are already in the *National Heavy Vehicle Strategy 2003-2010*, such as the clearance of roadside hazards, shoulder sealing, provision of passing lanes, and programs to minimise the risk posed by utility poles.

Further investigation of other promising measures such as the use of barriers to reduce the risks posed by roadside hazards, audible edgelining for heavy vehicles, and improved delineation was required. Other longer term measures warranting support include skid-resistance treatments and greater lane widths.

Heavy vehicle driver gap selection at intersections

The project sought to measure the gap sizes selected by drivers of heavy vehicles for a number of turning/crossing manoeuvres at intersections. Driver gap-taking decisions were analysed at six sites. Four were located in Melbourne and two in Brisbane; four sites were T-intersections and two were cross-intersections. The sites consisted of standard intersection geometry which satisfied ARRB selection criteria. Road-mounted traffic counters and video cameras were placed at each site, and data was recorded continuously for a period of approximately seven days.

The five heavy vehicle classes analysed in this study were:

- medium rigid truck
- heavy rigid truck
- semi-trailer
- truck-trailer
- B-double.

Data were only analysed during daytime hours (approximately 7.00 am to 5.30 pm), when the road was dry and when the driver of a subject vehicle made a complete stop before performing the entry manoeuvre.

It was found that the gap size chosen by the driver for the five vehicle classes increased in line with the size of the vehicle, namely medium rigid, heavy rigid, semi-trailer, truck-trailer and B-double. [2] This was an expected result as the latter vehicle classes have a longer length and a larger mass. The B-double vehicle class had a significantly larger gap size than the other classes. Gap sizes for the medium rigid, heavy rigid and semi-trailer vehicle classes were very similar for the majority of manoeuvres.

Further measurement of driver gap selection at night, during wet weather, and with laden and unladen vehicles would also provide valuable information on driver behaviour.

Future research directions

Heavy vehicle safety will remain an important area of research for Austroads and ARRB. The directions for future research are likely to include:

- assessment of the most promising vehicle technologies with an emphasis on intelligent transport systems
- investigation of representative heavy vehicle crash locations in order to identify the causes and risk factors
- development of measures in support of the national heavy vehicle safety strategy and action plans
- review of speed limits in relation to road standards and roadside development
- improvements in road design and traffic management practice which take greater account of their interaction with heavy vehicles
- the suitability and application of safety barriers to reduce the risk for heavy vehicles from roadside hazards
- review of the design of intersections on key freight routes to accommodate heavy vehicles more safely.

Notes

[1]Austroads membership comprises the Australian state and territory road transport and traffic authorities, the Commonwealth Department of Infrastructure and Transport, the Australian Local Government Association, and the NZ Transport Agency. Its purpose is to contribute to improved transport operations including the fostering of research in the road sector.

[2]The gap range for each vehicle was found to be: medium rigid (4.6 to 8.6 seconds), heavy rigid (5.2 to 7.2 seconds), semi-trailer (6.6 to 9.6 seconds), truck-trailer (5.0 to 9.6 seconds) and B-double (7.8 to 12.0 seconds).

Large truck crash avoidance

by Ronald R. Knipling Ph.D., Principal, Safety for the Long Haul
Arlington, Virginia, USA rknipling@verizon.net

Abstract

Large truck and other commercial vehicle crash causation can be conceptualized by a risk-cause timeline and model. Different types of risk factors interact continuously to raise or lower crash risks, though crashes are usually precipitated by a discrete driver error or other failure. Enduring individual differences in driver risk are strong, with personality and related risk attitudes as a major source. Roadway characteristics (e.g., divided vs. undivided roads) are comparable to driver differences in their effects on risk. For motor carriers, a distinction can be made between risk *reduction* (i.e., improving drivers and vehicles) and risk *avoidance* (reducing exposure to risk). Both can be effective strategies.

Keywords

Crash causation, Crash risk, Crash risk reduction, Crash risk avoidance, Driver risk, Divided roadways, Commercial motor vehicles, Truck safety

Introduction: What is crash risk?

