On-the-Scene Study of Commercial Vehicle Accidents

M. Wolkowicz[1]

ABSTRACT

On-the-scene investigations were conducted of 140 commercial vehicle accidents which occurred on Metropolitan Toronto area highways over a period of 249 calendar days.

Of these accidents, 108 involved commercial articulated vehicles (CAVs). Although a majority of the accident causes were driver-related, other factors such as tire wear and tread design, improper load retention, and inadequate maintenance contributed significantly to accident causation.

Traffic reports for accidents involving CAVs which occurred within the study area/time period were obtained from the police. The reports were then analyzed.

1. INTRODUCTION

Commercial vehicle (CV) accidents are very visible. They become the focus for public indignation, and the trucking industry and government is often adversely affected. CV accidents make good television news and newspaper copy, particularly if there is a dramatic loss of load or life. Automobile accidents, on the other hand, appear to be tolerated and do not seem to generate the same public response as do accidents involving large trucks.

CVs provide a fast, cost-effective method of transporting goods. In 1981, there were 1 089 855 trucks and truck tractors (35% of the national total) registered in the Province of Ontario. This represents an Ontario ratio of 1 truck or truck tractor for every 3.7 passenger cars.

The commercial vehicle accident study identified some of the causation factors and mechanisms of commercial vehicle accidents. This more specific data, supplemented with the general accident information obtained from Ontario Provincial Police (OPP) statistics, enabled the Ministry of Transportation and Communications (MTC) to identify problem areas and direct its research and legislation to better promote highway safety.

2. BACKGROUND

Of 2595 CVs involved in accidents within a 40-km radius of Toronto, 72% were "trucks," 26% were "tractor & semi-trailers," and 2% involved "truck & trailers." Less than 1% of commercial vehicle accidents involved fatalities. Approximately 62% of the accidents involving CVs were classified as property damage only, and a further 36.5% were classified as non-fatal accidents.

Table 1 gives an indication of the locational distribution of accidents involving articulated vehicles.

A check on the month in which these accidents occurred (Table 2) revealed that no particular month clearly dominated the others. The greatest occurrence of CV accidents was in January (11.9%). January was also the month in which the greatest number of articulated vehicles were involved in accidents (12.5%).

From Table 3 we observe that most CV accidents occurred on weekdays, with slightly more than 1/5 of the total CV accidents occurring on Fridays.

Table 4 indicates that a majority of CV accidents occurred between the hours of 12:00 and 18:00 (approximately 45%), while about 33% occurred within the 06:00 to 12:00 time period. Articulated vehicles tended to follow the same pattern.

The following patterns of CV accidents were identified:

- About 81% of the CV accidents occurred in the daytime (06:00 to 19:00).

1 Automotive Technology and Systems Office, Transportation Technology and Energy Branch, Ontario Ministry of Transportation and Communications, Downsview

- About 78% of CV accidents occurred on weekdays (Monday to Friday).
- There was a slightly higher concentration of accidents at both the beginning and the end of the year, namely: January, February, October, and November.

3. ON-THE-SCENE ACCIDENT INVESTIGATION STUDY METHOD

The CV On-The-Scene Accident Investigation Study was conducted during two consecutive winters, through the months December to April. The first winter survey area (Phase 1) encompassed all of the King's highways within a 45-km radius of the MTC Downsview head office. It was judged that an accident scene in this area could be reached within 30 min of notification. The expansion of this area during the second winter of the study (Phase 2) was requested by the Ontario Provincial Police (OPP). However, accident investigations more remote from base were limited to the more serious accidents due to the increased travel time.

Table 1 – Distribution of accidents involving articulated vehicles

Highway type	Occurence of accidents (%)	Articulated vehicles (%)
12-lane freeway	69.3	80.3
4- or 6-lane freeway	18.8	14.2
2-lane highway	11.9	5.5
	100.0	100.0

Total number of commercial vehicles = 2595
Total number of articulated vehicles = 730

Table 2 – Monthly breakdown of commercial vehicles in accidents

Month	Occurence of accidents (%)	Articulated vehicles (%)
January	11.9	12.5
February	7.4	9.3
March	6.6	7.2
April	5.3	6.6
May	7.6	8.8
June	8.2	8.8
July	6.7	6.0
August	8.3	6.0
September	8.1	6.0
October	10.0	9.3
November	11.7	11.6
December	8.2	7.8
	100.0	100.0

The survey area (Figure 1) included complex freeway systems (34 km, typically 12 lanes), simple freeway systems (216 km, typically 4 or 6 lanes), undivided multi-lane highway systems (53 km, typically 4 lanes), and undivided 2-lane highway systems (48 km).

The OPP officers in the field provided a selection process that eliminated investigation of those CV accidents judged to be of a minor nature. Details of severity and location for all other CV accidents, particularly those involving CAVs, was made via a 24-hour voice-paging system.

Upon notification of an accident, the investigating team (normally two people), providing 24-hours-a-day, six-days-a-week availability, would proceed to the scene using a prominently identified ministry vehicle. After identifying themselves to the police officer in charge, the following activities would be undertaken:

- take colour photographs of vehicles, skid marks, highway geography, etc., for records and analysis at a later date;
- take measurements including all road, vehicle, and physical evidence dimensions and relationships;

Table 3 – Breakdown of commercial vehicles in accidents by day of week

Day	Occurence of accidents (%)	Articulated vehicles (%)
Monday	18.7	20.5
Tuesday	14.9	15.5
Wednesday	14.9	16.0
Thursday	18.1	18.5
Friday	20.7	21.1
Saturday	7.6	6.2
Sunday	5.1	2.2
	100.0	100.0

Table 4– Breakdown of commercial vehicle accidents by time of day

Time period	Occurence of accidents (%)	Articulated vehicles (%)
24:00 - 06:00	7.4	8.2
06:00 - 12:00	32.6	36.0
12:00 - 18:00	44.5	42.2
18:00 - 24:00	15.5	13.6
	100.0	100.0

* consult with the investigating officer for additional information or assistance.

A visit to the accident scene the following day was often required to review data gathered at the time of the accident and to obtain additional data as felt necessary. Similarly, vehicles were often examined subsequently in greater detail.

The accident data was then transcribed onto forms which classified each mechanism of the accident, using a format suitable for computer entry. The accident mechanisms were investigated and an accident scenario was established. From this scenario, driver actions and accident causes were isolated and observations were made.

Upon completion of each phase of the accident survey, the OPP traffic accident reports from each detachment were examined. Reported accidents involving CAVs which occurred within the survey time-frame were selected for further statistical evaluation.

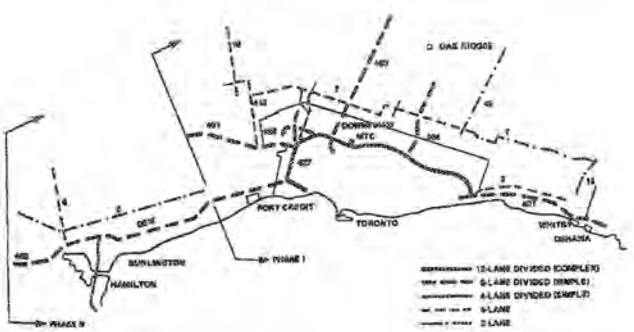
Accident information was prepared when requested for court presentation. Accident reconstruction was undertaken for specific cases and the investigators provided assistance to the Crown as expert witnesses.

