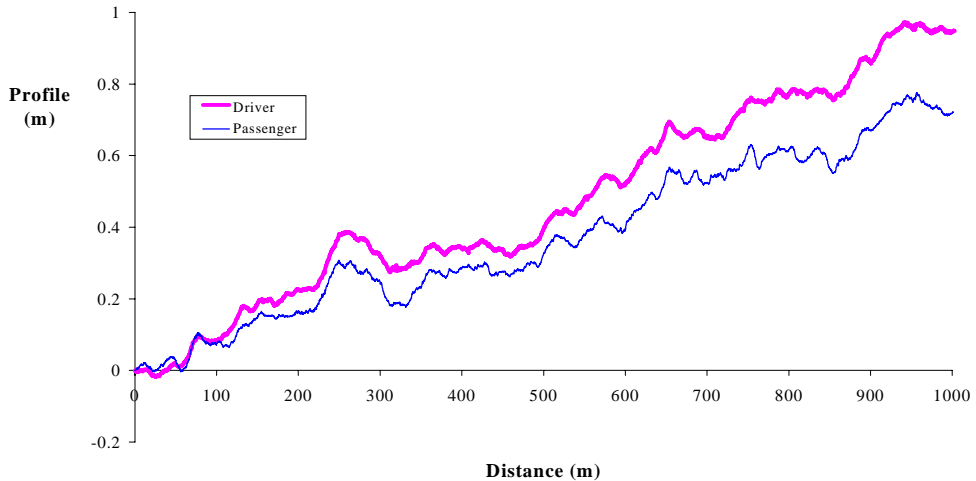
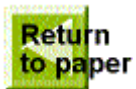


