Highway and Urban Speed Air Suspended Heavy Vehicle Accident Signatures

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Abstract

Knowledge of air flow, fluid dynamics and mechanical engineering system dynamics suggested heavy vehicles, with air suspended drive and towed axle groups, may exhibit particular accident signatures. The existence of these signatures was reinforced by knowledge of a limited number of accidents, unfortunately, the majority of which involved fatalities. Consolidation of the postulated accident signature demanded access to a more extensive heavy vehicle accident data base.

This deficiency was offset by 'on line' access to the VicRoads Crash Stats. With this access bulk data examination of articulated single vehicle loss of control on curves, on straights and articulated vehicle initiated head on fatal accidents, in rural Victoria, was conducted for the period 2003 – 2007. For each accident the approach route, for up to one kilometre prior, to the stated accident site, was inspected using 'Google Map' and where appropriate 'Google Street View. Fortunately, the extensive bulk data included details of the prime mover build dates. It was postulated that prime movers less than five years old at the accident date were fitted with air suspensions.

The examination of the fatal accident records suggests newer built heavy vehicles exhibit high accident risk in the following highway speed situations:

- exiting long sweeping curves
- negotiating the second curve of close alternate lock sequences
- negotiating a curve either during or immediately post torque application.

Unfortunately a significant number of non metropolitan heavy vehicle fatal accidents occur on narrow windy rural roads, both unsealed and sealed. Reduction of this proportion will demand utilization of heavy vehicles with optimised stability. Strategies for optimised stability include compromised vehicle productivity, minimal payload centre of gravity, vehicle illumination, restricted other road user access and/or warnings and improved suspension details.

Once identified at highway speed the high risk accident signatures were extrapolated to urban speed accident situations subject to certain operation scenarios. In common with highway speed accidents high load centre of gravity is a significant exacerbating factor. Unbeknown to most accident investigators air suspended driven axle groups exhibit torque dependent roll resistance. Due to the significance of this dependency, in regard vehicle handling stability, it is appropriate effort is made to understand same. This understanding demands, in turn, improved understanding of the paramount underlying drive axle air suspension characteristics and parameters.

The investigation highlights the need for vastly improved driver education, more extensive accident details and more thorough accident investigations. The identified accident signatures suggests the need for improved suspension hardware details and parameters. The same

identifies paramount implications for road maintenance, road design and the imminent introduction of advanced heavy vehicle handling and braking technologies.

Keywords

Heavy vehicle fatal accident signatures, crash data bulk examination, air suspension parameters.

Literature Survey

The Australian Federal Government Department of Infrastructure, Transport, Regional Development and Local Government regularly release National and State fatal heavy vehicle crash statistics. These statistics, in turn, are presented for crashes involving articulated trucks, heavy rigid trucks and buses. The most recent statistics declare 150 deaths from 130 crashes involving articulated trucks occurred in the 12 months ending December 2008 (ATSB July 2009). Of these fatalities over 70% resulted from accidents involving another vehicle, 12% involved pedestrian fatalities and over 16% resulted from single vehicle accidents. In 2008 at least 25 articulated truck driver fatalities occurred with Victoria contributing at least 3 to this population. Of equal concern is that for each truck driver fatality approximately 8.3 drivers incur injuries in articulated vehicle crashes (ATA 2005). According to the latter report of the 127 2002 driver fatalities 18.1%, 15%, 10%, 7.9%, 7.9%, 4.7% and 3.1% were attributed to running off the road, loss of control on a bend, speed, fatigue, rollover, alcohol and blowouts, respectively. Furthermore at specific high risk journey distances 33% of the accidents involved articulated trucks running off the road with general carriers representing some fifty-eight per cent of the crashes (Curnow 2002). Curnow also goes on to report some 65% of the articulated truck drivers killed in single vehicle crashes were not wearing a seat belt.

Another 2002 investigation reported in Australian truck crashes the proportion of persons killed that are truck occupants is 19% with approximately 70% occurring in single vehicle crashes (NRTC 2002). Furthermore the truck occupant rate per 10^8 kilometres travelled in Australia is only exceeded in New Zealand. This same report declared Australia has the highest proportion of single heavy vehicle accidents of the jurisdictions compared. Identified factors for the high incidence of single vehicle accidents included poorer road geometries, lower traffic volume, more night time driving, fatigue and higher speeds. Reasons stated for the tendency for the single vehicle accidents to be fatal included more dangerous roadside hazards, higher speeds, less protective cabin structures and lower use of seat belts. The latter three reasons were also repeated for the possible cause for crashes involving two or more trucks to be fatal. Poorer road quality was also stated to be the cause for non interstate roads incurring over 65% of (1994) fatal truck accidents in the USA (Clarke 1998). Characteristics of poorer quality road attracting higher heavy vehicle accident risk namely cross sectional geometry and lane width was aptly quantified by Milliken (2004) and McLean (1997), respectively.

Based on analysis of 325 crash incidents that occurred in 2007 Driscoll (2009) declared that some 27% of the reported incidents could be attributed to inappropriate speed particularly when altering direction. Furthermore the report reconfirmed the driver behaviourial factors of fatigue and inappropriate speed as the major two accident contributory causes. These adverse driver behaviourial factors accounted for over 47% of the incidents. Driscoll also reported semi trailers were disproportionately over represented in the incident statistics relative to those involving B doubles. Surprisingly, somewhat contrary to the ATSB fatal accident statistics, discussed above, over 75.4% of the serious truck crashes were single vehicle accidents. Equally alarming is that in the remaining 24.6% serious truck crashes, which involved multiple vehicles, the truck driver was totally responsible in 46.3% of the incidents.