4. DATA OBTAINED AND DISCUSSION

4.1 MTC ACCIDENT STUDY

4.1.1 Introduction

An accident code based on the opinions of the MTC investigators was used to classify the role of the CV in the accident. These opinions could differ



Highways systems covered by the commercial vehicle accident study

FIGURE 1

from those of the OPP because our investigators did not have to establish liability using the Highway Traffic Act. The code used is as follows:

Code 1: CV responsible, single motor vehicle accident;

Code 2: CV responsible, multiple motor vehicle accident;

Code 3: CV involved, did not precipitate the accident;

Jackknife accidents were classified as such only when the jackknife of an articulated vehicle preceded a collision with another vehicle or object.

4.1.2 MTC Study/Data

	Phase I	Phase II	Total
Survey Duration, Calendar Days	129	120	249
Number of Accidents Investigated	66	74	140
Number of Accidents Involving CAVs	51	57	108
Number of Accidents Involving Straight Trucks	15	17	32
% of All CAV Accidents, Reported to OPP	26.7%	20.1%	22.9%

Accident Classification	Phase I CAV	Phase I Straight	Phase II CAV	Phase II Straight	Total CAV	Total Straight
Fatal Injury	6	1	3	0	9	1
Non-fatal Injury	17	3	21	10	38	13
Property Damage	28	11	33	7	61	18
Total Property Damage (Estimated)	$712640		$1104355		$1816995	
Average $ Per Accident	$10798		$14924		$12978	
Code 1 Accidents						
Too fast, wet road	10	1	7	4	17	5
Too fast, dry road	1	4	2	0	3	4
Follow too close	1	0	0	0	1	0
Load related	5	1	2	0	7	1
Mechanical failure	6	0	6	3	12	3
Over-reaction	0	0	2	1	2	1
	23 45.1%	6	19 33.3%	8	42 38.9%	14
Code 2 Accidents						
Too fast, wet road	1	0	7	3	8	3
Too fast, dry road	2	0	2	0	4	0
Follow too close	3	2	2	2	5	4
Load related	0	0	1	0	1	0
Mechanical failure	0	0	1	0	1	0
Over-reaction	0	0	0	1	0	1
Improper passing/lane change	2	0	5	0	7	0
Fail to yield right-of-way	1	0	0	0	1	0
Driver fatigue	0	0	1	0	1	0
Disobey signal	1	1	0	0	1	1
Loss of control (alcohol)	1	0	0	0	1	0
	11 21.6%	3	19 33.3%	6	30 27.8%	9
Code 3 Accidents						
Impacted by out-of-control vehicle	0	2	0	1	0	3
Impacted out-of-control vehicle	8	1	3	2	11	3
Impacted by vehicle under control	2	3	5	0	7	3
Impacted vehicle under control (cut off)	5	0	4	0	9	0
Loss of control due to avoidance manoeuvre	2	0	7	0	9	0
	17 33.3%	6	19 33.3%	3	36 33.3%	9
Jackknife Accidents						
Number of Accidents involving a tractor jackknife or trailer swing	9		20		29	
Number of CAVs involved in jackknife accidents	10		22		32	
CAV empty, wet road	9		11		20	
CAV loaded, wet road	1		9		10	
CAV loaded, dry road	0		2		2	
Jackknife accident on straight road	6		17		23	
Jackknife accident on curved road	2		4		6	
Jackknife accident on ramp	2		1		3	
Accident Location						
On highways	59		58		117	
On ramps	13		16		29	
Number of commercial vehicles involved	72		84		156	

Accident Classification	Phase I CAV	Phase I Straight	Phase II CAV	Phase II Straight	Total CAV	Total Straight
Road Surface Condition						
Dry	35		31		66	
Wet	20		36		56	
Ice covered	5	31	4	43	9	74
Snow covered	6		4		10	
Light						
Daylight	45 (68.2%)		55 (74.3%)		100 (71.4%)	
Dark	20 (30.3%)		17 (23.0%)		37 (26.5%)	
Dawn	0		2 (2.7%)		2 (1.4%)	
Dusk	1 (1.5%)		0		1 (0.7%)	

4.1.3 OPP Traffic Report Summary

The OPP traffic reports which were compiled during the time periods of this investigation were reviewed by MTC investigators. The reports involving CAVs were selected for further analysis. The actions of the CAV as assessed by the investigating police officer were coded to indicate the role of the CAV in the accident, using the coding established in the MTC study. In certain cases, particularly jackknife accidents, MTC assessment was not the same as that of the investigating officer for the reasons mentioned in connection with the MTC study (Section 4).

4.1.4 OPP Traffic Report Data

	Phase I	Phase II	Total
Time period, calendar days	128	120	248
Number of traffic reports reviewed	2780	3640	6420
Number of traffic reports involving CAVs	191 (6.9%)	283 (7.8%)	474 (7.4%)
Accident Classification			
Fatal injury	6	4	10
Non-fatal injury	60	97	157
Property damage	125	182	307
Total property damage (estimated)	$896 463	$1 961 541	$2 858 004
Average $ per accident	$4 694	$6 931	$6 030
Code 1 Accidents (CAV only)			
Too fast, wet road	18	25	43
Too fast, dry road	1	6	7
Loss of control	4	0	4
Mechanical failure	11	10	21
Driver over-reaction	0	2	2
Load related	2	7	9
Driver fatigue	1	0	1
Improper reversing	0	1	1
Disobey traffic signal	0	1	1
	37 (19.4%)	52 (18.4%)	89 (18.8%)

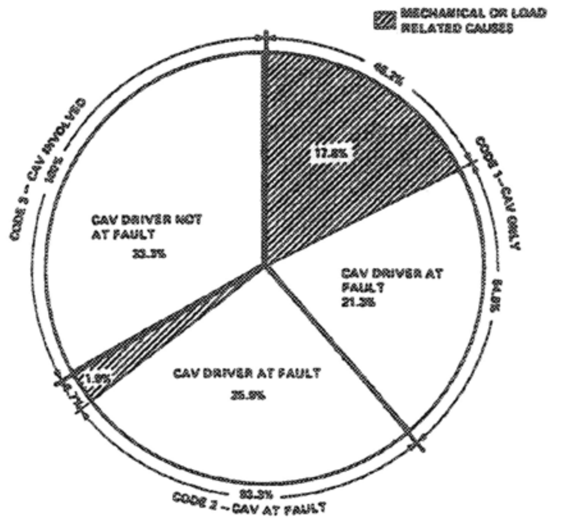
	Phase I	Phase II	Total
Code 2 Accidents (CAV only)			
Too fast, wet road	6	19	25
Too fast, dry road	2	5	7
Follow too close	9	16	25
Load related	2	6	8
Mechanical failure	4	9	13
Improper passing/lane change	15	31	46
Failure to yield right-of-way	6	2	8
Driver fatigue/inattention	3	2	5
Loss of control	2	6	8
Other	3	4	7
	52 (27.2%)	94 (33.2%)	146 (30.8%)
Code 3 Accidents (CAV only)			
Impacted by out-of-control vehicle	32	34	66
Impacted out-of-control vehicle	15	16	31
Impacted by vehicle under control	28	48	76
Impacted vehicle under control (cut off)	10	19	29
Loss of control due to avoidance manoeuvre	16	20	36
Pedestrian at fault	0	2	2
	102 (53.4%)	137 (48.4%)	239 (50.4%)
Jackknife Accidents			
CAV empty, wet road	22	19	41
CAV loaded, wet road	9	13	22
CAV empty, dry road	0	2	2
CAV loaded, dry road	1	1	2
	32 (16.7%)	35 (12.4%)	67 (14.1%)
Accident Location			
Complex freeway	96 (50.3%)	131 (46.2%)	227 (47.9%)
Simple freeway	47 (24.6%)	82 (29.0%)	129 (27.2%)
Undivided 2-way highway	26 (13.6%)	35 (12.4%)	61 (12.9%)
Ramp	22 (11.5%)	35 (12.4%)	57 (12.0%)
Road Surface Condition			
Dry	79	129	208
Wet	60	97	157
Ice covered	18	17	35
Snow covered	34	40	74
(Wet, Ice covered, Snow covered)	112 (58.6%)	154 (54.4%)	266 (56.1%)
Light			
Daylight	127 (66.5%)	193 (68.2%)	320 (67.5%)
Dark	57 (29.8%)	85 (30.0%)	142 (30.0%)
Dawn	1 (0.5%)	3 (1.0%)	4 (0.8%)
Dusk	6 (3.1%)	2 (0.8%)	8 (1.7%)

