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AN EMPIRICAL ANALYSIS OF CANADIAN GASOLINE AND LPG TRUCK RELEASES

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SUMMARY

In July of 1985, reporting of dangerous goods occurrences in Canada became mandatory under the Transportation of Dangerous Goods Regulations (SOR/85-77). Since that date the Transport Dangerous Goods Directorate of Transport Canada has collected data on numerous characteristics of each reported spill in a comprehensive data base. This paper examines the 1986 and 1987 data for gasoline and liquefied petroleum gas (LPG) truck spills that occurred en route, with the objective of calibrating the accident and release submodels for use in a transportation risk model that was developed previously for Transport Canada.

The most common accident types that were observed to cause releases of these two commodities were: overturn, collision followed by overturn, and collision. Similar accident types were recorded for both commodities; however, the frequency of non-transportation releases for LPG was higher, likely due to different reporting requirements or practices. It was found that overturn and collision/overturn accidents resulted in similar release sizes, while collision accidents resulted in statistically lower average release sizes. The other spill types were examined qualitatively. For example, fire was found to result in a 98% release of lading, 3 out of 4 times. Fire only occurred with gasoline spills, but the LPG spill sample size was much smaller than for gasoline. Of the three truck types represented in the database, tractor trailer, tractor trailer with pup, and tanker truck, the latter was the most common, and hence was used for the statistical analysis. It was found that the former two truck types could be considered as one sample in terms of release percentage, but they could not be combined with the tanker truck sample. The paper concludes with a number of recommendations for developing spill distributions and event trees for each accident type to be used in conjunction with the Transport Canada risk model.

1. INTRODUCTION

Transport Canada has collected data on dangerous goods spills since 1979, and in July 1985 reporting of spills became mandatory under the Transportation of Dangerous Goods Regulations (SOR/85-77), making the database more comprehensive. These data on dangerous goods accidents and the scenarios that follow, are invaluable for calibrating risk analysis models such as the one developed for Transport Canada (TC) by the Institute for Risk Research (1).

The information useful for risk analyses includes accident type and cause, spill type, percentage released, and truck type. Other information regarding consequences, such as injuries, fatalities, and evacuations, are also valuable. A previous report (2) examined the 1986 and 1987 TC spill records for all dangerous goods carried by truck and rail. This paper examines in more detail the gasoline and liquefied petroleum gas (LPG) truck en route releases in order to provide the TC risk model with accident and fault information (probability of release, given an accident). Previous to this data analysis, release sizes were estimated based on physical features of the containment system, and the likelihood of these releases were estimated with complicated models. Other studies have followed this same approach due to a lack of release data (see for example, Geffen, et al.,(3); Rhoads, et al.(4); Glickman and Rosenfield(5).

There were 41 gasoline incidents and 9 LPG incidents in the 1.7 years of data used for this study. (Since these data do not include annual truck kilometres travelled, and the reporting criteria are different for the 2

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commodities, this does not necessarily indicate that gasoline is more accident prone than LPG.) For both commodities, release sizes for accident, spill, and truck types are examined. Due to the reporting criteria established in Canada, where only dangerous occurrences and not all accident involvements are reportable, an overall fault rate similar to that established in the United States for HAZMAT trucks, could not be derived. According to Harwood, et al. (6), the Federal Highway Administration (FHWA) records collected by the Bureau of Motor Carrier Safety (BMCS) indicate that gasoline trucks release goods in 19% of all accidents and LPG trucks release goods in 8% of all accidents. From the Transport Canada data, however, consequences in terms of release size and in terms of human effects, namely injuries, fatalities, and evacuations can be evaluated

A few problems with the data were encountered, notably the mix of accident type and accident cause information, which caused difficulty in defining the type of accident for all data entries. As of April 1989, Transport Canada data collection procedures have been revised to include accident type, causal factors, and spill types in separate fields to eliminate this problem.

The paper is organized into four sections, including this introduction. Sections 2 and 3 are similarly organized for the two commodities. They begin with a discussion of the frequency of each accident, spill, and truck type, given a spill has occurred. The distribution of release sizes for accident types and for truck types are compared in order to combine small samples that may be similar. LPG did not have enough data for a statistical analysis, although qualitative observations are made. Consequences in terms of injuries, fatalities, and evacuations are also examined. The paper concludes with Section 4 which includes a number of recommendations for improvements to the Transport Canada risk analysis model and for future data collection and analysis.

2. GASOLINE

An event tree which shows the distribution of the 41 gasoline truck en route incidents is shown in Figure 1. The data is divided into four levels of which only the first, accident/non-accident, is derived indirectly from the data. The remaining levels, accident type (or cause if accident type was not given), release type, and truck type are all taken directly from the data base. Truck type is included in the figure to show any differences in release sizes due to truck type differences.

