THE EFFECTIVE EVALUATION OF TRUCK SAFETY FOR AN ALTERNATIVE PARALLEL SOUTH AFRICAN PBS LEGISLATION

Obtained a B.Sc. in Mechanical Engineering at the University of the Witwatersrand. Completing an M.Sc. in Mechanical Engineering. Working at the CSIR, Landward Sciences.

S. SHARMA
University of the Witwatersrand/CSIR (LS)
South Africa

Obtained B.Sc. and M.Sc. from the University of the Witwatersrand. Obtained a Ph.D. at Cambridge. Lecturer in the School of Mechanical, Industrial and Aeronautical Engineering at the University of the Witwatersrand.

F. KIENHÖFER
University of the Witwatersrand
South Africa

Abstract

Performance Based Standards (PBS) legislation provides an alternative regulatory framework for vehicles that exceed prescriptive mass and dimension limits, under condition that the PBS vehicle's safety is demonstrated either through physical tests or simulations. A wide selection of simulation software exists for vehicle modelling. The Australian National Transport Commission (NTC) found good agreement between the following simulation packages: ADAMS, Yaw/Roll and AUTOSIM. In this study, the NTC study is extended to include comparisons of the ease of use, flexibility, and cost. The following software packages were evaluated: ADAMS, Yaw/Roll and TruckSim. The evaluation results are that: ADAMS is the most flexible; Yaw/Roll is the cheapest; and TruckSim is the easiest to use. The evaluation was in part subjective but it is hoped that this study will provide useful insight and assist the beginner PBS analyst in choosing the best software package.

Keywords: Performance Based Standards, computational modelling, ADAMS/View 2011, TruckSim 8.0, Yaw/Roll

1. Introduction

1.1 The Need to Address Road Problems in South Africa

The productivity of a country is directly affected by the efficiency of its freight logistics system to transport raw materials and manufactured goods. Gauteng, the economic hub in South Africa, has no access to river or sea ports. A need exists to improve the productivity of the South African road transport system on which the economy is heavily reliant.

According to the Department of Transport (Thaw, 2010), the South African economy is taking strain from the cost of road accidents. The Automobile Association estimated that during 2009 more than R100 billion was spent on dealing with collisions and fatalities. Between years 2001 and 2008, the number of rigid trucks involved in accidents has been above 1,200 per year (with more than 700 deaths per year) between 2001 and 2006, and over 500 per year in 2007 and 2008 (with more than 330 deaths per year). This excludes the accident statistics for articulated trucks.

Road wear and associated road repair cost is a further concern in South Africa. According to the CSIR (Fleetwatch, 2010), 20% of all heavy trucks on the road at any one time are overloaded. These trucks are responsible for 60% of road damage.

Performance Based Standards (PBS) is proposed as a solution in South Africa: to reduce transportation costs; to reduce road accidents and fatalities; and to reduce road wear (Nordengen *et al.*, 2008).

1.2 What is PBS?

Current vehicle legislation regulates allowable mass and dimension limits. This prescriptive standards approach only indirectly addresses vehicle rollover tendency and the road width required by the vehicle when manoeuvring e.g. a maximum vehicle height limit indirectly ensures the centre of gravity of the vehicle is not too high to cause rollover problems.

PBS legislation provides an alternative regulatory framework for vehicles that exceed prescriptive mass and dimension limits, under condition that the PBS vehicle's safety is demonstrated either through physical tests or simulations. PBS vehicles are able to achieve higher productivity because they are not constrained by prescriptive mass and dimension limits. This is achieved without compromising safety as the vehicles are designed to meet the safety requirements specified by the PBS legislation.

1.3 Computer-Based Modelling of Vehicle Dynamics

A wide selection of simulation software exists for vehicle modelling. The Australian National Transport Commission (NTC), formerly NRTC, compared three separate computer-based modelling packages: ADAMS, UMTRI's constant velocity Yaw/Roll program (Yaw/Roll) and AUTOSIM (Prem *et al.*, 2001). This work addressed concerns raised by stakeholders about the reliability of the performance predictions from different computer-based models used by different service providers. Two consultants were provided with the same input data sets for two reference vehicles (a B-double and a truck and trailer combination) and four manoeuvres (an SAE lane change, a low-speed 90° turn, a pulse steer input, and a step steer input) were simulated. It was found that simulations involving only vehicle responses were in very close agreement. Simulations involving a driver model were found to be in good

agreement. Agreement in the outputs from the simulations in all manoeuvres was generally better than 7% for the performance measures considered.

