Table 4.9. Road En Route Cause Codes.

Transportation Accident - Code 1

Subcode	Description	Freq
1	Collision	11
2	Overturn	94
3	Collision/OT	14
4	Brake failure	2
5	Fire	5
6	Bridge Collapse	1
7	Mechanical failure	1
	SUBTOTAL:	128

Non Transportation Accident Release - Code 2

Subcode	Description	Freq
OPERATIONAL		
1	Loose valve, closure fail.	9
2	Negligence, carelessness	3
3	Package damage, dropped	14
4	Puncture	15
5	Improper package	2
6	Loadshift	5
7	Improper bracing	13
8	Improper loading	4
EQUIPMENT		
9	Fitting/vent/valve failure	17
10	Transfer equip. fail.	1
11	Hose failure	1
12	Package failure	21
13	Metal fatigue	2
14	Dome failure	2
15	Tanker rupture	16
OTHER		
16	Lost	1
17	Vandalism	1
18	Unknown, exercise	1
	SUBTOTAL:	132
	TOTAL:	260

b. Road Terminals

The road terminal spills were divided into 4 transportation accident releases and 230 non-transportation accident releases. Even the 4 releases classified as transportation accidents could be less since 3 of the four had fire listed as the cause and this may or may not have been the result of a transportation accident.

The 230 non-transport accident releases, representing 98% of road terminal accidents, were further classified into 133 operational related releases, 87 equipment related releases and 10 in the other category. The causes and their codes are listed in Table 4.10.

The road terminal spills resulted in 37 injuries, 1 fatality, and 15 evacuations. Six of the evacuations caused 259 people to be evacuated -- on average, 43 persons per evacuation -- which is much less than the 114 person average for road en route incidents. One injury, one death and an evacuation involving 80 people were caused by a fire (Toronto, June 17, 1987 -- classified as a transportation accident in this study). The remaining 36 injuries and 14 evacuations were caused by non-transportation accident releases.

Table 4.10. Road Terminal Cause Codes.

Transportation Accident - Code 1

Subcode	Description	Freq
1	Brakes	1
2	Fire	3
	SUBTOTAL:	4

Non Transportation Accident Release - Code 2

Subcode	Description	Freq
OPERATIONAL		
1	Improper package	1
2	Package damage, dropped, crushed, torn	39
3	Puncture, fl/puncture	35
4	Valve loose, closure failure	8
5	Package lost/dumped	4
6	Improper bracing	8
7	Overflow, overfill	18
8	Procedures, negligence, carelessness	5
9	Improper loading	12
10	Improper blocking	1
11	Loadshift	2
EQUIPMENT		
12	Equipment failure	1
13	Valve/vent/fitting failure	10
14	Package failure/cracked/split	49
15	TRSF failure	12
16	Hose failure	1
17	Tank failure/collapse	10
18	Seam/weld failure/crack	4
OTHER		
19	Unknown	8
20	Vandalism	1
21	Reaction	1
	SUBTOTAL:	230
	TOTAL:	234

4.3.3 Discussion of Contents of Transport Canada Data Base

In order to assess the comprehensiveness of the Transport Canada data base, the number of spills in the RTC annual summary was analyzed and compared to similar spills recorded in the Transport Canada data base. In a previous study, the Transport Canada data base was compared to a series of newspaper reports (Saccomanno, Shortreed and Van Aerde, 1988).

a. RTC Data

As part of their annual summary of statistics, the Railway Transport Committee (RTC, 1986) of the Canadian Transport Commission records the number of transportation accidents involving dangerous commodities as well as the number of dangerous commodities incidents which do not involve transportation accidents. This last statistic is used to determine the number of non accident leaks and spills occurring on the railways.

Statistics are available from 1979-1986 in the RTC 1986 report, as shown in Table 4.11. However, the last few years indicate more incidents per year due to more stringent monitoring (RTC, 1986). Since the implementation of the Transportation of Dangerous Goods Regulations in 1985 may have affected the way these statistics are gathered, it is probably better to use only very recent data, perhaps the 1985 and 1986 values only.

Table 4.11 also shows the Freight Billion Gross Ton Miles (BGTM) and Million Train Miles (MTM). It is proposed to use the BGTM statistic to translate the number of non-accident leaks into rates of occurrence.

Table 4.11. RTC Non-Accident Dangerous Goods Incidents.

