7. CONCLUSIONS, RECOMMENDATIONS AND POLICY IMPLICATIONS

7.1 Introduction

This study was one of a series of studies that have defined, calibrated and applied a risk analysis model for the transportation of dangerous goods in Canada. The application has been to address the relative safety and risk implications of moving specific dangerous goods by road or by rail.

Risk has been defined as the estimated total fatalities from the movement of a million tonnes of dangerous goods from a specific origin to a specific destination; the example used is the movement of LPG and chlorine from Sarnia to Toronto. Fatalities include those associated with a release of the dangerous goods as well as those resulting from the accident.

A number of areas where improvements could be made were identified in the risk analysis model. This study consisted of a number of individual studies on these areas. The findings of this study have in turn resulted in a number of conclusions and recommendations for the improvement of the risk analysis model which are listed below. In addition, the policy implications of the conclusions and recommendations are discussed.

7.2 Conclusions, Recommendations and Policy Implications

7.2.1 Conclusions

There is one overriding conclusion or comment which must be made. It is noted that the risks due to dangerous goods are generally lower than the risks associated with the accident itself. This suggests that the risks involved with the actual movement of dangerous goods are small, and it appears that the attention these risks are currently receiving is not warranted. The resources being invested could save more lives in other applications.

1. The probability of a rail car being involved in an accident was found to be related to the cause of the accident, the speed of the train and the position of the car in the train. For example, for derailments caused by roadbed defects or wheel and axel defects, the end of train marshalling was found to be safest. Methods have been developed to predict the expected point of derailment and the number of cars involved in the derailment.

2. Truck accidents were found to depend not only on the environmental situation (i.e., type of roadway, age of driver, age of truck, etc.) but also on the manoeuvre. Slowing and stopping manouevres were found to have the highest involvement in accidents. In addition, truck accidents on ramps and intersections were modelled and were found to depend on the type of ramp, the type of truck, the volume of traffic, the intersection alignment, and the truck load. It was found that, for comparable situations, a fully loaded "double" trailer has a higher accident rate per tonne-kilometer than a "single" trailer truck. Freeways were found to be safer than other roadway types.

3. The comparison of risk between road and rail for the movement of dangerous goods indicates that rail is safer for some types of dangerous goods. The main reason for this is higher truck accident rates per tonne-kilometer, and higher accident-associated fatalities. For example, for LPG, rail risk was only about 23% of road risk. For chlorine, the risk estimate for rail was higher than for road (about 70% higher).

4. Risk for rail and road movements depends on the commodity being shipped, the route, the environment, and vehicle and driver characteristics. The selection of the measures of risk will affect the comparison. For example, using accident rates, rail is safer; using a possible worst case comparison, road is safer; using a total risk approach, rail is generally safer, etc.

5. The detailed method for estimating persons exposed to dangerous goods incidents for the Toronto-Sarnia corridor provided different results than more general methods using the census data. For road routes, population estimates were 40% and 140% higher for the freeway and non-freeway routes, respectively. For the rail route, the detailed and census estimates were comparable. Thus, the use of general census-based estimates biased the comparison between modes.

6. No difference was found in public perceptions, as measured by newspaper reports, of road and rail incidents involving dangerous goods. When the severity of the incident and the characteristics of the dangerous goods were controlled, the number of articles per incident and the length of articles were the same for road and rail. For non-incident articles discussing policy and regulatory issues, more articles were found on rail than on truck even though there are many more truck incidents. This suggests that the public has a higher perception of rail "issues" than road "issues".

7. The newspaper articles identified a high proportion of incidents that were apparently not reported as required by law. It is not known if this biased any modal comparisons.

7.2.2 Recommendations

1. The interrelationship between causes of accidents and the probability of a release should be studied. The study could investigate the trends in causes of accidents and review the potential improvement in safety that would result from changes in the marshalling requirements for dangerous goods.

2. Because of the large number of fatalities involved in truck accidents (estimated at 400 deaths per year in Canada), it is recommended that further studies be done on the causes of truck accidents in Canada. Data for provinces other than Ontario should be used, and the study should focus on classifying accident causes, so the causes could be linked to policies for driver training as well as routing of dangerous goods movements.