The following section discusses the frequency of events in each level of Figure 1, followed by Section 2.2 which discusses the consequences of these same events in terms of release size and injuries, fatalities, and evacuations caused by the accident.

2.1 Frequency of Events

It was difficult to divide the data into transportation accident and non-transportation accident categories, since accident type was not always given as an explicit variable in the data used for this study. Therefore, entries such as brake failure, fire, puncture, and fitting failure could have caused or resulted from an accident, but could not be classified as such for this study. These categories are shown by a dashed line in Figure 1 in order to denote that they could be considered as either accident or non-accident events.

Because of the above noted uncertainty in the data, the proportion of accident-related releases ranges from 81 to 100 percent of the data while the proportion of non-accidents ranges from 0 to 19 percent. The low percentage of non-transportation accident releases is likely due to the reporting criteria for gasoline, as all

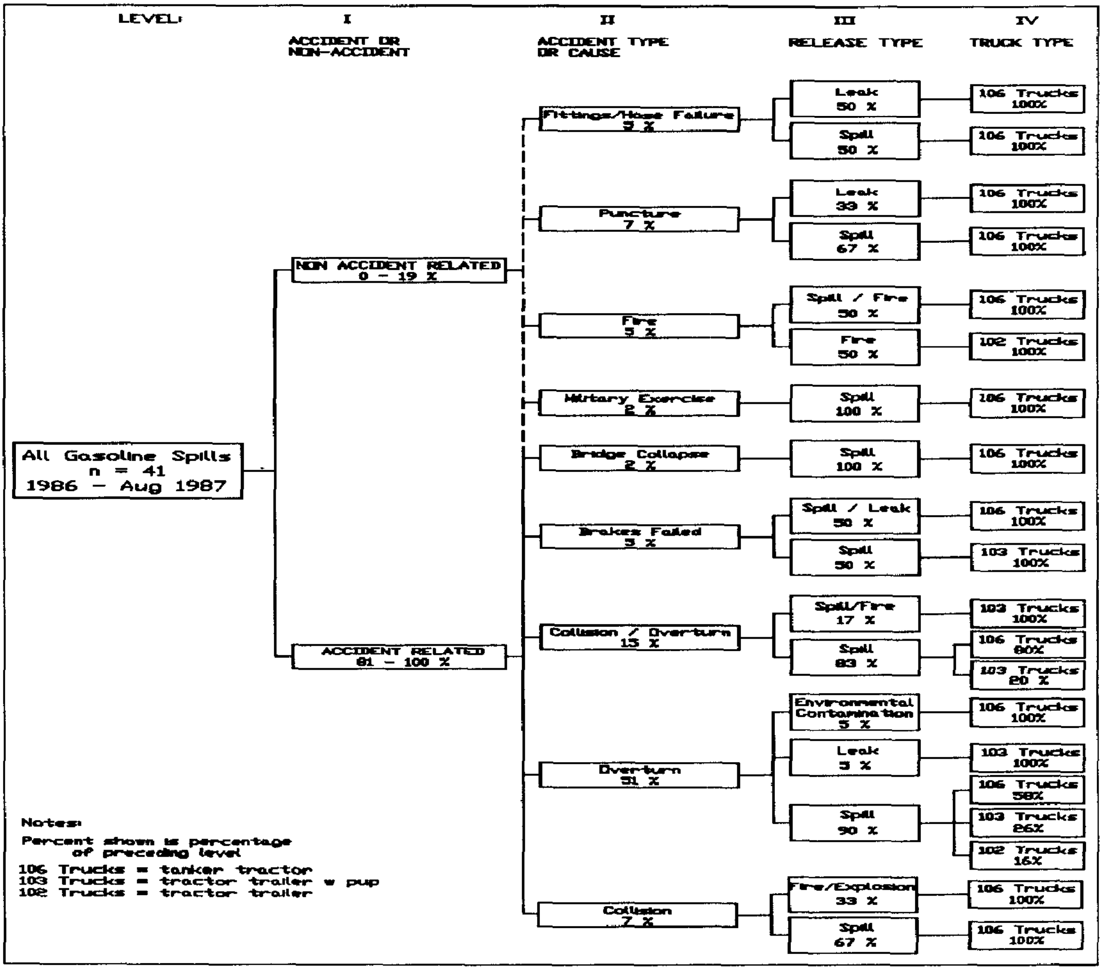

Figure 1: Relative Frequency of Gasoline Incidents in 1986 and 1987.

transportation accidents in which bulk containers are damaged must be reported, but only releases over 200 litres that represent a danger to health, life property, or the environment are reported.