4.1.5 Accident Severity

The screening process resulted in the investigation of the more severe CV accidents. Of those accidents investigated by MTC, 43.6% involved personal injury, as compared with the 35.2% of all CV accidents reported by the OPP. Nine of the ten fatal injury accidents reported were investigated. Those accidents investigated during the survey were 2.2 times more severe than average in terms of the mean estimated per accident damage cost.

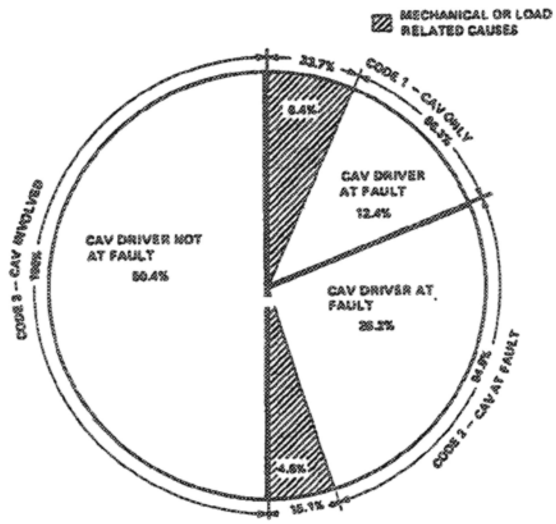
4.1.6 Driver at Fault

The common perception is that if a CAV is involved in an accident the fault usually lies with the driver of the CAV. This is essentially true for single CAV accidents. Both the MTC and OPP surveys provided data (Figures 2 and 3) to indicate that driver action was the major cause of single CAV accidents. However, in multiple vehicle accidents in which a CAV was involved, both surveys showed that the CAV driver was generally not at fault.



% distribution, accident causation factors, MTC Survey, Phase I & II

FIGURE 2



% distribution, accident causation factors, OPP Traffic Reports, Phase I & II

FIGURE 3

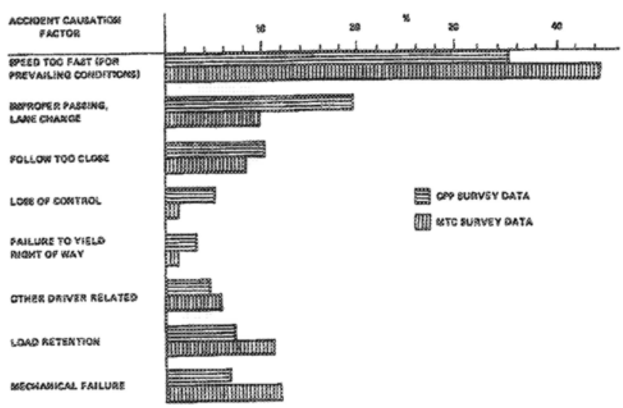
Using the Code 2 and Code 3 combined data and removing those accidents attributed to mechanical or load-related causes, it was found that the CAV driver was at fault in 43.8% (MTC) or 34.2% (OPP) of the total number of multiple vehicle accidents reported. Conversely, the driver of another vehicle, generally an automobile driver, was found to be at fault in 56.2% (MTC) or 65.8% (OPP) of the reported multiple vehicle accidents.

Using the combined data for Code 1 and Code 2 accidents, the percentage distribution of the various accident causation factors was as shown in Figure 4. The most significant driver-related cause where the CAV was responsible for the accident was "speed too fast" (for the conditions at the time of the accident). Of those accidents caused by excessive speed, 78.1% (MTC) or 82.9% (OPP) occurred on wet or slippery roadways.

The next most significant driver-related cause was improper passing/lane change by the CAV. Using the OPP data, improper passing/lane change manoeuvres accounted for 19.6% of all CAV-at-fault accidents. A suspected contributory factor to accidents caused by improper passing and lane changing is the reduced conspicuity of downsized passenger cars. This is discussed in Section 5.4.

4.1.7 Mechanical Failure

Figure 4 shows that 12.0% of the CAV accidents investigated by MTC and 7.2% of those investigated by OPP during the study period were attributed to mechanical failure. These figures are conservative, for in less serious accidents vehicle defects which may have contributed to the accident were likely to go undetected. A roadside safety inspection in Ontario of 11 387 CVs found 11.9% of these vehicles to be mechanically unsafe (1).



% distribution accident causation factors, CAVs only, Code 1 & 2 combined data

FIGURE 4

CV breakdown or involvement in an accident causes passing traffic to slow drastically. A single-lane blocking incident on a 3-lane highway reduces the capacity of the highway by 44%. Even after the disabled vehicle(s) are moved to the shoulder, the traffic flow returns to only 85% of normal. In 1982, an estimated 540 000 vehicle hours were lost in lane-blocking incidents occurring during peak hours on a 34-km stretch of a 12-lane freeway (2).

Both OPP and MTC investigators have noted that many CVs in operation have more than one item of equipment that just meets the minimum standard required by law. Each deficiency on its own might not noticeably affect safe vehicle operation, but compounded, as they often are, they can have a potentially disastrous effect on vehicle stability.

4.2 STABILITY

4.2.1 Introduction and Definitions

CV stability was taken to be a factor only in those accidents where evidence exists that the vehicle was not always fully under the control of the driver. Evidence of CV loss of control was classified into one (or more) of five categories as listed below. Loss of control due to impact with another vehicle or object is excluded as irrelevant to vehicle stability, so categories (a) to (d) must have occurred before impact.

a) **Directional Loss of Control**
The vehicle or part of it followed a path not chosen by the driver. This generally includes accidents in which the CV veered out of its lane for some reason. Braking may be a factor in inducing directional control loss.

b) **Skidding**
At least one wheel was locked by braking and skidding. The vehicle skidded essentially in a straight line distinguishing this from category (a).

c) **Tractor Jackknife**
A violent rotational instability caused by the loss of lateral traction at the tractor drive axles, as when locking wheels while braking, resulted in the rotation of the tractor to left or right about the king pin.

d) **Trailer Swing**
A rotational instability of the trailer caused by loss of lateral traction of the trailer tires. The tractor remains stable while the trailer swings to one side.

e) **Rollover**
A self-explanatory control loss.

4.2.2 Control Loss Results

Tables 5 and 6 list those vehicles which lost control during one of the accidents investigated. Table 5 lists CAVs and Table 6 lists straight trucks. Table 7 summarizes those accidents, involving 73 CAVs and 22 straight trucks or 95 vehicles out of the total of 151 CVs involved in the accidents investigated.

The summary emphasizes that rollover should be treated as a different kind of control loss from the others. While the majority of rollovers involved loaded vehicles and dry pavement (77%), the opposite applied to other cases. Only 14% of the vehicles in non-rollover loss-of-control accidents were loaded and 19% were on dry pavement.

