Effects of Safety Chains on Dynamics of Truck and Full Trailer Combinations in Event of Coupling Failure

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This paper describes an investigation of the effects of safety chains on the dynamics of truck and full trailer combinations in the event of a catastrophic failure of the primary pin coupling. Safety chains on drawbar couplings are not mandatory in Australia for truck and full trailer combinations but are recognized as having the potential to reduce the crash risk and the severity of crash outcomes. Some industry stakeholders, predominantly drivers, have expressed safety-related concerns about the potential unintended effects of the chains on the dynamics of the hauling unit in the event of a coupling failure. The on-road dynamics of truck and full trailer combinations connected only by safety chains was assessed in various scenarios through field tests of several driving maneuvers, in which dynamic performance data were recorded by a data-logging system. Through the analysis of the recorded data and observations made by the driver of the vehicle and other observers, it was found that neither the truck nor the trailer demonstrated unsafe behavior in any of the tested maneuvers. It was determined that a truck–trailer combination could be brought safely to a stop in the event of a primary connection failure, up to the highest tested speed of 80 km/h (50 mph). These findings strongly indicate that there is little potential for safety concerns to arise as a result of fitting safety chains to the drawbar couplings of these truck configurations.

At the time of writing, safety chains on drawbar couplings are not mandatory in Australia for truck and full trailer combinations but are recognized as having the potential to reduce the crash risk and the severity of crash outcomes in scenarios that involve the catastrophic failure of the primary pin coupling. Some industry stakeholders, predominantly drivers, have expressed safety-related concerns about the potential unintended effects of the chains on the dynamics of the hauling unit in the event of a coupling failure. The main concern is that the trailer could become unstable and may either contribute to, or directly cause, the loss of control or rollover of the truck. An Australian transport company considered fitting safety chains to its Australian fleet and engaged Advantia Transport Consulting to determine whether the concerns raised were justified. A literature search on this topic did not yield any results and therefore indicated that the research topic was unique.

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INVESTIGATION AIMS AND METHODOLOGY

The aims of the investigation were to (*a*) determine whether a truck and full trailer combination could be brought safely to a stop in the event of a primary connection failure; (*b*) analyze vehicle combination stability in a range of scenarios, covering speed, load configuration, road surface conditions, turning and cornering maneuvers, acceleration, and deceleration; and (*c*) determine the most adverse scenario under which the vehicle combination could be safely stopped in the event of a primary connection failure.

A field test method was chosen over other possible methods (e.g., the numerical modeling of vehicle dynamics) because of its real-world applicability and capacity to capture the numerous characteristics that influence dynamic stability, which are at the heart of the concerns raised by drivers. The method focused on the comparison of the on-road dynamics of a typical truck and full trailer combination (referred to as the "baseline" vehicle) in a range of normal driving scenarios against the dynamics of the same vehicle in the same scenarios but with the trailer uncoupled and connected only by safety chains (referred to as the "uncoupled" vehicle). Some tests used an automatic release mechanism to simulate an in-motion coupling failure.

Test Vehicle

The transport company provided a representative truck and full trailer for use in the field tests. It comprised a three-axle straight truck and a four-axle full trailer, both fitted with tanker bodies (Figure 1). The truck was fitted with a new pin-type coupling that featured a unique remote release mechanism, installed by the transport company's maintenance contractor. The mechanism allowed the pin coupling to be disengaged by activating a switch located within the truck cabin; this disengagement could be done while in motion. The coupling was also fitted with two 780-mm (31-in.) safety chains, manufactured and installed by a reputable local supplier (Figure 2). The chains were crossed underneath the coupling, as recommended by the supplier, to support the drawbar and limit lateral movement.

The truck was fitted with an antilock braking system, and the trailer was fitted with a load-proportioning braking system, with no antilock capability. Neither the truck nor the trailer was fitted with an electronic stability control system. This brake system specification was fairly typical for this type of vehicle in Australia but represented

FIGURE 1 Test vehicle.

FIGURE 2 Pin coupling, release mechanism, and safety chain arrangement.

the worst-case vehicle in terms of brake system performance for that company, as most of its other vehicles were fitted with an electronic stability control system. The vehicle was tested at two load scenarios: fully laden (with water) to maximum legal axle loads and partially laden to represent the least stable legal and operationally feasible load.

