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The influence of speed on concrete agitator vehicle stability

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Abstract

Concrete agitator vehicles have a relatively high centre of gravity and are therefore exposed to a risk of rollover. The stability of concrete agitator vehicles is also affected by the movement of the concrete in the rotating barrel. This report describes a study into the influence of speed and load on concrete agitator vehicle stability, using vehicle testing and computer based modelling.

It was found that (a) a rotating barrel decreased performance of the concrete agitator vehicles in static rollover threshold and load transfer ratio performance measures when compared to a stationary load, and (b) speed, modelled with the vehicle travelling through a roundabout, had a significant influence on the likelihood of rollover.

Keywords

Rollover, Stability, Heavy vehicle, Truck

Introduction

As with most heavy vehicles, the concrete agitator vehicle has a relatively high centre of gravity (COG) and is therefore exposed to a risk of rollover. The stability of the concrete agitator is also affected by the movement of the concrete in the rotating barrel. Holcim, a supplier of cement and aggregates, wished to assess the stability of their concrete agitator vehicles and investigate the effects of the moving concrete load in order to maximise the roll stability of their concrete agitator vehicles. This would minimise the chance of rollover and thus improve the overall safety of the vehicle fleet, with the aim to meet the company's commitment to zero harm.

The stability of a rigid vehicle is dependent upon many factors. Some of these factors are inherent in the cab chassis as supplied by the manufacturer, while others depend on the body fitted or use of the vehicle during operation, and others on the load condition.

The key factors that contribute to vehicle stability are:

- centre of gravity height
- mass
- load distribution
- suspension properties
- axle track width
- chassis and mounting restraint and rigidity
- characteristics of load (i.e. moving load)

Holcim engaged ARRB Group Ltd (ARRB) to conduct an investigation into the stability of their concrete agitator vehicles. As part of the investigation, ARRB was engaged to:

- perform static testing of a concrete agitator vehicle with the barrel rotating (completed for dry, medium and wet concrete mixes)
- determine the SRT (Static Rollover Threshold) via computer simulation
- conduct LTR (Load Transfer Ratio) analysis for a concrete agitator vehicle travelling through a roundabout via computer simulation.

Method

Static testing of vehicle with barrel rotating

The static testing of the concrete agitator vehicle was conducted at the Holcim batching plant in Bayswater, Melbourne, in

November 2006. The aim of the testing was to gain a better understanding of the influence that concrete moving in the rotating barrel has on the stability of the vehicle. This was achieved through observation and by acquiring data from sensors fitted to the vehicle.

The test vehicle was an Iveco Acco 8x4. Observations of the cement mixture moving inside the barrel were made from an overhead gantry. The vehicle was fitted with sensors to measure longitudinal acceleration, lateral acceleration, vertical acceleration and roll rate. The data acquisition system comprised a Panasonic CF-29 Toughbook, National Instruments Daqpad 6020E interface and Labview data logger software (Figure 1).

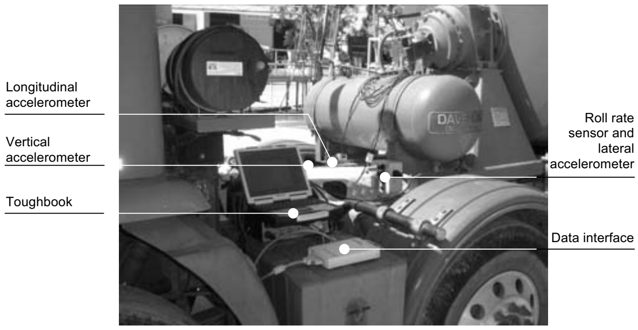

Figure 1. Instrumentation fitted to test vehicle

Tests were conducted using the following concrete mixes:

- '10 slump' – a dry mix often used to form kerbs
- '40 slump' – a medium mix often used for driveways
- '80 slump' – a wet mix often used for garage floors.

Tests were conducted with the engine speed between 600-1500 rpm and the barrel rotating at approximately two revolutions per minute. Two barrel revolutions per minute is typical of the rotation speed experience when driving on road.

With the barrel rotating, data was logged for a period of 1-2 minutes at a sample rate of 100 Hz. The data acquired during testing provided a quantitative measure of the forces transferred from the rotating barrel to the vehicle chassis and suspension.

This data was then used to determine the 'worst case' concrete mix, where the mix would be most detrimental to the rollover stability of the vehicle.