3. More work needs to be done to refine the risk analysis model. Examination of damage areas in the literature

indicated a wide variation in predicted areas for comparable events; additional research is required in this area. The federal data bank on spills is increasing every year, and is becoming a valuable resource for verification of the risk analysis model. Ongoing study of existing data will provide more definitive estimates of the spill probabilities in accidents, and the quantity of material released.

4. A study of the impact of "extra care" given to dangerous goods handling and transport by shippers and producers is recommended to determine how much risk estimates based on average transportation conditions are reduced. "Extra care" may reduce the estimated risk, and could impact policy decisions based on the relative importance of the risk in society.

5. The risk analysis model should be applied to the issue of routing in urban areas. The model can represent in detail the characteristics of urban routes and their impact on risk. In addition, the best truck route could be compared to the best rail route. The potential reduction in risk estimated by this study could form a basis for the evaluation of routing policies.

6. If routing policies are to be implemented, then the risk analysis model must be simplified and placed in a form that is much easier to use without losing its accuracy and its comprehensive characteristics. The development of a "handbook" approach, aimed at the municipal level, is suggested, since municipalities would likely implement routing requirements.

7. If a handbook is developed for the assessment of risk on a transport route, then the detailed method of estimating potentially exposed population should be used.

8. The number and characteristics of dangerous goods incidents that are not reported to government data banks should be investigated so that the interpretation of these data banks can be clarified.

7.2.3 Policy Implications

Current marshalling regulations have not been developed from detailed statistical analysis of the rail derailment data. Furthermore, improvements in track quality and the resulting shifts in the causes of accidents will impact the optimal choice of a marshalling strategy. There are still some further analyses required on the causes of accidents and the types of faults and releases that result from a particular cause of an accident before new policies can be formulated. The safety effectiveness of any marshalling regulations relative to random marshalling is also a question for further research.

A number of policies on the training and licencing of truck drivers are suggested by the study findings. For example, special licences for the movement of dangerous goods could be limited to experienced drivers, and the qualification process could stress the behaviours expected for minimizing accidents due to slowing and stopping manouevres and other high frequency accident-related manoeuvres.

There is an ongoing debate on the routing of dangerous goods to minimize risk, and on the selection of shipment modes to minimize the risks of dangerous goods movements. The work to date provides some interim guidance on these policy issues in regards to route and mode choice. Some components of the risk analysis model require further calibration to improve their accuracy and to make the comparisons less ambiguous. However, the estimates of risk are adequate for making policy decisions based on the magnitude of the risks involved, and the importance that should be attached to these risks in comparison to other risks in society.

The use of detailed "house count" methods of estimating potential damage areas appears to be more accurate and would likely be more understandable and acceptable to persons reviewing the results of the risk analysis. The use of separate estimates of residential and employment populations will also assist in the evaluation of policies related to the time of day a dangerous goods movement might take place.

The use of computer-based newspaper files was found to be an effective and efficient method of determining public perception of dangerous goods incidents, as well as identifying the more serious occurrences. Even for small numbers of incidents, the consistency of the relationship between the severity of the incident and the length and frequency of newspaper articles was surprisingly good. This appears to be an important area for those charged with the development of policy. For example, the relative importance of transport risks could be studied using this approach.

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APPENDIX A: REVIEW OF PREDICTED RISKS

INTRODUCTION

A number of issues were raised by reviewers of this study and the previous study in this series. These issues were related to the predicted risks for the movement of dangerous goods by rail and the comparison of these risks to the actual experience in North America. Table A.1 gives the occurrence of incidents involving the release of chlorine for all of North America for a sixteen year period (Comiskey, 1988). In this period there were 16 incidents and these in turn led to one accident with 8 fatalities. On the other hand, the risk analysis in this report predicts an expected value of fatalities that is many times higher than the observed values. The purpose of this appendix is to address this issue.

The approach taken in the review was:

1. To obtain data from other researchers and compare our predictions of risk with their predictions.

2. To obtain data on actual realizations of risks from the transportation of dangerous goods, in the form of FN curves, and to compare these results with predictions from the IRR model results.

3. To review the structure and probabilities used in the fault tree and release models since these models are based on existing models in the literature and were not further developed in the project.

4. To examine the use of expected value as a measure of risk for low probability events and to see what effect this use of expected value might have on interpreting the risk for policy purposes.