Because of the expected safety risks and unknowns associated with the field tests, the tests were undertaken at a privately owned vehicle proving ground to mitigate the safety risks as far as practicable. The largest safety risk was vehicle rollover or collision with a person or fixed object. To address these risks, the tests began with initial observations of the combination when driven in a straight line, at walking pace, with the pin coupling disengaged and the service brakes applied gently to stop the vehicle. When no unsafe vehicle behavior was observed after several repeat low-speed tests, the vehicle speed was gradually increased and the remainder of the tests were conducted.

All the tests were conducted on the highway circuit at the test facility. The highway circuit was considered to be the best of the available facilities, as its surface texture, roughness profile, and geometry were similar to those of a typical Australian rural highway. The highway circuit was 4.2 km (2.6 mi) long and comprised two 3.8-m (12.5-ft) wide lanes on the straight sections and an extra lane at each curve, for a total width of 11.2 m (37 ft) on the curves.

Test Maneuvers

Seven test maneuvers were conducted on the baseline and uncoupled vehicles. These maneuvers were straight-line travel at a constant speed, controlled braking, curve negotiation, swerving, pulling over and stopping (i.e., emergency braking), disengaging the coupling while traveling in a straight line at constant speed, and disengaging the coupling while cornering at constant speed. The aim of the swerving tests was to determine whether any unsafe dynamic performance resulted if the driver was required to swerve to avoid an object. For those tests, the driver was instructed to move the combination rapidly into the adjacent lane and then, after a short travel distance, back again. These tests were not conducted to any particular standard but were controlled to the extent that the results from subsequent tests were comparable.

The matrix of tests and tested speeds for each of the load scenarios and coupling configurations is shown in Table 1. Tests could not be conducted at speeds higher than 80 km/h (50 mph) because of the length of the highway circuit's straight sections and the vehicle's acceleration capability. The listed speeds were the target speeds for the tests; the actual tested speeds varied by up to ±5%.

Field Test Equipment and Data Logging

The test vehicle was fitted with a field data acquisition system. The system comprised a computer-controlled data logger that recorded data from various sensors fitted to the test vehicle. The system continuously recorded the speed and position (i.e., the latitude and longitude) of the truck; the lateral, longitudinal, and vertical acceleration of the sprung mass of the truck and trailer; and the yaw rate of the truck and trailer. The system also included two high-definition video cameras. The sensor data were collected at sampling rates higher than the expected highest frequency of the signals being sampled to reduce the risk of

TABLE 1 Matrix of Tests

	Tested Speed at Full Load (km/h)		Tested Speed at Partial Load (km/h)	
Test	Baseline	Uncoupled	Baseline	Uncoupled
Straight-line travel	20, 40, 60, 80	20, 40, 60, 80	60, 80	20, 40, 60, 80
Straight-line braking	20, 40, 60, 80	20, 40, 60, 80	60, 80	20, 40, 60, 80
Negotiating curves	20, 40, 60, 80	20, 40, 60, 80	60, 80	20, 40, 60, 80
Swerving	20, 40, 60	20, 40, 60	40, 60	40, 60
Disengaging coupling–straight line at constant speed	40, 60, 80		60, 80	
Disengaging coupling–cornering at constant speed	60		60	

data being unintentionally cut off by the logging system. Sensors with an appropriate measurement range and resolution were used.

Data Processing and Analysis

The data processing involved two steps. First, static offset values recorded while the vehicle was parked on flat ground without the engine running were used to zero the data. Second, a second-order, low-pass Butterworth filter, with a 5-Hz cutoff frequency and a sampling rate of 200 Hz, was used to filter the data. The filtering removed the high-frequency noise that may have obscured the low-frequency measurements of interest. The driver was also interviewed during and after each test to capture his feedback on the vehicle's behavior and on the feedback provided to him by the vehicle that indicated the effects of the safety chains on the dynamics and behavior of the vehicle.