Unfortunately the foregoing statistics provide scant attention to and mask possible contributory vehicle performance and stability factors in heavy vehicle, particularly articulated, accidents. Yet it is generally well known in the industry road haulage of a payload exhibiting a high centre of gravity will attract a higher risk of loss of control and rollover as validated by Mueller (1999) and as highlighted in the most appropriate industry guide published by the NZ Land Transport Safety Authority (undated). It is also noted Australian overall fatal single vehicle accident statistics typically fail to readily distinguish between rollovers to those involving loss of control.

Another overlooked and unreported vehicle performance factor is whether or not the involved heavy vehicle/s utilised air suspension either or both on the prime mover and trailer/s. Such omission in accident reporting is made despite the fact air suspensions display vastly different roll and handling characteristics relative to those displayed by mechanical or metal spring suspensions. This difference was highlighted in the investigation, which involved 27 formal complainant prime overs incurring handling difficulties. Of these prime movers 24 units were fitted with air suspension (Sweatman (2000)). In addition, in or about 1999, in excess of 50 additional air suspended prime movers with similar (or more adverse) handling problems were known to the author. Sadly, this latter population was reinforced by involvement in numerous accident investigations involving air suspended prime movers. At the time, the percentage of air suspended prime movers in the national vehicle fleet was relatively low. This percentage has gradually increased particularly in response to air suspended axle groups gaining misnomer (Davies & Sack (2004)) road friendly status and higher mass limit approval (subject to satisfaction of extremely crude minimum requirements (Australian Federal Government (2004)). In addition the average engine power supplied into the fleet has likewise gradually increased (Sweatman 2000 Appendix Q).

Noting the accident reporting deficiency, in specific regard air suspension utilisation, this investigation aimed to identify if the air suspension handling problems, formally reported in 1999, resulted in any articulated heavy vehicle accident signatures. It was postulated these signatures, in turn, could be identified by effecting characterisation of the assumed 'macro lead in' path associated with each examined accident. Categorisation of the assumed 'lead in' path characteristics was, in turn, possible by examining a finite and representative number of paths associated with individual 'random' accidents. With the latter 'random' accidents selected as a particular population sub set of a readily available, web accessible, heavy vehicle accident bulk data record. The apparent existence of accident signatures, confirmed by expected air suspension behaviour, prompts possible actions and techniques to effect road safety improvements.

It should be noted this investigation was conducted and reported remote from investigations and categorisations involving local articulated heavy vehicle accidents. These local accidents involved all level of seriousness including submissions to and review of Coronial findings.

The alarming ongoing heavy vehicle accident statistics, as experienced in Australia, and New Zealand (Mueller (1999) and elsewhere (NTC 2002) prompts this current investigation. This work is a complement to the ongoing research by numerous heavy vehicle researchers seeking to ebb heavy vehicle fatality statistics. More importantly the same seeks to make road transport safer in general and to reduce the horrid human trauma and economic loss associated with road accidents.

Introduction

Utilising VicRoads Crash Stats (VicRoads on line) articulated fatal single heavy vehicle accident attracting the accident description classifications (DCA) 120, 170 – 174 and 180 – 184 were considered. Notwithstanding the data records provide accident data for the period 1994 to 2007 particular attention was devoted to the most recent five year period, namely 2003 to 2007, inclusive.

Methodology

The methodology used in the statistical examination of the VicRoads Crash Stats is summarised in the schematic depicted in Appendix A.

Due to time resource limitations this investigations is restricted to generally single heavy vehicle fatal accidents. In the case of DCA 120 incidents the other involved vehicle/s may or may not involve another heavy vehicle and the population group was relaxed to include all levels of seriousness (S1, S2 and S3). It was observed articulated vehicle initiated head ons typically insult in a fatality.

For each listed incident the specific accident site was located using Google map search via knowledge of the nearest cross street/s. On noting the initial direction of travel of vehicle A an assessment of accident signature was conducted followed by conservative categorization of same. Subsequently a frequency count of the identified accident signatures were conducted. For additional background statistics of the vehicle age at accident date was also conducted. Here it is suggested that relatively new prime movers, at the accident date, would attract higher probability they were air suspended.

Findings

Complete historical records

The significant overriding findings from the overall VicRoads Crash Stats data records (conducted as a separate investigation) are:

- Movement of an out of control articulated vehicle into a near carriageway parked vehicle or object greatly exacerbates the risk the accident is fatal.
- Movement of an out of control articulated vehicle deviating to the offside associates with a higher risk of a more serious accident.

An expected large number of accidents involving minor injury (S3) and vehicle / property damage only are not reported.

Most recent five year records

The significance of the identified accident signatures and relation with vehicle build date for accident description classifications (DCA) 120, 170 – 174 and 180 – 184, with the latter restricted to single articulated vehicle accidents, has been declared at length elsewhere (McLean (2000)). In the same greater attention was devoted to the following accident scenarios, namely loss of control occurring on or at

Narrow windy road,
Post long sweeping curve
Entering the second curve of an alternate lock curve sequence

in the non metropolitan Victoria environs. This analysis completely ignored weather, time of day and lighting conditions as accident contributory factors and assumed the road alignment and pavement satisfied the Austroads Design Guide (Austroads (1997)). Opportunity was also taken to examine the likelihood the vehicle was air suspended and discuss the specific loss of control orientation (ie to the near or offside) to the involved air suspended vehicle ride height control valve expected number and location.