At any given time on the highway, many different factors interact to affect commercial motor vehicle (CMV) crash risk. Traditionally, crash risk factors and causes are classified as either *driver, vehicle or environmental*, with the latter including both the roadway and weather. Figure 1 is a schematic of these interacting factors, with some elaborations [1]. In regard to the truck driver, it is helpful to consider two general types of human factors. The first of these are from the driver's constitution: physical, medical, psychological, or other *enduring personal* risk factors. The second type of driver factor includes all the *temporary personal* risk factors that affect people in their daily lives. This includes last night's sleep, time awake, circadian status (peaks and valleys), recent meals, recent caffeine, and temporary emotions like anger and frustration (perhaps associated with delivery schedule pressure). Traditional terms for these two categories of human factors are *traits* and *states*.

Influences from *outside* the truck driver can be considered *situational* factors, with vehicle and roadway environment as major subcategories. Vehicle factors include the vehicle's basic configuration (e.g., single-unit vs. combination, trailer and cargo type), its mechanical condition, and its safety-related features. Roadway environment factors include road type, traffic density and patterns, surface condition, and weather. Thus, a simple taxonomy of the crash risk factors operative at any time during driving is as follows:

- Driver
  - enduring characteristics (traits)
  - temporary characteristics (states)
- Situational (outside the driver)
  - vehicle
  - environmental (eg.,roadway, weather, surface condition)

In recent convenience-sample surveys [2, 3] of US motor carrier safety managers and other experts, driver traits and driver states were regarded by respondents as the two most important factors affecting crash risk. These two factors were regarded as far more important than vehicle factors (equipment and condition), roadway characteristics, and weather conditions. Findings from the US Large Truck Crash Causation Study (LTCCS) and many other studies also find driver factors to predominate in crash causal scenarios [4].

Not seen in Figure 1 below are the many prior and 'macro' influences on driving safety which are less apparent in driving scenarios but operative nonetheless. Most notably, carrier practices 'create' many of the driver, vehicle, and roadway environmental elements seen in Figure 1. Government policies and practices form another overlay to driver-vehicle-roadway interaction and resulting crash risk. The following list highlights six categories and numerous specific crash risk factors.

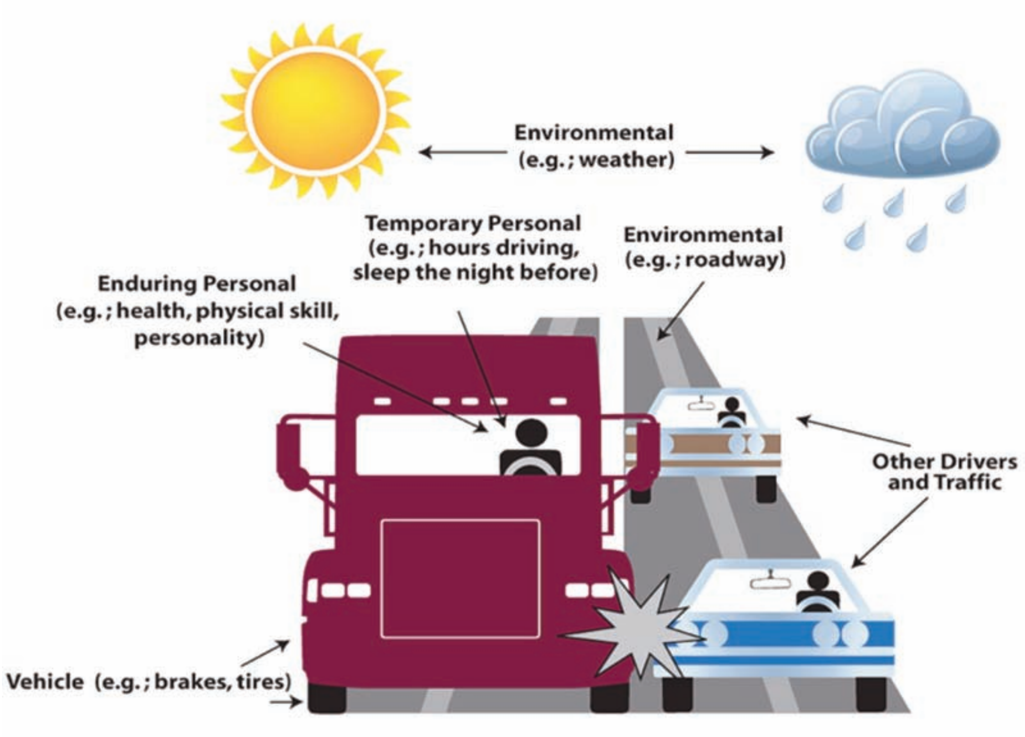

Figure 1. Multiple interacting factors in large truck crash involvement. Reprinted from [1]