Year	# of Incidents	Freight BGTM	MTM	#/BGTM	#/MTM
1979	51	307.9	91.6	0.16	0.56
1980	107	308.5	89.2	0.33	1.20
1981	157	309.2	85.8	0.51	0.17
1982	105	275.6	73.9	0.38	1.42
1983	288	298.5	76.0	0.96	3.79
1984	418	321.0	81.3	1.30	5.14
1985	336	314.7	79.1	1.07	4.25
1986	398	320.2	78.8	1.24	5.05

A comparison of RTC annual non-accident dangerous goods incidents to those reported in the TC database shows that the RTC recorded 398 dangerous goods incidents in 1986 compared to approximately 42 in the TC database (70 incidents * 12 months/20 months). Even though the TC summary report (1987) states that the origin of the TC data includes mandatory reporting forms, plus newspaper articles and other sources, the RTC reports almost 10 times the dangerous goods incidents. This may imply that the TC database includes only the worst cases.

The apparent shortfall in the TC database records may be due to the definition of a "dangerous occurrence" that requires reporting. This definition is shown in Figure 4.1. It should be noted that the definition includes a discharge of the amount shown in the table for each class of good and the qualification that the occurrence represents a danger to life, health, property or the environment. Those conditions are pre-empted for the following conditions which must always be reported:

- bulk pressurized containers,
- Class 7 (Radioactive) goods,
- unintentional explosions or
- fires involving dangerous goods,
- the loss or theft of class 1 or 7 goods,
- incidents involving a fatality or an injury requiring hospitalization following a release, or
- a suspicion that the integrity of the container has suffered from impact, stress or fatigue.

While the lack of data concerning minor incidents may not be a serious problem, some classes of goods (Class 1, Class 7, and all those in pressurized containers) must always be reported and will be overrepresented compared to other goods. In addition, if the integrity of the container is thought to be damaged, the incident is reported although no goods may have been released and the container may not be damaged. It is questionable whether this type of incident should be in the data base.

In any case, the data for each specific commodity are sparse. Even for gasoline, the most commonly involved commodity, there are only 69 incidents over the 20 month record. This may seem like a reasonable amount to draw conclusions from, but when divided over 2 modes and 2 locations per mode, the number soon diminishes. In addition, the range of locations for accidents is vast and no two accidents may be the same in consequences due to the variations in locale.

Consequences due to the dangerous goods alone were not available for this study. Other studies (Saccomanno et al., 1988) have indicated a large percentage of fatalities and injuries are due to the accident itself and may be an order of magnitude more likely than consequences due to the goods. Unfortunately, this conclusion could not be verified in this study, due to lack of appropriate data.

4.4 Potential Damage Areas

The nature and extent of potential areas of damage associated with spills of dangerous goods are affected by four factors: spill rates and volumes, the nature of the material, the type of damage being considered, and the environment. Typical sizes of dangerous goods spills are determined by the properties of the material spilled, and the shipment container. Given the spill size, damage propagation models are used to give areas of potential damage for different types of damage. Actual expected damages depend on the spill environment, including such things as population density, property density, and the presence of lakes and rivers.

Typical sizes and levels of spills have been determined for a number of representative dangerous goods, including chlorine, LPG's and sulphuric acid (Saccomanno et al., 1986). Given some typical sizes of tankers for the shipment of these materials

(Stewart et al., 1987a and b; Stewart, 1987a and b), damage propagation models developed by the Institute for Risk Research (Van Aerde et al., 1986) give as output potential areas of damage. Tables 4.12 and 4.13 present the potential damage areas for road and rail spills of chlorine; Tables 4.14 and 4.15 present areas for road and rail spills of LPG; and Tables 4.16 and 4.17 give areas for road and rail spills of sulphuric acid. Weather conditions for the spills are assumed to be Pasquill's (1974) weather conditions, Class D. In this class, wind speeds range from 1 to 30 m/sec. This is the most common weather type in Canada.

Critical distances from the source of each spill are output from the damage propagation models, based on assumed hazard levels. Note that hazards can be considered in terms of fatalities, injuries, property damage, or environmental damage.

The hazard areas are based on models of dispersion of spilled material, leading to certain levels of concentration of dangerous commodities that can produce some types of damage. The models do not take into account such factors as topography, which affect the spread of dangerous goods, or the presence of fire in an accident, which can lead to different hazards and dispersion characteristics. For example, the Mississauga train derailment involved a release of chlorine, but the presence of fire caused the gas to be carried higher and so lessened the consequences of the accident.

The actual damages from a release of a dangerous good depend on population and property in the spill area, along with such mitigating factors such as shielding from buildings, evacuation, etc. These will be discussed in the next section.