Subsequently this report devotes greater attention to torque frame rise induced accident scenarios for both non and urban road conditions.

Drive air suspension response negotiating a stand alone long sweeping curve

The response of a drive air suspension (and undriven axle groups), hence air suspended vehicle, when negotiating a standalone right lock long sweeping curve is depicted in the schematic sequence summarised in Appendix B. The indicated response, supported by in progress analytical and simulation research, engineering tuition and driver feedback, indicates vehicles fitted with a single high gain right hand side RHCV will relatively strongly 'memory' steer or dart to the nearside (left) post a left lock long sweeping curve, whereas vehicles fitted with a single high gain left hand side RHCV will relatively strongly 'memory' steer or dart to the offside (right) post a right lock long sweeping curve. (For right hand drive vehicles the former tendency results in a lower risk accident seriousness scenario (especially in high traffic density situations.) It therefore follows vehicles fitted with both left and right hand RHCVs (ie twin RHCVs) will display a tendency to strongly 'memory' steer or dart exiting both left and right hand lock long sweeping curves.

The foregoing discussion also explains the higher risk of loss of control when entering a subsequent opposite lock curve and the particular post steering deviation related to the RHCV number and location. Due to time limitations this extended discussion is not presented here. The same also applies to the behaviour of air suspended heavy vehicle negotiating round abouts. This accident scenario is hence extremely frequent, and becoming increasingly frequent, in metropolitan areas. Likewise brevity demands prevent discussion of traffic density, lane multiplicity and lane operation consequences.

Torque Application – Frame Rise Implication

Appendix C vividly reveals positive torque application can reduce a drive axle group roll resistance by up to some 22% to that when stationary. Even at or near highway speed the roll resistance, when accelerating, can be some 14% lower than that when stationary. Unfortunately, no data exists revealing how the air spring pressures respond to long duration torque application as which is necessary when fully laden vehicles ascend long grades.

The consequences of this drive axle group roll resistance torque dependence on vehicle stability, to uninformed drivers, is immense. Notably a significant number of air suspended heavy vehicle loss of control and/or roll overs, especially those hauling high centre of gravity loads, may have been precipitated by this hitherto overlooked primary contributory factor.

These loss of control and roll overs attract distinctive rural, highway and urban accident signatures a number of which will be illustrated should time permit.

This drive air suspension roll resistance deterioration with positive torque application may also account for reported 'B double' (typically with SWB prime movers) loss of control on seemingly high quality near level low minimal curvature roadways. This same torque dependence eliminates the opportunity for drivers to power or accelerate out of difficulty should loss of control be imminent. In converse the necessary driver action approaching each and every curve (non urban) and corner (urban) is to cancel positive torque application and/or bab the prime mover brakes. This action will maximise the drive suspension instantaneous roll resistance.

Obviously extremely serious accident risk scenarios associate with incorrect torque application simultaneous to negotiating long sweeping curves and /or alternate lock sequences. In the latter situation vehicle stability is greatly exacerbated by possible typical underdamped dynamic rocking phenomenon.

In regard urban heavy crashes at intersections attracting high involvement in casuality crashes fifteen sites were investigated in both Sydney and Melbourne (FORS 1995). Coogle Map and Street View (Melbourne) and Street Directory (Sydney) examination of these accident sites revealed torque application / frame rise was a possible contributory factor in 46% and 33% of the Melbourne sites and Sydney sites, respectively. In regard the Sydney sites local knowledge suggests 33% of the examined sites involved bus heavy vehicle traffic. In comparison, with lesser local knowledge applying, at least 6% of the Melbourne sites most likely involved bus movements in heavy traffic density. A further 20% of the Melbourne accident sites attracted a 'maybe' classification noting at least one of the sites attracted heavy traffic density. For several of the Melbourne accident sites categorization confidence was reinforced by author driving experiences.

Implications

Confluence

The accident statistics is supported by the expected behaviour of air suspended heavy vehicles in long sweeping curves, through alternate lock curve sequences and post high torque application situations. Conversely the predicted behaviour of air suspended heavy vehicles in the stated situations is supported by the accident statistics.

Road Safety Benefits

Accident Details

Investigations of this enquiry would be greatly enhanced should fatal accident statistics record whether the involved heavy vehicle was air suspended or not, the type or make of suspension, the number, location of ride height control valve/s and estimate and report the load centre of gravity.

Accident classification descriptors (DCA) should be extended to include those occurring on narrow windy roads and those from a straight carriageway in close proximity to an approach bend with the particular bend detail recorded. DCAs should also be extended to distingush between a loss of control to a loss of contol resulting in a roll over.

Accident Investigation Reports

In regard single heavy vehicle accident reports all should clearly declare the involved vehicle suspensions details. If air suspended the relative relevance of the following accident signatures, namely :

Narrow windy road,
Post long sweeping curve
Entering the second curve of an alternate lock curve sequence
During and post a high torque application
(Overcorrecting to one of the above scenarios.)

should be examined and formally declared.

Coronial accident reports should be considered incomplete should such details be omitted.