Non-accident percentages are not further used in Figure 1, that is, the percentages shown for level II, accident type, represent the frequency of occurrence relative to all the data. For levels III, spill type, and IV, truck type, the percentage breakdown of the immediately preceding levels are shown. The following sections describe accident type, release type, and truck type in more detail.

a. Accident Type

The major accident types are overturn (51%), collision followed by an overturn (15%), and collision (7%), which jointly comprise 73% of all the data. As noted previously, the accident type category is not included for all cases. For example, if the definition of a dangerous occurrence is not met, or there is no loss of contamination, the event would be further coded to clarify that either there was no release, or that the incident was not regulated. Two cases where accident type was not known involved brake failure and military exercise (7% of the data). They are shown as separate categories in the figure, but they likely should be included as part of one of the other major accident types.

Other difficulties arose when classifying certain incidents as transportation-accident related or non-accident related incidents. These included puncture (7% of the data), which are skin failures usually resulting from external forces (7). Whether the puncture occurred while en route (scraping collision), or whether it resulted following one of the accident types noted above, was not clear in the data base. In either case, they are considered transportation accident releases. Another accident type, namely, infrastructure failure, whether classified as an accident or non-accident spill, is a rare occurrence that is not currently included in the Transport Canada risk model. Another incident, fitting or hose failure (5% of the data), is included in the database. This could be caused by a transportation accident, or could be a non-accident release.

The fire (5% of the data) accident type may have resulted from a transportation accident or a fire on the truck. There have been cases where a fire has developed en route and caused the contents to burn and explode, for example, a punctured tire lead to a fire in a truck carrying explosives in Norway (8).

In summary,the above data analysis suggested the types of accidents that should be considered in the modelling of dangerous goods incidents, namely, collision, collision/overturn, and overturn. In addition, one new non- transportation accident release type, which is initiated by fire, should also be considered. Two new transportation accident types may be needed for the Transport Canada Dangerous Goods Model: infrastructure failure and scraping collisions (which lead to puncture).

b. Release Type

Release type data is used to define and describe the accident types in terms of their likely spill rates. The release types in the data base include: spill, leak, fire/explosion, environmental contamination, spill/fire, spill/leak, and fire. When two types are separated by a slash, it is considered that the first occurred, and then was followed by the second. Environmental contamination was removed from the release type data field in 1987 and placed in a separate data field for defining spill consequences.

Of all the release types, "spill" was the most common and was usually the major release category type for each accident type. A "leak" type release, which denotes a release over time (7), was also noted but the time element associated with the leak was not given in the data base. One incidence of a spill followed by leak was recorded. When fire was noted as a spill type, it could have been either the initiating release mechanism, or it could have occurred after an initial spill had already occurred (spill/fire). In one case, for example, a fire was initiated by a collision and was followed by an explosion.

c. Truck Types

In order to compare similar containment systems in terms of release size, the data were separated by truck type. Three truck types were listed in the database, and these are shown in Table 1, below. The most frequently recorded truck type was tanker tractor,(68% of the data), which carried on average the most goods. The next highest average load was carried by trailer with pup (and gasoline drums) or tanker with pup (22% of the data). The latter category of tanker truck was not a separate truck type option during these years of data collection. Recently, more truck type categories have been added (Rose, 1989) which should simplify and clarify truck type identification. The final truck type tractor trailer, carried less on average and likely contained gasoline drums in non-bulk shipments.

Table 1: Gasoline Truck Types and Average Load Carried in Litres

	Average Load (l)	St. Dev.	Range
1. Tractor trailer (10% of data)	23,000	8,600	14,000-31,300
2. Tractor trailer with pup (22% of data)	35,200	12,700	17,000-50,000
3. Tanker tractor (68% of data)	45,300	81,600	1,135-445,000

2.2 Consequences

Consequences were evaluated in this study in terms of amount of goods released and the associated consequences to humans, namely, fatalities, injuries and evacuations. Both release size and human consequences are used in the Transport Canada Risk model as measures of risk.

a. General Release Characteristics

Figure 2 shows the average percentage of lading lost (R) for each accident cause, and the conditional probability of occurrence of an event, given a gasoline accident has already occurred. The percentage released for the major accident types does not seem very different, but when the release type and truck type has been accounted for, certain differences emerge. The following section presents the results of a statistical analysis of these release sizes and lists recommendations regarding the types of categories that can perhaps be amalgamated. A final section describes the consequences for each accident type in terms of injuries and fatalities.

