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THE DEVELOPMENT OF HIGH PRODUCTIVITY LONG COMBINATION VEHICLES USING “VIRTUAL PROTOTYPING”

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Significant productivity and safety gains in transportation of bulk commodities can be obtained through the use of innovative Long Combination Vehicles (LCVs). Innovative LCVs generally utilise B-coupled trailers, triaxle suspension groups and air suspension.

By using “Virtual Prototyping” techniques such as heavy vehicle dynamic simulation and animation it is possible to demonstrate to regulatory authorities that new vehicle concepts are capable of having dynamic performance that is equivalent to the mid-range of heavy vehicles which are currently operating. Dynamic performance measures such as Rearward Amplification, Load Transfer Ratio, High-Speed Dynamic Offtracking, High-Speed Offtracking, Low-Speed Offtracking and Trailing Fidelity have been found to be important in assessing innovative LCV designs.

This paper discusses examples of innovative LCVs such as the 3B, the AB-triple, and the 2B3 and the techniques used to assess them. The 3B has been operating for over 2 years hauling mineral concentrates 24 hours a day from the MacArthur River Mine in the Northern Territory, travelling 120 km on public roads to a port facility. The 3B’s operating costs are the lowest in the world for a road vehicle. The AB-triple is an alternative to a conventional double road train and has significant advantages in productivity and safety. The 2B3 is the latest and greatest in innovative vehicle design. It has very significant productivity and dynamic performance advantages when compared to conventional triple road trains.

INTRODUCTION

Innovative vehicles have become topical in Australia. Through negotiation, larger more productive vehicles such as the 3B, the AB-triple and the 2B3 are beginning to appear on Australian roads. These vehicles exceed the current mass limits by incorporating more axle groups and more trailers than conventional designs.

These vehicles have been developed with idea of improving freight vehicle productivity while maintaining or improving safety.

Performance based standards and “Virtual Prototyping” techniques (simulation modelling and animation) are the key to integration of larger innovative vehicles into selected portions of the existing infrastructure.

There are currently no performance-based standards implemented in Australia. However, it is possible to demonstrate to regulatory authorities that new vehicle concepts, which are capable of having dynamic performance that is equivalent to the mid-range of heavy vehicles are suitable alternatives to conventional vehicles.

CURRENT REQUIREMENTS

Heavy vehicles in Australia are currently required to meet a range of regulations, which affect their on-road performance. These regulations cover braking, length, width and height, “internal” dimensions, turning circle and mass limits. Industry practices, with respect to selection of vehicle configuration and components, together with the characteristics of loads carried, combine with these regulations to define the dynamic performance of heavy vehicles using Australian roads. The dynamic performance of vehicles making up the national fleet, in turn, affects traffic safety and interaction with the road system.

In Australia, limited-access vehicle configurations are termed Medium Combination Vehicles (MCVs) and Long Combination Vehicles (LCVs). These configurations exceed 19 m in overall length and 42.5 t in Gross Combination Mass (GCM); MCVs are limited to 25 m and 62.5 t, while LCVs are generally limited to 53.5 m and 115.5 t.

INNOVATIVE VEHICLE DESIGN

Innovative vehicles can involve a wide range of B-coupled and A-coupled trailers but generally utilise the following design features:

- “B-coupled” trailers
- triaxle groups
- air-suspensions

These are shown in **Figure 1**.

THE OPERATIONAL ENVIRONMENT

In Australia the infrastructure is unique in that distances are large and road conditions, although relatively straight, may be less than ideal for the operation of large combination vehicles. **Figure 2** shows a typical Northern Australian road section on which road-train doubles and triples operate.

PERFORMANCE-BASED STANDARDS

Performance-based specifications are intended to focus heavy vehicle regulations on desired outcomes (ie. safety and the interaction with other traffic and the road system) and provide a rationale for assessing the implications of design modifications and vehicle innovations.

Performance-based specifications, when combined with quality assurance mechanisms, offer the prospect of significant gains in the productivity of the road freight industry because vehicle design could directly address the needs of a particular transport task, instead of being constrained by generalised configurations and limits. On the other hand, there are perceived difficulties with performance-based standards in that they may be complex, highly technical and difficult to enforce. For example, it is easier to regulate overall length than to regulate swept path of a vehicle combination.

When applied to limited-access vehicle configurations, performance-based analysis is additional to all other traditional vehicle standards applicable to heavy vehicles, including braking, lighting, mechanical integrity, noise, emissions, etc.

MODELING OF DYNAMIC PERFORMANCE

Simulation modelling provides a practical means of quantifying the dynamic performance of innovative vehicle configurations. It also permits the effects of individual vehicle parameters to be investigated and vehicle configurations to be optimised for particular road environments. Simulation models, when validated against experimental data, offer powerful insights into the dynamic performance of heavy vehicle configurations.