Noting that more than half of all CV accidents (56.2%) involved empty or lightly-loaded vehicles suggests the possibility that drivers of loaded vehicles, being aware of their long stopping distances, drive them slower and more cautiously than when they are empty. It is estimated that 50% or more of CVs on the roads are loaded in order to provide revenue income; however, this is not an area in which data are available.

Forty-eight percent of all jackknife accidents reported by the OPP were investigated (compared with 23% of all accidents), a very high percentage. This is probably because a jackknife usually involved a total loss of control of the CAV, frequently resulting in serious and/or spectacular accidents. This study found that a jackknife was a relatively common result of a loss of traction, occurring in 54% of all such CAV accidents (25% of all CAV accidents) It must be recognized that this study was conducted in winter when poor highway conditions make loss of traction more likely and that a jackknife is a spectacular event that is often difficult to clear up, affording the research team ample time to research the scene.

A jackknife proceeds particularly rapid when the vehicle is articulated, as when turning. Nevertheless, only 18% of jackknives investigated occurred on curves and 9% occurred on ramps, whereas 19% of all accidents investigated occurred on ramps. Of the 30 jackknives, only two happened to loaded vehicles, and only one on a dry road, emphasizing the common cause of wheel lock-up in braking. Wheel lock-up is so much easier when an empty vehicle, with lightly-loaded drive axles, is on wet, snowy, or icy pavement.

No vehicle involved in an accident was equipped with a jackknife control device, despite the availability of several devices (3). All antilock systems found on vehicles had been rendered inoperative. Tire type also played a role in jackknife accidents and this is discussed in section 4.3.

Instances of trailer swing were far less common in accidents, with only three being recorded. Since trailer wheels are as easy to lock up as tractor wheels, this may seem surprising. However, the instability grows more slowly in the case of a trailer swing, and the tractor generally remains under driver control; these two factors may make them rarer events.

It is remarkable that 20 of the 22 ruptured fuel tanks recorded during these accident investigations occurred when a CAV went out of control. Jackknives accounted for half of these, for the simple and obvious reason that the tractor fuel tanks are singularly prone to rupture in such an event. They are generally hung from each side of the frame in front of the drive axles. In a jackknife, the tractor rotates about the trailer king-pin until, usually, tractor/trailer body contact is made. Because of the distance between the fifth wheel and the fuel tank, during a jackknife the tank often strikes the large, usually angular metal leg and ruptures. The oil spill generally creates a hazard to other traffic and must be cleaned up, causing additional delays and traffic congestion. In view of the size of fuel tanks, it is difficult to locate them elsewhere; however, better protection and integration for improved crash protection is certainly in order.

Table 8 lists the vehicle configurations involved in loss-of-control accidents while Figure 5 explains vehicle configuration terminology used in the survey.

Although A-trains make up only 1% of all heavy trucks, they were involved in five of the 22 rollovers observed, or 23%. This number should be treated with caution since A-trains are invariably very large vehicles and a rollover was a spectacular event that was likely to have been investigated. However, these data still support research demonstrating that A-trains are less stable than most other configurations and will roll over with relative ease. Only one B-train (an A-train with a "rigidized" hitch) rollover was reported, even though it is a configuration nearly as common as the A-train. This is consistent with full-scale tests by MTC in which a B-train configuration reached a rollover condition at speeds 8 to 14% higher than

Table 5 – CAVs with unstable responses

Accident Type		Load				Surface					Traction Tires				Tread Depth (mm) Greater than ...				Fuel Tank Rupture	Class of Accident
Accident Number	Config	E	%	F	u/k	D	W	Sn	Sl	Ice	Cr	M+S	XZA	u/k	1.5	3.0	4.5	u/k	(✓ = YES)	
Loss of Control																				
014	3S2	✓				✓								✓					✓	Ft
051	3S2			✓				✓			✓								✓	PD
141	3S2			✓		✓						✓					✓			?
157	2S2				✓	✓						✓							✓	I
168	2S2	✓					✓				✓					✓			✓	
174	3S3	✓				✓						✓								
Skidding																				
009	3S2				✓	✓					✓						✓			PD
012	3S2				✓		✓							✓						I
016	3S2		60						✓			✓				✓	✓			?
017	3S2	✓				✓						✓								I
032	2S2	✓					✓				✓									?
035	3S3S2	✓						✓			✓					✓				?
042	3S2-3	✓				✓						✓								Ft
052	3S2	✓								✓			✓		✓					PD
116	3S2	✓								✓	✓						✓		✓	PD
119	3S2	✓								✓		✓				✓	✓			I
134	3S2-4	✓						✓						✓						PD
144	3S2	✓					✓				✓						✓			PD
147	3-3	✓					✓				✓									PD
160	3S2	✓						✓			✓									PD
162	3S2			✓				✓					✓							I
167	3S2	✓				✓						✓							✓	I
176	3S2		30				✓					✓					✓			
Jacknife																				
994	3S3	✓					✓				✓						✓			PD
005	3S2						✓							✓						PD
012	2S1		50				✓				✓						✓			I
043	2S1		5							✓	✓									PD
047	3S2	✓						✓				✓					✓			PD
049	3S2-3	✓					✓					✓					✓			PD
059	3S2	✓								✓		✓							✓	PD
061	3S2				✓				✓					✓						I
061	3S2	✓							✓		✓						✓			I
063	3S2	✓					✓					✓					✓			PD
108	3S2	✓				✓						✓					✓		✓	PD
109	3S2-3	✓					✓					✓					✓			PD
114	2S1			Lt			✓					✓					✓			PD
118	2S1				✓		✓				✓						✓		✓	I
123	3S2		25					✓				✓					✓		✓	I
126	3S2				✓		✓				✓						✓		✓	I
127	3S2		20			✓	✓					✓					✓			I
129	3S3			✓			✓		✓			✓					✓			I
133	3S2	✓					✓					✓				✓			✓	PD
136	2S1-2			Lt				✓						✓						PD
137	2S1		25				✓				✓						✓			PD
143	3S2		20				✓				✓						✓			PD
145	3S2			✓			✓					✓					✓		✓	PD
150	2S2	✓					✓				✓					✓				PD
151	2S1		20				✓				✓					✓				PD
154	3S2	✓					✓					✓					✓		✓	PD
155	3S3	✓					✓					✓				✓	✓			PD
160	3S2	✓						✓				✓					✓			PD
180	2S2	✓						✓			✓						✓			PD
182	3S3S2	✓						✓			✓								I	
Trailer Swing																				
111	3S2	✓						✓				✓					✓			PD
182	3S2			✓					✓					✓						
I																				
168	2S2	✓				✓					✓					✓			✓	PD
Rollover																				
008	3S2-2			✓		✓								✓				✓		
010	3-4			✓			✓							✓				✓		
023	3S2-1			✓			✓					✓							✓	
037	3S2-3			✓		✓						✓								
039	3-2			✓		✓						✓					✓			
055	3S3			✓		✓					✓						✓			
062	3S3-3			✓		✓						✓					✓			
106	3S2			✓		✓					✓					✓			✓	
130	3S2-3			✓		✓						✓							✓	
146	3S2			✓			✓				✓					✓				
153	3S3		25			✓					✓									
163	3S2			✓		✓						✓							✓	
164	3S2			✓		✓					✓									
170	3S2			✓		✓														
171	3S2-3			✓		✓						✓								
174	3S3	✓				✓						✓								
175	3S2			✓		✓						✓								

LEGEND: E = Empty; F = Full; Lt = Lightly Loaded; D = Dry; W = Wet; Sn = Snow Covered; Sl = Slush; PD = Property Damage; I = Injury; Ft = Fatal; Cr = Cross-Rib, Bias; M+S = Mud and Snow, Radial; XZA = Rib Type, Radial; U/K = Unknown a similar A-train during identical lane-change manoeuvres. This results from the B-train having one less point of articulation, and also being stiffer in roll than the A-train (because that vehicle's pintle hook connection of the converter dolly to the lead trailer usually provides little roll restraint).