Accident Record Statistical Investigations

All jurisdictions should conduct and report statistical examination of past accident records for at least the last five years. This examination should involve accidents at all level of seriousness including were possible property damage only. This statistical examination should identify whether the involved vehicle was air suspended or not. Most importantly such effort should identify the relative statistical relevance of the identified accident signatures. The information so gleaned should be used to advance long term road safety improvement

Accident Investigator Expertise

Accident investigators must take into account the vehicle response to the road curvature, terrain and topology for typically up to one kilometre prior to the actual accident site. These same investigators must be fully conversant with the behaviour of heavy vehicle air suspensions whilst cornering and accelerating. Likewise the vast response difference between air and mechanical suspended heavy vehicles must be fully appreciated.
It therefore follows accident simulation must utilize advanced software which account for time, torque and route history dependent air suspension parameters.
It is expected a further primary contributory factor to a vehicle loss of control / roll over is that the driver was applying positive torque to the drive axles not simply speed as the dominant contributory factor.

Driver Education

The typical highway speed air suspended heavy vehicle steering behaviour in long sweeping curves, in close coupled alternate lock sequences particularly those possessing vastly different curvature and post torque application responses should be made known to drivers. Furthermore drivers should be informed of the high risk accident scenarios and techniques to allay the risks. Techniques to improve steering smoothness and effect optimal route selection, to minimise accident risk, should also attract high priority. Here chain of responsibility implications suggest drivers unfamiliar with particular routes should be informed of high risk curve and road situations prior to the journey commencement. Here enhanced ‘in cabin’ electronic navigation devices will greatly assist.

The advantage for drivers to dab prime mover brakes and cancel positive power entering each and every corner must be made ubiquitously known.

Driver Fatigue

Noting air suspended heavy vehicle drivers need to dab their prime mover brakes and cancel / counteract for possible 'memory' steer each and every corner (with the intensity becoming more intense with curve extent and load centre of gravity) it is apparent unyielding vigilence is paramount to maintain vehicle control.

Road Design

Close coupled alternate lock curve sequences exhibiting vastly differing curvature should attract 'black spot' status, appropriate speed restriction signage, and particular situation signage (especially should the haul route be utilised by vehicles hauling payloads exhibiting high centre of gravity). Obviously, road design parameters should be selected remote from those attracting high accident risk. Road designers, installers and maintenance managers and personnel must pay particular attention to the exit zones of long sweeping curves over a distance covered by highway speed vehicles in up 5 T_s seconds plus one vehicle combination length.

Improved suspension parameters

It is recommended highway speed right hand drive vehicles be fitted with no more than one low gain RHCV located biased towards the right hand side (RHS) (and rear most drive axle) and receive feedback of no more than 50% of a specific attached axle ride height. Furthermore frame rise should be minimised to minimise variation in air suspension roll resistance sensitivity. Frame rise can be minimised by adopting non torque reactive suspensions, dynamic load sharing and maximising the number of drive axles.

All towed axle groups should utilise a single low gain ride height control valve biased to the left hand side. This location is necessary in reponse to typical Australian road cambers. The same recommendations apply to air suspended steer axle groups.

The roll resistance of each air suspended axle group should be maximised.

All jurisdictions should conduct vehicle fleet audits to ensure these optimal suspension parameters apply. Should deviations be identified chain of responsibility implications suggest modifications / retrofit be enforced as soon as possible.

Payload parameters

Every effort should be made by transport engineers and operators to minimise payload (and to a lesser extent tare) centre of gravity.

Introduction of electronic stability and advanced braking technologies

Noting the majority of fatal heavy articulated vehicle accidents occurred subject to adverse 'rural' or 'near rural' including unsealed road conditions it is doubtful electronic stability and advanced braking technologies will assist allay the accident frequency.

Future research

Future investigations should include examination of VicRoads CrashStats data records DCA 170 – 179 and 180 – 189 accidents at all levels of seriousness. Initially this investigation should consider those occurring in the last five years. This extended work is necessary to consolidate the relevance of the identified accident signatures and to enhance the correlation between the ride height control valve location and the specific accident scenario. It would be most appropriate all jurisdictions conduct similar investigations with the findings web accessible to the public.

Conclusions

General

The investigation highlights the need for improved driver education, improved suspension hardware details and parameters and identifies implications for road maintenance, road design and the imminent introduction of advanced heavy vehicle handling and braking technologies.

Heavy vehicle characteristics

The statistical investigation suggest newer heavy vehicles typically exhibit :

- high risk of loss of control exiting long sweeping curves
- high risk of loss of control entering the second curve of a alternate lock sequence.

The risk of loss of control is particularly acute should the lead curve be a long sweeping curve and the successive alternate lock curve be relatively sharp relative to the former.

Newer vehicles are most likely to be fitted with air suspensions.

Suspension parameters

The statistical findings are consistent with standard air suspended vehicles be fitted with:-

- a single left RHCV to exhibit a strong tendency to 'memory' steer to the right post long sweeping right lock curves.
- a single right RHCV to exhibit a strong tendency to 'memory' steer to the left post long sweeping left lock curves.

It therefore follows that vehicles fitted with twin ride height control valves tend to exhibit a strong tendency to 'memory' steer to both the left and right.

The inherent 'memory' steer actions may result in a path deviation or loss of control should the driver incur a lapse of vigilance or if the vehicle experiences a pavement induced disturbance. In regard the latter a disturbance to the steer axle/s is most significant.