For the major accident types, namely, collision, overturn, and collision/overturn, the former two appear to cause spills of about 40% of the lading, while the latter appears to cause spills of about 30%. However, collision followed by a spill is a smaller release than collision/overturn followed by a spill, which in turn is smaller than overturn with spill. These differences may be a result of an effect whereby accident forces are being partly dissipated in the collision, resulting in less container damage and smaller releases. Overturns on the other hand cause more container damage. This difference in release percentage was tested and results are discussed in the next section.

Generally, a release type of fire means a large release (98% in three cases) except in one case where a spill followed by a fire resulted in only a 3% release. This latter case could represent the rapid application of emergency response measures, a factor not yet recorded in the data base.

Spill and leak release categories are not readily ranked by size. This is due to the time varying nature of leaks, i by definition they are relatively small releases which occur over time. No data record regarding duration of release is given, hence leaks vary from 2% released to 70% released, while spills range from 11% to 98%.

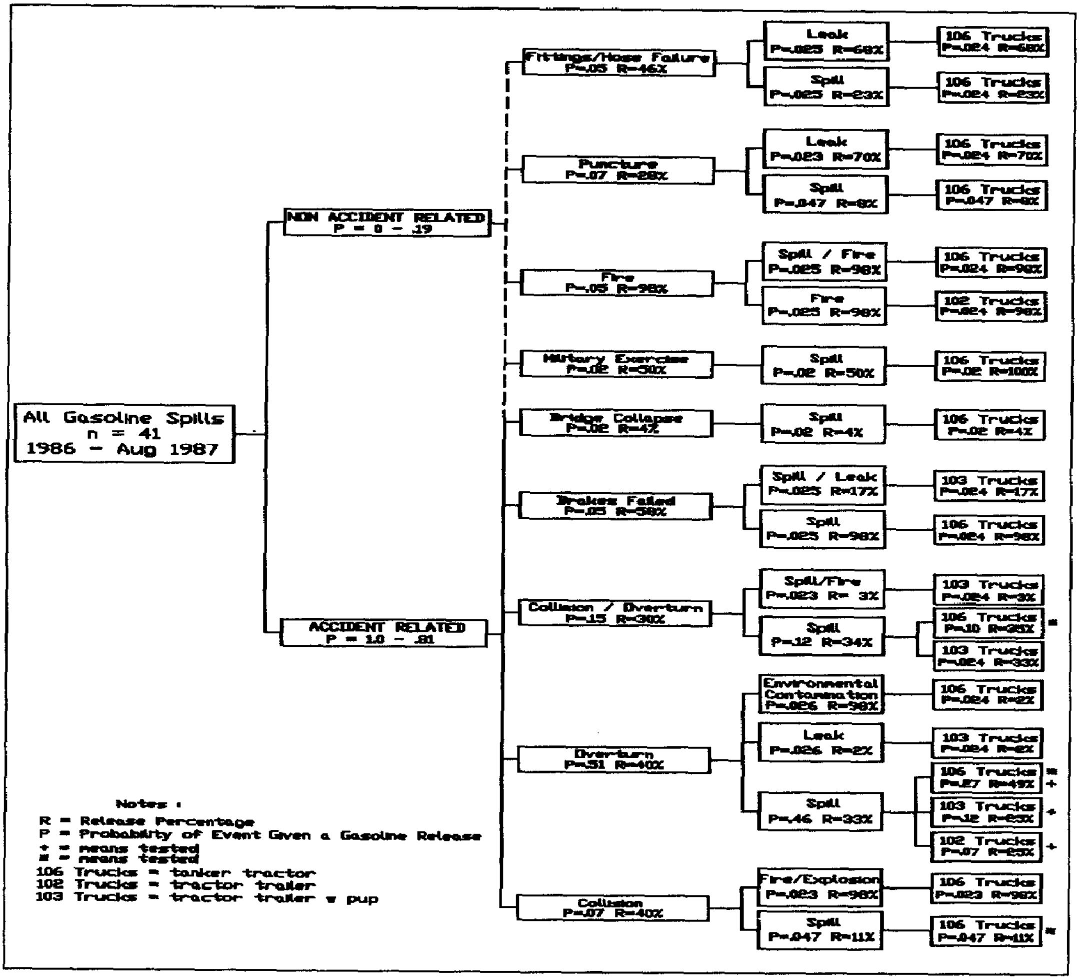

Figure 2: Probability of Gasoline Incidents and Average Release per Incident.

