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FINDINGS FROM A LEVEL III HEAVY TRUCK STUDY

Abstract

The design and findings of a Level III (on-scene) heavy freight vehicle collision study are presented. The University of New Brunswick's Accident Research Team conducted 55 on-scene investigations over a three year period. The findings are based on a relatively small sample yet a number of common, issues have been identified. The analysis highlights the need for increased safety regulations directed to the design and operation of these vehicles and associated infrastructure. Common problems identified include the propensity of heavy trucks to rollover, encounter load security problems and have inadequate crash protection for the occupant compartment. A discussion of issues related to the establishment of an intense investigation protocol is presented based on the investigations over the research period. Recommendations are presented on refinements of Level III protocol for further heavy vehicle studies.

FINDINGS FROM A LEVEL III HEAVY TRUCK STUDY

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1. INTRODUCTION

Expansion of the heavy commercial truck population on the public highway network and their involvement in collisions will continue to be a public safety issue. Increased truck densities competing for operating space on the highway system will probably result in over representation in collisions resulting in serious injuries or death. The numbers of commercial vehicles are increasing and truck size, weights and configurations are changing as operating jurisdictions move towards harmonized regulations.

Existing data on heavy truck collisions exhibit limited detail for in-depth analysis. Often the collection of documents prepared by individual sources have differing objectives which limit their usefulness. In response to the data deficiency, Transport Canada's Road Safety Directorate undertook a pilot study in 1991 for a period of six months to evaluate the feasibility of conducting detailed heavy freight vehicle collision investigations. Following this effort, Transport Canada contracted the University of New Brunswick's (UNB) accident research team to initiate a Level III (on-scene) study of heavy truck collisions commencing in June of 1993. The UNB study produced 55 in-depth investigations. This paper, discusses the on-scene data collection technique and presents some findings/trends evolving from the study.

2. A LEVEL III HEAVY TRUCK STUDY

Highlights of study protocol and data collection techniques developed during the 30 month project are presented in this section.

2.1 Study Protocol

Complexities associated with collisions involving heavy trucks, necessitated at the onset that if reliable in-depth data were to be obtained an on-scene team approach would be required. Earlier studies found that a significant amount of information associated with a heavy truck collision is time sensitive. Scene evidence tends to deteriorate or become contaminated especially when the vehicle is being extricated. Trailers and cargo are frequently moved from the scene soon after the collision thereby eliminating important evidence which limits the analysis of load security problems.

Important aspects to be targeted in this study were identified in Transport Canada's pilot study in 1991. They included vehicle instability, load security, underride, and conspicuity. Rather than investigate heavy truck collisions at random, potential cases were screened as they were reported to the team. Only those cases which potentially involved one of the above factors were selected for in-depth investigation.

One of the challenging aspects of the initiation of the UNB study was the establishment of a reliable notification system. The response time of the team to the collision site is critical. It was important that the team be notified promptly in order that a reasonable coverage area could be maintained. A relationship had previously existed between the team and the Royal Canadian Mounted Police (RCMP), several municipal police detachments, trucking firms, and a number of tow truck operators. A number of discussions were held with each of these sources as well as the major local trucking companies. Most major trucking companies have dedicated accident investigators who are called to the scene of all relevant cases. A large majority of the operating fleets of heavy trucks are owned by a small number of local firms making direct contact easier.

It was decided that the police agencies would be the primary source of notifications. In order to provide a consistent response, it was necessary for the accident team to be continuously on-call.

As Hendrick and Comeau (1995) noted, very few collision investigators have heavy truck experience and training opportunities are limited. For this reason a *special study* was undertaken at the onset of this research project which essentially gave the investigators a trial period to obtain experience into the intricacies of heavy truck investigation. This period also allowed refinement of the protocol to be adopted before the full study was initiated.

2.2 Level III Experiences Obtained in the Study

The experiences of undertaking a Level III investigation involving heavy trucks have been mixed. There are a number of difficulties associated with the establishment and maintenance of such an intense investigative approach. Despite the attention to detail and care taken during the planning stages, the team is often required to make many changes in mid-stream.