In this study, the NTC accuracy comparison of software is extended to include comparisons of the ease of use, flexibility, and cost. While AUTOSIM is no longer commercially available, the AUTOSIM multibody symbolic code generator algorithms have been included into the commercially available heavy vehicle dynamics simulation package, TruckSim.

1.4 Study Objective

The objective of this study was to assess ADAMS/View 2011 (ADAMS), Yaw/Roll, and TruckSim 8.0 as suitable modelling packages for the effective evaluation of PBS in South Africa. The project focused on comparing the *ease of use, cost, and accuracy* of the software packages.

Measuring the ease of use of a software package is subjective. Nevertheless, user opinion gained while learning each software package can provide useful insight. In the results section of this study, the cost comparison of the software will look at initial purchase cost and support costs. The software package features such as driver controllers, and speed controllers will be discussed.

The three software packages chosen for evaluation are not the only packages which could be used to evaluate PBS compliance. Other possible packages include RecurDyn, DADS and SIMPACK. ADAMS/Car provides templates for ADAMS with libraries of driver models, event builders, road builders, test rigs, and truck-trailer assemblies. The ADAMS/Car add-on was not evaluated in this study.

A benefit from this comparison study was the development of truck modelling expertise using each software package e.g. the developed tyre models, steer and velocity controllers in ADAMS will not require starting from scratch for future vehicle PBS evaluations.

2. Methodology

The reference B-double simulated by Prem *et al*. (2001) was modelled to perform four standard manoeuvres: an SAE lane change, a low-speed 90° turn, a pulse steer input, and a step steer input. The three software packages ADAMS, Yaw/Roll and TruckSim (as discussed in Section 1.4 Study Objective) were used.

The ease of use of the software packages was evaluated by an engineering graduate with no prior experience of working with the software packages. Software quotations were obtained from the local software agents in South Africa. The accuracy of the software packages was determined by plotting and comparing the results as calculated by each software package.

The following two sections give brief descriptions of the modelled manoeuvres and software packages.

2.1 Modelled Manoeuvres

SAE Lane Change

The SAE lane change is used to evaluate rearward amplification and high-speed transient offtracking. The manoeuvre was conducted at a speed of 88 km/h. The lateral displacement

was 1.46 m over a longitudinal distance of 61 m. A closed-loop control was used for this simulation.

Low-speed 90° Turn
The low-speed 90° turn is used to evaluate low-speed swept path, tail swing, and frontal swing. The centre of the steer axle is required to follow a path comprising of a straight entry segment, 11.25 m radius, 90° arc and a straight exit segment. The manoeuvre was conducted at a speed of 10 km/h.

Pulse Steer Input
The pulse steer input is used to evaluate yaw-damping. The steer angle was increased from 0° to 10° and then back to 0° over a 0.5 s period. The manoeuvre was conducted at a speed of 100 km/h.

Step Steer Input
The step steer input is not required for PBS assessment (NTC, 2008) but has been used in previous validation studies by Prem *et al*. (2001) and Sayers and Riley (1996). The steer angle was increased from 0˚ to 1˚ over a 0.25 s period and then held steady. The manoeuvre was conducted at a speed of 100 km/h.

2.2 Software Packages

ADAMS
ADAMS is the most widely used multibody dynamics and motion analysis software in the world (MSC Software, 2012). The ADAMS user is required to either build a geometric model or else import CAD geometries of the system. The bodies can be rigid or flexible and the interconnections between bodies relating the motion of body A to body B must be defined. From these geometrical inputs, ADAMS generates the mathematical equations that describe the kinematic and kinetic motion of the system. The ADAMS solver integrates the differential equations providing a solution which can be viewed in the post-processor: a number of integrator algorithms are offered. ADAMS is used extensively in the automotive industry but any conceivable mechanical system can be modelled and analysed.