A separation of the data by truck type shows that, generally, " tractor trailers" and "tractor trailers with pups" tend to loose less of their load than tanker-tractors, which likely reflects the difference between non-bulk and bulk shipments. The difference in means was tested and described in the following section.

b. Statistical Analysis of Release Percentages

Because of the small sample sizes and the resultant difficulty in selecting a distribution for release percentage data, nonparametric models were used. In particular the Wilcoxon test for means was used in which the data points of two samples are combined and ranked. The sum of the ranks of the two samples are then compared with the normal, t- and chi-squared distributions, since the ranking has been shown to approximate a normal distribution (9). The test values consider if the samples likely have the same mean. For example, in this analysis, any test value that is under .20 (20%) is considered to indicate that the means are significantly different.

Initially, the mean release percentages of different truck types were compared keeping accident type (overturn) and release type (spill) constant. Then, using the same truck type, tanker-tractors, and the "spill" release type, the means of the three major accident types (collision, collision/overturn, and overturn) were compared. The differences between spill type was not tested due to sparse data in many categories.

The test results for truck types are shown in the first three rows of Table 2. These results indicate that tractor trailers and tractor trailers with pup are not likely different in release percentage. Tractor trailers with pup may be different from tanker tractors, and possibly tractor trailers are different from tanker tractors. Accordingly, tractor trailers and tractor trailers with pup samples were combined and compared to the tanker tractor in Test 4. The results indicate that the former truck spills are significantly different from the latter. Results from the other truck combinations are also shown in Tests 5 and 6.

The test results, for accident types with 106 trucks experiencing "spills", are shown in Table 3. The first three tests appear to indicate that collision and overturn are statistically different in terms of their mean release percentages (test 1); collision and collision/overturn may also be different (test 3); but likely collision/overturn and overturn are not different (test 2). In Test 4 collision/overturn and overturn were combined and compared to collision. The results indicate a significant difference in means. In Test 5 collision/overturn and collision were

Table 2: Results for Truck Type Categories for Overturn Accidents and the "Spill" Spill Type

Test No.	Categories Tested	Sample Size (n)	Normal	T-test	Kruskal-Wallis (Chi-Squared)	Significant Difference in means
1	Tractor trailer vs Tanker tractor	5 11	.212	.2312	.1920	possible
2	Tractor trailer vs Tanker tractor	3 11	.2747	.2945	.2419	possible
3	Tractor trailer vs Tractor trailer with pup	3 5	.7656	.7742	.6547	not likely
4	Tractor trailer + tractor trailer with pup vs. Tanker tractor	8 11	.1263	.1437	.1164	yes
5	Tractor trailer with pup vs. Tanker tractor + tractor trailer	5 14	.2467	.2619	.2283	possible
6	Tractor trailer vs Tank tractor + tractor trailer with pup	3 16	.5383	.5460	.5020	no

Table 3: Test Results for Accident Type Categories for Tanker Tractors Experiencing "Spills"

Test #	Categories Tested	Sample size (n)	Normal	T-test	Kruskal-Wallis (Chi-Squared)	Significant Difference in means
1	Collision vs Overturn	2 11	.0925	.1183	.0749	yes
2	Collision/OT vs Overturn	4 11	.6005	.6087	.5558	no
3	Collision vs Collision/OT	2 5	.2472	.2994	.1649	possible
4	Collision vs Overturn + Collision/OT	2 15	.0859	.1052	.0731	yes
5	Collision + Collision/OT vs Overturn	6 11	.1905	.2090	.1741	possible

combined and compared to overturn, which indicated a possible statistical difference, although the difference is not as prevalent as in Test 4.

Figure 3 illustrates the cumulative probabilities for the percentages of loads that were spilled for each of the 3 accident types. It is shown that the percent of load released for overturn accidents varies virtually continuously from 0 to 100%. However, the limited data for collision and collision/overturn indicate that the amount spilled for these accident types only reaches up to 20% and 60%, respectively. Based on these limited data, it would appear that collisions have consistently lower percentages of load released per accident.

In summary, it appears that accidents involving tractor trailers and tractor trailers with pup releases can be