Heavy Vehicle / Road Interaction

The statistical findings suggest standard air suspended vehicles are non optimal for 'typical' rural Australian roads. Notably, approximately 1 in 10 fatal vehicle accidents described as occurring on bends occur on narrow windy roads.

This same suggest heavy vehicles operating in rural environs, based on Victorian conditions, do so on non optimal roads.

The accident statistics suggests standard simple trailing arm suspensions are non optimal for Australian near typical 'rural road' conditions. Hence the handling stability of standard trailing arm type suspensions should be thoroughly examined especially on non optimal local 'rural' or 'near rural' roads.

References

Australian Federal Government (2004), Certification of Road Friendly Suspensions, Vehicle Safety Standards: Vehicle Standards Bulletin VSB 11.

Australian Transport Safety Bureau (2009) Fatal Heavy Vehicle Crashes Australia Quarterly Bulletin October – December 2008 ISSN 1835-0240 ISBN 978-1-921659-07-2 July 2009/ INFRA-09106

Australian Trucking Association (ATA) (2005), Report on Heavy Vehicle Crash Statistics

Austroads (1997), Rural Road Design – A Guide to the Geometric Design of Rural Roads, ISBN 0 85588 231 X Austroads Publications No. AP-1/89

Clarke, R. M. (1998) Safety Considerations Associated with Truck Size and Weights Policy Deliberations, SAE paper 982818 SAE SP – 1400 Truck and Bus Safety Issues pp 41–56

Curnow, G. (2002) Australian Safety Bureau heavy truck crash databases What do the statistics tell us?, NRTC / ATSB National Heavy Vehicle Road Safety Seminar Melbourne, October

Davis, L. and Sack, R. (2004), Analysis of heavy vehicle suspension dynamics using an on-board mass measurement system, 27th Australasian Transport Research Forum, Adelaide 29 September – 1 October 2004

Driscoll, O. (2009) Major Accident Investigation Report 2009, National Centre for Truck Accident Research, National Transport Insurance, February (www.nti.com.au)

Federal Office of Road Safety (FORS) (1995) (CR155) Sweatman, P. F., et al, Heavy Vehicle Crashes in Urban Areas

Federal Office of Road Safety (FORS) (2000) Investigation into the Specification of Heavy Trucks and Consequent Effects on Truck Dynamics and Drivers: Final Report Prepared by Roaduser International Pty Ltd for The Federal Office of Road Safety (FORS) (Australia), April

McLean, A., (2009), Suggested Heavy Vehicle Air Suspension Contributions to Fatal Accident Statistics and Signatures, 32nd ATRF Auckland NZ September

McLean, J. (1997), Review of accident and urban arterial cross-section treatments, ARR 309, ARRB Transport Research Ltd, Victoria, Australia.

Milliken, P. and de Pont, J., (2004) The Effect of Cross Sectional Geometry on Heavy Vehicle Performance and Safety, Transfund New Zealand Research Report No 263, ISBN 0-478-25374-5, 46p.

Mueller, T.H., De Pont, J.J., Baas, P.H., (1999), Heavy Vehicle Stability Versus Crash Rates, A report prepared for the land Transport Safety Authority by Transport Engineering Research New Zealand Limited, July, 53p.

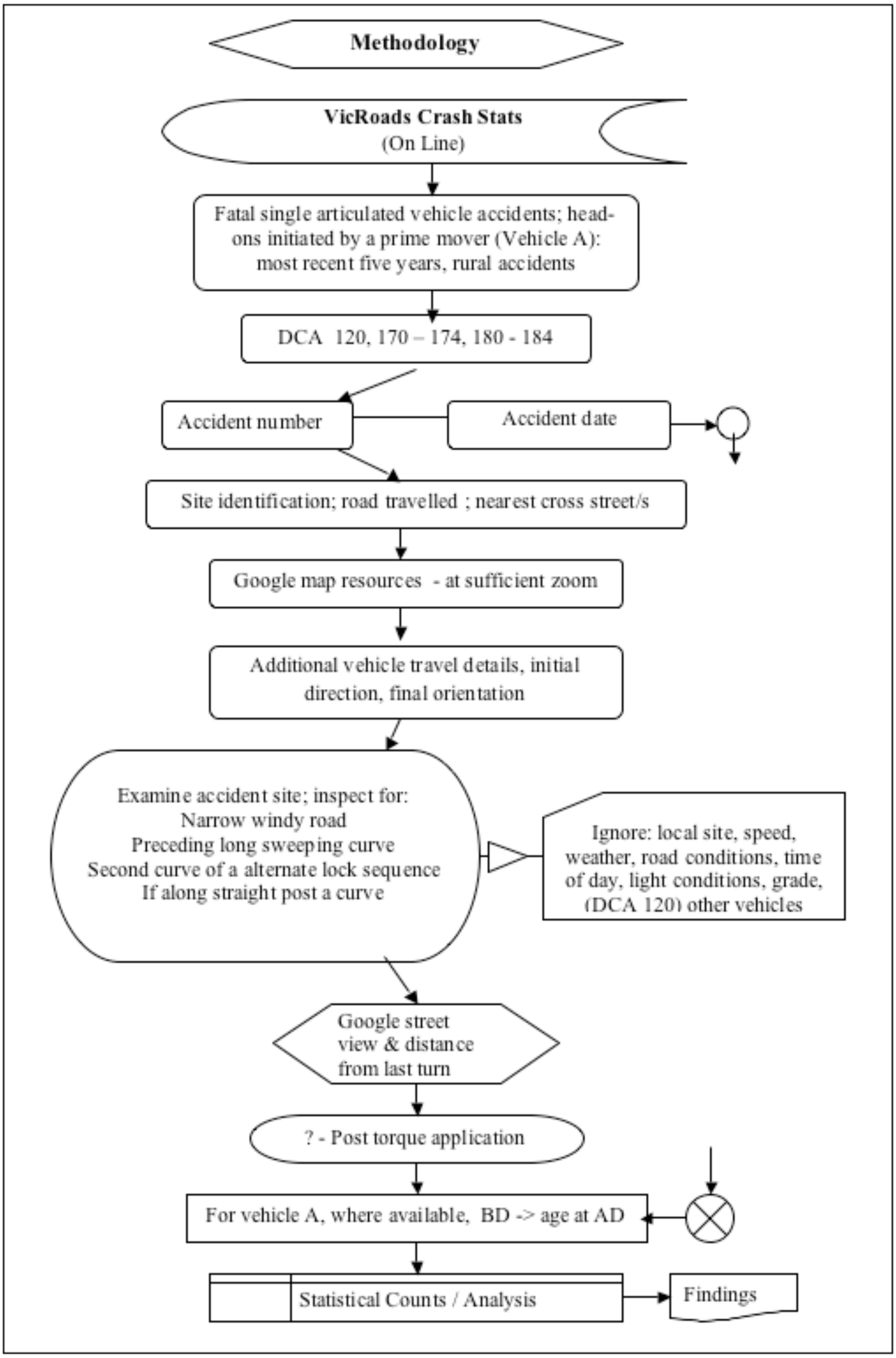
NRTC (2002), Truck Safety Benchmarking Study March 2002 prepared by Haworth, N., Vulcan, P., Sweatman, P., presented NRTC / ATSB National Heavy Vehicle Road Safety Seminar Melbourne, October