A number of studies have considered potential damages from dangerous goods spills. A comparison of these results with those obtained from the damage propagation models is presented in Table 4.18. There was difficulty in making a direct comparison between some of the results, since damage types and damage categories were variable. However, some conclusions can be drawn:

1. There is a wide range in damage areas in the literature. There seems to be no consensus on typical or expected damage areas, especially in the case of chlorine. This is to be expected, since the damage models for LPG are generally based on simple assumptions. The modelling of chlorine dispersion is more complex, because of the difficulty of accurately representing heavier than air gases, and taking into account the terrain where the spill occurs (this is especially important for a heavier than air gas, which tends to collect in lower land areas).

2. There seems to be some confusion between the representation of expected damage areas (for a certain concentration of dangerous good) from a spill, and the 'lethal' zone or the area where deaths will occur. For example, in the output from the damage propagation models, areas of 50% lethality are given, but this does not necessarily imply that 50% of the total population within this area will be killed.

Table 4.12. Potential Damage Areas for Truck - Chlorine.

Release Type: Level:	Instantaneous High (100%)	Medium (69%)	Low (39%)	Continuous (24 hr max) High (14.5 kg/s)	Medium (3.9 kg/s)	Low (0.1 kg/s)
Damages - 27 tonnes	Potential Damage Areas (km^2)					
Fatality 1 (50%)	8.7	5.5	2.7	8.7	8.6	2.1
Fatality 2 (1%)	9.5	6.0	3.0	9.5	9.5	2.3
Injury 1	29.5	18.8	9.5	29.5	29.4	7.6
Injury 2	109.1	71.7	38.1	108.9	108.7	30.8
Damages - 16 tonnes	Potential Damage Areas (km^2)					
Fatality 1	4.5	2.9	1.4	4.4	4.5	2.1
Fatality 2	5.0	3.1	1.6	4.9	5.0	2.3
Injury 1	15.7	10.1	5.1	15.3	15.6	7.6
Injury 2	60.6	40.1	21.6	59.2	60.2	30.8

Note: Fatality 1 - Fatal after few breaths (3.0 g/m^3)
Fatality 2 - Death in 30 min. (2.4 g/m^3)
Injury 1 - Pulmonary edema in 30 min. (0.18 g/m^3)
Injury 2 - Tolerance limit for 30 to 60 min. (0.012 g/m^3)

Table 4.13. Potential Damage Areas for Rail - Chlorine.

Release Type:	Instantaneous			Continuous (24 hr max)		
Level:	High (100%)	Medium (69%)	Low (39%)	High (14.5 kg/s)	Medium (3.9 kg/s)	Low (0.1 kg/s)
Damages - 90 tonnes	Potential Damage Areas (km^2)					
Fatality 1 (50%)	41.1	25.6	12.4	40.9	41.1	2.1
Fatality 2 (1%)	45.1	28.1	13.6	44.8	45.1	2.3
Injury 1	135.0	84.9	41.7	134.3	135.2	7.6
Injury 2	460.2	295.2	150.7	457.8	460.7	30.8
Damages - 55 tonnes	Potential Damage Areas (km^2)					
Fatality 1	21.9	13.7	6.5	21.8	21.9	2.1
Fatality 2	24.1	15.1	7.2	24	24.1	2.3
Injury 1	72.9	46.1	22.4	72.6	72.9	7.6
Injury 2	255.6	165.4	84.3	254.6	255.5	30.8

Note: Fatality 1 - Fatal after few breaths (3.0 g/m^3)
Fatality 2 - Death in 30 min. (2.4 g/m^3)
Injury 1 - Pulmonary edema in 30 min. (0.18 g/m^3)
Injury 2 - Tolerance limit for 30 to 60 min. (0.012 g/m^3)

Table 4.14. Potential Damage Areas for Truck - LPG.

Release Type:	Instantaneous - 18 tonnes		
Level:	high (100%)	medium (90%)	low (69%)
Damages - 18 tonnes	Potential Damage Areas (km^2)		
Fatality 1 (Fireball)	0.070	0.070	0.050
Fatality 2 (Fireball)	0.130	0.120	0.090
Injury 1 (Fireball)	0.100	0.090	0.070
Injury 2 (Fireball)	0.430	0.390	0.300
Fatality 1 (Pool Fire)	0.005	0.005	0.004
Fatality 2 (Pool Fire)	0.010	0.009	0.007
Injury 1 (Pool Fire)	0.006	0.005	0.004
Injury 2 (Pool Fire)	0.032	0.029	0.022
Property 1 (Vapour Cloud)	0.004	0.004	0.003
Property 2 (Vapour Cloud)	0.022	0.020	0.017
Property 3 (Vapour Cloud)	0.036	0.033	0.028
Property 4 (Vapour Cloud)	0.176	0.164	0.138

Note:
Fatality 1 - 50% Mortality
Fatality 2 - 1% Mortality
Injury 1 - Ignition of Cellulose Material
Injury 2 - Blistering of Bare Skin
Property 1 - >90% Damage
Property 2 - >50% Damage
Property 3 - >10% Damage
Property 4 - <10% Damage

Table 4.15. Potential Damage Areas for Rail - LPG.