RESULTS AND DISCUSSION

General Observations of Vehicle Behavior

The coupling was initially disengaged while the combination was parked on flat ground. The combination was driven at walking pace, and the movement of the drawbar eye and trailer was carefully observed. While the combination was in motion at low speed, the trailer appeared to track a similar path to the truck, and no adverse behavior was observed, with the exception of the trailer alternately shunting the truck in both the fore and aft directions as the slack in the chains was taken up. At 20 km/h (12 mph), the trailer was observed to slightly wander laterally (i.e., from left to right) on the roadway when the chains were slack. The extent of the lateral movement in all cases was limited by the chain length and the location of the chain attachment points, such that the range of motion of the drawbar eye resembled an irregular shape, approximated in Figure 3.

The magnitude of the trailer wandering was not sufficient to prevent the trailer from being effectively towed by the truck; again, no adverse performance was observed, with the exception of the shunting, the magnitude of which was slightly higher at higher speeds. At 40 km/h (25 mph) and above, the trailer exhibited movements similar to those observed at 20 km/h (12 mph). The driver of the truck highlighted the shunting of the truck by the trailer as the key indicator that the trailer was no longer coupled to the truck and commented that in all cases it could not possibly have gone unnoticed. Surprisingly, this behavior was noted by the observers of the test program as being difficult to discern, and they highlighted that there were very few visual cues that the behavior was occurring. The observers noted that the wandering of the trailer was slightly more noticeable than the shunting, but still not obvious. The trailer tended to wander less when cornering than when driving straight. The driver noted the wandering of the trailer as being a far less obvious indicator than the shunting, as the only cue available to him that the trailer was uncoupled was the motion of the trailer, visible in the side mirrors.

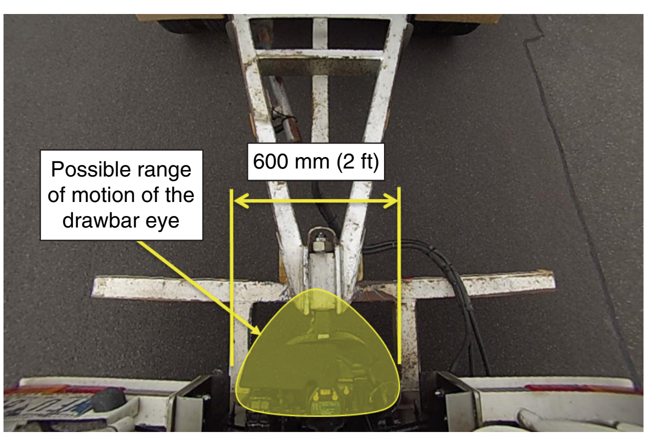

FIGURE 3 Observed possible range of motion of the drawbar eye.

When braking from speeds between 40 km/h (25 mph) and 80 km/h (50 mph), the driver indicated that the shunting was the main effect experienced but again noted that the handling of the truck was not affected and that it was still safe to pull over and stop in an emergency. The driver noted the tendency of the trailer, when the brakes were applied, to dive to the left more heavily than normal. This behavior was reasoned to be a result of slight differences in the brake effectiveness at each wheel. The behavior did not occur consistently and was not considered to be a safety concern.

Similarly, no unsafe performance was noted as a result of the driver undertaking the swerving maneuvers. Trackside observers noted that any difference in performance between the baseline and uncoupled cases was difficult to discern. The driver also made comments to that effect. Nevertheless, no swerving maneuvers were conducted at speeds higher than 60 km/h (37 mph) because of limited trailer stability, in both the baseline and uncoupled scenarios.

The disconnection of the coupling while the combination was in motion, either while traveling straight or on a curve, appeared to result in behavior no different from that described previously. The only difference was that the truck was initially subjected to a rearward tug by the trailer as the chains were pulled taut after the release of the coupling.

When partially laden, the combination demonstrated the same overall behavior as the fully laden vehicle in all of the maneuvers tested. The driver, when asked specifically if the movement of the fluid in the tank barrels resulted in any noticeable difference in the behavior of the truck or the trailer, indicated that the shunting was less, which was reasoned to be a result of the reduced payload mass. There were no other discernible effects on the stability of the combination.