New Zealand Land Transport Safety Authority, Heavy Vehicle Stability Guide, Version 1.0, Wellington, web accessed heavy-vehicle-guide.pdf (downloaded August 2009)

Sweatman, P. and McFarlane, S. (2000) Ditto FORS (2000) Appendix Q

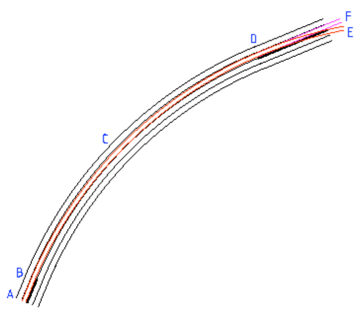
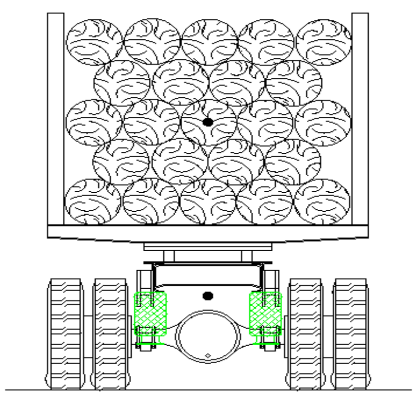
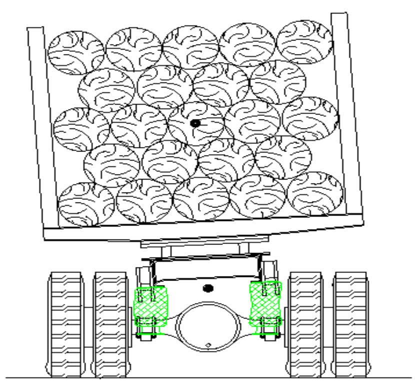
VicRoad CrashStats, http://crashstat1.roads.vic.gov.au/crashstats/crash.htm via http://www.vicroads.vic.gov.au/Home/RoadSafety/StatisticsAndResearch/

Appendix A Methodolgy Schematic



Appendix B Drive air suspension response negotiating a stand alone long sweeping curve

The response of a drive (and towed axle group) air suspension, hence air suspended vehicle, when negotiating a standalone right lock long sweeping curve is depicted in the schematic sequence summarised in the following table. Examination of this table confirms every air suspended vehicle exhibits a 'memory' steer post every curve (ie tendency to veer along path D to E). The extent of this memory steer effect is most vivid post a stand alone long sweeping curve. Further the dominant 'memory' steer effect and extent is dependent on the suspension type, the ride height control system feedback gain and the location of the ride height control valve. Brevity requirements limits further discussion. Further details are presented in McLean (2009). However, it must be stated that unyielding driver vigilance is necessary to apply steering correction to maintain vehicle control (ie to steer along path D to F).