Potential crash risk factors

Enduring Driver Factors
- Demographics; e.g., age, gender
- Driving knowledge & skills
- Personality; e.g., aggressiveness, sensation-seeking, stress level
- Risk perception& attitudes
- Psychomotor skills; e.g., reaction time
- Medical status & conditions, including fatigue susceptibility
- Behavioural history
- Mental abilities

Temporary Driver Factors
- Recent sleep
- Time-of-day & circadian rhythms
- Time awake (e.g., > 16 hours)
- Time-on-task (hours working & driving)
- Short-term illnesses
- Moods & recent stress
- Recent food & fluids
- Drugs, medications, & alcohol
- Familiarity with road

Vehicle
- Vehicle design & configuration
- Mechanical condition
- Safety features & technologies

Roadway & Environmental
- Mileage exposure in general
- Divided vs. undivided roads
- Level of access/types of intersections
- Traffic density
- Curves & ramps
- Intersections
- Lane restrictions
- Construction zones
- Weather & road surface condition

Carrier Operations & Management
- Organization & operation type
- Driver selection
- Fleet-based driver training
- Communications & dispatching
- Driver performance monitoring & evaluation
- Rewards & discipline
- Pay & benefits

Government Policies & Practices
- Driver qualifications & licensing
- Hours-of-Service
- Enforcement practices
- Information & education programs.

If you came upon a truck crash and wondered how it happened, you would probably not think about all the factors listed in the textbox. Instead, you would likely ask what driver error (mistake or misbehaviour) or other failure (vehicle, environmental) was the immediate or 'proximal' trigger of the crash. Examples include driving too fast, following too closely, failure to see another vehicle, falling asleep at the wheel, or vehicle brake failure. In the LTCCS, the term *Critical Reason* (CR) was used for proximal crash causes [4]. Most were driver errors of various types, but they also included vehicle failures and extreme environmental conditions like icy roads and wind gusts.

Figure 2 shows a conceptual crash timeline encompassing predisposing risk factors and proximal causes [1].

Risk factors set up a situation where driver errors or other failures are more likely to occur or to have greater consequences. Multiple risk factors can exist at the same time, and have compounding effects on total risk. For example, a driver with aggressive, risk-taking tendencies (driver risk factors),pulling a top-heavy load (vehicle risk factor), enters a sharp curve (roadway risk factor),is going too fast (proximal cause or Critical Reason), and rolls over (crash).

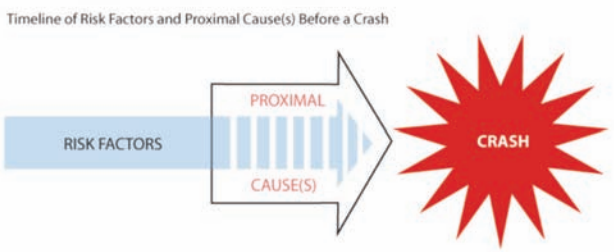

Figure 2. Timeline of risk factors and proximal cause(s) before a crash. Reprinted from [1]

Though simplistic and general, the above risk model views multiple risk factors as interacting in potentially complex ways. It does not seek a 'root cause' [5] but rather sees a multitude of interacting factors which can each raise or lower risk to various degrees. All of these set up conditions for a proximal error to trigger a crash.In the model, proximal causesare distinguished from risk factors by the fact that they are more discrete triggering behaviours or other events, as opposed to pre-existing driver, vehicle, or environmental conditions. The model is heuristic in that it frames analyses of crash and naturalistic driving data as well as safety interventions at the fleet level.

Differential driver risk

'Metaprinciples' of human nature and behaviour [6] include:

- individual differences: each person is physically and psychologically unique
- behavioural consistency: each person behaves relatively consistently over time and in different situations.

These two 'metaprinciples' are different sides of the same coin: people are different from each other, and these differences may permeate life. Many personal dimensions affect driving styles, performance, and behaviour. Driver individual differences are of great potential concern in CMV transport because of the high mileage (and, therefore, risk) exposure of many commercial vehicles and because of the high potential severity of their crashes. The *paradox of large truck safety* [1] is the fact that, even though long-haul trucks are generally driven safely and have generally low crash rates, there is a high premium on making trucks and their drivers safer. This is because of their inherent high exposure and crash severity risks. The same principle applies to long-haul bus operations, with the added concern for commercial vehicle passengers as well as for the motoring public.