Data Analysis

Figure 4 shows the probability density functions of the longitudinal accelerations for the truck and trailer in the baseline and uncoupled configurations when traveling at 80 km/h (50 mph). A comparison of the shapes of the density functions provides insights into the relative behavior of the combination in the baseline and uncoupled scenarios. The plots are very similar in overall shape; this result indicates that there is no substantial difference in the range of the longitudinal accelerations experienced between the baseline and uncoupled combinations. The functions for the baseline truck and trailer (i.e., the blue lines) are slightly taller and narrower and indicate that when coupled, the truck and trailer will spend a slightly higher proportion of time at very low levels of longitudinal acceleration. In contrast, the functions for the uncoupled truck and trailer (i.e., the orange lines) are shorter and slightly wider and indicate that, when connected only by the safety chains, both the truck and trailer will be more likely to experience a wider range of longitudinal accelerations. In practical terms, however, these differences are minor and point toward the only difference between the baseline and uncoupled scenarios being the shunting of the truck by the trailer when uncoupled. The general observations supported this finding.

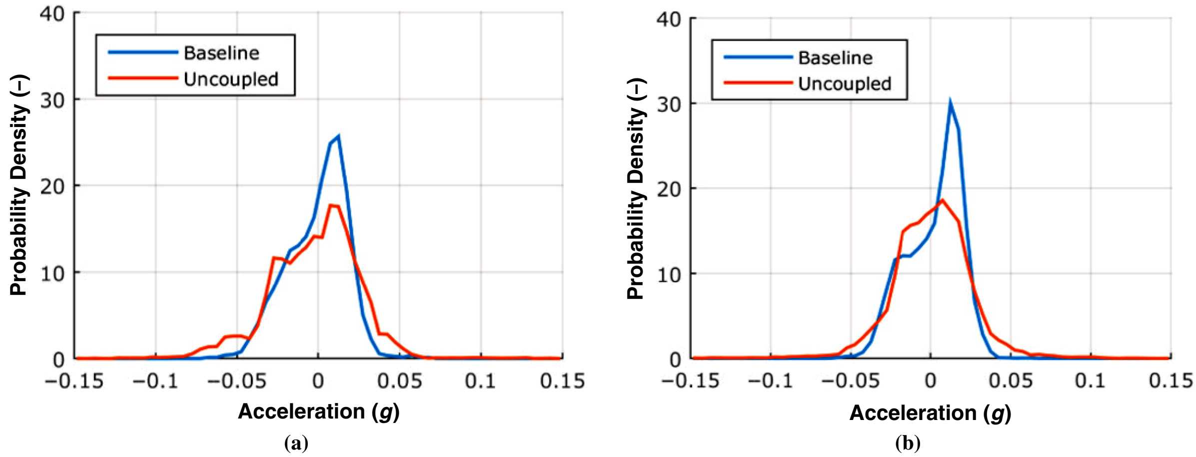

FIGURE 4 Probability density functions of longitudinal accelerations for (*a*) truck and (*b*) trailer at 80 km/h (50 mph).

Figure 5 shows the probability density functions of the lateral accelerations for the truck (left) and trailer (right) of the baseline vehicle and the uncoupled vehicle when traveling at 80 km/h (50 mph). Again, a comparison of the shapes of the functions provides insights into the relative behavior of the trailer in the baseline and uncoupled scenarios. The key result is that the shapes of the functions for the truck and trailer are nearly identical in both the baseline and uncoupled scenarios and therefore indicate that there are negligible effects on lateral acceleration for either the truck or trailer as a result of the disconnected coupling and that the observed tendency of the trailer to wander causes a negligible increase in lateral acceleration for the truck. The numerical results of the root mean square and peak values for the longitudinal and lateral acceleration of the fully laden vehicle are shown in Table 2.

The following statements can be made about the numerical results:

- Uncoupling caused the truck and trailer to experience root mean square longitudinal accelerations that were twice as high as the baseline case.
- Uncoupling caused the truck and trailer to experience peak longitudinal accelerations that were between seven and 10 times higher than the baseline case.
- Uncoupling caused a negligible difference in the lateral acceleration of the truck and the trailer.
- Uncoupling caused the trailer to experience peak yaw rates that were twice as high as the baseline case; however, the truck was relatively unaffected.

The peak longitudinal acceleration values experienced as a result of the fore–aft shunting were similar to the theoretical peak values that could be experienced in an emergency braking scenario, but because of the impulsive nature of these movements (i.e., a short, instantaneous application), they feel more severe to the driver. The numerical results for cornering were largely similar to those presented above for straight-line travel.

