6. RISK ANALYSIS METHODOLOGY

6.1 Framework of Risk Analysis Model

The risk analysis model was developed to perform a quantitative analysis of the risks associated with the transport of a dangerous good. The model consists of a shell program that acts as an administrator and organizer. It interacts with the user, and based on the responses and input data, calls on the task submodels to carry out the analysis. These task submodels are:

i. derivation of release frequencies given an accident
ii. derivation of release consequences
iii. calculation of link implications given accident rates, population exposed, etc.
iv. calculation of network implications given flows
v. summary of analysis.

The model structure permits considerable flexibility as users may carry out only certain parts of the analysis. The interrelationship of the submodels is described briefly below.

The release frequencies and release consequences consist of a series of generic tables. The values in these tables are determined by assuming an accident has occurred involving a vehicle carrying a specific commodity, and using the component modules of the risk analysis model to determine fault probabilities, release probabilities, damage areas, and risk and operating costs. These tables are then applied to specific links on the road and rail networks, to get a measure of the risks along each link. The risks are given for each link in terms of fatalities, injuries, property damage, lake, river and soil damage, other damages (such as evacuation costs), and operating costs. Multiplying these risks by the accident rate determined for each link, and summing over all the links in the corridor gives a measure of the total risk of routing a shipment of a representative dangerous good along the corridor. The representative commodity chosen for this study is liquefied petroleum gas (LPG).

The data used in the risk analysis come from a number of sources. There is a lack of data in some areas, so that some extrapolation and estimation of numbers is necessary at this time. Where estimates have been used, they have been clearly identified, and the rationale behind the choice of these numbers is given. Additional work to give better estimates on these numbers is outside the scope of this report, but it is a possible area for future investigation.

6.2 Generic Tables of Release Likelihoods and Rates

a. Fault Rates

The probabilities of different fault types given an accident or non-accident occurrence were found using fault trees (Saccomanno et al., 1986). These fault trees model a head event by combining a number of basic events with known probabilities, each of which contributes to the head event failure. The following head events are modelled: shell release non-accident, shell release accident with fire, shell release accident, no-fire, valve release non-accident, valve release accident with fire, and valve release accident, no-fire.

The fault trees are based on those developed by Pacific Northwest Laboratories (PNL) for LPG (Geffen et al., 1980). The basic event probabilities used for the transport of LPG by rail were extracted from the PNL studies and adjusted as required to represent changes in Canadian regulations resulting from the Grange Commission recommendations (Grange, 1980). The PNL studies are based on a 105A500W rail tank car that has a test pressure of 500 psi. The double shelf coupler now required in Canadian regulations was not included in the PNL analysis, therefore the probability of a puncture probe being produced has been reduced by 93%, the reduction recorded by the Railway Progress Institute (1985). Average trip lengths of 450 km for rail, and 210 km for road have been used to give fault probabilities per car-km.

The fault trees give fault probabilities for a composite accident at an average speed. For derailments, the study by A.D. Little and Associates (1985) gives the probability of release vs. the speed at derailment (see Figure 6.1). The fault probability determined by the fault tree was assumed to be for an accident at an average speed; Figure 6.1 was used to extrapolate this value to high and low speed numbers. In addition, a study on rail accident rates (Rose, 1984) stated that, out of 437 train derailments from 1973 to 1981, there were 73 releases, and 17 fires for a 23% rate of release involving fires. Using these correction factors, the derailment fault probabilities for LPG were determined. These very crude assumptions must be evaluated as more data on incidents becomes available.

In order to determine the collision fault probabilities, it would be necessary to review the data on collision accidents involving dangerous goods releases, and perform a statistical analysis of accidents occurring on mainline and yard. The data required for this were not available for this study, so the collision values were assumed to be identical to those for derailment (it should be noted that there are significantly fewer collisions than derailments). The fault probabilities for other accidents (crossing accidents) were assumed to be lower than those for derailments and collisions, but again there is very little data available to establish accurate values. In any case, crossing accidents involve only 5% of the dangerous goods related accidents.