The study design was based on a coverage area with a radius of approximately 1-hour travel time. It was quickly found that the response area could be extended to approximately a 2-hour radius in light of the time normally taken to move the vehicles from the scene -particularly if a rollover or loadspill occurred. In fact, of the 55 cases sampled, only 22 have been within the original boundaries established at the onset of the study.

A reliable notification source has been perhaps the most difficult aspect to cultivate. It has been the team's experience that the rapport established with its contacts must be constantly nurtured. Without question, the most reliable source has proven to be individual RCMP officers, particularly those who have had experience working with the team. All evening and night collisions within any RCMP jurisdiction are dispatched through a provincial office and this contact was a relatively reliable source of information. It should be noted, however, that the trucking company investigators affiliated with the major local firms were very supportive of the team's efforts when one of their vehicles was involved.

Team response time to the scene, from the time of collision, is presented in Table 1. The team's response time was in several cases been less than optimal. Unfortunately, the occasional failure of the notification system prevented the team from being on-scene for 17 of the 55 cases. This coverage is, however, considered excellent given that a 2-person team, was providing 24-hour coverage. Although team response to a collision scene was infrequent (5-6 times per month), both members needed to be ready to respond quickly at any time. A team size of three, with two experienced investigators, should be considered the minimum for the long term success of such an intense effort.

Table 1: Team Response Time to Collision Scene

Response Time	Number of Cases
˜ 1 hour	10
1 to 2 hours	7
2 to 4 hours	13
4 to 6 hours	8
6 to 10 hours	2
10 to 24 hours	8
š 24 hours	7

The advantages of being on-scene were identified and included:

- determination of exact resting positions of vehicles and cargo
- detailed cargo information
- detailed load security information
- pre-extrication vehicle damage
- pre-extrication scene evidence

It is interesting to note some of the cases where critical information would have been misinterpreted had the team not been on-scene. For example, in one case, extra tie down straps were applied to further secure a loaded semi-trailer before the vehicle was moved from the scene. Had the investigators not been on scene to observe this, it may have been assumed that these extra straps were in place pre-collision. In many cases, especially involving vehicle rollover, additional damage is done to the vehicle as it is being righted and removed from the scene. This can obviously lead to incorrect assumptions if the proper source of damage is not known. Furthermore, the extrication process will often leave additional tire and gouge marks at the scene which can confuse the reconstruction of the collision.

3. ANALYSIS

The dataset includes 55 cases. Although the sample is limited in size, the detail of the investigations resulted in a number of interesting findings. A breakdown of the frequency of various factors related to the collisions investigated is presented in Table 2. The majority of collisions investigated involved vehicle rollover which may or may not have been the initial event. Nevertheless, the high frequency of rollover collisions is directly related to the high observance of excess speed as a contributing factor.

The analysis indicated that the areas of vehicle instability, underride, load security, crash worthiness, and driver characteristics were important and these are detailed in following sections.

Table 2: Frequency of Common Factors

Configuration	Light Conditions	Weather Conditions	Road Conditions	Contributing Factors
rollover = 33	daylight = 28	clear = 31	dry = 35	speed = 18
loadspill = 20	dark = 20	cloudy = 10	wet = 11	inattention = 10
frontal = 7	dawn = 4	raining = 7	snow/icy = 7	visibility = 7
underride = 8	dusk = 3	snowing = 3	slush = 2	road cond. = 8
sideswipe = 6		foggy = 4		road design = 6
angle = 2				fatigue = 4
T-type = 5				load shift = 5
runaway = 1				mechanical = 2
				inexperience=2
				terrain = 2

3.1 Underride

Of the 55 cases studied, 10 involved underride of a second passenger vehicle. Five of these cases were side underride engaging the trailer, three involved underride of the rear end of the trailer, while the other two involved the front of the tractor (sometimes referred to as overrun). Not surprisingly, 3 of the 5 side underride cases resulted in fatalities, while the fourth yielded serious injuries to the driver of the passenger vehicle. Both overrun cases and one of the rear underride cases resulted in fatalities.

The classic side underride case is considered that of a T-type configuration which often occurs as a heavy vehicle crosses the path of an oncoming vehicle. A case involving an unstable B-train combination which slid perpendicular into an oncoming passenger vehicle exemplified this type of collision (Figure 1). Trailer swingout is not an uncommon occurrence. The UNB team, outside of this study, have investigated three other cases - one being another B-train. All trailer swingouts investigated have occurred under unloaded conditions.