Yaw/Roll
Yaw/Roll was developed at the University of Michigan Transport Research Institute (UMTRI) to predict the directional and roll response of generalized articulated vehicles. The program can be used for stability, rollover as well as low-speed turn simulations. The turning behaviour of the vehicle can be controlled either by defined steering inputs or by a driver model following a prescribed trajectory. The differential equations defining the vehicle response are hardcoded, limiting any extension of the model to account for specific requirements e.g. a steering trailer axle. The differential equations are solved using a predictor-corrector integration method (Gillespie and MacAdam, 1982).

TruckSim
TruckSim is a dedicated software tool for simulating and analysing the dynamic behaviour of medium to heavy trucks, buses and articulated vehicles (Mechanical Simulation Corporation, 2012). The truck data and control inputs defining the manoeuvre concerned are entered using data screens with a graphical user interface (GUI). An extensive variety of axle, suspension, tyre, brake, steering, payload and trailer configurations can be selected. TruckSim can be

linked with Matlab Simulink if the required truck component, feature or input cannot be modelled using the data screens offered.

3. Software Package Ease of Use Comparison

The ease of use of the software comparison focused on the time and effort to build a model, the solver time, animation, system of units and the flexibility of the package.

ADAMS/View required significant effort to build the geometric model and joint connections of the vehicle. The gains and structure for a longitudinal speed controller and driver model needed to be designed by defining the mathematical relationships of the drive torque and steering in terms of the vehicle states. ADAMS/View provides a number of tyre models, which require tyre parameter or coefficients to be entered. The package was not able to directly read in the tyre side force and tyre aligning moment tables presented by Prem *et al*. (2001). A regression analysis was performed on these tables to determine the coefficients of the magic tyre formula which were entered into ADAMS. The Pacejka 89' model (Bakker, Pacejka and Lidner, 1989) was used.

The ADAMS software developers, MSC Software, have developed a module, ADAMS/Car, specifically for vehicle dynamics studies. The module includes speed controllers, driver models, event builders, road builders, and preconfigured vehicle configurations including a truck and trailer assembly. The module addresses the significant effort required to build a vehicle model using ADAMS/View.

When using Yaw/Roll, the text file input must conform exactly to the input format requirements i.e. even an extra trailing zero added to an input parameter or a spurious space will cause an error. Substantial care was required to correctly enter the vehicle data into the text file.

The TruckSim GUI required significantly less effort to input the vehicle model as compared to Yaw/Roll. The TruckSim model is inputted using an easy to use tree structure of components. The parameters for each component were entered into clearly labelled input boxes and tables.

Using a standard PC (of average computational power at the time of writing this study), the ADAMS/View model solved in approximately two to five minutes, the TruckSim model in half a minute and the Yaw/Roll model in a second.

Both ADAMS and TruckSim offer sophisticated post-processor animation capabilities which allow the vehicle motion to be viewed as a video. Yaw/Roll cannot animate the vehicle motion. The animations were found to be extremely useful in debugging models as well as convincing the South African road authorities and truck operators of the benefits of PBS and the fidelity of the simulation results.

ADAMS offers a choice of systems of units (including metric and British-American). TruckSim uses metric units. The vehicle model in Yaw/Roll must be entered in British-American units. This was found to be particularly frustrating as the vehicle input parameters needed to be converted.

Of the software packages evaluated, ADAMS/View offered the most flexibility. There are no limitations in ADAMS on the number of vehicle units or axles that can be modelled.

Yaw/Roll is limited to modelling a maximum of four vehicle units (including dollies) and eleven axles. Prem *et al*. (2001) list a number of assumptions made by Yaw/Roll. The most important of these is that the road surface must be flat and horizontal, damping in the tyre is assumed to be small with no tyre relaxation length being modelled, the suspension damping is considered to be linear and no load sharing occurs between axles. A further drawback is that Yaw/Roll must be run using the DOS operating system or else a DOS emulator must be used.

The TruckSim solvers are optimised for each vehicle and axle configuration. The standard package offers the thirteen configurations shown in Table 1. If a vehicle and axle configuration not listed in Table 1 is required then this configuration must be purchased as an add-on.