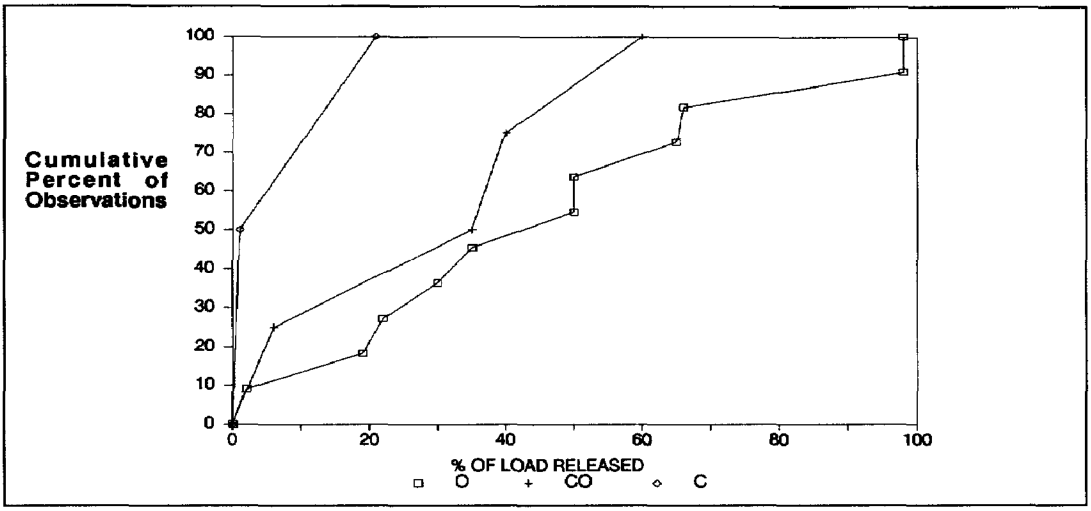

Figure 3: Cumulative Frequency of Percentage Spilled for Tanker-Tractor Carrying Gasoline (following overturn, collision/overturn and collision accidents).

combined for overturn accidents (a result which may be similar for other accident types). It appears that it is also possible to combine overturn accidents with collision/overturn accidents, since these accidents are similar in terms of the percentage released. However, after one considers the consequences in terms of injuries, fatalities and evacuations, versus spill size, the accident types may still need to be left separate, as discussed in the following section.

c. Injury/Fatality Statistics by Accident, Spill, and Truck Type

The consequences of a dangerous goods spill can also be measured in terms of the number of injuries, fatalities, and evacuations resulting from the accident or spill. However, injuries and fatalities are usually due mostly to the actual accident itself, rather than the subsequent spill. Table 4 indicates the injury-fatality-evacuation likelihood for the gasoline accidents classified by accident type and spill type. Some general observations are discussed in the following paragraphs.

Although these data are relatively sparse in some categories, the injury/fatality statistics appear to indicate that overturn accidents have less serious consequences than both collision/overturn and collision accidents.

This may reflect the difference in accident severity between single truck accidents and accidents that involve private vehicles, which generally result in higher injury and fatality rates. These data indicate that collision/overturn and overturn accident types should perhaps be retained as separate categories, since they have different

Table 4: Injury, Fatality and Evacuation Likelihood per Gasoline Accident

			Probability Per Accident of		
Accident Type	Release Type	Samples Size (n)	Injury	Fatality	Evacuation
Collision (7% of data)	All data	3	1	0.33	0
	Spill	2	1.5	0	0
	Fire/Explosion	1	0	1	0
Overturn (51%)	All data	21	0.1	0.1	0.1
	Spill	19	0.05	0.05	0.1
	Leak	1	1	0	0
	Environmental Contamination	1	0	0	0
Collision/ Overturn (15%)	All data	6	1.8	0.5	0.2
	Spill	5	2	0.4	0.2
	Spill/Fire	1	1	1	0
Brake Failure (5%)	All data	2	0	0	0
	Spill/Leak	1	0	0	0
	Spill	1	0	0	0
Puncture (7%)	All data	3	0	0	0.3
	Spill	2	0	0	0
	Leak	1	0	0	1
Fire (5%)	All data	2	0	0	0
	Fire	1	0	0	0
	Spill/Fire	1	0	0	0
Fitting & Hose Failure (5%)	All data	2	0	0	0
	Fire	1	0	0	0
	Leak	1	0	0	0
Military Exercise (2%)	Spill	1	0	0	0
Bridge Collapse (2%)	Spill	1	0	0	0

injury/fatality potential.

Evacuations are usually only called following accidents that have large release potential, reflecting the possibility of danger to the surrounding public, and hence are less frequent than injury/fatality accidents. In these data, evacuations occurred about once in every 10 overturn accidents; a similar frequency was experienced for collision/overturn accidents. Evacuations also occurred following puncture accidents at a frequency of 1 evacuation for every 3 puncture accidents.