Roaduser Research has carried out a number of investigations of innovative vehicle combinations, using the University of Michigan Transportation Research Institute (UMTRI) AUTOSIM modelling software. Custom yaw/roll models, an example of which is illustrated in **Figure 3(a) & 3(b)**, have been developed. These models are designated as the Roaduser Autosim Truck Engineering Dynamics (RATED) models and they allow the rapid quantification of dynamic performance.

MODEL CHRACTERISTICS - The models are based on a rigid-body yaw/roll formulation similar to that used in [1]. However, by using AUTOSIM it is possible to extend the models to a larger number of trailers and also allow the modelling of a three-dimensional road surface. These custom models have been used to indicate the relative performance quality of various innovative vehicle options and have facilitated negotiation with Australian road managers in order to bring about the construction and trialing of the most promising vehicle configuration options. New vehicle configurations have been tested, and the resulting data have been used to validate the RATED models for future simulation projects. The results have shown a very good comparison between measured and simulated performance.

TIRE MODELING – The tire model used in a vehicle dynamics simulation is the key to a good approximation of the real world. Various truck tire models have been developed [2,3]. However, unlike car tires there is insufficient data available on truck tires to include in the more complex models. The most practical tire model that can be used in heavy vehicle dynamic model is that of a dual parameter look up table. This type of tire model assumes that the lateral tyre force and aligning moment is a function of instantaneous vertical load and slip angle. Truck tire data is readily available from tire manufactures for models with this level of complexity.

PERFORMANCE ATTRIBUTES MODELED

The Roads and Transportation Association of Canada (RTAC) Weights and Dimensions Study [4] broke new ground by integrating a useful set of performance attributes into a size-and-weight decision process. These performance attributes were modelled using UMTRI simulation programs, including Yaw/Roll. Recent work by Roaduser Research has utilised a number of the RTAC performance attributes and has developed some additional attributes in the area of trailing fidelity performance.

The RTAC performance attributes considered are:

- steady-state roll stability
- rearward amplification
- load transfer ratio
- high-speed dynamic offtracking
- high-speed offtracking
- low-speed offtracking.

AUTOSIM has also been used to model certain aspects of trailing fidelity. When a combination vehicle is travelling at highway speed, the rear unit of the combination tends to exhibit more lateral movement than the hauling unit. This may be caused by external disturbances such as road roughness, changes in crossfall, wind effects, etc. The ability of the vehicle to control and damp out such motions is termed trailing fidelity. Alternatively, the total excursion of the rear unit is sometimes called the swept width of the vehicle.

Trailing fidelity caused by external disturbances such as road roughness, changes in crossfall, wind effects, etc; has received little research. The following specific aspects of trailing fidelity have been included in the RATED system:

- response to the vehicle suddenly encountering a depression in one wheel path **(Figure 4)**
- response as the vehicle travels on an isotropic road surface **(see Figure 5)**

In the case of the road depression the peak lateral motion of the rear trailer has been computed for a speed of 80 km/h. The lateral motion of the rear trailer is asymmetric so the peak excursion was computed for both inboard and outboard movements. The motion of the rear trailer was also characterised in terms of the time required to damp the trailer motion to 10% of its peak value.

In the case of the vehicle travelling on the isotropic road surface the 95th percentile of the difference between the front and rear motions of the rear is computed.

EXAMPLES OF SIMULATED VEHICLE PERFORMANCE

TRAILING FIDELITY PERFORMANCE - Consideration of the use of larger, more productive road trains on specific routes is often dependent on the ability of the combination vehicle to track well on narrow bitumen roads. The additional road width required to accommodate sway at the rear of the combination vehicle is of concern to road managers in relation to the interaction of the combination vehicle with oncoming traffic. The innovative vehicle configuration known as the 3B was evaluated for potential trailing fidelity performance. This vehicle consists of three B-double trailer sets connected via triaxle converter dollies and is discussed later in the paper. It should be noted that the GCM of this configuration is 204,500 kg, as compared to 115,000 kg for the A-triple.

Depression - The results in **Figure 6(a)** show the trailing fidelity time history as the 3B road-train travels through the depression in the road-surface. The results in **Figure 6(b)** are for an A-triple.

Isotropic-road - The results in **Figure 7(a)** show the trailing fidelity time history as the 3B road-train travels on 1km of the artificially generated road-surface with IRI of 3.0. The results in **Figure 7(b)** are for an A-triple. The results show that the 3B vehicle tends to exhibit less movement at the rear than the A-triple

DYNAMIC PERFORMANCE - In order to assess the dynamic performance of combination vehicles, simulation of a single-lane-change avoidance manoeuvre, as shown in **Figure 8**, may be carried out. This manoeuvre is similar to the standard SAE manoeuvre. However, as the maximum operational speed of the 3B is 80km/h the speed at which the manoeuvre was conducted was reduced to 80km/h.