The fault analysis table for LPG is given in Table 6.1. Note that data for empty containers are not yet available, so that no risks are estimated for unloaded vehicles. Subsequent research work indicates a higher incidence of fires in truck releases than

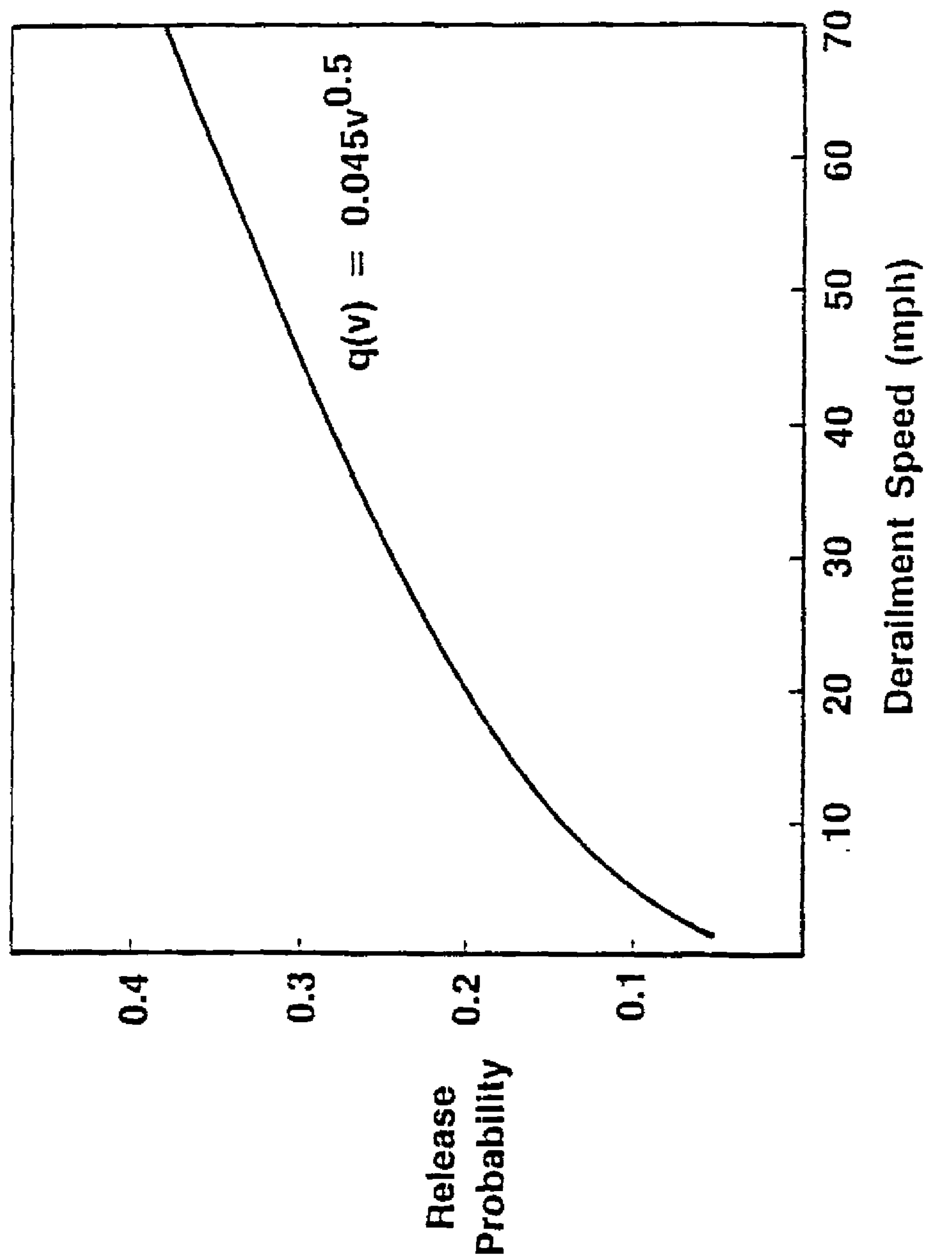

Figure 6.1 Release Probability vs. Speed at Derailment.

(A.D. Little and Associates, 1985)

TABLE 6.1

PROBABILITY OF RELEASE GIVEN AN ACCIDENT FOR LPG

	Rail Accident:	Derailment		Collision		Other		Non-accident	
		low	high	low	high	low	high	low	high
								(Prob. per car-km)	
RAIL	loaded shell fire	0.0050	0.0090	0.0050	0.0090	0.0009	0.0020	0.0000	0.0000
	loaded shell nofire	0.0160	0.0280	0.0160	0.0280	0.0030	0.0060	1.803E-05	1.803E-05
	loaded valve fire	0.0005	0.0009	0.0005	0.0009	0.0005	0.0009	0.0000	0.0000
	loaded valve nofire	0.0016	0.0028	0.0016	0.0028	0.0015	0.0030	9.058E-05	9.058E-05