Table 1 - Standard TruckSim Configurations

TruckSim designation	SAE designation	Common name
s_s	11	2-axle truck
s_ss	12	3-axle truck
ss_s	21	3-axle truck
ss_ss	22	4-axle truck
s_s + s	11s1	2-axle tractor & 1-axle semi-trailer
s_s + ss	11s2	2-axle tractor & 2-axle semi-trailer
s_s + sss	11s3	2-axle tractor & 3-axle semi-trailer
s_ss + s	12s1	3-axle tractor & 1-axle semi-trailer
s_ss + ss	12s2	3-axle tractor & 2-axle semi-trailer
s_ss + sss	12s3	3-axle tractor & 3-axle semi-trailer
s_ss + ss + ss	12s2s2	7-axle B-double
s_ss + sss + sss	12s3s3	9-axle B-double (used in this study)
s_s + s + ds + s	11s1-1s1	5-axle A-double

4. Software Package Cost Comparison

Table 2 compares the costs of the three software packages evaluated in this study. The costs are from quotations provided by credible software agents in South Africa. Yaw/Roll is freely available and the costs of ADAMS and TruckSim are comparable. Both ADAMS and TruckSim costs include software support for one year.

Table 2 Software Package Purchase Costs

Yaw/Roll	ADAMS/View	TruckSim 8.0
$0	$31,673	$32,625

5. Software Package Accuracy Comparison

5.1 SAE Lane Change

Figure 1 and Figure 2 show the respective yaw rate and lateral acceleration of the vehicle units during the SAE lane change. The results show good agreement between the three software packages.