Figure 1: Swingout Resulting in Side Underride

Interestingly, three of the other side underride cases were very shallow angle impacts which were the consequence of drivers of the oncoming passenger vehicles either losing control or falling asleep and drifting into the tractor semi-trailer units. The significant event in both of these collisions was the impact with the tandem axles. A relatively light underride protection frame forward of the tandem trailer axles could probably have mitigated these collisions.

Case HFVP-1237 reports on a typical rear underride involving a 1994 Dodge Shadow and a 1987 GMC Straight Truck. The current lack of Canadian underride standards[1] allowed the straight truck to operate without any protective device despite a rear overhang of nearly 3 metres between the rear axle and the end of the cargo deck. The Shadow underrode the frame to such an extent that the truck frame penetrated the full length of the occupant compartment.

Although case HFVP-1228 was a relatively low delta-V collision with the rear of a semi-trailer, it did demonstrate that existing rear underride protection frames are still substandard. The case involved a 1992 Chevrolet Corsica which struck the rear of a van semi-trailer. The Corsica's front

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The United States National Highway Traffic Safety Administration issued a safety standard in January, 1996 requiring new truck trailers and semi-trailers to be equipped with a rear guard effective January, 1998.

bumper underrode the horizontal member of the semi-trailer's underride frame despite the fact that when measured they are at virtually the same height. This was due to the fact that the weight shift during braking caused the Corsica's bumper to drop. Both rear end underride cases were perhaps not as serious as they might have been because the rearmost trailer wheels were so close to the rear that they negated any overhang of the trailer frame.

3.2 Rollover

Of the 55 cases reconstructed, 33 involved rollover. The rollover was the initial factor in 15 of these cases, while it was a secondary factor following an impact with another vehicle (4 cases) or an embankment (14 cases). Load security contributed to 10 of the rollover collisions. Table 3 details the relevant factors associated with those cases where the rollover was the *initial* factor of the case.

A rollover threshold was calculated for each of the 15 cases in the study. The rollover threshold is simply a measure of lateral acceleration (in *g's*) which the vehicle can tolerate before tipping over. The higher the value, the more stable the vehicle. Calculated values ranged from 0.26 to 0.52. This would appear to be in agreement with much of the literature which generally assumes the rollover thresholds to range from 0.25 to 0.40 (UMTRI, 1988). Note that a secondary rollover threshold is presented which takes into account any superelevation present at the accident scene. In several cases a *negative* superelevation was present which contributed to the propensity for the vehicle to roll rather than abate the condition.

The posting of general speed limits and advisory speeds in curves do not consider the propensity of heavy vehicles to roll over before sliding. It is therefore perhaps not surprising to note that there were two cases (HFVP-1217 and 1219) where the posted speed limit exceeded the safe speed for the tractor semi-trailer unit. In all but two cases, excessive speed directly related to driver error was found to be a primary contributing factor.

Table 3: Critical Rollover Factors

Case	Rollover Threshold * (g's)	Curve Rollover Threshold Speed (km/h)	Posted Speed Limit (km/h)	Main Contributing Factor
hfvp-1201	0.39 / 0.36	24	T-intersection	excessive speed
hfvp-1204	0.41 / 0.45	126	90	excessive speed
hfvp-1214	0.42 / 0.52	115	90	erratic steering and load shift
hfvp-1215	0.52 / 0.63	76	50 **	excessive speed
hfvp-1217	0.37 / 0.44	45	50 **	excessive speed
hfvp-1218	0.34 / 0.41	115	80	excessive speed
hfvp-1219	0.26 / 0.21	33	50	excessive speed
hfvp-1223	0.40 / 0.50	51	30 **	excessive speed
hfvp-1224	0.36 / 0.39	77	50 **	excessive speed
hfvp-1231	0.39 / 0.45	79	no posting	excessive speed
hfvp-1233	0.49 / 0.55	54	50 **	speed & load shift
hfvp-1236	0.41 / 0.41	85	80	road surface
hfvp-1240	0.32 / 0.41	112	80	excess speed
hfvp-1241	0.32 / 0.38	120	90	speed & mech. failure
hfvp-1246	0.40 / 0.41		80	excessive speed

* second value includes affect of roadway superelevation

** temporary advisory speed tabs posted in conjunction with a curve warning sign

3.3 Load Security

Of the 55 cases investigated, 50 trailers were loaded prior to the collision, 29 involved either partial or full loadspill. Most (22 of 29) loadspills occurred during rollover.