Studies of both commercial and non-commercial drivers consistently show that risk among drivers is neither random nor evenly distributed[1, 7]. Rather, within almost any group of drivers, some will show greater likelihood of involvement in at-fault incidents whereas most others will show relatively low involvement rates. With relatively infrequent events such as crashes, such variation *could* be due to chance alone. To distinguish true differences in underlying risk from variations due to chance, one needs more data. Naturalistic driving studies quantify individual risk by capturing many incidents, not just crashes. In these studies [8-9] trucks are instrumented with multiple cameras and sensors. Volunteer drivers drive them in regular operations for an extended period, typically several months. Driving data is recorded by an onboard computer, and incidents (e.g., a crash, hard braking, or other sharp manoeuvre to avoid a crash) are captured and analyzed. Comparing incident involvement to exposure allows researchers to quantify the relative risk (e.g., odds ratio) associated with any measured factor, including different drivers.

Figure 3 gives an example from a large truck naturalistic driving study conducted by the Virginia Tech Transportation Institute [9] and sponsored by the US Federal Motor Carrier Safety Administration (FMCSA). In the study, 95 drivers were rank-ordered by their frequency of involvement in at-fault (preventable) incidents. The average driver had about seven at-fault events. At the extremes, the worst driver had 43 while, at the other extreme, 18 drivers had *zero* at-fault incidents in several months of driving. When exposure (hours of driving) was compared to incident involvement, the worst 19% of drivers (i.e., those with the highest rates) were found to be associated with 53% of all observed at-fault incidents. The risk ratio for incident involvement versus exposure for the high-risk drivers versus the rest of the drivers was 4.9. In other words, hour-for-hour, the high-risk drivers were 4.9 times riskier than were other drivers.

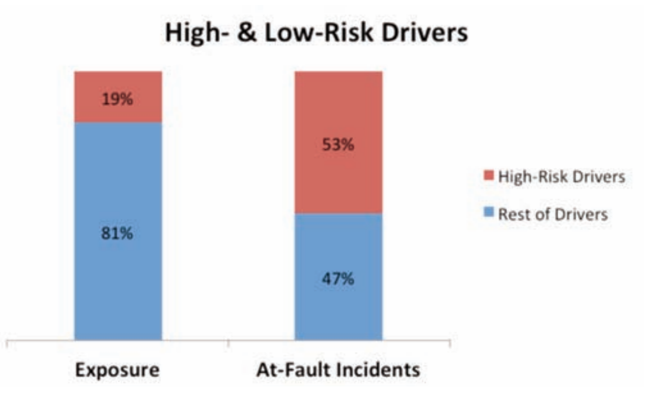

Figure 3. Exposure (hours of driving) and at-fault incidents for worst drivers and rest of drivers in truck naturalistic driving study. Data from [9]

A principal object of commercial driver selection for hiring, and assessment in general, should be to identify as many as possible of these high-risk drivers [2, 7]. They should be excluded from the fleet to *avoid* the risk that they create, or remediated(e.g., through training, rewards, or discipline) to *reduce* their risk to acceptable levels.

Naturalistic driving study results have their caveats [1]. They are not controlled experiments but rather detailed observations of driving in the real world where confounding factors may be operating. It is possible that some drivers are assigned more difficult routes or otherwise are exposed to greater risks than others. Also, few of the incidents captured are actual crashes. More typically, they are hard-braking or other sharp avoidance manoeuvres to avert a crash. No studies have been conducted over years of driving, but most of the study time periods have been long enough (e.g., two months) to reliably discern individual driver patterns. While empirical data on the long-term stability of driver risk is hard to come by, most carrier safety managers and other experts believe that relative CMV driver risk is generally consistent from year to year [7].

Distribution of 51 ESC activations among 18 drivers:
16, 16, 10, 3, 2, 2, 1, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0.