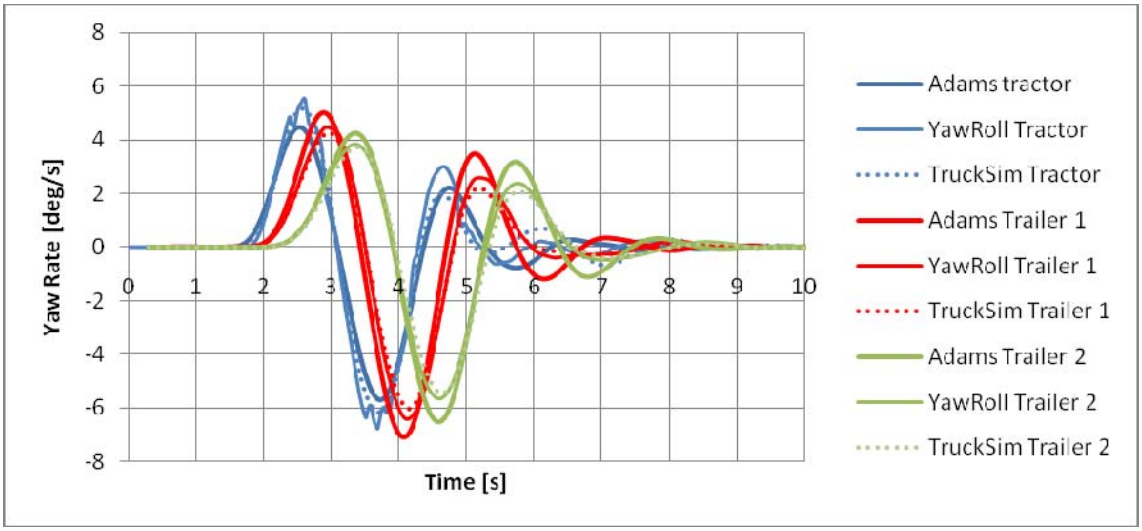

Figure 1 - SAE Lane Change: Yaw Rate

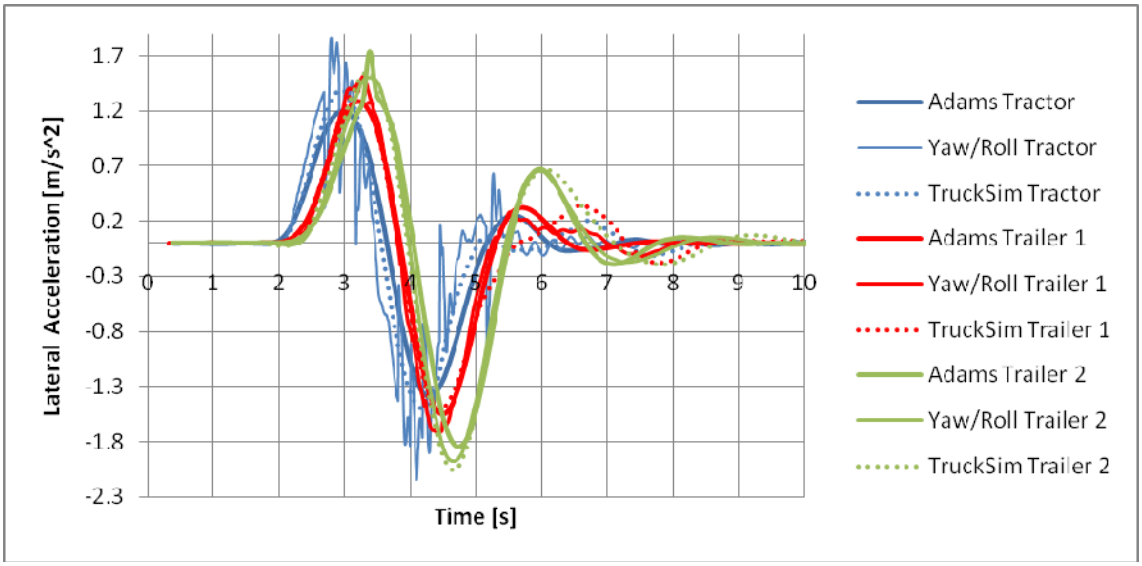

Figure 2 - SAE Lane Change: Lateral Acceleration

5.2 Low-Speed 90˚ Turn

Figure 3 shows the paths of the steer, drive, and trailer axles during the low-speed 90° turn. The centre points of the axles are plotted and the trailer axles are for the rearmost axle. There is excellent agreement between the software packages.

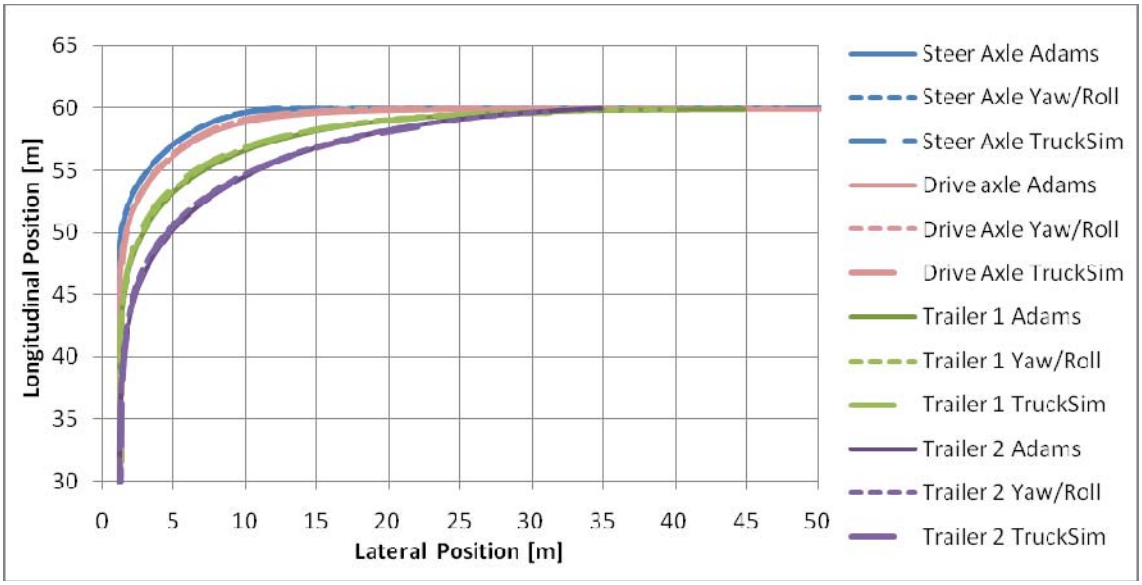

Figure 3 - Low Speed 90˚ Turn

5.3 Step Steer Input

Figure 4 shows the yaw rates of the vehicle units during the step steer input. There is excellent agreement between the software packages.