Release Type:	Instantaneous		
Level:	high (100%)	medium (90%)	low (69%)
Damages - 63.5 tonnes	Potential Damage Areas (km^2)		
Fatality 1 (Fireball)	0.230	0.210	0.160
Fatality 2 (Fireball)	0.410	0.370	0.290
Injury 1 (Fireball)	0.260	0.240	0.190
Injury 2 (Fireball)	1.350	1.230	0.960
Fatality 1 (Pool Fire)	0.019	0.017	0.013
Fatality 2 (Pool Fire)	0.034	0.030	0.023
Injury 1 (Pool Fire)	0.020	0.018	0.014
Injury 2 (Pool Fire)	0.112	0.101	0.078
Property 1 (Vapour Cloud)	0.009	0.009	0.007
Property 2 (Vapour Cloud)	0.050	0.046	0.039
Property 3 (Vapour Cloud)	0.082	0.077	0.064
Property 4 (Vapour Cloud)	0.407	0.379	0.318

Note:
Fatality 1 - 50% Mortality
Fatality 2 - 1% Mortality
Injury 1 - Ignition of Cellulose Material
Injury 2 - Blistering of Bare Skin
Property 1 - >90% Damage
Property 2 - >50% Damage
Property 3 - >10% Damage
Property 4 - <10% Damage

Table 4.16. Potential Damage Areas for Truck - Sulphuric Acid.

Release Type:	Instantaneous		
Level:	High (100%)	Medium (70%)	Low (50%)
Damages - 28 tonnes			
	Potential Damage Areas (km^2)		
River 1	11.60	5.70	2.90
River 2	57.10	28.00	14.30
River 3	1156.90	566.90	289.20
Lake 1	0.02	0.01	0.01
Lake 2	0.04	0.03	0.02
Lake 3	0.17	0.12	0.08
	Potential Damage Volumes (m^3)		
Soil 1	70004.40	49003.08	35002.20
Soil 2	70.00	49.00	35.00
Soil 3	0.07	0.05	0.04
Damages - 22 tonnes			
	Potential Damage Areas (km^2)		
River 1	7.10	3.50	1.80
River 2	35.30	17.30	8.80
River 3	714.20	350.00	178.50
Lake 1	0.01	0.01	0.01
Lake 2	0.03	0.02	0.01
Lake 3	0.13	0.09	0.07
	Potential Damage Volumes (m^3)		
Soil 1	55003.46	38502.42	27501.73
Soil 2	55.00	38.50	27.50
Soil 3	0.06	0.04	0.03
Damages - 15 tonnes			
	Potential Damage Areas (km^2)		
River 1	3.30	1.60	0.80
River 2	16.40	8.00	4.10
River 3	332.00	162.70	83.00
Lake 1	0.01	0.01	0.00
Lake 2	0.02	0.01	0.01
Lake 3	0.09	0.06	0.05
	Potential Damage Volumes (m^3)		
Soil 1	37502.35	26251.65	18751.18
Soil 2	37.50	26.25	18.75
Soil 3	0.04	0.03	0.02

Note: River 1 - Aquatic life killed 6 hrs (100 mg/l)
River 2 - 50% aquatic life killed 48 hrs (45 mg/l)
River 3 - 4 day median lethal toxicity rating (10 mg/l)
(Lake damage categories identical to those for River)
Soil 1 - Contaminated volume in coarse sand
Soil 2 - Contaminated volume in silty sand
Soil 3 - Contaminated volume in clay till

Table 4.17. Potential Damage Areas for Rail - Sulphuric Acid.