More recent data corroborating differential risk among commercial drivers comes from a Field Operational Test [10] of Electrically Controlled Braking Systems (ECBS) and Electronic Stability Control (ESC). These systems were installed on 18 long-haul trucks, each with a dedicated driver. After a six-month baseline period, each driver drove his or her ECBS/ESC-equipped vehicle on daily runs of roughly 500 miles for another six months. ESC activations occurred when a vehicle was experiencing yaw or roll instability indicative of potential loss-of-control. During the six-month test period there were a total of 51 ESC activations among the 18 drivers and trucks, for an average of about three activations per driver. There was only one 'average' driver however. Instead, the distribution of ESC activations (indicative of potential loss of vehicle control) was as shown in the textbox. Three drivers with 16, 16, and 10 events accounted for 42 of the 51 events (82%). The other 15 drivers together accounted for 9 events (18%). These data further demonstrate differential risk among drivers. They also attest to the value of employing Onboard Safety Monitoring (OBSM) of driver behavior along with prevention systems like ESC to record system sensor data and activations for driver evaluation and remediation.

What enduring driver factors underlie differential driver risk? All of those listed in the textbox can contribute. No one has sorted out the relative influence of various factors quantitatively, but it appears that driver personality and risk attitudes are most central [1-2, 7, 11]. In contrast, variations in psychomotor skill seem to affect driving safety only in extreme cases [2]. Medical conditions like obstructive sleep apnea and cardiovascular illness cause performance failures triggering crashes, but many more crashes are triggered by misbehaviours like speeding and tailgating [4]. The general rule in driving safety is 'Behaviour trumps performance.'

Roadway, traffic and operational risk

A survey mentioned earlier [2, 3] found roadway and traffic factors to be regarded by carrier safety managers and other experts as having less influence on crash risk than do driver factors. Naturalistic driving data suggest that the effects are comparable, however. That is, a 'bad' road raises crash risk about as much as a 'bad' driver does. In the same naturalistic driving study described above [9], analysts classified the road type in each incident video and in randomly selected driving periods. The random periods captured overall exposure to the two road types. Only 10% of tractor-semitrailer driving was on undivided roadways, but 38% of incidents occurred on them. This is shown in Figure 4. Here the risk ratio was 5.3. In other words, driving on undivided roads had 5.3 times the incident risk of driving on a freeway or other divided road. This is not too surprising when one considers the risk differences between divided and undivided roads. On divided roads, vehicles are all traveling in the same direction at relatively uniform speeds. On undivided roads, there usually are traffic signals, stops and starts, crossing vehicles, turning vehicles, pedestrians, many opportunities for distraction, and little margin-of-error [3]. Undivided roads probably carry even greater relative risks for trucks than for cars because of these small margins of error.

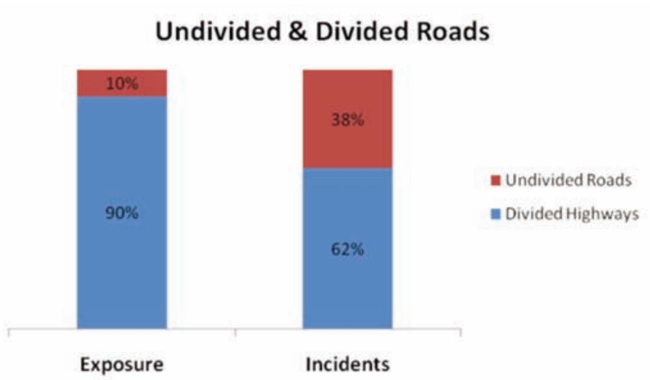

Figure 4. Exposure (percent of randomly selected time periods) and incidents for undivided and divided roadways in truck naturalistic driving study. Data from [9]

The same analysis approach finds that dense traffic, compared to light-to-moderate traffic, has very similar relative risk effects. Driving in work zones elevates relative risk even more. In the same study [9], 0.7% of driving was in work zones, but 6.0% of incidents occurred there - an odds ratio of 8.5. Work zone risks were also highlighted by the LTCCS, where 13% of all its crashes (all with serious injuries or fatalities) occurred in work zones [4]. Like most crash investigation studies, the LTCCS had no accompanying exposure data, but if one acceptsthe naturalistic driving exposure estimate of 0.7%, the resulting estimated relative risk of serious truck crashes in work zones compared to normal roads is more than 20.