Fig. 1 - Profile of the medium roughness test section east bound



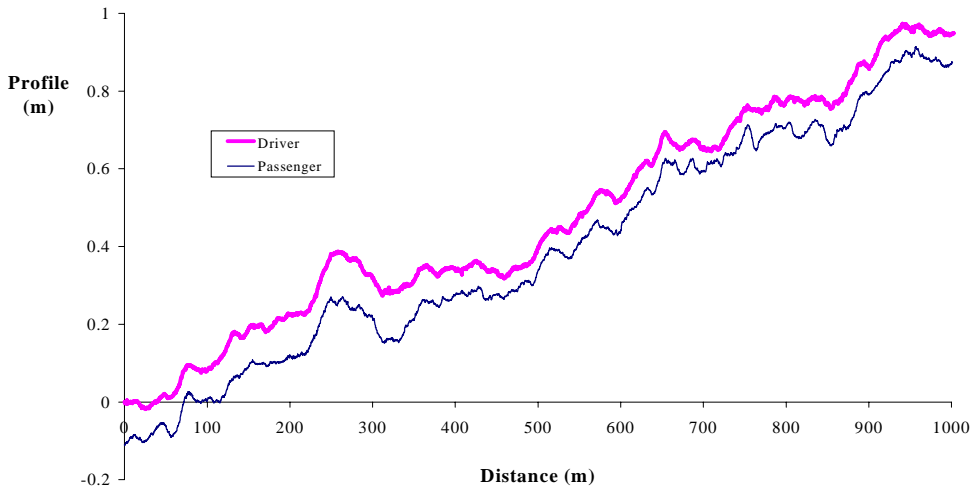


Fig. 2 - Medium roughness test section profile corrected for cross-slope



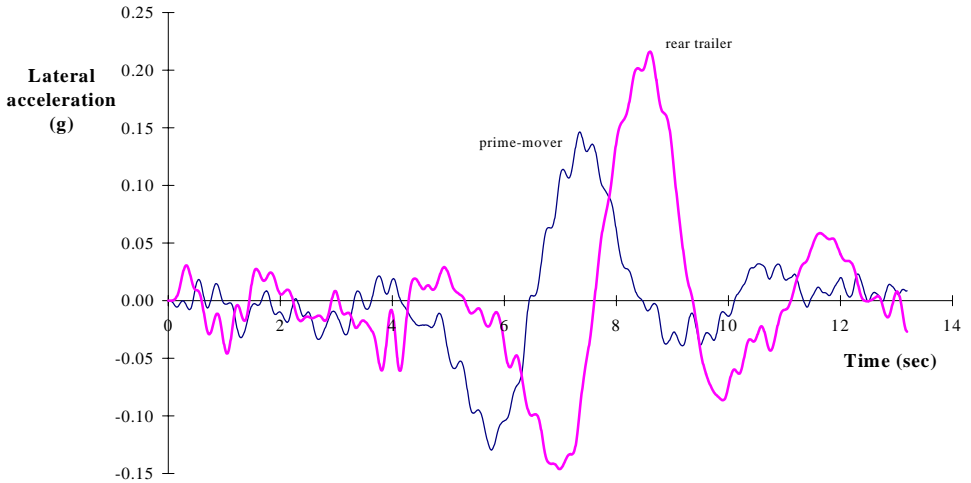


Fig. 3 - Typical lane change time history



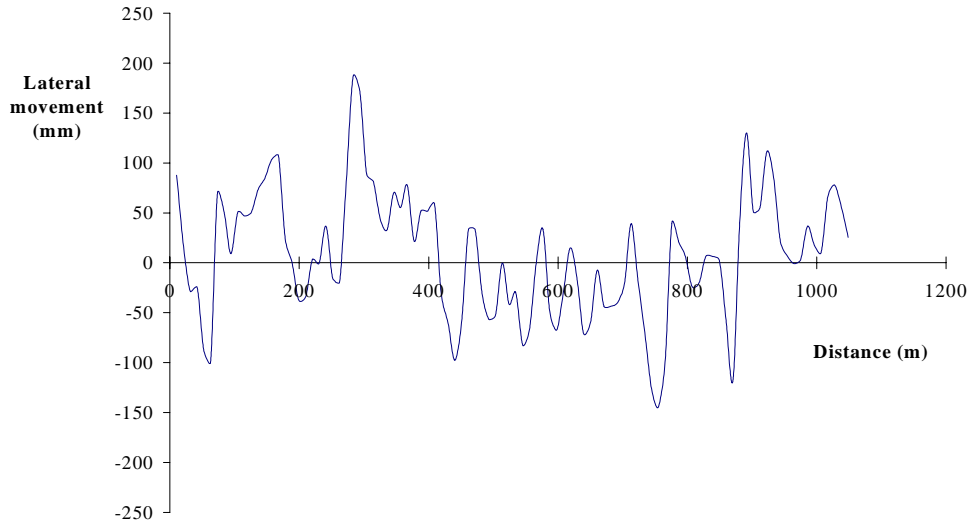
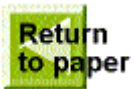
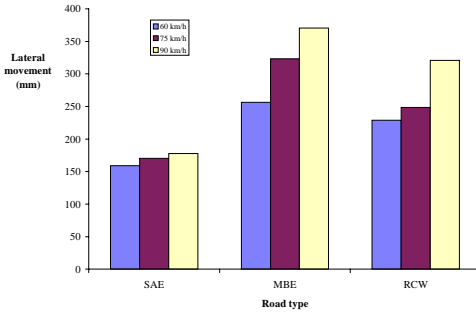
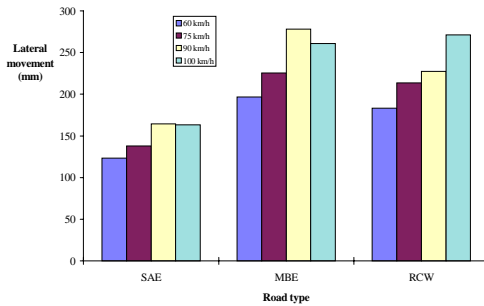


Fig. 4 - A-double: Lateral position travelling over a medium road at 75 km/h



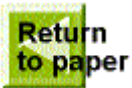


5a - A-double



5b - Truck/trailer

Fig. 5 - Measured relative lateral movement



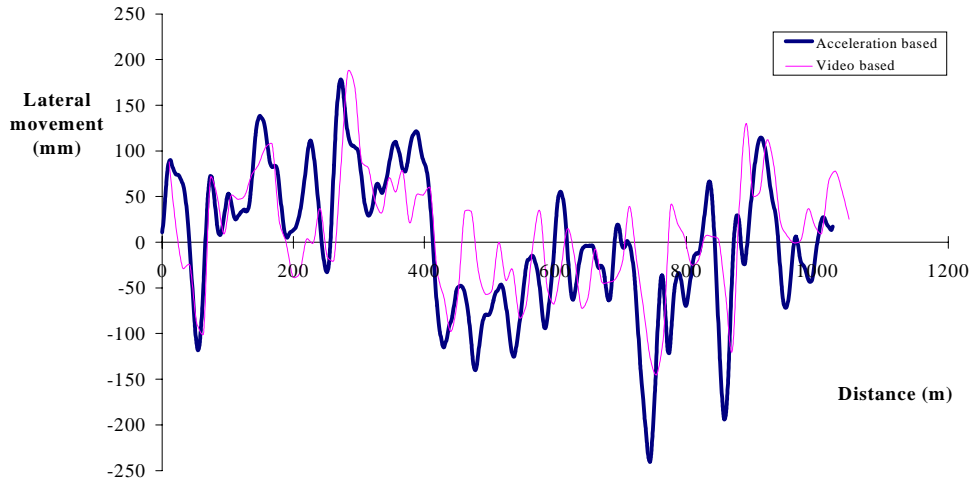
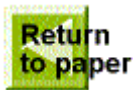