The following dynamic-performance measures for the 3B were quantified and compared to those of existing vehicles:

- rearward amplification
- load transfer ratio

- high-speed dynamic offtracking

The results in **Figure 9(a)** show the motion of the front and rear of the 3B as it travels through the lane-change manoeuvre. The results show that there is approximately 1.2 m of high-speed dynamic offtracking. The results in **Figure 9(b)** are for an A-triple. The results show that the 3B vehicle tends to exhibit similar performance to the A-triple in the lane-change manoeuvre.

The results in **Figure 10(a)** show the lateral acceleration time histories for the prime mover and each trailer of the 3B in the lane-change manoeuvre. The results in **Figure 10(b)** are for an A-triple. The results show that the 3B vehicle has higher rearward amplification than the A-triple.

The results in **Figure 11(a)** show the load transfer ratio for each roll-coupled unit (RC1-RC3) of the 3B in the lane-change manoeuvre. The results in **Figure 11(b)** are for an A-triple. The results show that, despite the 3B having higher rearward amplification than the A-triple, it has Load Transfer Ratio which is approximately 30% less than that of the A-triple. This is due to the roll-coupling in the B-double trailer sets. The results also show that the A-triple approached a roll-over condition (LTR=1.0).

EXAMPLES OF PERFORMANCE EVALUATION USING SIMULATION

TRAILING FIDELITY PERFORMANCE - While the simulated time histories give large amounts of information regarding the performance of the vehicle it is necessary to reduce this to a single or small set of defining criteria in order to optimise vehicle configurations. In the case of the vehicle travelling through the depression the peak inboard and outboard motion and the time required for the vehicle to damp the motion is used.

The results in **Figure 12** show that the outboard movement of the 3B vehicle is slightly greater than the range of performance of the A-triple configurations.

The results in **Figure 13** show that the inboard movement of the 3B vehicle is equivalent to the range of performance of the A-triple configurations.

The results in **Figure 14** show that although the 3B has lateral movement similar to the maximum of the A-triples, it has good lateral damping characteristics.

The results in **Figure 15** show the 95th percentile of the difference between the front and rear motions for the vehicles travelling on an isotropic road surface. The results show that the 3B vehicle has trailing fidelity performance similar to that of the better of the A-triples.

DYNAMIC PERFORMANCE - The results in **Figure 16** show the rearward amplification of the 3B vehicle as compared to existing A-triples. The results show that the rearward amplification is 10% greater than the range of A-triple performance.

The results in **Figure 17** show that the load transfer ratio of the 3B is similar to the better performing A-triples.

The results in **Figure 18** show the high-speed dynamic offtracking of the vehicles as they conduct the lane-change manoeuvre. The results show that the 3B vehicle has characteristics similar to those of the better performing A-triples.

THE RESULTS OF THE DESIGN BY SIMULATION PROCESS

Figure 19 shows a large innovative vehicle designed by Roaduser Research. This vehicle, known as the 3B, incorporates both triaxle dollies and a triaxle-drive prime-mover and consists of a three B-double trailer sets connected via triaxle converter dollies.

Two vehicles of this type have been operating for over two years hauling mineral concentrates 24hrs per day from the MacArthur River Mine in the Northern Territory, travelling 120km on public roads to a port facility. The 3B’s operating costs per tonne of payload moved are believed to be the lowest in the world for a road legal vehicle.

Figure 20 shows a smaller innovative vehicle designed by Roaduser Research. This vehicle, known as the AB-triple, incorporates a tractor semi-trailer and a B-double trailer set connected via a triaxle converter dolly.

These vehicles have been granted access to double roadtrain routes in Northen Australia as an alternative to the double roadtrain. The payload of the AB-triple can approach that of a triple roadtrain, providing a significant productivity benefit on double roadtrain routes.

Figure 21 shows a more recent innovative vehicle designed by Roaduser Research. This vehicle, known as the 2B3, incorporates both triaxle dollies and a triaxle-drive prime-mover and consists of a two B-triple trailer sets connected via a triaxle converter dolly.

This vehicle is a prototype operating on mineral concentrate haulage at the BHP Cannington Mine in Queensland. This vehicle represents the future of high-productivity innovation and was developed using the RATED simulation and animation system. Both the dynamic performance and productivity of this vehicle are superior to that of triple roadtrains. Vehicle testing has been carried out to validate the RATED model predictions. Excellent results are evident at the time of writing.

CONCLUSION

This paper has attempted to demonstrate the use of “Virtual Prototyping” techniques such as heavy vehicle dynamic simulation and animation in developing larger more productive Combination Vehicles.

Dynamic performance measures such as Rearward Amplification, Load Transfer Ratio, High-Speed Dynamic Offtracking, High-Speed Offtracking, Low-Speed Offtracking and Trailing Fidelity have been found to be important in assessing innovative LCV designs.