Table 6 – Straight trucks with unstable responses, trucks only

Accident Type		Load				Surface					Traction Tires				Tread Depth (mm)				Fuel Tank Rupture
Accident Number	Config	E	%	F	u/k	D	W	Sn	Sl	Ice	Cr	M+S	XZA	u/k	Greater than ... 1.6	3.0	4.8	u/k	(✓ = YES)
Loss of Control																			
003	3	T					✓												
033	3	✓				✓					✓								
040	2			✓		✓					✓								
101	3	✓								✓			✓				✓		
148	2	✓					✓				✓								
149	2		50				✓				✓								
161	2			✓				✓			✓						✓		
169	2		25			✓													
177	3	✓				✓						mix							
9		5	2	2		4	3	1		1	5		1				2		
Skidding																			
036	2		20				✓				✓						✓		
064	2		25				✓												
103	3	✓					✓					✓					✓		
112	3			✓				✓			✓						✓		
120	3	T					✓					mix							
122	2	✓				✓					✓								
125	2		30				✓				✓					✓			
132	2	✓					✓				✓					✓			
8		4	3	1		1	6	1			5	1				2	3		
Rollover																			
024	2		45			✓					✓								
038	2		75			✓					✓						✓		
048	2	✓									✓						✓		
121	3	✓				✓						✓					✓		
152	2			✓			✓				✓					✓			
5		2	2	1		3	1		1		4	1				1	3		

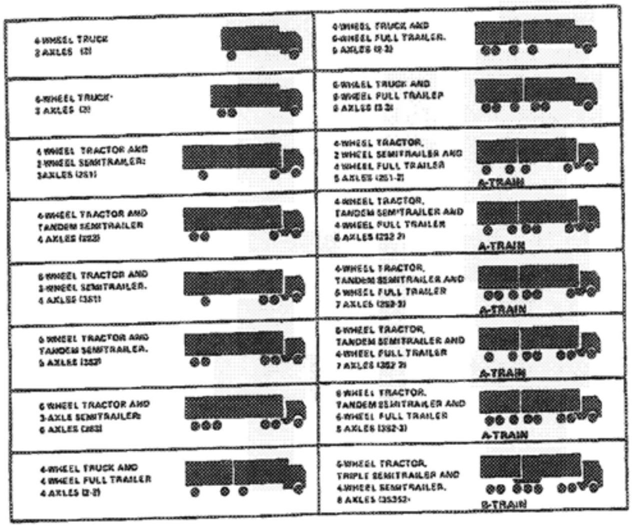
LEGEND: E = Empty; F = Full; D = Dry; W = Wet; Sn = Snow Covered; Sl = Slush; PD = Property Damage; I = Injury; Ft = Fatal; Cr = Cross-Rib, Bias; M+S = Mud and Snow, Radial; XZA = Rib Type, Radial; U/K = Unknown

Table 7 – Loss-of-control accidents

		Load			Surface				
		Empty 50%	Full 50%	Unknown	Dry	Wet	Snow slush ice	Total number	Fuel tank rupture 1
Loss of direction control	CAV	3	2	1	4	1	1	6	4
	Straight	7	2	0	4	3	2	9	0
Skid	CAV	13	2	2	4	5	8	17	1
	Straight	7	1	0	1	5	1	8	0
Jackknife	CAV	24	2	4	1	19	10	30	8
Trailer swing	CAV	2	1	0	0	1	2	3	1
Rollover	CAV	2	22	0	14	3	0	17	4
	Straight	3	5	0	3	1	1	5	0
Total	CAV	44	22	7	23	29	21	73	20
	Straight	17	5	0	8	9	4	22	0
	Total	61	27	7	31	38	25	95	20
	%	64.2	28.4	7.4	32.6	40.0	26.3	100.0	21.0
All accidents	(%)	56.2	34.2	9.6	44.4	31.9	23.6	151.0	6.9

1 These are minimum values as fuel tank rupture is not necessarily noted. The data is based on a review of accident photographs and notes for evidence of fuel spills.

Some other results were consistent with the proportion of vehicles on the roads: the ratio of straight trucks to tractor-semitrailer accidents closely matched their relative numbers in use, and the ratio of jackknives involving two- and three-axle tractors (8/18 = 0.440) was matched by their frequency on the roads (0.41 to 1). The latter result conflicts with a US study (4) that indicated a two-axle tractor was 3.6 times more likely to be involved in a jackknifing accident than a three-axle tractor. This might also have been expected



Vehicle configuration terminology

FIGURE 5

as theoretical studies (5) have shown short-wheel-base tractors (typically with two-axles) are less stable under the braking conditions that lead to a jackknife.

4.2.3 Driver Actions

As were able to be determined, the drivers' actions during the 95 control-loss accidents under discussion are shown in Table 9. It is seen that, as is well known, the first action of drivers was most often to apply the brakes. However, steering before braking was used quite often, though only 30% as often.

Though a jackknife is normally thought to be the result of excessive braking for the conditions, in at least three cases no braking was established. These cases were thought to be power jackknives, in which drive torque was sufficient to spin the drive axles. However, the vast majority resulted from braking, often followed by steering.

4.3 TIRES

Whenever a loss-of-control accident appeared to be caused by skidding, the focus of the investigators' attention was directed to examination of the tires. This examination included determination of tire manufacturer, size, type, load rating, tread pattern and depth, and pressure of each tire. Deflated tires were examined to the extent possible on the site without removal to

Table 8 - Vehicle configurations in control-loss accidents

Configuration		Directional loss of control	Skid	Jackknife	Trailer swing	Rollover	Total	% of population (heavy trucks)
Straight	2	5	5			4	14	7.2
Trucks	3	4	3			1	8	15.0
Tractor-semitrailers	2S1			6			6	4.6
	2S2	2	1	2	1		6	16.6
	3S2	3	12	15	2	6	38	40.7
	3S3	1		3		3	7	10.6
Truck-trailers	3-2				1		1	0.0
	3-3		1				1	0.3
	3-4				1		1	0.4
A-trains	2S1-2			1			1	0.1
	3S2-2					1	1	0.1
	3S2-3		1	2		3	6	0.5
	3S2-4		1				1	0.1
	3S3-3						1	0.0
B-trains	3S2S1					1	1	0.0
	3S3S2		1	1			2	0.4

lish the cause of the deflation and its relationship to the events of the accident.

It must be kept in mind, however, that other variables such as air brake adjustment and other air brake related factors might have contributed to the loss of control assumed to be the result of skidding. Unless the air brake system was identified by the driver or other witness at the accident scene as the suspected cause of the accident, the operation of the air brake system was not investigated in detail. More often than not, the air brake system was rendered inoperable by the accident damage to the vehicle and the air brake system could not be evaluated.

4.3.1 Tire Pressure

The measurement of tire pressure was not as easy as expected, particularly on the inner tire of a dual tire assembly mounted on the common spoked wheel. It was frequently found that a wheel rim had rotated relative to the spokes, presumably because of deformed wheel space or insufficient tightening of the wheel nuts. The inner tire valve stem was thus bent and trapped behind the wheel spoke, inaccessible to a tire gauge. When pressure could be measured, no frequent or consistent pattern of overly high or low tire pressures was observed.