Flatbed semi-trailers utilizing nylon tie-down straps revealed some potential safety issues. Nine cases were investigated which involved the use of nylon straps in conjunction which ratchet-type tighteners and a short length of chain and a hook at the other end. Five of these cases had straps which were severed as a result of friction burns between the asphalt pavement and either a side rubrail or a corner of a load bundle. Four of the cases had straps which failed in tension during a rollover. Interestingly, the two cases where the nylon straps did not fail involved relatively light cargo bundles (cedar shakes and foam filled construction panels) and the rollovers occurred on grassy embankments.

The structural integrity of van semi-trailers failed in a number of cases resulting in loadspill of the contents. Nine cases studied had loadspills as a result of the van roof or sides being torn open during the rollover sequence (see Figure 2). This was often due to external forces (tree, utility pole, rock, etc.) but also due to internal loading by the cargo. Provisions were normally made to provide lateral load support; however, in several cases the load had not *cubed-out* resulting in a significant amount of free-space between the top of the load and the van roof. During rollover the load shifted vertically and punctured the roof panels. Case HFVP-1201 is a typical example which involved compressed gas cylinders that were ejected through the roof during rollover.

Three cases involved bulk materials being transported in an open-top semi-trailer. New Brunswick regulations require that the load be covered with a tarp to prevent any materials from being ejected during transport. Obviously, this does not provide containment during a rollover. Examples of load spills of bulk potatoes, hot asphalt, and wood chips were studied.

Two tanker semi-trailers carrying petroleum products were involved in rollover collisions. Both cases resulted in a breach of the tanks and a subsequent load spill. The speeds at which rollover occurred were both relatively high at 70 and 100 km/h.

Four cases were investigated where an insufficient number of tie-down assemblies according to provincial regulations (NB Motor Vehicle Act -regulation 85-25) were used to secure loads to a flatbed semi-trailer. It was felt that inadequate load security contributed directly to loadspill in both collisions.

Case HFVP-1242 illustrated one of the few successes with respect to load security. The case involved the rollover of a flatbed carrying 32 coils of rolled steel each with a mass of nearly 1,000 kilograms. The coils were stacked 4 high and secured with steel chains, load binders, and reinforced anchor points. Despite the unit rolling onto its top, all cargo remained secured.

Figure 2: Loss of Semi-Trailer Integrity

3.4 Tractor Crash Worthiness

The analysis of the cases studied relative to the crash worthiness of the tractor units yielded useful data. Of the 55 cases, 33 resulted in a rollover (of at least ¼ turn) of the tractor unit. The most obvious problem noted was that of windshield retention. Over 80% of those tractors which rolled, lost at least partial bonding between the windshield and the frame. Surprisingly, 18 of the 26 cases involving bond separation yielded total separation. This is a loss of occupant compartment integrity which obviously compromises occupant safety. Figure 3 illustrates a typical case where the windshield has completely separated from its frame despite the tractor having only been involved in a relatively minor rollover. This figure also depicts a problem which has occurred in a number of the rollover cases studied. The *westcoast* mirrors will often be deformed rearward and actually intrude into the occupant compartment during the sequence of a rollover. No injuries have been reported as a direct result of the intrusion of the mirror assembly into the occupant compartment but the potential does exist.

Figure 3: Windshield Bond Separation and Mirror Assembly Deformation

The second main finding relative to crash worthiness of tractors is the apparent lack of roof and A-pilar integrity in the event of a rollover collision. A total of 12 of the 33 rollover cases were noted where extensive roof intrusion and A-pillar collapse was evident. Figure 4 depicts a typical example. This lack of structural strength compromises the integrity of the so called *greenhouse* or occupant compartment in the event of a rollover collision. There were several cases where the vehicles only underwent a 1/4-roll (i.e. onto its side) yet significant A-pillar intrusion resulted.