Vehicle modelling

Holcim selected a 10x4 concrete agitator vehicle for assessment via simulation. The vehicle properties were based on information supplied by the vehicle manufacturer, including vehicle centre of gravity (COG) height, mass, load distribution, suspension properties and vehicle dimensions.

The vehicle was modelled at maximum axle weights, being 11 tonnes on the steer axle group and 20 tonnes on the drive axle group.

A computer model of the 10x4 vehicle with rotating barrel was created and the data collected during testing of the 40 slump (medium) mix was used to characterise the movement of the load in the rotating barrel. ARRB completed this assessment using modelling techniques developed in-house and validated in numerous field tests and comparative studies over the last 12 years.

An example of validation of the computer model against test data can be seen in Figure 2, where there is a close relationship between the yaw rates measured during a field test of an innovative multi-combination vehicle and the yaw rates determined in the simulations.

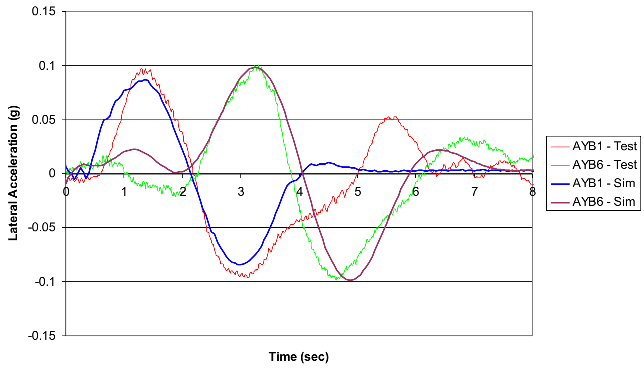

Figure 2. Example simulation validation

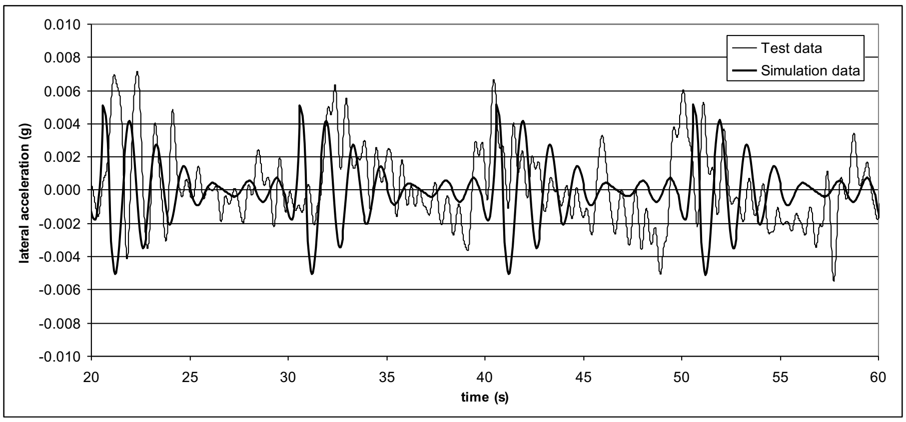

Figure 3. Calibration of vehicle model

The behaviour of the '40 slump' (medium) mix concrete load in the rotating barrel was modelled using computer simulation and compared to the test data. The input parameters of the model were calibrated against the test data and adjusted to closely match the behaviour measured during testing. Figure 3 shows an overlay of the simulation and test data outputs.

Simulations were completed for the 10x4 vehicle (subject vehicle) loaded to maximum axle weights with a rotating barrel at 2 rpm and a moving concrete load. The characteristics of the moving concrete load were based on the '40 slump' test data. The performance of this vehicle was compared to the 10x4 vehicle with the same dimensions and properties except that the barrel and load were stationary at all times (i.e. the barrel was not rotating and there was no slosh effect from the concrete load).

Static rollover threshold

Simulations were completed to determine the Static Rollover Threshold (SRT) of the vehicle as well as the Load Transfer Ratio (LTR) when negotiating a roundabout.

A common measure of rollover stability is SRT which is the level of lateral acceleration that a vehicle can sustain without rolling over during a turn. The SRT is expressed as a fraction of the acceleration due to gravity in units of 'g', where 1 g is an acceleration of 9.807 m/s^2 corresponding to the force exerted by the earth's gravitational field. High values of SRT imply better resistance to rollover and hence better stability.