Simulation modelling has gained considerable acceptance as an indicator of the performance qualities of newly proposed innovative-vehicle configurations. Use of simulation models has indicated that such configurations can result in significant gains in transport efficiency and productivity as well as dynamic performance equal to, or better than, currently permitted combination vehicles.

The three examples of the innovative vehicles developed also indicate the transport industry willingness to adopt this new non-conventional technology.

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AUTHOR BIOGRAPHIES

Scott McFarlane (Project Engineer)

Mr Scott McFarlane plays a leading role in advancing Roaduser’s worldclass developments in computer simulation of heavy road vehicle systems. His accomplishments include computer simulation, assessment and evaluation of the dynamic performance of heavy vehicle configurations, investigations into stability, braking, safety, design and road effects of heavy vehicle configurations, accident analysis, reconstruction and investigation.

His ability to develop complex, cost-effective models of heavy vehicles has significantly contributed to Roaduser’s understanding of how vehicle size and weight interact with the transportation infrastructure. Mr McFarlane is recognised as a world leader in the use of the powerful AUTOSIM™ simulation tool for creating dynamic simulation models and advanced modelling and animation of heavy road vehicle dynamics. He recently completed the MADYMO training course at TNO in The Netherlands and has begun to develop models of complex road vehicle systems with this versatile simulation tool.

A regular attendee at international conferences concerned with the investigation of heavy road and rail vehicle dynamic systems, he is also a member of the International Society of Automotive Engineers (SAE).

A graduate of Royal Melbourne Institute of Technology, Mr McFarlane earned a Bachelor’s degree of Engineering (Aerospace) with Honours.

Dr Peter Sweatman (Founder and Managing Director of Roaduser Research)

Dr Peter Sweatman is an acknowledged world leader in the scientific field of heavy vehicle interaction with infrastructure. Dr Sweatman’s research has crossed the boundaries of traditional engineering disciplines and his work has been widely recognised in the fields of vehicle design and engineering, vehicle safety, road safety, highway condition monitoring, heavy vehicle standards and regulations and transport economics and policy.

Dr Sweatman was elected a Fellow of the Australian Academy of Technological Sciences and Engineering in 1997.

Dr Sweatman founded Roaduser Research in 1989 and has built it into an internationally successful research organisation, with clients in both the private and public sectors.

During his career, Dr Sweatman has been honoured to play a key role in major industry associations and committees. He is a frequent speaker at international industry events, as well as a regular columnist for the magazine Truck & Bus Transportation. A Fellow of the Society of Automotive Engineers of Australia (SAE-A), he has served on the SAE-A National Council & Executive and chaired the SAE-A National Conference Committee. He is currently Vice-President (Asia-Pacific) of the International Forum for Road Transport Technology. Dr Sweatman also chairs the OECD Road Transport Research Scientific Expert Group (IR6 – DIVINE Project), having the honour of being the first Australian to hold such a post.

Dr Sweatman was selected by the US Federal Highway Administration (FHWA) to author a worldwide review of the Highway/Commercial Vehicle Interaction, including technologies recommended for consideration in the US. He is also a member of the US Transportation Research Board's Vehicle Size and Weight Committee.

A graduate of the University of Melbourne, Dr Sweatman earned his PhD in Mechanical Engineering for research into the handling of passenger cars. He served as Chief Scientist at the Australian Road Research Board from 1984-89 and founded and developed ARRB's heavy vehicle research from 1976-89.

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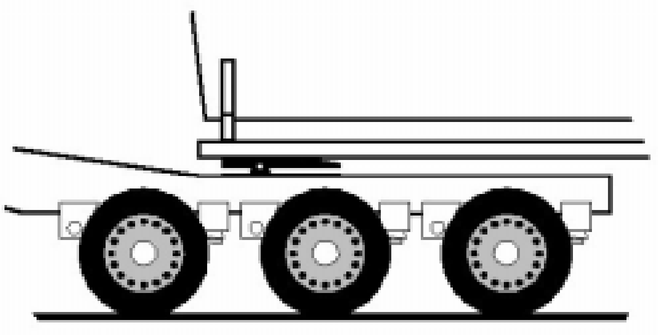

Figure 1 Design features of innovative vehicles

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Figure 2 Northern Australian road section