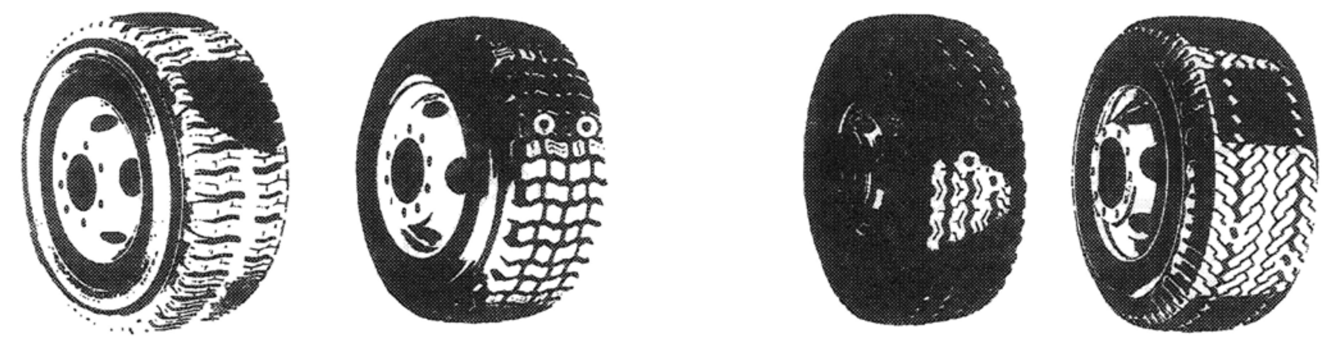
4.3.2 Tread Pattern of Traction Tires

Tire tread design and condition significantly affect the stability of commercial vehicles. The traction tires are of particular importance, especially for articulated vehicles. Steering and trailer axle tires were normally of rib/groove tread pattern design; a wider variety of tread patterns was observed on the drive axles of both straight trucks and articulated vehicles. For purposes of the study, the tread was classified into three common pattern types illustrated in Figure 6.

- **Cross-rib**
  In this type, transverse ribs extend from the shoulders towards the centre plane of the tire. The ribs from opposite sides do not meet, but leave a central area, essentially a wide circumferential rib between them, that

Table 9 – Driver actions in control-loss accidents

	Directional loss of control	Skid	Jackknife	Trailer swing	Rollover	Total
Steer only	5	3	2	0	6	16
Steer, then brake	0	0	1	0	0	1
Brake only	3	12	16	1	3	35
Brake, then steer	1	5	7	1	4	18
Trailer brake only	0	1	1	1	1	4
None	1	0	1	0	3	5
Unknown	5	4	2	0	5	16
Total	15	25	30	3	22	95



Crossrib tires – ribs extending from the shoulder toward the center of the tire (nearly always bias ply)

Mud and snow – vertical and horizontal tread (nearly always radial)

Radial and bias ply rib tire - vertical tread

Tire tread patterns

FIGURE 6

contains only relatively shallow sipes. Usually of bias ply construction.

- **Mud and Snow**
  The tread of mud and snow tires are divided into blocks by transverse and circumferential grooves running the full width and circumference respectively. Usually of radial ply construction.

- **Rib**
  This conventional tread design has major circumferential grooves and ribs of either bias or radial ply design.

Table 10 tabulates the traction-tire type used by CVs that lost control during an accident. Section 4.2 deals with loss-of-control.

These results can only be interpreted in relation to the traction-tire tread-type distribution among CVs on the highways in the survey area. This was determined in an MTC report (6) and is summarized in Table 11. Figure 7 compares usage and accident involvement.

The cross-rib tire was overrepresented in all cases in loss-of-control accidents, particularly for articulated vehicles. Based on their usage, these tires would be expected to be present on a quarter of articulated vehicles in accidents. Deleting those with unknown tire type, they were present in 44% of loss-of-control accidents, independent of the type of control loss. The sample was sufficiently large that the probability that this was a chance result was miniscule. It is expected that vehicles using these tires are more likely to have an accident involving loss of control than other, similar vehicles. As tire performance and particularly, maximum traction capability, is intimately connected with controlability, it is natural to conclude that cross-rib tires produce low braking and/or lateral traction. A low peak braking friction coefficient is very likely a factor in jackknife accidents (usually caused by traction wheel lock-up), because wheels equipped with such tires require relatively low brake pressure to lock them up.

This suspicion is supported by the unfavorable response MTC has experienced from drivers of Ministry vehicles equipped with cross-rib design traction tires. The major complaints were of the lack of traction, particularly during adverse weather conditions, and the resultant vehicle instability.

New cross-rib (bias ply) tires have significantly less braking traction than other truck tire types (11). A review of the literature, References 7 to 11, has provided supporting evidence of the low traction capabilities of these tires under conditions in which control loss is most likely to occur -- wet, slushy or snow-covered pavement, and low tire load. A further and significant reduction was measured on a cross-rib truck tire with reduced tread depth (7). Figure 8 shows this loss of traction capability of the cross-rib as compared to a rib-type tire.

It is felt that this type of tire is adequate for low-speed city and farm use, but not for high-speed inter-city use. Its main strength, that of a long wear life, is a poor trade-off in terms of vehicle stability and driver safety.

4.4 TRAILER COUPLINGS

Pup trailer rollover accidents are often classified as being the result of coupling failures. A more in-depth examination usually reveals that some manoeuvre has initiated pup trailer instability which consequently causes rollover. It is during the overturning action that mechanical failure in the trailer coupling (Figure 9) occurs. This failure is usually confined to the locking device. Once it occurs, the pup trailer can become free of the towing unit and restraint is left to the safety cables which, more often than not, also fail.

Table 10 – Traction tire types in control-loss accidents

Vehicle type	Type of control loss	Number				Percentage			
		M + S	X-rib	Rib	Unknown	M + S	X-rib	Rib	Unknown
Straight trucks	Directional	0	5	1	3	0	55	11	33
	Skid	1	5	0	2	12	63	0	25
	Total	1	10	1	5	6	59	6	29
Articulated vehicles	Directional	3	2	0	1	50	33	0	17
	Skid	6	7	2	2	35	41	12	12
	Jackknife	15	12	0	3	50	40	0	10
	Trailer swing	1	1	1	0	33	33	33	0
	Total	25	22	3	6	45	39	5	11

The failure of the locking device is caused by the rigid tow eye on the dolly. As the pup trailer overturns, the tow eye rotates in the coupling device shearing off the mechanism.

Other factors, such as, failure of attachment rings for safety cables or safety chains, inadequate safety cable size, lack of coupling pin retention, and metal fatigue in chassis members have been evident in the various accidents investigated. In all of these cases the trailers were loaded near to or at their maximum allowable gross vehicle weight. The loads, such as lumber, had a high centre of gravity. A summary of puptrailer accidents is shown in Table 12.

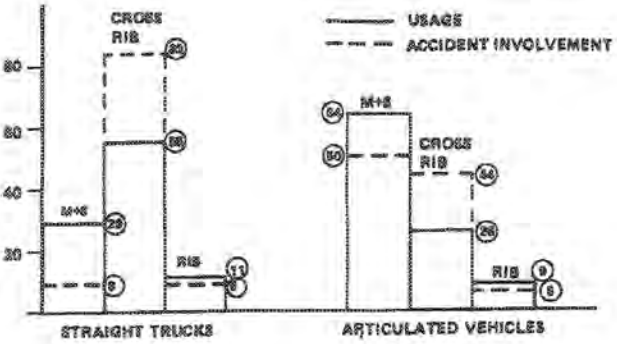
4.5 SPRING BRAKES

All present-day tractors equipped with air-activated brake systems are also equipped with spring brakes. These spring brakes are found on the tractor drive axle(s), depending upon vehicle design and date, and country of manufacture. All air-brake-equipped trailers, on the other hand, do not necessarily have spring brakes. The determining factor again is date and country of manufacture.