ARRB completed the SRT analysis in accordance with the National Transport Commission (NTC) Performance Based Standards (PBS) Rules (2008). The nationally accepted performance target for SRT, adopted under the NTC's PBS is 0.35 g for heavy vehicles and 0.40 g for buses and dangerous goods vehicles. The value of 0.40 g roughly equates to the 62 degree stability angle required of dangerous goods vehicles. The result of the SRT analysis, therefore, provides a measure of the vehicle's roll stability which can be directly compared against a recognised national standard. The SRT analysis modelled the subject vehicle with a moving load as well as a stationary load.

As the proposed vehicle is still within prescriptive dimension limits for a rigid truck, there is currently no enforced stability requirement that this vehicle must satisfy.

Load transfer ratio

Load Transfer Ratio (LTR) is a measure of the amount of load transfer from one side of a vehicle to the other in a dynamic manoeuvre. An LTR of 0.0 indicates straight line travel (i.e. no load transfer), while an LTR of 1.0 indicates that all of the vehicle's mass is supported by the wheels on one side (i.e. complete wheel lift-off on the other side, rollover is imminent).

An LTR of 0.6 is considered, on the basis of ARRB's experience, to be the maximum safe level while travelling around a roundabout, bend or corner, which means that 60% of the vehicle mass usually carried by the inside tyres when travelling around a corner has been transferred to the outside tyres.

ARRB completed a LTR analysis for the subject vehicle negotiating a roundabout. ARRB selected road geometry suitable for assessing the vehicle stability during a manoeuvre, which would likely be encountered during normal driving conditions. The road geometry selected for the LTR analysis was the roundabout located at Baxter-Tooradin and Dandenong-Hastings roads and represents typical roundabout road geometry. The roundabout comprises varying negative crossfall with an average value of 2% and an approximate horizontal radius of 20 m (to road centre line). This road geometry can result in a vehicle rollover if negotiated at high speed. A 3D environment that accurately represents the actual road surface (including crossfall, elevation, curvature and position of the road) was created. Figure 4 shows an example of a 3D environment created from the measured road geometry data.

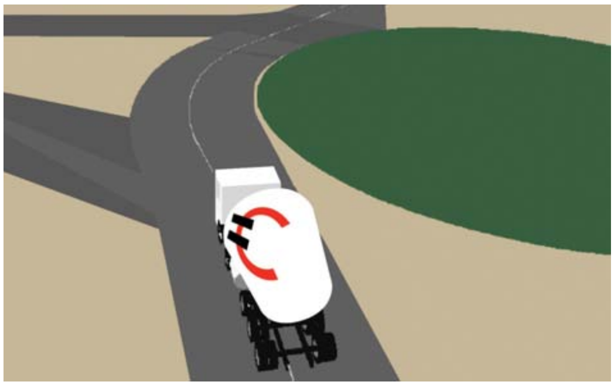

Figure 4. 3D computer model of roundabout road geometry

The vehicle's approach and negotiation of the roundabout were analysed using computer simulation. The speeds simulated ranged from 25 to 35 km/h. For each of the speeds simulated, the LTR was recorded during the manoeuvre. Simulations were completed for both the subject vehicle (moving load) and baseline vehicle (stationary load).

Results

Static testing of vehicle with barrel rotating

From the static testing of a vehicle with the barrel rotating at a speed of 2 rpm, the effect of the rotating barrel and moving concrete load on vehicle roll stability was quantitatively measured for three variations in concrete mixes. It was shown that:

- The effect of the rotating barrel and moving concrete load on vehicle roll stability was quantitatively measured for three variations in concrete mixes.
- The '40 slump' (medium) mix resulted in the highest recordings of body roll rate.
- The '10 slump' (dry) mix resulted in the next highest recordings of body roll rate.
- The '80 slump' (wet) mix resulted in the lowest recordings of body roll rate.
- The '40 slump' (medium) mix was considered to be the least stable load condition.

- The magnitude and frequency of '40 slump' (medium) was determined and the test data deemed suitable for simulating and assessing vehicle stability when driving on road with the least stable load condition (worst case scenario).

Static rollover threshold

Table 1 shows the results obtained from the simulation for the 10x4 concrete agitator vehicle.