Release Type:	Instantaneous		
Level:	High (100%)	Medium (70%)	Low (50%)
Damages - 94.1 tonnes			
	Potential Damage Areas (km^2)		
River 1	130.70	64.10	32.70
River 2	645.20	316.50	161.70
River 3	13066.10	6408.20	3273.50
Lake 1	0.06	0.04	0.03
Lake 2	0.13	0.09	0.06
Lake 3	0.56	0.40	0.28
	Potential Damage Volumes (m^3)		
Soil 1	235264.00	164760.00	117757.00
Soil 2	235.26	164.76	117.76
Soil 3	0.24	0.16	0.12
Damages - 61.1 tonnes			
	Potential Damage Areas (km^2)		
River 1	55.10	27.00	13.80
River 2	272.00	133.50	68.20
River 3	5508.70	2703.10	1381.70
Lake 1	0.04	0.03	0.02
Lake 2	0.08	0.06	0.04
Lake 3	0.37	0.26	0.18
	Potential Damage Volumes (m^3)		
Soil 1	152759.00	107006.00	76504.80
Soil 2	152.76	107.01	76.50
Soil 3	0.15	0.11	0.08

Note: River 1 - Aquatic life killed 6 hrs (100 mg/l)
River 2 - 50% aquatic life killed 48 hrs (45 mg/l)
River 3 - 4 day median lethal toxicity rating (10 mg/l)
(Lake damage categories identical to those for River)
Soil 1 - Contaminated volume in coarse sand
Soil 2 - Contaminated volume in silty sand
Soil 3 - Contaminated volume in clay till

Table 4.18 Comparison of Potential Damage Areas.

Comparison - Potential Damage Areas / IRR Results

Source	Commodity	Damage Type	Amount Spilled	Damage Category	Damage Radius/Area	IRR Results Commodity	Damage Type	Amount Spilled	Damage Category	Damage Area
Jordaan et al. (1984)	chlorine	Vapour Cloud	38.2 tonnes	LD-50	88.1 km^2	chlorine	Vapour Cloud	55 tonnes	50% Fatality	21.9 km^2
			76.4 tonnes	LD-50	113.2 km^2			90 tonnes	"	41.1 km^2
		Potential Lethal Zone	1 or 2 rail cars		0.89 km^2			90 tonnes	1% Fatality	45.1 km^2
Wade (1986)	chlorine	Toxic Gas Release	full rail tank car	Lethal zone	2000 feet = 0.37 km^2	chlorine	Vapour Cloud	55 tonnes	50% Fatality	21.9 km^2
Env. Canada (1984)	chlorine	Vapour Cloud	20 tonnes	10*TLV (0.03 g/m^3)	171.6 km^2 (max dist)	chlorine	Vapour Cloud	16 tonnes	Injury 2 (0.012 g/m^3)	60.6 km^2
Concord (1987)	chlorine	Vapour Cloud	large rel. (rail)	50% lethality	1.5 km (range) = 2.25 km^2	chlorine	Vapour Cloud	55 tonnes	50% Fatality	21.9 km^2
Jordaan et al. (1984)	LPG	Potential Lethal Zone	1 or 2 rail cars		0.002 km^2	LPG	Fireball	63.5 tonnes	1% Fatality	0.41 km^2
Purdy et al. (1987)	LPG	BLEVE	20 tonnes	50% lethality	110 m range = 0.012 km^2	LPG	Fireball	18 tonnes	50% Fatality	0.07 km^2
				1% lethality	175 m range = 0.031 km^2				1% Fatality	0.13 km^2
			40 tonnes	50% lethality	160 m range = 0.026 km^2			63.5 tonnes	50% Fatality	0.23 km^2
				1% lethality	245 m range = 0.06 km^2				1% Fatality	0.41 km^2
		Flash Fire	20 tonnes	50% lethality	70 m range = 0.005 km^2		Pool Fire	18 tonnes	50% Fatality	0.005 km^2
				1% lethality	90 m range = 0.008 km^2				1% Fatality	0.01 km^2
			40 tonnes	50% lethality	80 m range = 0.006 km^2			63.5 tonnes	50% Fatality	0.019 km^2
				1% lethality	110 m range = 0.012 km^2				1% Fatality	0.034 km^2
Wade (1986)	LPG	Pool Fire	full rail tank car	Lethal zone	600 feet = 0.03 km^2	LPG	Pool Fire	63.5 tonnes	50% Fatality	0.019 km^2
		Vapour Fire	"	"	1180 feet = 0.13 km^2					
		Vapour Cloud Explosion	"	"	3600 feet = 1.2 km^2		Vapour Cloud Explosion	63.5 tonnes	50% Fatality	0.009 km^2
		BLEVE	"	"	590 feet = 0.032 km^2					
Clay et al. (1987)	LPG	Fireball		radius of fireball	R = 29m^0.33=0.006 km^2 (m= 18 tonnes)	LPG	Fireball	18 tonnes	50% Fatality	0.07 km^2
Concord (1987)	propane	Flash Fire	large rel. (rail)	50% lethality	100 m (approx) = 0.01 km^2					
	gasoline	Pool Fire	large rel. (rail)	50% lethality	100 m (approx) = 0.01 km^2	LPG	Pool Fire	63.5 tonnes	50% Fatality	0.019 km^2

3. The results of the damage propagation model for LPG are fairly consistent with those found in the literature, although there is some doubt in equating the damage areas for a BLEVE with a fireball, and a flash fire with a pool fire.