Figure 4: Cab Roof Collapse of Tractor

Four cases resulted in a complete separation of the cab from the tractor chassis. Obviously this deficiency compromises the integrity/survivability of the occupant compartment. Cases HFVP-1216 and HFVP-1241 had the entire fifth-wheel assemblies separate from the tractor chassis. The problem was similar to that experienced with the separation of tandem axles from trailer frames (see section 3.6 Semi-Trailer Performance).

The typical location of the fuel (saddle) tanks leave them exposed in the event of multi-vehicle collisions. Five cases investigated involved a sideswipe type collision by a passenger vehicle involving the tractor's fuel tanks. Two of the cases resulted in a puncture to the tanks and subsequent fuel loss; however, given the low volatility of diesel fuel there were no fuel related fires. Three other cases were investigated where the tanks ruptured following vehicle rollover.

3.5 Semi-Trailer Performance

Two cases occurred (HFVP-1222 and AFS-S-1214) where the dual tandem axle assembly separated from the semi-trailer frame (see Figure 5). Both semi-trailers permitted the longitudinal adjustment of the axle assembly position with parallel frame members on the outboard sides of the assemblies. The frame members had several holes to accept a holding pin from the axle assembly. In both cases, the application of a lateral force component essentially spread the frame securing the assembly in place allowing it to separate from the semi-trailer.

Figure 5: Separation of Tandem Axle Assembly

Cases HFVP-1238 and HFVP-1240 involved the rollover of van semi-trailers which resulted in a shearing of the frame rails immediately rearward of the kingpin assembly. It would appear that this transition from a structurally rigid area to one which is less stiff is susceptible when exposed to the dynamics of a rollover.

3.6 Driver Fatigue

Driver fatigue is a complex issue involving a myriad of factors (Hurley, 1995) including :

- number of on-duty hours	- opportunities for breaks
- time of day	- health problems/stress
- amount of sleep	- alcohol/drug use
- quality of sleep	- environment of cab
- nature of task	- frequency of rest areas

Some safety researchers are of the opinion that the current system of tracking the hours of service is an inadequate proxy for measuring a driver's fitness for duty. Nevertheless, a review of the cases investigated attempted to evaluate the contribution that driver fatigue may have played in the cause of each collision.

Detailed information was obtained for each case regarding the drivers' hours of service for an extended period prior to the collision. This information was compared with the provincial hours of service regulations (NB Motor Vehicle Act -regulation #89-147). Only two cases indicated a violation in the regulations.

Only one case (ASF-S-1208) could be reliably determined to be a direct result of driver fatigue involving the truck driver. The driver fell asleep causing the unit to leave the roadway. A total of six cases were identified where driver fatigue *may* have been a contributing factor. Five of these 6 collisions occurred between the hours of midnight to 5:30 am. The amount of driving time immediately prior to the collision averaged only 6 hours. In fact, two cases occurred after the driver had been on-duty less than 1 hour. This may indicate that the propensity for fatigue to be a contributing factor could be more influenced by the time of day, change in work schedules, etc., rather than the hours of service factor.

3.7 Driver Restraint Use

Evidence obtained from the collision scene, police reports, and driver interviews indicate the restraint usage rates of the heavy truck drivers involved in the 55 cases in the study was 62%. There were few cases where restraint use could be positively verified with loading evidence. Other national estimates would indicate that this rate may be closer to one-third (Hendrick and Comeau, 1995). There is a mixture of three-point and lap belts as standard equipment being used in the commercial vehicle fleet.

3.8 Vehicle Conspicuity

Given the adoption of new conspicuity regulations in December 1993 by the U.S. Federal Highway Administration, and in January 1997 by Transport Canada, the issue of conspicuity was considered for all cases investigated. There were three cases where the conspicuity of the semi-trailer was an obvious issue: HFVP-1228, 1229, and 1252.