Table 11 - Traction tire type usage (%)

	M + S	Cross-rib	Rib	U?K
Straight trucks & truck trailers	29	55	11	6
Tractor-semitrailers	64	26	9	1
A- and B-trains	85	12	3	0

U/K = Unknown



Comparison of traction tire usage and accident involvement by tire type

FIGURE 7

Through conversations with CAV drivers and fleet supervisors, it has been noted that the use of spring brakes in an emergency stopping situation is not generally recommended. In fact, there is a tendency to instruct drivers to use spring brakes only when parking the vehicle and never when the vehicle is in motion.

Trailer designs such as those used for low beds and drop centre cattle vans make brake servicing very difficult. The lack of accessibility leads to longer air tank draining and brake adjustment intervals. This can lead to air system contamination, freeze-up, and a reduction in braking efficiency, as was the case in three of the accidents investigated during the study.

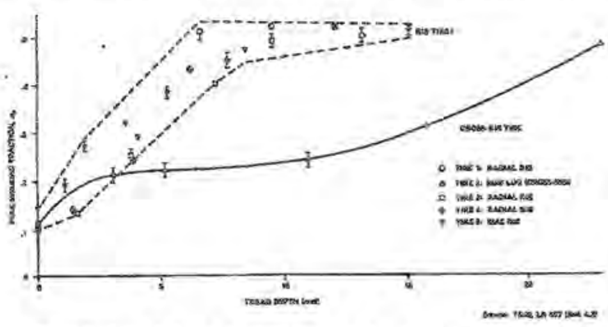
In those accidents, there was no attempt by the driver to use the spring brakes to slow or stop the vehicle. In each instance, the severity of the collisions could have been substantially reduced had the spring brakes been activated.

4.6 TACHOGRAPHS

Only 7 of 77 commercial vehicles involved in Phase 2 of the study were known to have been equipped with tachographs. Important information was obtained from this device:

- In one case, the speed estimate of CAV by an independent witness was discredited.
- In two cases, speed was in excess of the posted limit.
- In four cases, the information not a factor.

Commercial vehicle tachographs, mandatory in Europe, are one means of recording vehicle opera-



Peak braking traction of various truck tires 80 km smooth wet concrete (1/2 mm water depth)

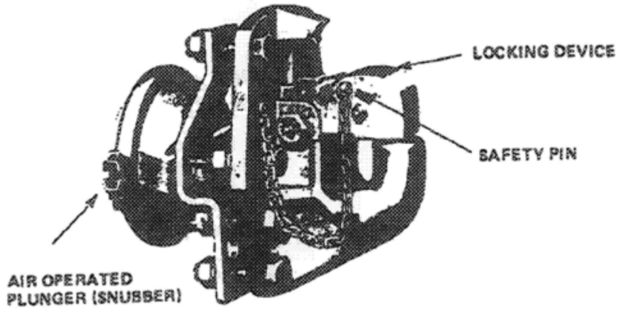
FIGURE 8

tion for purposes of both monitoring fleet operation and law enforcement. Their use should be encouraged and would contribute greatly towards safe and cost-effective commercial vehicle operation.

5 GENERAL OBSERVATIONS

5.1 INTRODUCTION

The commercial vehicle accident survey has produced other observations which, while not easily substantiated by statistics, are nonetheless considered to be valid and worthy of note. These observations have been based upon feedback from concerned OPP officers, discussions with CAV drivers and fleet managers, and the increased awareness of the traffic scene on the part of the authors.



Pintle hook type coupling device.

FIGURE 9

5.2 ACCIDENT INVESTIGATION NEEDS

The experience gained from the CAV accident investigation programme and reinforced by court appearances indicates that there is a need for specially-trained personnel to be available for technical, on-the-scene accident investigation. The levels of skill necessary to meet these needs go beyond normal accident reporting and the basic on-the-scene accident investigation currently practiced.

Traffic accident reports used by the OPP are the most basic of data gathering methods in the accident investigation process. The reports use a square-filling format that can only provide general information pertaining to the vehicle, accident mechanism, and driver. The report of the Uffen Commission on truck safety (16) recommended that an Ontario truck accident report be designed to supplement the existing traffic report, and that MTC and OPP jointly establish at least one permanent multidisciplinary accident investigation

Table 12 - Summary of accidents involving pup trailer towing attachments

Accident number	Config	Load >75%	Load shift	360°	Toweye Rigid	Failure	Safety cable attach. failure	Pintle hook lock device failure
008	3S2-2	X		X				
101	3-4	X	X		X			X
037	3S2-2	X			X			X
039	3-2	X	Possible		X			
062	3S2-3	X			X		X	X
130	3S2-3	X			X		X	
158	3S2-3	X			X		X	
171	3S2-3	X			X			
81-Misc-02	3S2-3				X	X	X	

Accident number	Config	Air snubber equipped	Human or maintenance factor	Uncouple	Rollover Trailer	Rollover Complete vehicle	Vehicle speed and manoeuvre
008	3S2-2				X		Evasive @ 80 km/h
101	3-4				X		Turning low speed
037	3S2-3				X		Evasive with braking @ 100 km/h
039	3-2					X	Drive into steeply sloped road shoulder
062	3S2-3				Lead unit		Evasive and loss of control @ 70 km/h
130		X				X	Evasive and impact @ 100 km/h and loss of control
158	3S2-3		X	X			Going ahead @ 80 km/h
171	3S2-3		X	X	X		Going ahead @ 80 km/h
81-Misc-02	3S2-3		X		X		Going ahead @ 85 km/h

team to investigate heavy truck accidents in Ontario.

The gathering of acceptable and meaningful data is necessary for accident reconstruction and evidence. The determination of accident causation can only be accomplished by having relevant information acquired by a skilled and knowledgeable technical accident investigator. It is also important, since most accident reconstruction is done by individuals using accident data at secondhand, that the on-the-scene investigator be qualified and accepted in a court of law as an expert in this field.

The importance of obtaining on-the-scene information by using credible personnel cannot be overemphasized. The knowledgeable recording, refining, and interpreting of the accident data will provide a package of information useful for both research and litigation purposes. It will benefit both the trucking industry and the general public in terms of safe vehicle operation.

5.3 DRIVER EDUCATION

At present, little is offered to inform the student passenger-car driver of his or her role in establishing a safe passenger-car/CV interface. Little information is offered outlining the needs of CVs to maintain a safe, traffic-oriented envelope and the effect of the passenger car on the integrity of this envelope. Agencies such as the Canadian Automobile Association and the Ontario Trucking Association are attempting to address this problem through their publications (12, 13). While these attempts to inform automobile drivers of how to share the highways with trucks are a step in the right direction, a larger effort in this area on the part of all of the agencies concerned with highway safety is felt to be necessary.

5.4 PASSENGER CAR DOWNSIZING

In an effort to use fuel more efficiently, cars have been re-engineered to produce lighter, more fuel-efficient vehicles. 1985 models weigh between 827 and 1790 kg, while the 1976 model cars ranged in weight from 936 to 2322 kg. Truck weights, however, have remained static. Therefore, the weight savings achieved through better engineering and manufacturing practices have been negated by an increase in payload.