	Road Accident:	Off-road		Collision		Fixed-object		Non-accident	
		low	high	low	high	low	high	low	high
								(Prob. per truck-km)	
ROAD	loaded shell fire	0.0025	0.0045	0.0025	0.0045	0.0005	0.0010	0.0000	0.0000
	loaded shell nofire	0.0080	0.0140	0.0080	0.0140	0.0015	0.0030	1.803E-05	1.803E-05
	loaded valve fire	0.0005	0.0009	0.0005	0.0009	0.0005	0.0009	0.0000	0.0000
	loaded valve nofire	0.0016	0.0028	0.0016	0.0028	0.0015	0.0030	9.058E-05	9.058E-05

that given in Table 6.1.

b. Release Rates

Release sizes have been divided into 6 categories: low, medium and high instantaneous releases, and low, medium and high continuous releases. The size of the release expressed as a volume or rate associated with these categories are defined by the physical properties of each commodity and the containers used in shipping the commodity. Table 6.2 gives a description of the release categories for LPG. Instantaneous releases are expressed as a volume of the container spilled in 10 minutes, and continuous rates are expressed in kilograms per second.

In order to determine the probabilities of release for LPG, the road and rail accident data base involving dangerous goods spills from January 1986 to August 1987 (Transport Canada, 1987) was examined. All Class 2 (compressed gases) accidents on rail, rail terminal, road, and road terminal were examined (Class 2 includes LPG - Class 21). There were a total of 38 observations from the CANUTEC data; 6 were rail accidents and 32 were road accidents. These accidents were grouped according to release size (given as a percentage spilled of total load), and release type. A spill was assumed to be an instantaneous release, and a leak as a continuous release, and all valve incidents were assumed to be continuous releases. The accident cause was expressed as shell release with fire, shell release (no fire), valve release with fire, and valve release (no fire). Some accident causes given in CANUTEC were not used in the analysis since they could not be identified as either a shell or a valve failure (i.e., overturn). Each accident used was put into the appropriate category of release type and level, and then expressed as a probability of occurrence.

Some accident categories did not have any observations; there were no fire releases for rail and only one for road. Most categories did not have a large number of observations. Because of this lack of data, the release probabilities for LPG were adjusted from the CANUTEC data. These probabilities may be altered in the future as additional data become available, and when more research into accident causes, fault trees, event trees, etc., is performed. Table 6.3 gives the release probabilities used for LPG, along with the CANUTEC data for comparison purposes.

6.3 Generic Tables of Damage Areas and Consequences

a. Damage Areas

The damage areas are determined using the damage propagation model for LPG developed by Van Aerde et al. (1986). This model is based on Roberts (1982), the CRC Handbook (1976), Rose (1984), Clancey (1982), and Mizner and Eyre (1982). The classes of possible damage are: fatality, injury, property damage, lake damage, river damage, soil damage, and other (this category can be used to represent evacuation area). Table 6.4 gives the damage categories for LPG from the damage propagation model; these are based on predetermined concentrations at which harm to people, property, or the environment will occur. Given the release types and levels of Table 6.2, where the loaded rail tank

TABLE 6.2

RELEASE SIZES FOR LPG

INSTANTANEOUS (% of volume)			CONTINUOUS (kg/s)		
High	Medium	Low	High	Medium	Low
90-100%	70-90%	<70%	53	25.3	1.1

Instantaneous

High (90-100%)

All instantaneous releases occur after a catastrophic failure of the container. This scenario involves fire present and safety relief valves inoperable. The liquid temperature reaches 68° C, according to Geffen et al. (1980), and the container explodes. Flash vaporization involves 61% of the tank contents, and including liquid entrainment, the entire volume of the container contributes to instantaneous vapour formation.

Medium (70-90%)

This scenario involves fire with safety relief valves operating. Up to 30% of the tank contents will be vented before fire induced tank failure. With a liquid temperature of 60° C, the flashing fraction is 56%. Including the liquid entrained, all of the tank's contents are released. Considering that up to 30% of the tank's contents have been vented, the range of release is 70 to 90%.

Low (<70%)

This involves catastrophic failure with no heating. At 20° C, the amount of the tank's contents that contribute to instantaneous vapour formation is 68%; at 0° C this amount is 46%.

Continuous

High (53 kg.s)

This involves a liquid release from a safety relief valve (7.6 cm opening) in a fire (Geffen et al., 1980).

Medium (25.3 kg/s)

This represents a vapour release from a safety relief valve in a fire.

Low (1.1 kg/s)

This rate involves a release from a 2.5 cm opening, representing a leak from a crack in the container's welds.