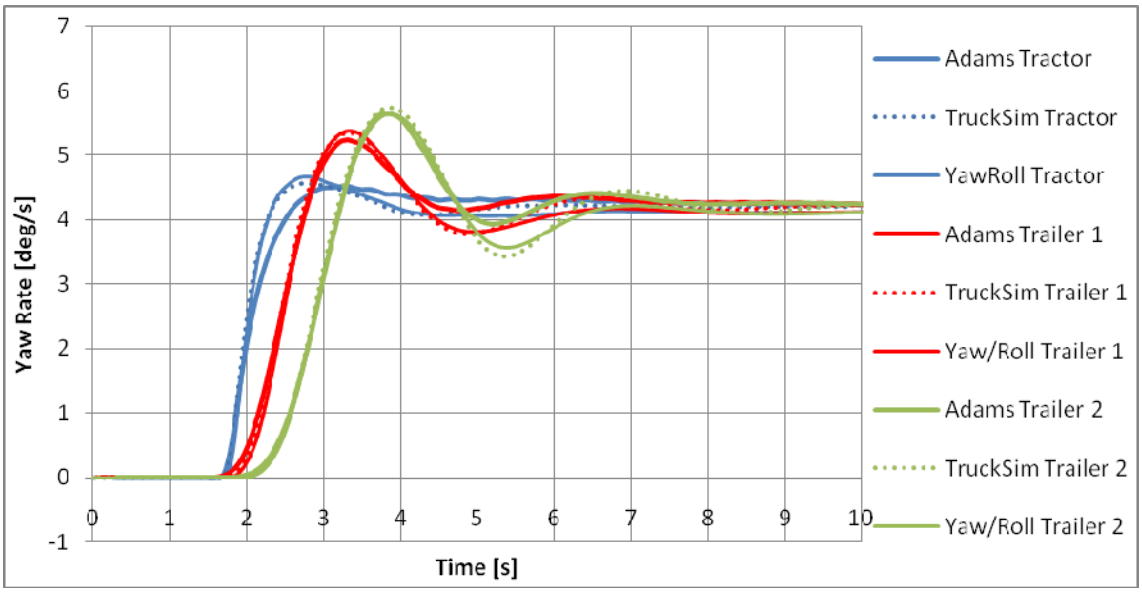

Figure 4 - Step Steer: Yaw Rate

5.4 Pulse Steer Input

Figure 5 and Figure 6 show the respective yaw rates and lateral accelerations of the vehicle units during the pulse steer input. There is good agreement between the software packages.