Table 1. Results of SRT simulation

Vehicle	PBS Performance target	Performance achieved
Subject vehicle		
(with '40 slump' moving load)	≥ 0.35 g	0.36 g
Baseline vehicle		
(with stationary load)	≥ 0.35 g	0.38 g

The 10x4 concrete agitator vehicle simulated with a rotating barrel and moving load achieved a SRT value of 0.36 g and 0.38 g with a stationary load. The simulation results indicate that the 10x4 vehicle with a rotating barrel and moving load is less stable than if the barrel and load were stationary.

Both vehicles achieved a SRT value that satisfies the NTC's PBS target of ≥ 0.35 g.

Load transfer ratio

Figure 5 shows the variation of LTR with distance travelled at various speeds. The LTR plot exhibits minor variation during the vehicle's approach to the roundabout (Section A) due to small variations in crossfall on this section of the road. The LTR then increases to a peak value as the vehicle negotiates the apex of the curve (Section B), then falls as the vehicle exits the roundabout (Section C).

When travelling at 25 km/h the subject vehicle reaches a peak LTR of approximately 0.5 as the vehicle negotiates the bend then reduces to less than 0.1 as the vehicle exits the roundabout. This result indicates that 25 km/h is a safe speed for this vehicle to negotiate this roundabout.

When travelling at 30 km/h the vehicle exceeds the recommended safe LTR of 0.6, reaching a peak of 0.75 for the subject vehicle (moving load) and 0.70 for the baseline vehicle (stationary load). The LTR then reduces to less than 0.1 upon exiting the roundabout. This result indicates that negotiating this roundabout at a speed of 30 km/h puts the vehicle at risk of rollover. At this speed, the difference between the subject and baseline vehicle is more obvious, with the 10x4 vehicle with the rotating barrel and moving load at a greater risk of rollover.

When travelling at 35 km/h the subject reaches a LTR of 1.0 and subsequently rolls over. The baseline vehicle (stationary) does not rollover, but is highly unstable reaching a peak LTR greater than 0.9.

Discussion

The behaviour of the concrete moving inside the barrel was observed and recorded during the testing process using three different slump types, being dry ('10 slump'), medium ('40 slump') and wet ('80 slump').

With the barrel rotating at approximately two revolutions per minute – simulating the typical barrel rotation speed of the vehicle on the road – data was logged to provide a quantitative

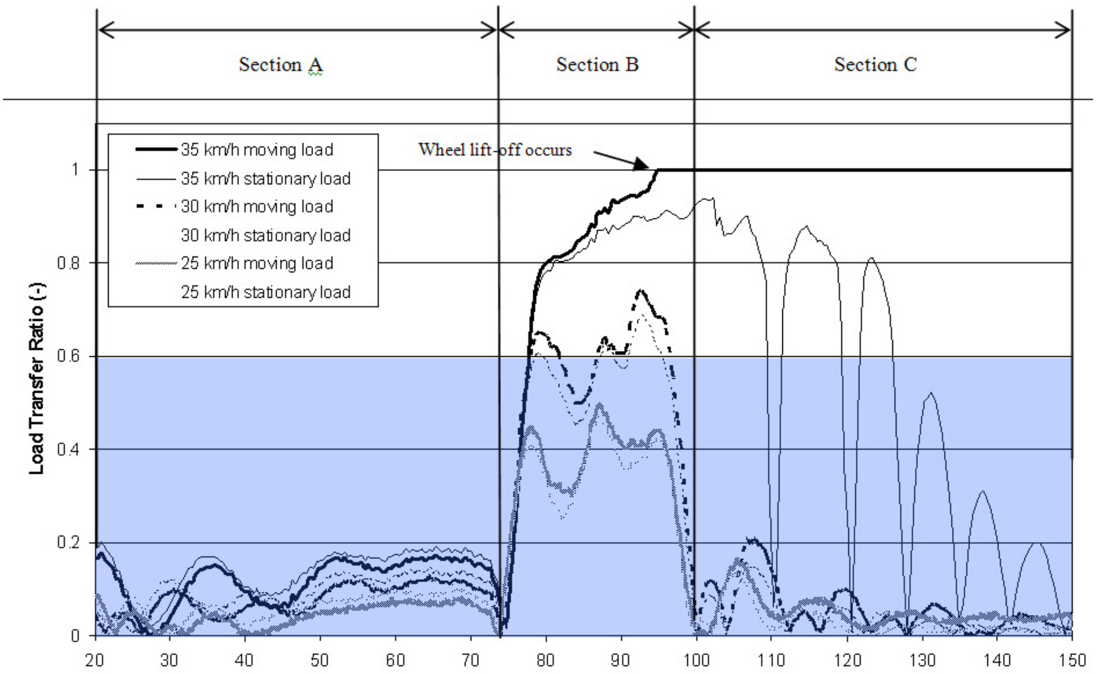

Figure 5. Load Transfer Ratio against distance travelled

measure of the forces transferred from the rotating barrel to the vehicle chassis and suspension.