TABLE 6.3

RELEASE PROBABILITIES FOR LPG

	Release type:	instantaneous			continuous		
	Release level:	high	medium	low	high	medium	low
RAIL	loaded shell fire	0.200	0.500	0.300	0.000	0.000	0.000
	loaded shell nofire	0.200	0.300	0.400	0.100	0.000	0.000
	loaded valve fire	0.000	0.000	0.000	0.200	0.400	0.400
	loaded valve nofire	0.000	0.000	0.000	0.300	0.300	0.400
ROAD	loaded shell fire	0.200	0.300	0.400	0.000	0.000	0.000
	loaded shell nofire	0.200	0.200	0.300	0.100	0.100	0.100
	loaded valve fire	0.000	0.000	0.000	0.300	0.400	0.300
	loaded valve nofire	0.000	0.000	0.000	0.300	0.300	0.400

Incidents for CANUTEC Data (Source: Transport Canada, 1987)

	Release type:	instantaneous			continuous		
	Release level:	high	medium	low	high	medium	low
RAIL	loaded shell fire	0	0	0	0	0	0
	loaded shell nofire	0	0	1	0	0	0
	loaded valve fire	0	0	0	0	0	0
	loaded valve nofire	0	0	0	1	0	4
ROAD	loaded shell fire	0	0	1	0	0	0
	loaded shell nofire	1	0	3	1	0	5
	loaded valve fire	0	0	0	0	0	0
	loaded valve nofire	0	0	0	2	1	5

TABLE 6.4

DAMAGE CATEGORIES FOR LPG

Fatality	1	50% mortality
	2	1% mortality
Injury	1	Ignition of cellulose (severe)
	2	Blistering of bare skin (moderate)
Property	1	Slight <10%
	2	>10%
	3	>50%
	4	>90%
River	1	-
	2	-

Lake - same as river

Soil	-
Other	-

car is 63.5 (metric) tonnes for LPG shipments, and the full load of a truck tanker is 18.1 tonnes, the area (square kilometers) of hazard is determined by the propagation model. Table 6.5 gives the resultant damage areas.

b. Risk and Operating Costs

In order to calculate risk and operating costs, a dollar cost is assigned to each damage type and level. The costs for fatality, injury, and property damage have been developed by Needleman (1986), and are given in Table 6.6 in mid-1987 dollars. The cost of a fatality is based on health and legal costs, lost output, and a valuation of the reduction in risk, both by those at risk and by their relatives. Injury costs are for mild, moderate and severe injuries. These are based on degree of disability, degree of distress, and length of time the disability - distress state persists. Property damage (for residential, industrial, commercial and institutional properties) is based on an average construction cost, estimated value of contents, value of physical assets other than buildings, and output of establishments using the property. Note that these are written down values and not replacement values.

Clean-up costs for environmental damage depend on the type and amount of material spilled, and the environment where the spill occurs. An average clean-up cost of $10 U.S. per pound of spilled material has been suggested by Amson (1982), but no estimate of the cost of environmental damage per pound of spilled material has yet been made.

TABLE 6.5

DAMAGE AREAS FOR LPG

	Release type:		instantaneous		
	Release level:		high	medium	low
			(damage areas in km^2)		
RAIL	fatality	50% mortality	0.190	0.160	0.120
	fatality	1% mortality	0.340	0.280	0.210
	injury	severe	0.220	0.190	0.150
	injury	moderate	1.130	0.920	0.710
	property	>90%	0.009	0.009	0.007
	property	>50%	0.050	0.047	0.039
	property	>10%	0.083	0.077	0.065
	property	<10%	0.408	0.380	0.321
ROAD	fatality	50% mortality	0.080	0.060	0.050
	fatality	1% mortality	0.140	0.110	0.090
	injury	severe	0.100	0.080	0.070
	injury	moderate	0.460	0.370	0.290
	property	>90%	0.004	0.004	0.003
	property	>50%	0.022	0.020	0.017
	property	>10%	0.036	0.033	0.028
	property	<10%	0.176	0.164	0.139

TABLE 6.6

RISK AND OPERATING COSTS (1987 CDN DOLLARS)

Cost Type	Damage Category	Unit Cost
fatality		$ 702,960.00/death
injury	1 (severe)	50,002.00/injury
injury	2 (moderate)	4,754.00/injury
injury	3 (mild)	987.00/injury
property	residential	57.21/sq. ft.
property	industrial	41.76/sq. ft.
property	commercial	88.81/sq. ft.
property	institutional	104.82/sq. ft.