3. LIQUEFIED PETROLEUM GAS

There were only 9 LPG incidents in the 1.7 years of data, which are shown in an event tree in Figure 4. The accident types were similar to those for gasoline, although only 5 types were actually noted:

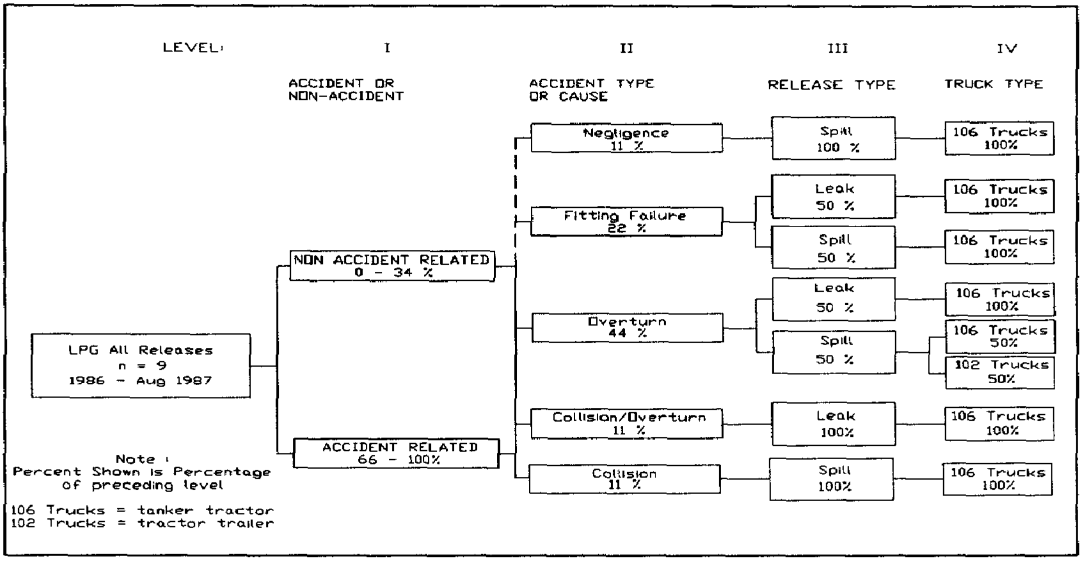

Figure 4: Frequency of LPG Incidents 1986-1987.

- Collision (44%)
- Overturn (11%)
- Collision/overturn (11%)
- Fitting/Valve Failure (22%)
- Negligence (11%)

For similar reasons as for the gasoline analysis, it was difficult to divide the accident types into accident and non-transportation accident. Possible non-transportation accident releases are shown beside a dashed line in Figure 4.

3.1 Frequency of Events

Similar to gasoline releases, LPG releases from overturn accidents were the most frequent (44% of the data). The three major accident types comprised 66% of the data. Fitting failures comprised 22% of the data, which is 4 times more frequent in relation to its occurrence during gasoline releases. This is likely due to reporting

Table 5: Truck Types and Volumes carried of LPG for Accident Data

	Average Load (litres)	Standard Deviation	Range
1. Tractor trailer (11% of data)	17,700	-	-
2. Tanker tractor (89% of data)	14,600	17,700	120-48,500

requirements, since any release of goods for LPG transported in containers larger than 100 litres must be reported, while gasoline spills must be greater than 200 L to be reported. This difference in reporting is also borne out by average release sizes for this failure, as for gasoline the average was 46%, while for LPG the average was only 1%.

Only two spill types were recorded, namely, spill and leak. Of the nine incidents, no fires or explosions were recorded for LPG, while for gasoline there were 4 fires in 41 incidents. Although the sample size used in this study was very small, it appears that LPG is involved in fire no more often than gasoline, when transported by truck on the highways. Of the 9 incidents, one involved a tractor trailer, while all the others involved tanker tractors. The volume carried by truck type is shown in Table 5.