The following observations were noted:

- Large masses of the 40 mm slump mix were observed to stick to and climb up the inside of the barrel then fall in slabs as the concrete mass approached the top of the barrel, and resulted in the highest recordings of body roll rate.
- The 10 mm slump mix did not bind together nor climb as high inside the barrel and tended to crumble and fall and resulted in the next highest recordings of the body roll rate.
- The 80 mm slump mix did not stick to the inside of the barrel and exhibited a self- levelling behaviour, and resulted in the lowest recordings of body roll rate.

The SRT analysis showed that having a moving load destabilised the vehicle and resulted in a poorer SRT performance than the same vehicle with a stationary load. While the vehicle under both loading conditions was able to meet the required performance level, this indicates that the moving load decreases the stability of the vehicle, and makes the vehicle have a higher likelihood of rollover.

From the LTR analysis using the simulated model with a rotating load and the dimensions of the particular roundabout it was observed that:

- The vehicle was able to negotiate the simulated path through the selected roundabout at 25 km/h* and remain below the recommended LTR of 0.6 (Table 2).
- At only 5 km/h faster (30 km/h), the vehicle exceeds the recommended safe limit. This result indicates that negotiating this roundabout at 30 km/h momentarily puts the vehicle at risk of rollover.
- At another 5 km/h faster (35 km/h), the vehicle reaches a LTR of 1.0 and subsequently rolls over.

Table 2. Effect of speed on peak LTR through a roundabout

At speed of 25 km/h	5 km/h faster (+5 km/h total)	5 km/h faster (+10 km/h total)
Below LTR of 0.6	Above safe limit	Truck rolls over

** It should be noted that a safe speed is very variable and is dependent upon the environment (such as crosswinds), the load characteristics and the truck type.*

Table 3. Effect of load condition on peak LTR through a roundabout

Load case	At speed of 25 km/h	5 km/h faster (+5 km/h total)	5 km/h faster (+10 km/h total)
Subject vehicle (stationary load)	0.47	0.70	0.95
Baseline vehicle (moving load)	0.50	0.75	1.00

The LTR analysis was also able to determine the effect that the moving load had upon the stability of the vehicle as it passed around the roundabout (Table 3). The LTR increased (decreased in performance) when the moving load was modelled over the case where a stationary load was modelled, further indicating that a moving load and rotating barrel will destabilise a vehicle and increase the risk of rollover.

Conclusion

Simulations were completed for a 10x4 concrete agitator vehicle loaded to maximum axle weights with a rotating barrel at 2 rpm and a moving concrete load. The characteristics of the moving concrete load were based on the '40 slump' test data. The performance of this vehicle was compared to the 10x4 vehicle with the same dimensions and properties except that the barrel and load were stationary at all times (i.e. the barrel was not rotating and there was no slosh effect from concrete load).

ARRB completed the SRT analysis in accordance with the Performance Based Standards Rules (NTC 2008).

From the SRT analysis it was concluded that:

- The vehicle achieved a minimum SRT value of 0.36 g (rotating barrel and moving load) and 0.38 g (stationary load - simulated with the barrel not rotating and no slosh effect from concrete load).
- This result means the SRT value of the 10x4 subject vehicle is better than the recommended ≥ 0.35 g and therefore satisfies the SRT requirements of PBS (NTC 2008).
- As the proposed vehicle is still within prescriptive dimension limits for a rigid truck, there is currently no enforced stability requirement that this vehicle must satisfy.

ARRB completed a LTR analysis for the subject vehicle negotiating a roundabout. ARRB selected road geometry suitable for assessing the vehicle stability during a manoeuvre, which would likely be encountered during normal driving conditions and represents typical roundabout road geometry. The roundabout comprises varying negative crossfall with an average value of 2% and an approximate horizontal radius of curvature of 20 m. This road geometry can result in a vehicle rollover if negotiated at high speed.