4. Damage areas for chlorine are in the middle of a wide range of results from the literature.

4.5 Expected Damages to People and Property

Expected damages are determined by considering the product of accident rates, spill probabilities and potential damage areas, and applying this product to the amount of people, property or environmental factors under consideration within a given damage range. For a transportation route or corridor, it is generally convenient to break the route down into a number of sections or links, each of which will have certain densities of population, property and environmental characteristics (i.e., rivers and/or lakes). The risk analysis model developed by the Institute for Risk Research applies accident rates, spill probabilities and damage areas to the links of a given corridor, with the result being expected damages to people, property and the environment. Chapter 5 presents an application of the model to a specific corridor for a number of dangerous goods. In this section, accident rates, spill probabilities, potential damage areas, and expected damages for road and rail transport are presented for representative dangerous goods for some typical route environments, and identical population densities, to allow a direct comparison to be made of the risks for road and rail.

Table 4.19 presents some typical transportation and link characteristics for road and rail. For this analysis it is assumed that population and property are distributed uniformly with distance from each spill site. However, where the population distribution in a given area is not uniform, it is possible to generate expected damage levels for selected distance bands from each spill site. Each band would have unique population and property densities, and hence similar expected impacts.

The characteristic links presented in Table 4.19 were chosen in order to present some comparable dangerous goods shipments for road and rail. Table 4.20 presents the risk components for these links. Loglinear models (Saccomanno, Shortreed and Van Aerde, 1988) were used to determine the basic accident rates for road and rail. An average accident rate of 0.15 per million vehicle movements was added to the calculated road accident rate, to represent non-link accidents (predominantly ramps and intersections; see Table 4.1 for the rates). Rail collision and crossing accident rates (Saccomanno, Shortreed and Van Aerde, 1988) were added to derailment rates, and the derailment accident rates were reduced by 20% to reflect the downward trends in rail accident rates. Spill probabilities were determined from fault trees (Saccomanno et al., 1986; Saccomanno, Shortreed, Van Aerde, 1988), and the potential damage areas were presented in Tables 4.12 to 4.15. The population densities were chosen to model urban and rural populations. The table includes only the travelled portion of the journey and not the rail or truck terminals.

In order to determine expected damages to people, the

Table 4.19. Some Typical Link Characteristics.

ROAD

1) Dangerous Good - Chlorine
Load - Loaded (27 tonnes)
Truck Type - D (Tractor-Trailer)
Route - Freeway, High Volume
Spill - Instantaneous High
Population Density - 1000/km^2

2) Dangerous Good - Chlorine
Load - Loaded (16 tonnes)
Truck Type - D (Tractor-Trailer)
Route - Non-Freeway, Low Volume
Spill - Instantaneous Low
Population Density - 100/km^2

3) Dangerous Good - LPG
Load - Loaded (18 tonnes)
Truck Type - D (Tractor-Trailer)
Route - Freeway, High Volume
Spill - Instantaneous High
Population Density - 1000/km^2

4) Dangerous Good - LPG
Load - Loaded (18 tonnes)
Truck Type - D (Tractor-Trailer)
Route - Non-Freeway, Low Volume
Spill - Instantaneous Low
Population Density - 100/km^2

Table 4.19. (continued)

RAIL

1) Dangerous Good - Chlorine
Load - Loaded (90 tonnes)
Route - Mainline, Central Region, Multiple Track, High Speed
Volume - Volume Class 4
Spill - Instantaneous High
Population Density - 1000/km^2

2) Dangerous Good - Chlorine
Load - Loaded (55 tonnes)
Route - Mainline, Central Region, Multiple Track, High Speed
Volume - Volume Class 3
Spill - Instantaneous Low
Population Density - 100/km^2

3) Dangerous Good - LPG
Load - Loaded (63.5 tonnes)
Route - Mainline, Central Region, Multiple Track, High Speed
Volume - Volume Class 4
Spill - Instantaneous High
Population Density - 1000/km^2

4) Dangerous Good - LPG
Load - Loaded (63.5 tonnes)
Route - Mainline, Central Region, Multiple Track, High Speed
Volume - Volume Class 3
Spill - Instantaneous Low
Population Density - 100/km^2

Table 4.20. Expected Damages for Spill.