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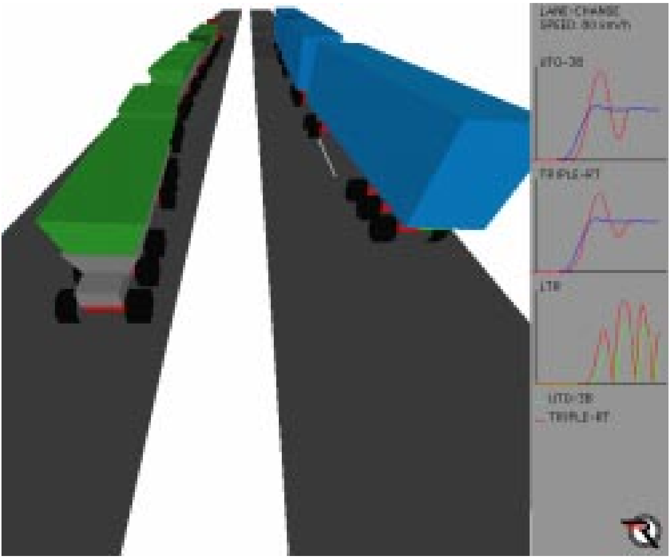

Figure 3(a) AUTOSIM model of 3B and A-triple

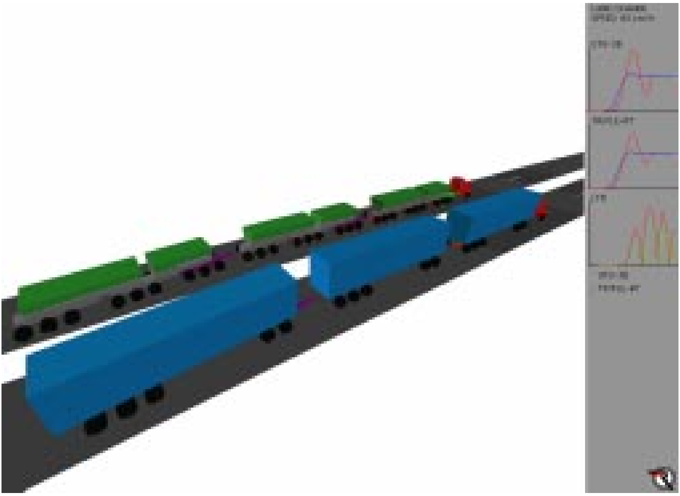

Figure 3(b) AUTOSIM model of 3B and A-triple

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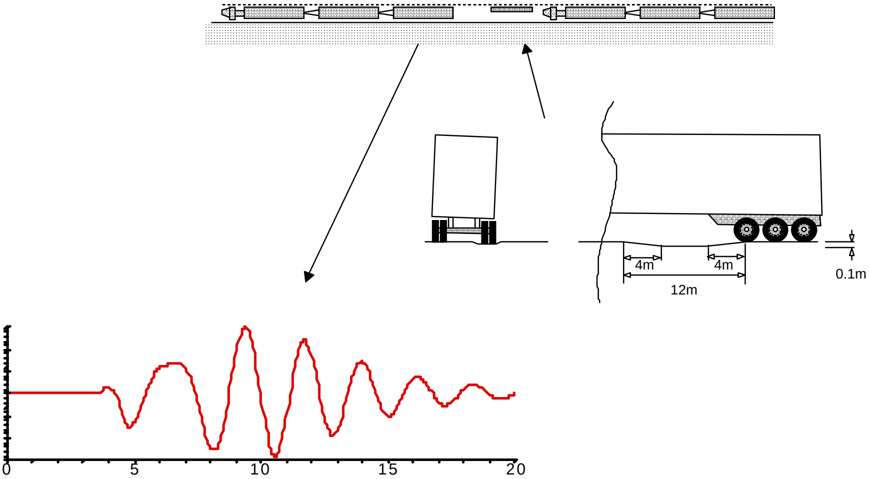

Figure 4 Trailing fidelity on road depression.

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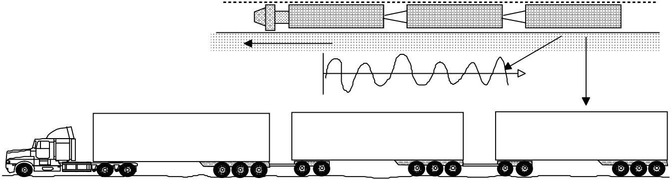

Figure 5 Trailing fidelity on isotropic road surface.

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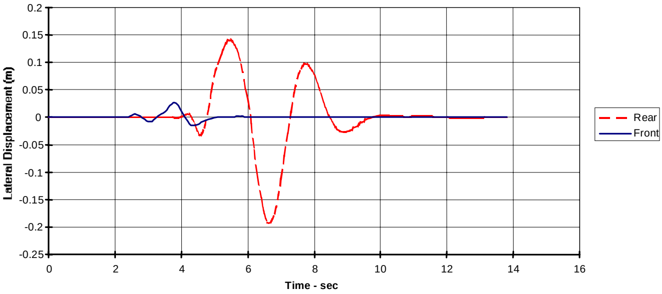