The primary effect on vehicle dynamics when braking from a constant speed was, again, the tendency of the trailer to shunt the truck from behind, which generally occurred if the chains were either slack or taut in the rearward direction when the truck's brakes were applied. Figure 6 shows a plot of the longitudinal acceleration experienced by the truck during a braking maneuver, for the baseline and uncoupled scenarios, from an initial speed of 60 km/h (37 mph). The start of the braking period is annotated.

The baseline vehicle achieved a peak initial deceleration of between 0.4 and 0.5 *g*; this deceleration reduced slightly as the driver

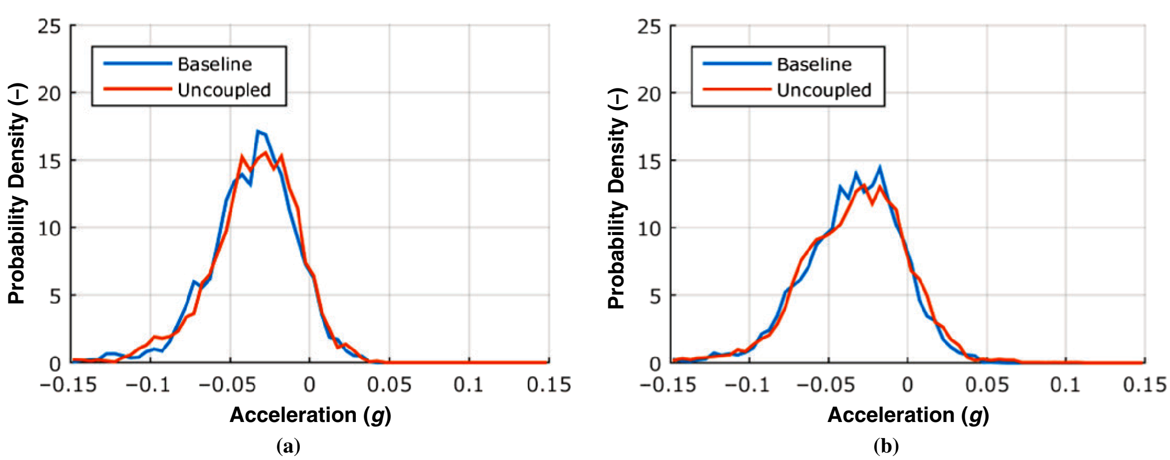

FIGURE 5 Probability density functions of lateral accelerations for (*a*) truck and (*b*) trailer at 80 km/h (50 mph).

TABLE 2 Numerical Results of Various Parameters for Straight-Line Travel

		Truck		Trailer	
Value	Acceleration	Baseline	Uncoupled	Baseline	Uncoupled
Root mean square	Longitudinal (*g*)	0.018	0.033	0.017	0.034
	Lateral (*g*)	0.045	0.044	0.046	0.047
Peak	Longitudinal (*g*)	0.069	0.524	0.062	0.606
	Lateral (*g*)	0.146	0.152	0.155	0.169

modulated the brake pedal force and brought the vehicle to a stop. In contrast, the deceleration of the truck for the uncoupled vehicle followed a similar slope but was interrupted by the shunt from the trailer. This shunt is evident as a positive spike in the acceleration plot and is annotated by the shaded red box. The lower magnitude of the peak acceleration in the uncoupled case was simply a matter of the driver having applied different amounts of brake pressure in different tests.

Nevertheless, there were no increases in lateral acceleration or trailer yaw rate as a result of the shunting. This finding supports the observations made by the driver that the shunting action was unlikely to cause the combination to jackknife under heavy application of the brakes.

Figure 7 shows plots of the lateral acceleration experienced by the truck and trailer during the swerving maneuver, for the baseline and uncoupled scenarios, conducted at 60 km/h (37 mph). The plots show that the uncoupled trailer experienced a marginally higher lateral acceleration than the baseline trailer during the swerving maneuver. This difference was not identified by the observer group or the driver, as the difference was difficult to discern by eye.

The numerical results of the peak values for the above parameters are shown in Table 3. These data are intended to provide an indication of the differences in the peak lateral acceleration and the yaw rate for the baseline and failed coupling scenarios, rather than the absolute maximums that were experienced.