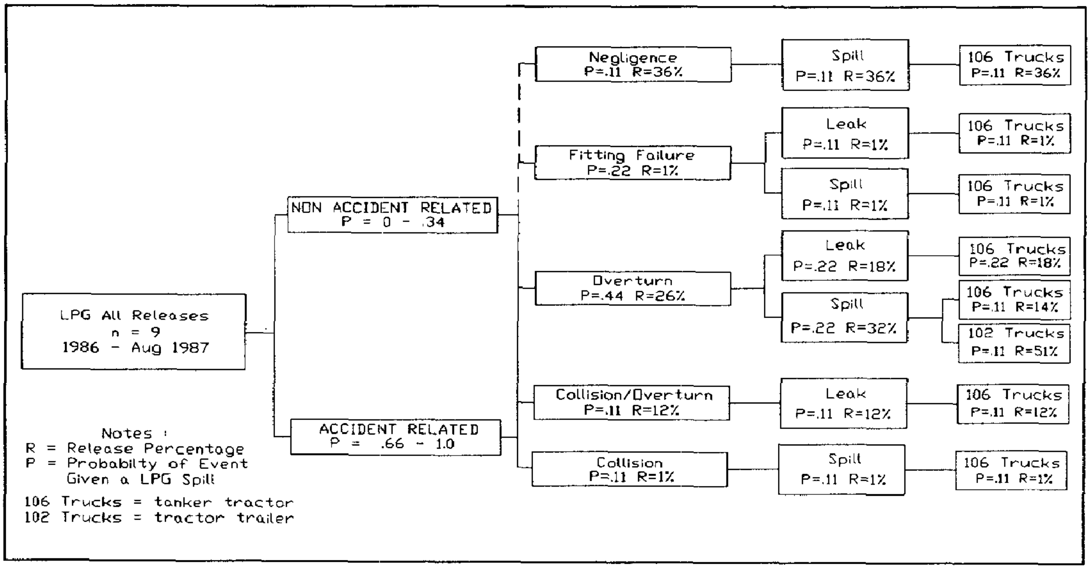

Figure 5: Probability of LPG Incidents and Average Release per Incident.

3.2 Consequences

a. Release Percentages

The percentage lost for all accident types, spill types and truck types is shown in Figure 5 as "R". In addition, the probability of the event, given an LPG incident has occurred, is also shown.

Although there seem to be similar trends as for gasoline, such as overturn accidents release more than other accidents, and collision accidents release the least amount, the loss percentages appear to be less for LPG than for gasoline. This may be due to the stronger containment system used for the pressurized, liquefied petroleum gas system. Unfortunately, the lack of common data points prevents a statistical comparison of the two commodities in terms of release percentages.

b. Injury, Fatality, and Evacuation Statistics

For LPG, injury accidents only occurred in overturn accidents and no fatality accidents were recorded (see Table 6). Evacuations occurred following overturn and collision/overturn accidents, which are similar events

Table 6: Probability of Injury, Fatality and Evacuation per LPG Incident.

			Probability Per Accident of		
Accident Type	Release Type	Samples Size (n)	Injury	Fatality	Evacuation
Collision	Spill	1	0	0	0
Overturn	All	4	0.5	0	0.5
	Spill	2	0.5	0	0.5
	Leak	2	0.5	0	0.5
Collision/ Overturn	Leak	1	0	0	1
Fitting/Valve Failure	All	2	0	0	0
	Spill	1	0	0	0
	Leak	1	0	0	0
Negligence	Spill	1	0	0	0

to those that caused gasoline related evacuations. Although there are few data in the samples, it appears that evacuations may be slightly more frequent with LPG incidents (3 evacuations in 9 incidents) compared to gasoline incidents (4 evacuations in 41 incidents).

CONCLUSIONS AND RECOMMENDATIONS

There were 41 gasoline incidents and 9 LPG incidents in the 1.7 years of data used for this study. If all the data were collected from July 1985 to July 1990, assuming the same number of data records per year, one would have approximately 120 gasoline records and 25 LPG records, and some of the problems, due to the availability of only very small samples, may be eliminated. If all data from Transport Canada were used from 1979, there may be 200 and 50 records, respectively, depending on the comprehensiveness of the data base. For fault and event types of analyses (i what type of accidents, and how much is released) all of the available data are useful. However, if exposure measures are to be matched, only data from 1985 is relatively comprehensive.

Even with the small samples in the data used for this study, important conclusions regarding accident types and their frequency can be made. The most frequent accident types were (most frequent to least) for gasoline:

- overturn - collision/overturn - collision

and for LPG:

- overturn -fitting failure - collision/overturn and collision

Other incidents that resulted in releases that may be classified as transportation accident-related are:

- infrastructure failure, - puncture (scraping collision)

Incidents that may be classified as either transportation-accident related or non-transportation accident are:

- fitting failure - fire

Conclusions regarding release type are that the "spill" classification is the most frequent, followed by "leak". For truck type, tanker tractors are the most common vehicle reported for both gasoline and LPG. It appears that the truck samples can be combined, but are distinct from tanker-tractors truck samples.

Clearly, the preliminary conclusions drawn from the above analysis would become much more meaningful if more data could be used to calibrate these relationships. It is important that an agreement be reached on how accident data should be classified, and furthermore, it is important that compatible exposure data be collected.

More comprehensive data would allow the development of specific spill-type frequency distributions for each accident type, as well as release size distributions for each spill type. Finally, although the cost may be a drawback by recording all transportation accidents involving dangerous goods, whether a release occurred or not, overall release percentages, such as those recorded for HAZMAT trucks in the United States could be estimated for Canadian conditions.

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