Figure 6(a) Trailing fidelity time history –Depression - 3B

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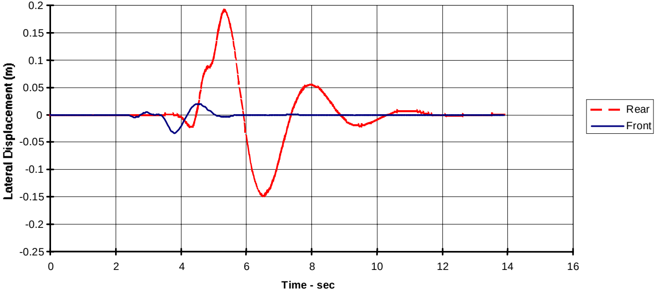

Figure 6(b) Trailing fidelity time history –Depression - A-triple

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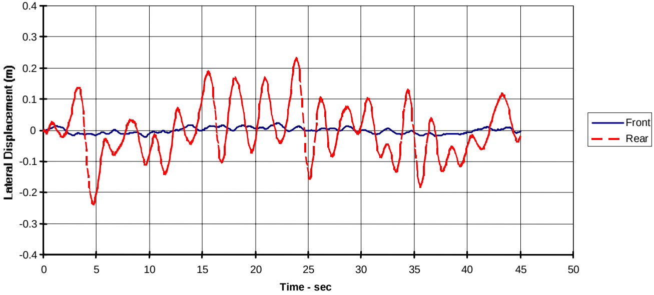

Figure 7(a) Trailing fidelity time history –Isotropic - 3B

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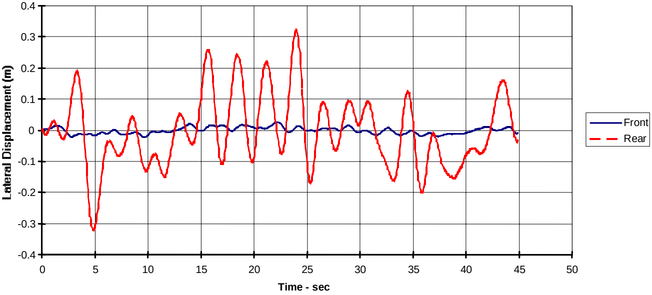

Figure 7(b) Trailing fidelity time history –Isotropic – A-triple

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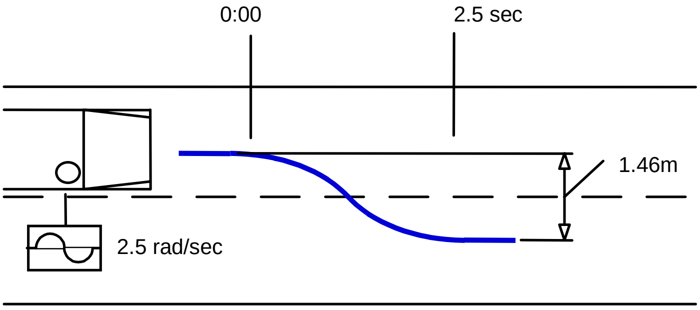

Figure 8 Lane change manoeuvre

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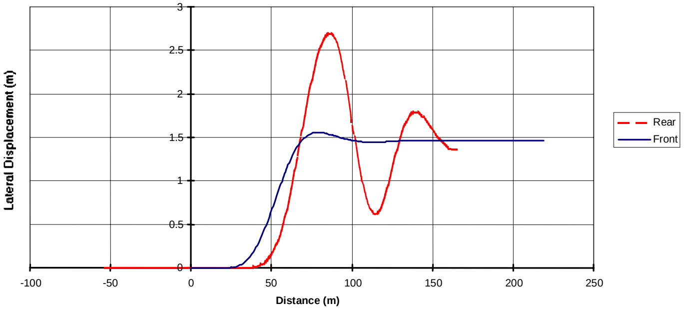

Figure 9(a) Vehicle motion thru lane-change - 3B

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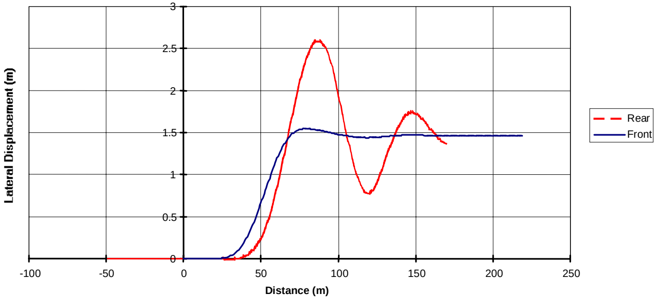

Figure 9(b) Vehicle motion thru lane-change - A-triple

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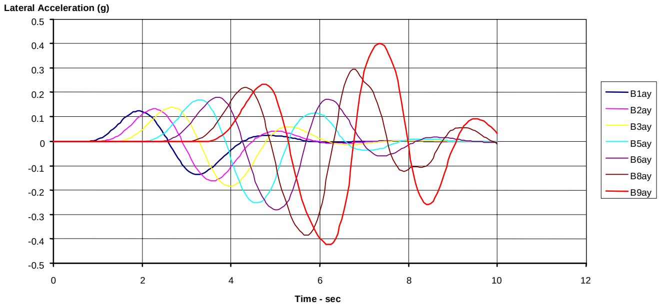