The following statements can be made about the numerical results:

- The trailer experienced the same peak lateral acceleration as the truck for the baseline configuration, but a slightly higher lateral acceleration than the truck for the uncoupled configuration.
- The trailer experienced a slightly higher peak yaw rate than the truck in both the baseline and uncoupled configurations.

An increase in both the peak lateral acceleration and the peak yaw rate of the trailer was expected for this type of maneuver when the trailer was uncoupled. The magnitudes of the peak values were within the range expected for this type of vehicle in a normal operational configuration. A typical truck and full trailer combination commonly assessed by Advantia under the Performance-Based Standards Scheme (*1*) experiences peak lateral accelerations of more than 0.30 *g* and peak yaw rates of around 8 to 13 degree/s in a standard lane change maneuver.

The coupling was released while in motion to determine whether its release resulted in any additional effects on vehicle dynamics and handling, as all previous tests had begun with the coupling being

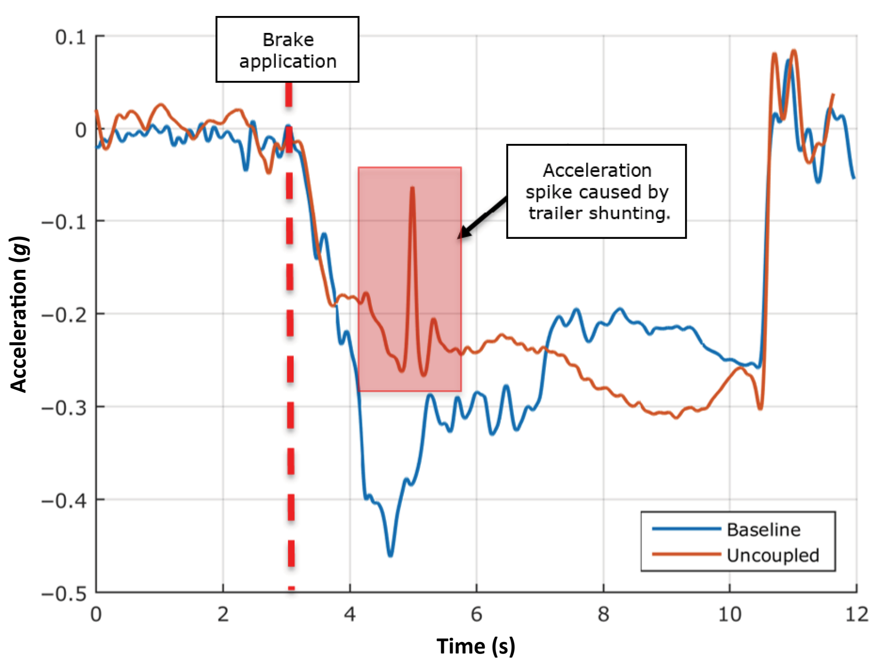

FIGURE 6 Longitudinal acceleration of truck when braking from 60 km/h (37 mph).