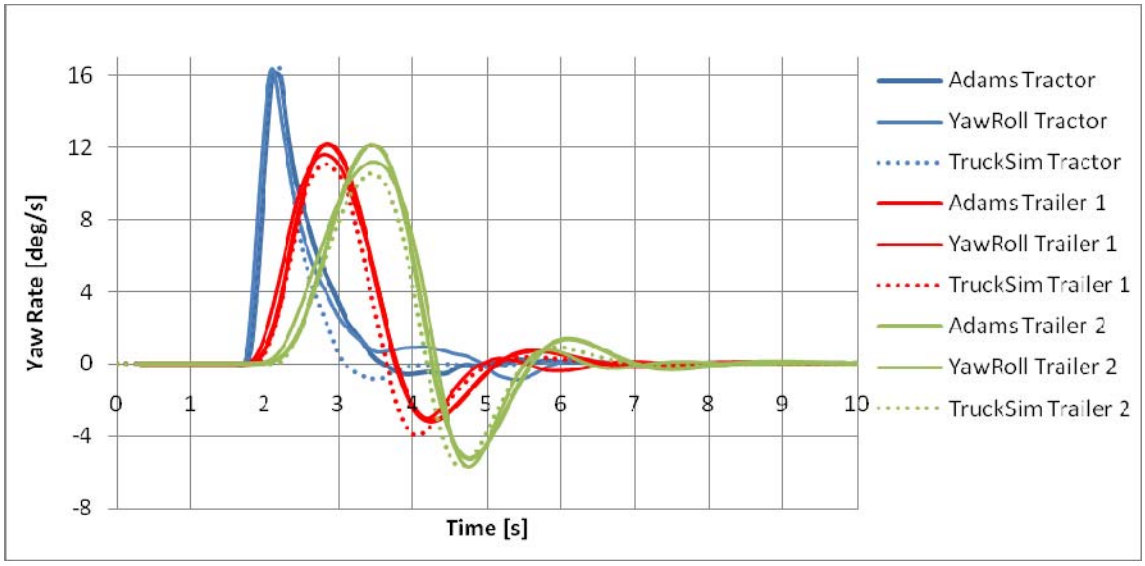

Figure 5 - Pulse Steer: Yaw Rate

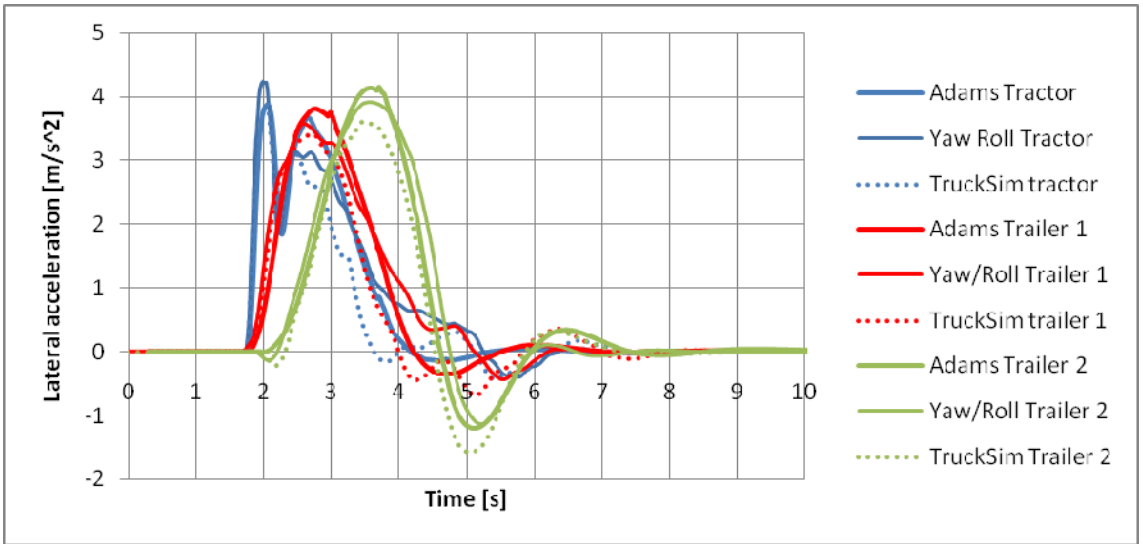

Figure 6 - Pulse Steer: Lateral Acceleration

Figure 7 shows the comparison of the articulation angles between the units of the vehicle for the pulse steer input. Again, there is good agreement.