Figure 10(a) Lateral Acceleration time history - 3B

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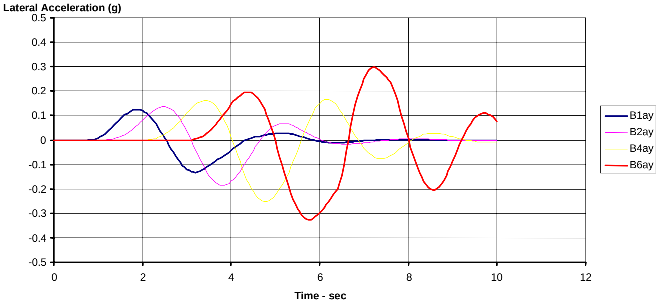

Figure 10(b) Lateral Acceleration time history - A-triple

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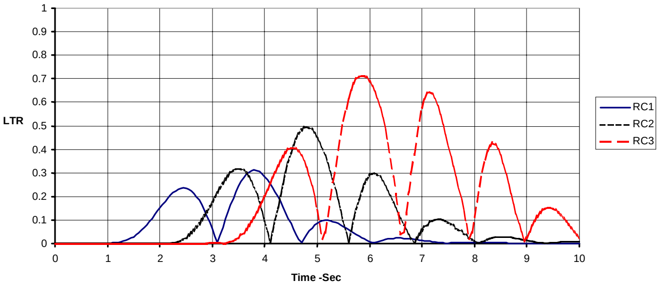

Figure 11(a) Load Transfer Ratio time history-3B

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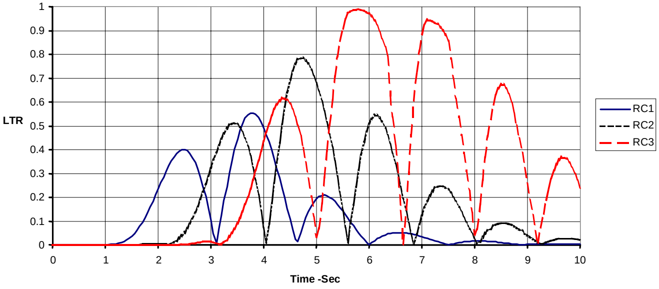

Figure 11(b) Load Transfer Ratio time history-A-triple

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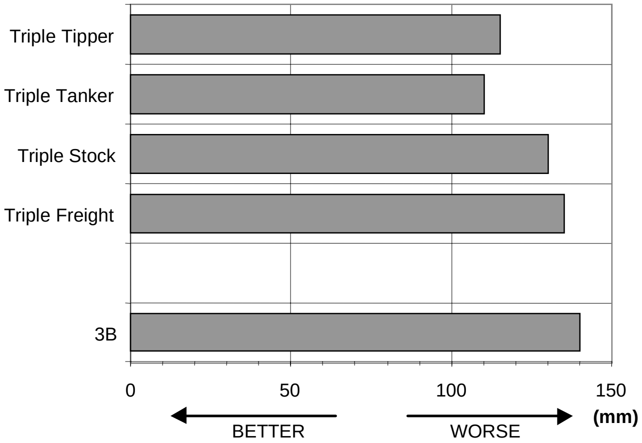

Figure 12 Maximum outboard movement after travelling through road depression

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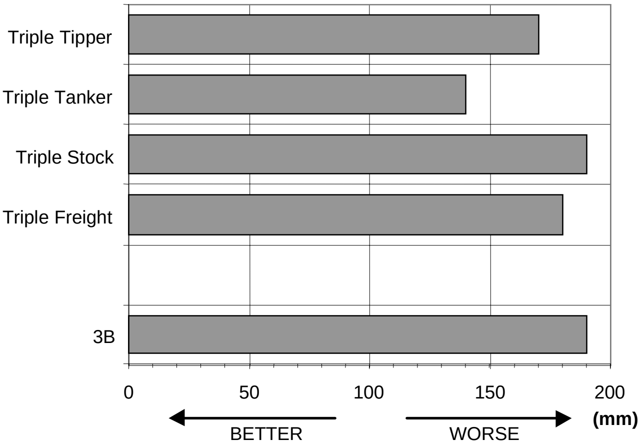

Figure 13 Maximum inboard movement after travelling through road depression

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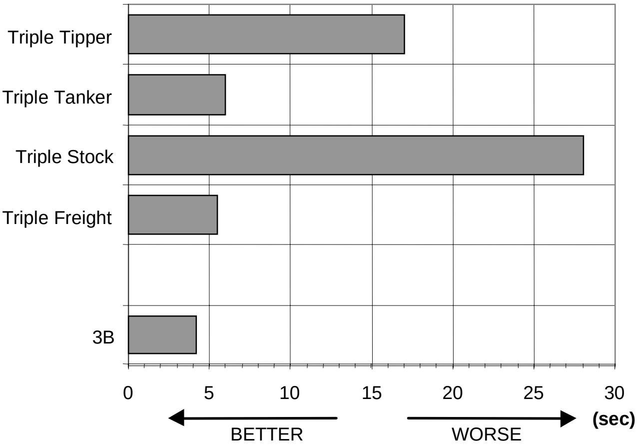

Figure 14 Time to 10% of maximum excursion.