Link #	DG	Amt in tonnes	Accident Rate /mil veh-km	Accident Rate /mil tonne-km	Spill Prob	Pot Damage Areas (km^2)	Pop Density (/km^2)	Shield Factor	Emerg Response Factor	Expected Damages - for Spill (c) Fatality 1 /mil veh-km	Fatality 1 /mil tonne-km	Injury 1 /mil veh-km	Injury 1 /mil tonne-km
Road													
1	chlorine	27	0.77	0.0285	0.004	8.7 (a)	1000	0.1	0.3	0.40194	0.01489		
						29.5 (b)						1.36290	0.05048
2	chlorine	16	0.65	0.0406	0.005	2.7 (a)	100	0.1	0.3	0.01316	0.00082		
						9.5 (b)						0.04631	0.00289
3	LPG	18	0.77	0.0428	0.0046	0.07 (a)	1000	0.1	0.6	0.00744	0.00041		
						0.1 (b)						0.01063	0.00059
4	LPG	18	0.65	0.0361	0.0074	0.05 (a)	100	0.1	0.6	0.00072	0.00004		
						0.07 (b)						0.00101	0.00006
Rail													
1	chlorine	90	0.48	0.0053	0.007	41.1 (a)	1000	0.1	0.3	2.07144	0.02302		
						135 (b)						6.80400	0.07560
2	chlorine	55	0.46	0.0084	0.01	12.4 (a)	100	0.1	0.3	0.08556	0.00156		
						41.7 (b)						0.28773	0.00523
3	LPG	63.5	0.48	0.0076	0.0002	0.23 (a)	1000	0.1	0.6	0.00066	0.00001		
						0.26 (b)						0.00075	0.00001
4	LPG	63.5	0.46	0.0072	0.0004	0.16 (a)	100	0.1	0.6	0.00009	0.000001		
						0.19 (b)						0.00010	0.000002

Notes: (a) is potential damage area for Fatality 1 (50% fatality)
(b) is potential damage area for Injury 1 (50% injury)
(c) Damages for spill type given in Table 4.19

effects of shielding (i.e., being inside a building), and of evacution or emergency response are important to consider. The actions of people during a spill of a dangerous good are often difficult to predict. One cannot always assume that evacuation will always take place (since people often tend to congregate around the scene of an accident), and evacuation may not necessarily be the best course of action. In the case of a chlorine vapour cloud, it may be safer to remain indoors until the cloud passes, rather than try to escape. The probability that people will be indoors during an accident (and will remain indoors) is taken to be 0.1 (Purdy et al., 1987). Emergency response and evacuation are assumed to contribute 70% reduction in damages in the case of chlorine, and 40% for LPG. These numbers are very preliminary estimates, and will be revised as more data become available.

The comparison of damages from spills alone for road and rail in Table 4.20 show that expected damages for rail accidents per vehicle-kilometer are on average 5 times higher than road accidents for chlorine, and 1/10th the road rate for LPG. When damages are considered per tonne of material shipped, rail is 1.5 times higher than road for chlorine, and 1/50th the rate for road shipments for LPG.

The attempt has been made to compare risk measures for similar dangerous goods shipment situations. The conditions in Table 4.19 were chosen to represent expected shipping conditions. The characteristics for road and rail were meant to be as similar as possible to allow an accurate comparison of the risks associated with each.

The damages given in Table 4.20 are for spills only. It is important to consider damages from the accident itself, which have been shown to be significant in the consideration of total risk (Saccomanno, Shortreed and Van Aerde, 1988). Fatalities due to the accident were previously estimated for road and rail (Saccomanno, Shortreed and Van Aerde, 1988). Table 4.21 presents these fatalities, along with expected fatalities from all spill types for some typical population densities. Accident rates, shielding factors and emergency response factors are taken from Table 4.20. Hazard areas for LPG assumed both pool fire and fireball incidents. These are combined to give total fatalities, assuming a frequency of occurrence of 0.6 for pool fires and 0.4 for fireballs (Purdy et al., 1987).

When expected fatalities for spills and for the accident are combined (and considered per tonne-kilometer), rail fatalities for chlorine are approximately 2 times higher than for road, while for LPG, road fatalities are 10 times higher for road than for rail.

In general, consideration of consequences due to the accident itself has significance when expected damages from the spill of a dangerous good are low. In the case of chlorine, potential damages are higher from the spill itself than from the accident, leaving rail slightly more hazardous than LPG. For LPG, fatalities due to the accident are higher than those expected from the spill, hence road has higher total consequences than rail.