The first collision HFVP-1228 involved a passenger vehicle which rear-ended a tractor hauling a van semi-trailer. The tractor semi-trailer had just stopped on an arterial highway due to construction. The accident occurred at dusk, just prior to full darkness. Weather and road conditions were clear. The rear of the van semi-trailer was completely covered with a white film of road salt, partially *camouflaging* its presence. The driver of the passenger vehicle was unable to perceive the velocity change of the tractor semi-trailer in time to react.
The second collision involved a tractor hauling a flatbed semi-trailer. The vehicle suddenly slowed down as a result of mechanical problems. The driver pulled partially onto the shoulder but was subsequently struck in the rear by a passenger vehicle. Weather conditions were dark but clear at the time of the accident. The collision between the two vehicles was not laterally offset to any significant degree. It appears that the conspicuity of the tractor semi-trailer was an issue as well as the ability to perceive its relative velocity. The semi-trailer was carrying a large piece of machinery covered with a dark tarp. The only markings present to enhance its conspicuity were 4 small active lamps and two reflector markers. All of which were in less than optimal working order as they were covered with road salt and dirt.

Both cases demonstrate how the rear of semi-trailers can become relatively inconspicuous particularly when covered with road salt and dirt. The effectiveness of retro-reflective tape under such circumstances is questionable.

HFVP-1252 involved a tractor semi-trailor entering a roadway from a driveway under extremely foggy conditions. Two on-coming vehicles could not recognize the unit in time to stop. Retro-reflective markings were not present, however, their effectiveness would have been negligible given the post-dawn light conditions.

3.9 Driver Visibility

A rather interesting issue related to driver visibility was raised as a result of the investigation into case HFVP-1208. This particular case involved a T-type collision between a tractor and a passenger vehicle. The tractor was stopped at a stop sign before it pulled out in front of a passenger vehicle approaching from the driver's right. The collision occurred at a typical 4-leg intersection with stop sign control on the two minor approaches. An in-depth time-motion analysis was undertaken which explored the role that the blind spot created by the A-pillar, the westcoast mirror, and an auxiliary convex circular mirror on the passenger side. Inspection of the case vehicle indicated that a total of 29cm of lateral distance is blocked by the presence of the A-pillar and mirror assembly. The tractor involved was a 1994 Navistar International cab-over-engine style tractor.

The analysis found that the total time taken for the oncoming passenger vehicle to pass through the tractor's blind stop, even with an approach speed of 95 km/h was approximately 7 seconds. This is a sufficient amount of time to conceal the oncoming vehicle from the tractor driver even if he looked at the approach a second time.

4. CONCLUSIONS

An investigation strategy incorporating a more targeted or directed approach would enable the collection of detailed information specific to a problem area. For example, an investigation into tractor crash worthiness would provide a substantial dataset to provide a basis for the establishment of relevant safety standards. A more directed approach would require an increased study area thereby affecting team response time.

Perhaps the most blatant finding of the study is the lack of occupant protection afforded the occupants of a road tractor in the event of a rollover. As a result, it is recommended that the extension of a revised Canadian Motor Vehicle Safety Standards (CMVSS) #212 *Windshield Mounting* and #216 *Roof Intrusion Protection* directed to heavy trucks should be considered. These standards currently only apply to passenger vehicles.

Evidence derived from this study indicate that several other existing standards should be reviewed within the context of heavy trucks including: CMVSS #108 *Lighting Equipment/Conspicuity*, CMVSS #111 *Rearview Mirrors*, CMVSS #215 *Bumpers* and CMVSS #301 *Fuel System Integrity*. Conspicuity standards need to reflect the adverse weather conditions under which heavy trucks often operate. Potential safety standards should be developed or enhanced which address trailer deficiencies such as underride protection, load security, stability, and crash worthiness. The study results indicate a potential for the development of side underride protection to mitigate shallow angle impacts.

Different highway design practices have been illustrated to be lacking when heavy truck safety is considered. A number of cases have shown that steel flexbeam guiderail systems are not capable of retaining heavy trucks within the roadway. The practice of setting advisory speed limits for curves does not consider the stability of heavy trucks. Currently, the comfort of drivers of passenger vehicles is the basis for setting advisory limits. The rollover threshold speed for trucks has been shown to be less than the posted speed in certain cases.

As more is learned about the performance of heavy trucks during a collision and their interaction with passenger vehicles, a foundation for the revision and modification of several other safety standards will be established.

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