Fig. 6 - A-double: Comparison of measured and acceleration-based estimate of the lateral movement



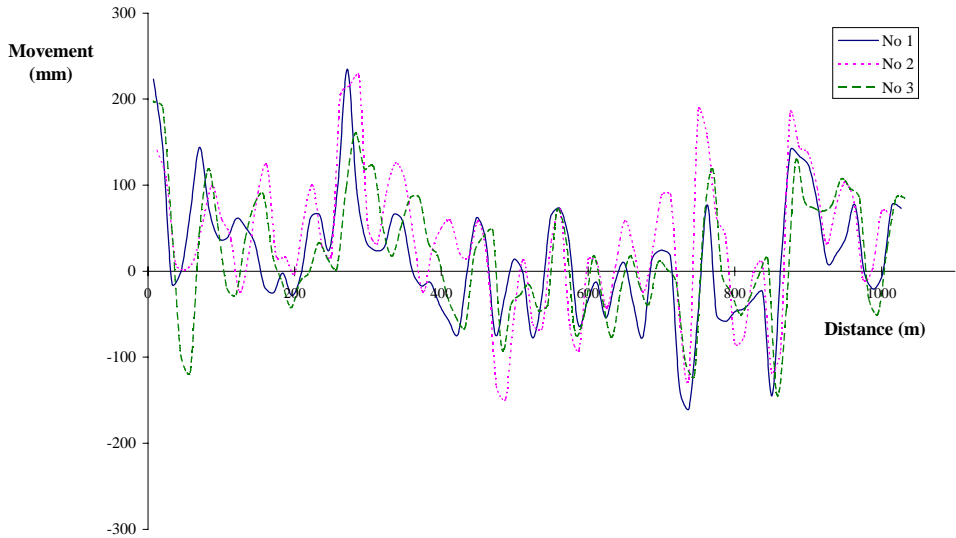


Fig 7 - A-double: Measured lateral movement - MBE 90 km/h



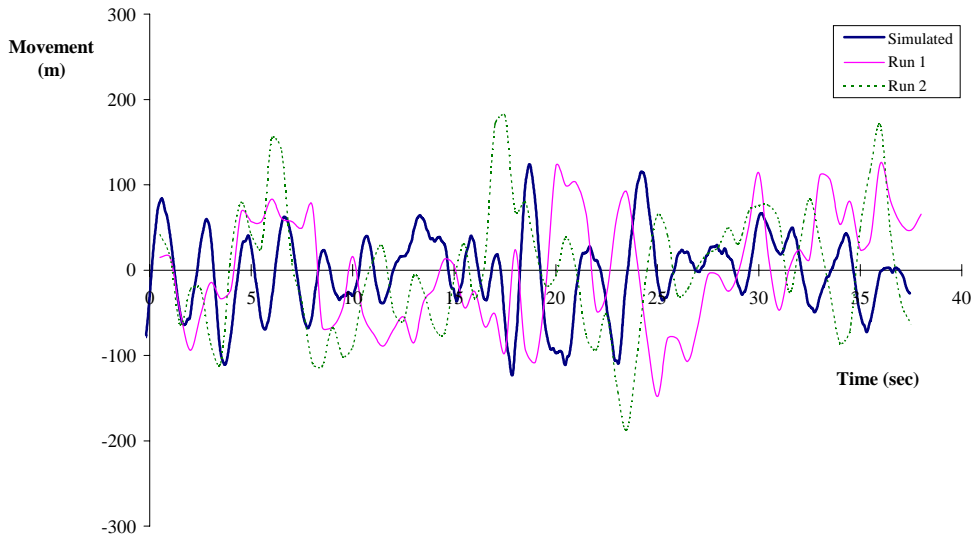


Fig 8 - A-double: Measured and simulated lateral movement - RCW 90 km/h