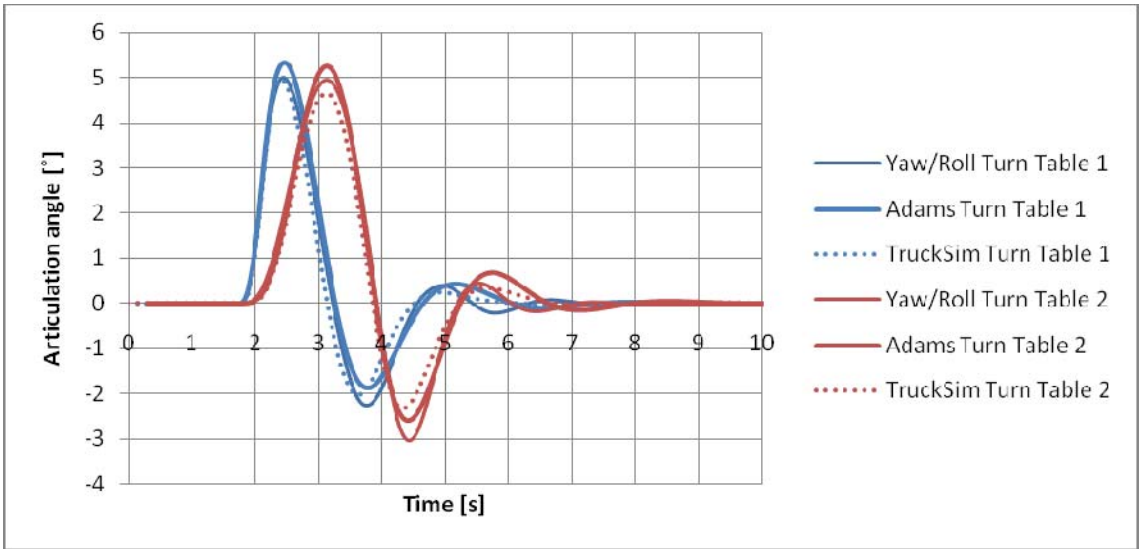

Figure 7- Pulse Steer: Articulation Angles

6. Discussion

Of the three software packages evaluated, ADAMS required the most user effort to build a vehicle model able to evaluate PBS compliance. The geometry of the truck defining the relationships between the moving bodies of the truck system as well as a speed controller and driver model needed to be developed. It was necessary in ADAMS to complete a regression analysis of tyre tables in order to determine the required coefficients of the magic tyre formula. The advantage of ADAMS was that it offered the most flexibility. Any vehicle configuration could be modelled with any number of axles.

Yaw/Roll required an intermediate user effort. The need to convert parameters from metric to American-English units to analyse the vehicle and converting the results back into metric units was time-consuming. Furthermore the text input files, DOS operating system, and rigid rules governing number formatting were difficult to work with. Yaw/Roll was the most limited of the software packages evaluated: the modelled vehicle was limited to a maximum of four vehicle units and eleven axles and the road surface was constrained to be flat. The latter restriction precludes the use of Yaw/Roll to calculate the tracking ability on a straight path PBS measure, which requires the vehicle to traverse an uneven surface.

TruckSim required the least user effort to build a vehicle model. The vehicle details were captured in easy to use data screens. The modelled vehicle was limited to thirteen vehicle and axle configurations (See Table 1); although add-on modules expanding the vehicle configurations could be purchased.

The Yaw/Roll restrictions on vehicle configurations and the need to buy expanded vehicle configurations as add-on modules in TruckSim are pertinent drawbacks when evaluating the software's effectiveness for PBS analyses. PBS promotes innovation to improve vehicle safety and productivity and the innovative vehicle solutions may not conform to standard configurations.

The purchase cost of either ADAMS or TruckSim is just over $30,000 compared with Yaw/Roll which is free. The beginner PBS analyst, evaluating the best choice of software package must decide if the increased flexibility and ease of use justifies the cost of commercial software.

There is good agreement between the software packages as seen from the results of the yaw rate and the lateral acceleration of the vehicle units for the SAE lane change, pulse steer input and step steer input; and the positions of the steer axle, drive axle, trailer 1 and trailer 2 for the low-speed 90° turn. For the SAE lane change, the high frequency variation of the Yaw/Roll results (See Figure 1 and Figure 2) is due to the irregular and rough steering of the Yaw/Roll driver model.

7. Conclusions

- Three software packages (ADAMS, Yaw/Roll and TruckSim) were successfully evaluated for the suitability to evaluate PBS compliance of vehicles. The evaluation was in part subjective but it is hoped the study provided useful insight. In summary the evaluation results are that:
  - ADAMS is the most flexible
  - Yaw/Roll is the cheapest
  - TruckSim is the easiest to use
- There is good agreement between each of the software packages.
- ADAMS and TruckSim are capable of evaluating all the PBS measures required for an assessment. Yaw/Roll is able to evaluate almost all PBS performance measures; the Yaw/Roll limitation that the road must be flat would preclude its use to evaluate tracking ability on a straight path.
- In developing vehicle models in ADAMS, Yaw/Roll and TruckSim, the expertise to evaluate PBS compliance in South Africa has been extended. The results of this study will assist the beginner PBS analyst in evaluating the best software package for analysis.

8. Acknowledgements

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