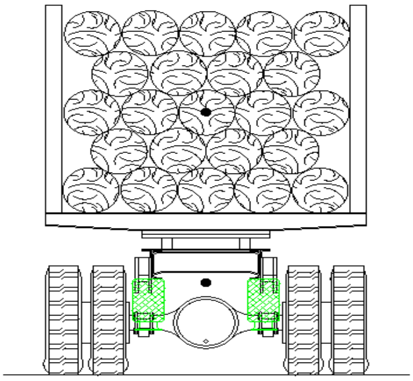
	Suspension phases experienced negotiating curve: < B lead in straight, lock application at B A to B lead in straight B to D constant radius long sweeping curve B to C curve lead in transient phase C to D curve steady state phase D to E uncorrected 'memory' steering transient phase D to F driver corrected 'memory' steering transient phase F >> post curve steady state phase D > post curve straight, lock cancellation at D Air Spring Conditions - (SP – Set Point)
Stand alone curve phases	Legend
	
Phase pre B Air Spring Conditions	Phase B to C Air Spring Conditions

Phase pre B Air Spring Conditions

p_L	h_L	p_R	h_R
SP	SP	SP	SP

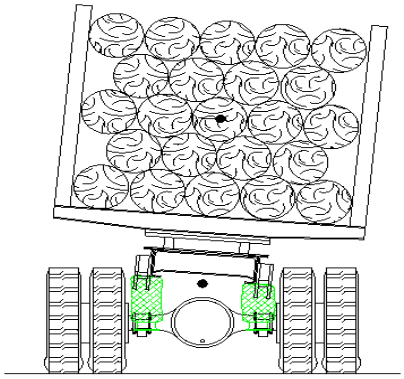
Phase B to C Air Spring Conditions

p_L	h_L	p_R	h_R
>	<	<	>



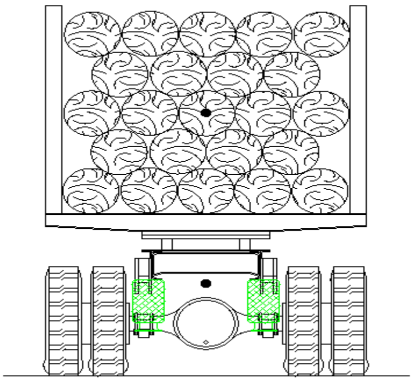
Phase C to D Air Spring Conditions

p_L	h_L	p_R	h_R
>	SP	<	SP



Phase D to E or F Air Spring Conditions

p_L	h_L	p_R	h_R
<	>	>	<



Phase post F Air Spring Conditions

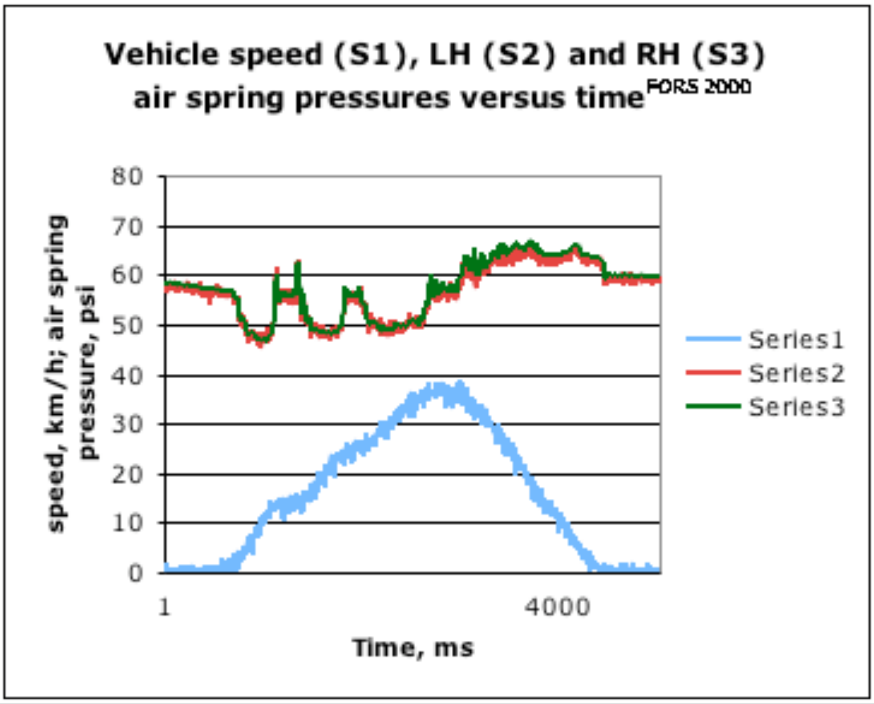
p_L	h_L	p_R	h_R
SP	SP	SP	SP

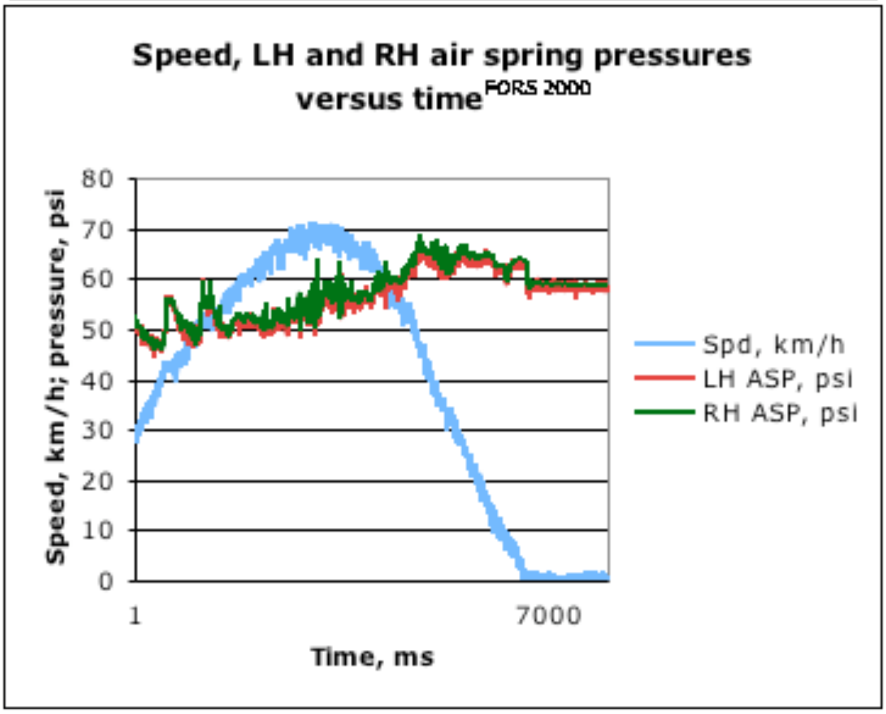
Vehicle moving into page
Vehicle operating at a speed conservatively below that associated with the vehicles' static roll threshold
A high quality uncambered pavement assumed
Suspension auxiliary roll resistance effects neglected
Time lag effects of towed axle groups neglected
Sudden lock application and cancellation assumed
Suspension assumed to be in high state of repair
Suspension stiction effects neglected