From an operational perspective, risk avoidance means planning truck trips to minimize exposure to undivided roads, dense traffic, work zones, and similar higher risk locations. Generally speaking, such risk avoidance strategies are also operational *efficiencies*; that is, they make transport faster as well as safer. Other CMV operational efficiencies with apparent safety benefits include reducing empty backhaul ('deadhead') trips, minimising loading/unloading delays, optimising routing and navigation, optimising travel times (with evening travel appearing to be best), assigning familiar routes to drivers, avoiding adverse weather, and using higher productivity (i.e., larger) vehicles when possible [3]. In general, efficiency means safety, as long as 'efficiency' is achieved by proactive planning rather than by applying pressures for faster speeds and tighter schedules [3, 12].

Most carrier safety interventions may be considered risk reductions – they are efforts to improve the safety performance of individual drivers and vehicles. This includes proven methods like driver training, rewards and discipline, safety technologies on vehicles, and sound maintenance. Others may be conceived as risk avoidance, that is, proactively reducing or eliminating a risk factor. Differential driver risk is one ever-present concern in risk avoidance. Improved driver selection, with follow-up assessments of employed drivers, is paramount. Roadway and traffic risks can be avoided through proactive planning to make operations more efficient and decrease exposure to known travel hazards.

References

1. Knipling RR. Safety for the Long Haul; Large Truck Crash Risk, Causation, & Prevention. Arlington, Virginia, USA, American Trucking Associations (ATA). 2009.
2. Knipling RR, Burks SV, Starner KM, Thorpe CP, Bergoffen G.Synthesis Report on Driver Selection Tests & Measurements. Draft in review, Transportation Research Board (TRB) Commercial Truck and Bus Safety Synthesis Program (CTBSSP). To be available at www.safetyforthelonghaul.com. Summer, 2011.
3. KniplingRR. Synthesis Report on Safety Effects of Carrier Efficiencies. Draft in review, TRB CTBSSP, To be available at www.safetyforthelonghaul.com. Summer 2011.
4. Starnes M. Large Truck Crash Causation Study (LTCCS): An Initial Overview. US National Highway Traffic Safety Administration National Center for Statistics & Analysis, DOT HS 810 646, August 2006.
5. Mooren L. Work-related road safety management systems. Journal of the Australasian College of Road Safety. 2010; 21(4):14-16.
6. Holland MK.Using Psychology; Principles of Behaviour and Your Life. Little, Brown, & Co. Boston, 1975.
7. Knipling RR, Boyle LN, Hickman JS, York JS, Daecher C, Olsen ECB, Prailey TD. Synthesis Report #4: Individual Differences and the High-Risk Commercial Driver. TRBCTBSSP. Available at www.safetyforthelonghaul.com.2004.

8. Blanco M, Hickman JS, Olson RL, Bocanegra JL, Hanowski RJ, Nakata A, Greening M, Madison P, Holbrook T, Bowman D. Investigating Critical Incidents, Driver Restart Period, Sleep Quantity, and Crash Countermeasures in Commercial Vehicle Operations Using Naturalistic Data Collection. FMCSA Contract No. DTFH61-01-C-00049. March 2008.
9. Hickman JS, Knipling RR, Olson RL, Fumero M, Hanowski RJ, Blanco M.Phase 1 - Preliminary Analysis of Data Collected In The Drowsy Driver Warning System Field Operational Test: Task 5, Phase I Data Analysis, for the FMCSA under National Highway Traffic Safety Administration (NHTSA) Contract DTNH22-00-C-07007, September 30, 2005.
10. Silvani S, Skorupski D, Stinebiser R, Nicosia B, Van Order D.Independent Evaluation of Electronically Controlled Braking Systems, NHTSA. DOT HS 811 078. February 2009.
11. Lancaster R, Ward R.The Contribution of Individual Factors to Driving Behaviour: Implications for Managing Work-Related Road Safety. Entec UK Limited, Health and Safety Executive, Research Report 020, United Kingdom, 2002.
12. Mayhew C, Quinlan M. Economic pressure, multi-tiered subcontracting and occupational health and safety in Australian long-haul trucking. Employee Relations, 2006; 28:212-229.

The influence of speed on concrete agitator vehicle stability

by A Germanchev[1], P Eady[2] and D McKelvie[3]

[1]*Team Leader - Heavy Vehicles, ARRB Group*
[2]*Vehicle Dynamics Engineer, ARRB Group*
[3]*National Safety and Health Manager, Holcim (Australia) Pty Ltd*

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