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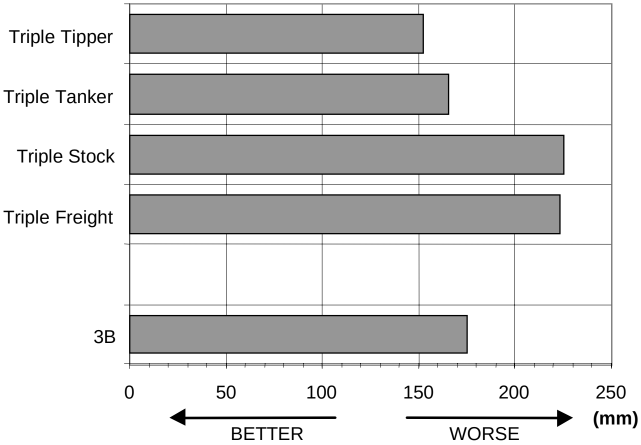

Figure 15 95th percentile movement

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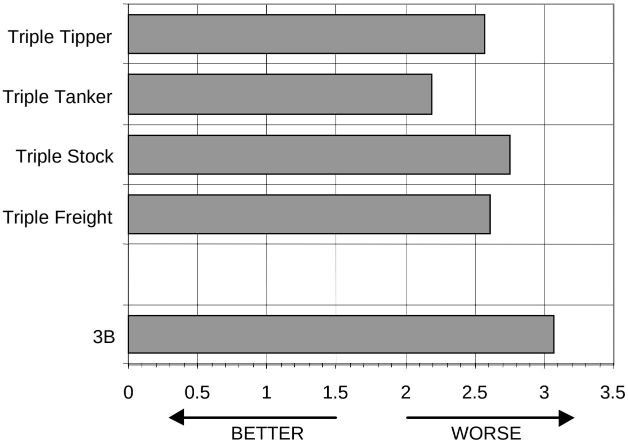

Figure 16 Rearward amplification

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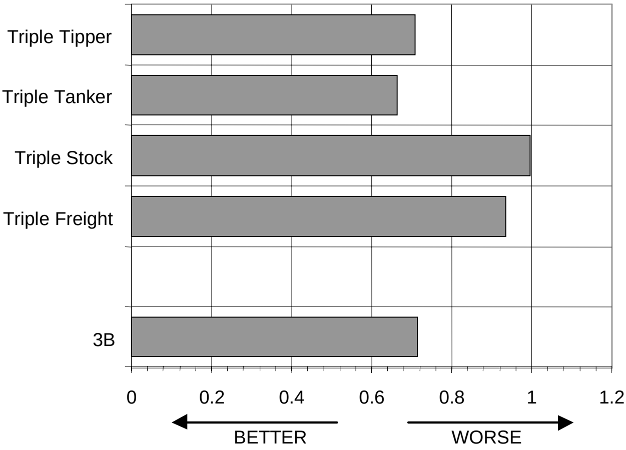

Figure 17 Load transfer ratio

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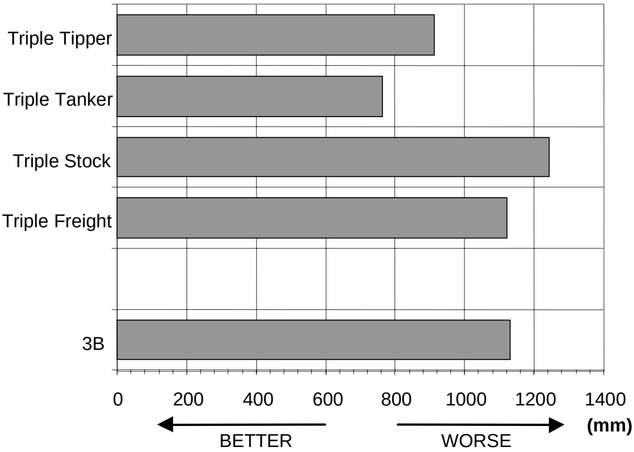

Figure 18 High-speed dynamic offtracking

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Figure 19 Innovative vehicle 3B

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Figure 20 Innovative vehicle AB-Triple

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Figure 21 Innovative vehicle 2B3

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