The downsized passenger car has lost a certain amount of "crash-worthiness" -- the ability of the body of the car to absorb and dissipate the energy of a collision -- through the greater utilization of plastics, alloys, and lighter gauge metals in the battle to trim weight from the automobile body and chassis.

While the fuel-saving benefits of smaller cars have been clearly enunciated, the injury penalty of smaller cars has not been clearly defined (14). The US Department of Transportation has found (15) that the shift to smaller, lighter cars has resulted in the occupant of a small car being eight times more likely to be killed than the occupant of a full-size car when a collision between the cars occurs. Although the sample of passenger car/CAV accidents in the MTC survey was insufficient to provide conclusions, it was observed by the investigators and stated by enforcement officers that damage to the downsized car and possibility of injury to the occupant(s) was generally greater than in similar accidents involving full-sized cars.

Downsizing has precipitated another problem in the commercial vehicle/passenger car interface. Downsizing has produced cars that are dimensionally smaller and therefore not as visible as the older generation full-size cars. A smaller car, when viewed in CV rearview mirrors, may be less readily noticed, particularly during traffic situations when the truck driver is subjected to a momentary environmental overload.

5.4 LOAD RETENTION

The proper loading of CVs is a very important aspect of truck safety. Loading affects the braking ability, handling, and stability characteristics of trucks; particularly CAVs. Observations made from the investigation of 12 accidents caused by or abetted by improper load retention are:

- Load integrity is not checked regularly; chains loosen as a divisible load settles while a CV is moving.
- Few platform-type trailers are equipped with headboards.
- Garbage containers are often unevenly loaded, affecting vehicle stability and braking efficiency.
- Too much reliance is placed on friction between load and trailer deck as a method of load retention.

- Use of frozen or ice-covered timber spacers in winter months, between bundles of plate steel, results in the loss of friction forces in restraining load movement.
- Use of steel rollers on trailers results in the loss of friction forces in restraining load movement.
- Loads are often inadequately secured in enclosed type trailers or trucks.
- Shipping containers carried on platform trailers are often very lightly secured.
- Load-locking mechanisms on container trailers are often not maintained properly thus affecting their operation.

6. CONCLUSIONS

1. The objectives of the CV on-the-scene accident survey have been achieved, and an understanding of some of the causes and contributing factors of commercial vehicle accidents has been developed.
2. The common perception that fault lies with the driver of a CAV involved in a multiple vehicle accident is false. It was found during the survey that the CAV driver was at fault a maximum of 47.2% of the time.
3. Jackknife accidents usually involve lightly-loaded or empty CAVs and usually occur on wet or slippery pavements.
4. The use of jackknife control devices is not common. These devices should be optimized for empty articulated vehicles and their use should be recommended.
5. Rollover accidents usually involve heavily-loaded vehicles and occur on dry pavements.
6. Cross-rib traction tires are overrepresented in loss-of-control accidents. Research into the sideforce and traction characteristics of various designs of commercial vehicle tires should be undertaken. Indications are that alternative tire tread designs and proper usage are a cost-effective means of increasing commercial vehicle resistance to loss-of-control.
7. Mechanical failure is a significant but not large cause of commercial vehicle accidents.
8. Speed too fast for the prevailing conditions accounted for 32% of the accidents in which the commercial vehicle was at fault.
9. Tachographs in commercial vehicles are a useful tool for law enforcement purposes and control by owners.
10. The operation and control of a commercial vehicle is complex and demanding. Driver education should be offered to commercial vehicle drivers so that they might better understand the operational limits and condition of the vehicle. The implementation of an air brake endorsement for the driver of an air-brake-equipped vehicle is a suggested method of promoting this knowledge.
11. To maximize the use of highway systems, it is necessary to safely interface passenger cars and commercial vehicles. Driver education should be offered to all student car drivers to inform them of the requirements of a commercial vehicle driver, to increase awareness of a safe operational "envelope," and to the maintenance of a proper commercial vehicle/passenger car interface.
12. Accident reconstruction and investigation is a complex undertaking. A course of instruction to teach the techniques of technical accident investigation should be established for law enforcement officers. An accident reconstruction and technical advisory service should be established to complement this course and assist officers in the more demanding cases.
13. Research should be undertaken to better understand the effects on vehicle stability and control of using spring brakes in emergency situations as they are not widely used by commercial vehicle drivers when braking capability is lost on the vehicle.

ACKNOWLEDGEMENTS

The author would like to thank the following people and agencies for their contribution:

- Mr. A.M. Billing (formerly of MTC), investigation team member & co-author of the MTC report from which this paper is derived.
- Mr. W. Stephenson & Mr. C. Blamey, MTC; investigation team members.

- OPP Constables, Supervisors & SLEP team members.
- Mr. H.C. Pang, MTC; statistical analyst of study background data.

REFERENCES

1. A Public Policy Direction for the Highway Transportation of Goods, final report of the Select Committee of the Legislature on Highway Transportation of Goods, Toronto, Ontario, 1977, pp. vi-34.

2. Fearon, E., et al, "Highway 401 Corridor Traffic Systems Management Study, Volume 2, Problem Identification," Research and Development Branch, Ministry of Transportation and Communications, Downsview, Ontario.

3. Snelgrove, F.B., Billing, A.M., Choi, C., "Performance Evaluation of Several Jackknife Control Devices," Research and Development Branch report CVOS-TR-80-03, Ontario Ministry of Transportation and Communications, Downsview, Ontario, September 1981.

4. Fleischer, G.A., "Commercial Vehicle Accident Factors," Highway Research Record 706, Transportation Research Board, Washington, D.C., pp. 28-36.

5. Mikulcik, E., "Hitch and Stability Problems in Vehicle Trains," University of Calgary, Calgary, Alberta, November 1973.

6. Wilhelm, T., Billing, A., "Surveys of the Commercial Vehicles and Truck Tires Used in the Toronto Area," Research and Development Branch report TVS-CV-81-112, Ontario Ministry of Transportation and Communications, Downsview, Ontario, December 1981.

7. Williams, T., Meades, J.K., "Effects of Tread Pattern Depth and Tyre Grooving on Lorry Tyre Skidding Resistance," Laboratory Report 687, Transport and Road Research Laboratory, Crowthorne, U.K., 1975.

8. Boyd, P.L., Neill, A.H., Hinch, J.A., "Truck Tire Cornering and Braking Traction Study," U.S. DOT report HS-804-732, March 1979.

9. Dijks, A., "Wet Skid Resistance of Car and Truck Tires," Tire Science and Technology, Volume 2, Number 2, May 1974, pp. 102-116.

10. Billing, A.M., Slauin, J., "Measurement of Longitudinal Tire Friction Properties for the MTC Articulated Test Vehicle," Research and Development Branch report CVOS-77-03, Ontario Ministry of Transportation and Communications, Downsview, Ontario, 1977.

11. Thurman, G.A., Leasure, W.A., Jr., Editors, "Noise and Traction Characteristics of Bias-Ply and Radial Tires for Heavy Duty Trucks," U.S. DOT report DOD-TST-78-2, October 1977.

12. Sportsman-Like Driving, Canadian Automobile Association, 3rd Canadian Edition, 1981, pp. 7-8.

13. Sharing the Road with a Truck, Ontario Trucking Association.

14. Campbell, B.J., "Safety, Small Cars, and the Gasoline Shortage," Highway Safety Research Centre, University of North Carolina, 1975.

15. U.S. Department of Transportation News, NHTSA-6-81, January 1981.

16. Report of the Ontario Commission on Truck Safety, Robert J. Uffen Commissioner, 1983.