Although these results are based on limited data, they do

Table 4.21. Total Expected Damages.

	Pop Density (/km^2)	Fatalities (given accident)	Fatalities from spill /mil veh-km	Fatalities from spill /mil tonne-km	Fatalities due to accident (a) /mil tonne-km	Total Fatalities (b) /mil tonne-km
CHLORINE						
Road (27 tonnes)	1000	1.28	0.99	0.036	0.0012	0.0372
	100	0.112	0.086	0.0032	0.0012	0.0044
Rail (90 tonnes)	1000	14.796	7.1	0.078	0.00015	0.07815
	100	1.48	0.71	0.0078	0.00015	0.00795
LPG						
Road (18 tonnes)	1000	0.02903	0.02235	0.00124	0.0012	0.00244
	100	0.00258	0.00199	0.00011	0.0012	0.00131
Rail (63.5 tonnes)	1000	0.00489	0.00235	0.00004	0.00015	0.00019
	100	0.00049	0.00024	0.000004	0.00015	0.000154

Notes: (a) Fatalities from accident (Saccomanno, Shortreed and Van Aerde, 1988)
(b) Total Fatalities = fatalities from spill + fatalities from accident

Average value of analysis but error is at least one order of magnitude illustrate the fact that both the material under consideration, and the accident itself, are important in the determination and comparison of risk.

4.6 Discussion

A number of risk measures have been developed for incidents involving representative dangerous goods. The relative risks of transporting dangerous goods by rail and truck depend essentially on the nature of the risk measure used as a basis of comparison. The conclusions regarding this comparison are:

1. Regardless of material shipped or transportation conditions, trucks reflect higher accident rates than rail. When rates are expressed on a per vehicle basis (truck or rail car), the accident rate for a single trailer configuration is typically 0.8 per vehicle kilometer, compared to a typical value of 0.5 per rail car kilometer. These accident rates are averaged over all track classes and road types. When the higher carrying capacity of a rail car is taken into consideration, the comparative accident rate between truck and rail becomes even more significant. For trucks (single trailer configurations) the accident rate is typically 0.03 accidents per tonne-kilometer compared to a value of 0.005 per tonne-kilometer for rail.

2. For most tanker systems, the probability of release in an accident situation is higher on rail than on trucks for most track and road environments. Among other factors, the release process in an accident situation is affected by the operating speed and size of the vehicle. Since rail bulk tankers tend to be larger than truck tankers carrying the same material, the likelihood of forces generated in an accident impinging on the tank to induce a loss of lading is higher for rail. Furthermore, the close proximity of rail tankers to other rail cars increases the likelihood that in an accident, puncture loads will be developed that induce releases.

3. Potential damage areas for chlorine, LPG's and sulphuric acid spills are a function of spill rates, spill volumes and weather conditions. As such, for the same volume of material involved in each accident, the hazard areas associated with truck and rail incidents do not differ. However, since rail bulk tankers carry more material than truck tankers, the hazard areas associated with rail accidents are higher than for trucks. There is considerable variation in the prediction of damage areas and these values should be used with extreme caution.

4. For a given location, the expected damages to population and property is a function of the hazard area associated with a given spill, the probability of release in an accident situation, and the accident rate. To the extent that trucks reflect higher accident rates than rail, the expected impacts of dangerous goods for rail incidents as compared to trucks are significantly lower than would be suggested by the more extensive hazard areas associated with rail incidents. Considering the same volume of material in transit over

a similar distance, the expected damages of truck incidents involving dangerous goods are similar to those estimated for rail. For LPG incidents occurring at a site with a uniform population density of 1000 persons per square kilometer, the expected fatalities from all causes for trucks is typically 0.0024 per million tonne-kilometer shipment compared to a value of 0.00019 for rail for approximately similar levels of exposure. For chlorine, the respective values are 0.04 for road and 0.08 for rail. Consideration of expected damages in terms of fatalities from the spill and from the accident itself is important, especially if damages from the spill are low.

The results of this study suggest that the treatment of risk under different measures can lead to widely different conclusions regarding the relative risks of transporting dangerous commodities by truck and rail. The situation is rendered more complex by the need to consider the nature of the transportation environment under which shipments of different materials take place. To suggest that one mode is "riskier" than another for one set of conditions, adopting a single measure for risk, is inappropriate. The result is policies directed at improving safety on each mode that could be ineffective under most conditions in which these shipments take place.