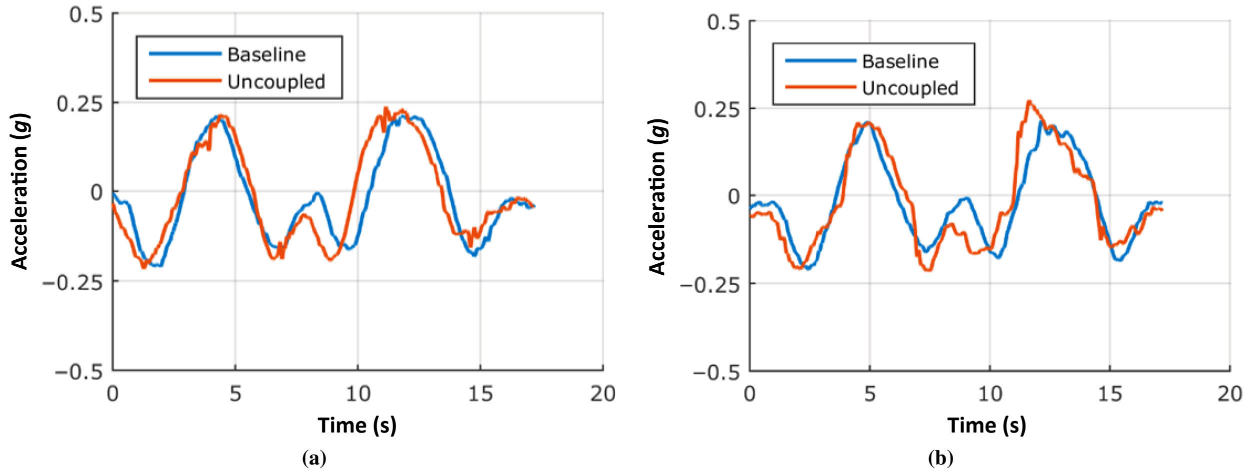

FIGURE 7 Lateral accelerations for (*a*) truck and (*b*) trailer at 60 km/h (37 mph).

disengaged while the vehicle was stationary. When the coupling was disengaged while in motion, the test data showed that the trailer experienced slightly higher longitudinal accelerations after the coupling was disengaged. There were no other effects observed as a result of disengaging the coupling at speeds up to 80 km/h (50 mph).

CONCLUSION

The objectives of this project were to determine whether a truck and full trailer combination could be brought safely to a stop in the event of a primary connection failure, as well as the most adverse scenario under which the combination could be safely stopped.

The field test program addressed these objectives. The general observations made during the field test program provided robust evidence about the overall dynamic behavior of the truck and trailer. The numerical results quantified the level of the effect of the disconnected coupling and provided certainty in relation to the findings from the observations. The key finding was that when uncoupled, the drawbar eye had a limited range of motion within the constraints of the chains and permitted the trailer to alternately push and pull the truck while driving and to sway from left to right on the roadway. Neither the fore–aft shunting nor the left–right wandering affected the handling or dynamic behavior of the truck in an unsafe manner, nor did the effects reduce the level of control that the driver had over steering or braking. In all tested scenarios in which the combination was driven with the coupling disengaged or in which the coupling was disengaged while the vehicle was in motion, the driver was able to continue operating the vehicle safely and to pull over and stop when directed.

On this basis, it was considered that the first of the project's objectives was achieved: a truck and full trailer combination could be brought safely to a stop in the event of a primary connection failure, up to the highest tested speed of 80 km/h (50 mph). The most adverse scenarios tested involved left–right swerving while traveling at 60 km/h (37 mph) and emergency braking from 80 km/h (50 mph). No swerving maneuvers were conducted at speeds higher than 60 km/h (37 mph) because of limited trailer stability in both the engaged and disengaged scenarios. The test speeds were otherwise limited by the constraints of the test facility as opposed to concerns about vehicle stability.

The test vehicle represented the worst-case vehicle in terms of brake system performance, as most other vehicles were fitted with an electronic stability control system and the test vehicle was not. Electronic stability control would not reduce the stability of trucks and trailers in coupling failure scenarios; such systems typically reduce yaw motions and lateral accelerations, both of which would improve the dynamic stability.

Although speeds higher than 80 km/h (50 mph) were not tested, speeds higher than 80 km/h [up to the maximum legal road speed in Australia of 100 km/h (62 mph)] were not considered to have the potential to cause vehicle instability or reduce the ability of the driver to control the vehicle and bring it safely to a stop in scenarios in which the primary connection failed. This assertion was based on an analysis of the effects of increasing speed on the lateral acceleration and yaw (within the tested speed range).

These findings strongly indicate that there is little potential for safety concerns to arise as a result of fitting safety chains to the drawbar couplings of truck and full trailer combinations and that the safety risk of errant trailers in failed coupling scenarios can effectively be eliminated.

TABLE 3 Peak Values of Lateral Acceleration and Yaw Rate During Swerving Maneuver

	Truck		Trailer	
Parameter	Baseline	Uncoupled	Baseline	Uncoupled
Peak lateral acceleration (*g*)	0.16	0.19	0.16	0.21
Peak yaw rate (degrees/s)	4.42	5.64	4.76	6.97

REFERENCE

1. *Performance-Based Standards Scheme: The Standards and Vehicle Assessment Rules.* National Transport Commission, Melbourne, Victoria, Australia, 2007.

The Standing Committee on Trucking Industry Research peer-reviewed this paper.