From the LTR analysis it was concluded that:

- The vehicle with a stationary load (simulated with the barrel not rotating and no slosh effect from the concrete load) was able to negotiate the selected roundabout at a higher speed than the vehicle with a rotating barrel and moving load.
- The rotating barrel and moving load reduces the stability of the 10x4 subject vehicle and puts it at a higher risk of rollover.
- The subject vehicle is able to negotiate the simulated path through the selected roundabout at 25 km/h and remain below the recommended load transfer ratio of 0.60.

The assessments show that some small variations in slump type, load condition or speed can result in significant changes in performance, and most importantly, regardless of the vehicle or the load, too great a speed through a bend, roundabout or corner will result in the vehicle rolling over.

It does not take much to cross the line of safety as the road variables such as road camber and crosswinds as well as vehicle parameters such as slump type can change frequently. Drivers need to adopt a very conservative speed - less than they think is the maximum safe speed - so as to maintain a greater safety margin when approaching, entering, driving through or departing a bend, roundabout or corner.

The findings of this safety study have been used by Holcim to produce a training video. The video aims to provide drivers with a better understanding of the influence of speed and moving loads on vehicle stability. Subsequently, videos relevant to other types of truck have been produced - all with the aim of improving understanding and reducing the risk of truck rollovers.

Acknowledgements

This safety study was a collaborative effort between ARRB Group and Holcim. For the purpose of the study, Holcim made available their facilities, staff, vehicles and drivers and funded the safety study to be completed via the testing and simulation methods employed by ARRB Group.

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Australian major accident investigation report on 2009 NTI Data: Heavy vehicle losses > $50,000

by Owen P. Driscoll, National Manager – Industry Relations, National Transport Insurance, Director – TruckSafe Pty Ltd – Australian Trucking Association, National Coordinator – National Truck Accident Research Centre

Introduction

Fundamentally, truck crash research is a prerequisite for achieving sustainable improvements in road safety, with benefits not only for customers but for all transport operators who share the road.

This report continues a unique series of longitudinal studies involving the tracking of Australian heavy vehicle crashes where National Transport Insurance (NTI) is the insurer, since 1998. These studies are undertaken every two years by the National Centre of Truck Accident Research.

NTI provides insurance, risk appraisal, claims and accident management services to the road transport and earthmoving industry. It currently insures more than 131,000 items of plant and equipment having an insured asset value of $9.4 billion. Since 2002, NTI has settled 41,000 notified losses (per item) with claims payments exceeding $570 million (AUD).

The research into major losses in 2009 follows quantitative studies completed on major truck crash incidents reported during 2003, 2005 and 2007. Since the initial study conducted in 2003, NTI-insured equipment numbers has grown by 48% whilst major crashes over (>) $50,000 have increased marginally by 7%. There was a 1% decrease in the number of major incidents reported, when compared to those investigated for the prior period, the average financial loss per incident increased by 6.2% to $136,472. For the duration of the 2009 period, 323 major incidents were reported at a total cost of $44 million.

Methods

This research focuses on primary data specifically reviewing major heavy truck crashes managed by the National Claims Centre. Such incidents have an aggregate cost greater than (>) $50,000. The loss per incident includes property damage, crash scene repatriation, load transhipment, salvage, recovery and towing outlays. Losses in relation to freight on-board and personal injury are not included. This research concentrates on heavy vehicle accidents in the hire and reward freight sector with vehicles having a payload exceeding five tonnes where National Transport Insurance (NTI) is the insurance underwriter.

Findings

In terms of portfolio growth, during 2007, NTI insured 113,526 items that increased to 120,567 by the end of 2009. Representing a growth of 6.2% in numbers, the crash frequency rate, in relation to major incidents > $50,000, improved to 2.7 incidents per 1000 units. Figure 1 shows rates in years 2003, 2005, 2007 and 2009.

Information compiled and analysed in the 2009 study found the worst day of the week to be Monday with 18.9% of major incidents occurring within this 24 hour cycle (Figure 2). This was slightly down on prior results; nevertheless, Mondays and Tuesdays still accounted for 37.5% of crashes. This is consistent with earlier studies.

Otherwise, excluding Saturdays and Sundays, crash rates progressively decreased during each week before a marginal increase on Friday. Irrespective of the fact that for various freight tasks the working week may commence on different days, it could be argued that there is a correlation with a driver's fitness for duty, or lack thereof, where they have not worked and not had sufficient rest throughout the weekend.