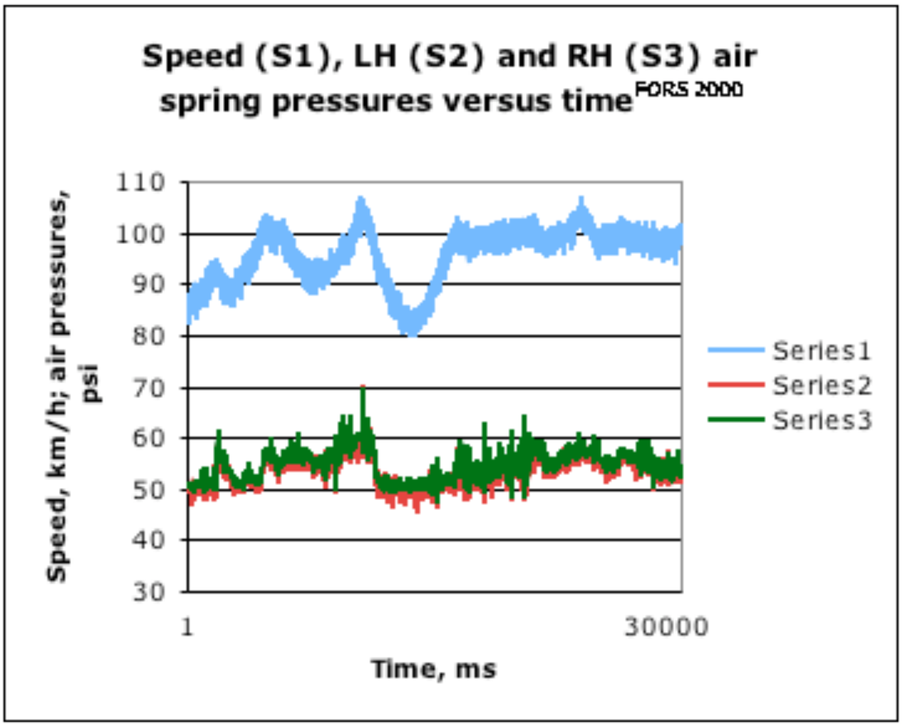
Notes

Appendix C Typical drive air suspension air spring pressure time variations

The following table provides typical time variations of the left and right air spring pressures in a floating flexible trailing arm torque reactive bogie drive air suspension fitted with a single RH RHCV attached to the rear drive axle of a 6 x 4 prime mover hauling a mechanical sprung tri axle tray trailer loaded to 38.7 t GCM, trailer and trailer / payload GoG 2.0 m. These time variations are presented for low (top), intermediate (middle) and highway (bottom) speed operation.







Examination of the foregoing charts indicates the air spring pressure in both the left and right hand is approximately invariant 58 psi when stationary. However, when the vehicle is mobile significant pressure variations occur. In fact for this limited data record the pressures fluctuate between, approximately, 70 psi to 45 psi.
Closer examination reveals
- the right hand air spring exhibits a higher pressure than that of the left hand air spring. This trend is consistent with the drive line torque reaction applying to the right hand side air springs.
- the air spring pressure decreases whenever the vehicle (generally) accelerates
- the air spring pressure rapidly increases (generally) when the vehicle (generally) decelerates.

Enhanced analysis would be require knowledge of gear change, engine speed brake, throttle, exhaust brake (setting and application), traffic conditions, road conditions and road topology.

From previous knowledge the sudden pressure increases occur whenever the drive line positive torque is suddenly cancelled and/or the prime movers' brakes are dabbed.

Of greatest concern here is that when the vehicle is subject to significant acceleration the bogies' roll resistance could be some 22% lower than that when stationary. At typical steady state highway speed the foregoing chart suggests the bogies' roll resistance could be some 8% lower than that when stationary. Even at an intermediate speeds (60 – 90 km/h) the air spring pressures can drop to approximately 50 psi when accelerating suggesting under such conditions the vehicles' roll resistance could be some 14% lower than that which would be observed should the vehicle be stationary.

Extrapolation of the analysis presented here noting, the required steady state drive torque increases with increasing vehicle GCM, the number of vehicle undriven axles, and speed squared (due to vehicle aerodynamic drag and rolling resistance (component)), suggests the drive axle group roll resistance will adversely deteriorate with increase in the stated variables.