RISK PREDICTIONS FOR THE MOVEMENT OF DANGEROUS GOODS

This study examined the movement of chlorine and LPG from Sarnia to Toronto, a route which was thought to be typical of dangerous goods movements in Canada with a mixture of urban and rural densities along a 280 kilometer corridor. The risk was expressed in terms of the probability of accidents and fatalities per tonne-kilometer of goods moved. In order to compare this to other results in the literature, it was necessary to revise the predicted results and express them in the form of an FN curve. An FN curve is a plot of the frequency (F) (of N or greater fatalities) versus the number of fatalities (N). For example, Figure A.1 shows the results of the Sarnia to Toronto movements for chlorine, by truck and rail. The vertical axis gives the frequency of observing an incident with N or more fatalities for the movement of 180 million tonne-kilometers on the Sarnia-Toronto corridor (approximately representative of the annual volume of rail movement of chlorine in Canada). The size of the accident or the number of fatalities (N) is plotted on the x axis and represents a particular accident with N fatalities. The frequency represents the occurrence of an event of size N or larger.

Table A.1 Summary of Accident Data for Chlorine Cars with Lading Loss.

TABLE I - Summary Of Accident Data For Chlorine Cars With Lading Loss

(Data Covers Period 1965 thru 1980 and taken from RPI/AAR Tank Car Safety Project Files)

Date	10-10-65	10-10-65	8-27-66	11-18-67	12-11-71	3-18-72	3-1-73
Location	Helena, GA	Helena, GA	Winslow, IN	Waterford, AL	Corbin, LA	Hammond, PA	Loos, BC
Car Number	ACFX 19016	ACFX 19017	DAX 431	NCPX 1127	UTLX 28101	ACDX 60715	UTLX 82198
Test Pressure	500	500	500	500	500	500	500
Cap'y. in Tons	55	55	30	55	90	55	90
Mat'l. Spec.	A-212-B	A-212-B	A-285-C	TC-128-B	TC-128-B	A-212-B	TC-128-B
Shell Thk.	.875"	.875"	.937"	.753"	.779"	.875"	.779"
Head Thk.	.875"	.875"	.937"	.753"	.812"	.875"	.812"
Insulation	4" Urethane	4" Urethane	4" Cork	4" Urethane	4" Urethane	4" Cork	4" Urethane
Train Speed, Cars in Train and Derailed	35 mph 82 car train 14 cars derailed	35 mph 82 car train 14 cars derailed	44 mph 153 car train 27 cars derailed	30 mph 110 car train 51 cars derailed	33 mph 118 car train 17 cars derailed	32 mph 42 car train 17 cars derailed	40 mph 36 car train 24 cars derailed
Car Movement and Position After Derailment	Car rolled-jacket damaged	Car rolled-jacket damaged	Car went down 12 ft. incline-manway tilted 20°	Car rolled down incline-landed upside down on flat car loaded with wallboard	Car came to rest on "SL" side	Car rolled and slid several hundred ft. - manway tilted 45°	Car went down 40 ft. incline-came to rest - overturned 110°.
Magnitude and Location of Tank or Fittings Damage	Fittings- (Since tank shell and heads not damaged)	Fittings- (Since tank shell and heads not damaged)	Safety and angle valves damaged	18" hole in shell and 6" hole in head. Safety valve discharge and fittings damaged by heat	1-1/2" x 1/2" slit in head-12" above sill	Bonnet cover torn off, valve handles off and safety valve stem bent	3-1/2" x 6" hole at bottom of head extending into shell
Possible Cause of Damage	Mechanical Impact	Mechanical Impact	Mechanical Impact	Car exposed to fire for 30 hours	Coupler	Mechanical Impact	Coupler
Amount of Lading Loss and Corrective Action	Very slight leak	Very slight leak	Slight leak stopped by tightening nuts and applying repair kit	55 Tons. No corrective action necessary. All chlorine dissipated	18 Tons - remainder transferred	3 Gal. - leak stopped by tightening bolts at 4 angle valves and manway cover	17 Tons - plug stopped leak-remainder transferred
People Evacuated	Unknown	Unknown	Unknown	3,400 people evacuated	300 people evacuated	3 families evacuated	None
Injuries and Deaths	None	None	None	None	None	None	One person gassed - no deaths

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Table A.1 (continued)

TABLE I - Continued

Date	1-14-74	1-14-74	7-20-74	12-10-77	2-26-78	4-8-79	11-10-79
Location	White Haven, PA	White Haven, PA	Thelma, GA	Hamilton, MS	Youngstown, FL	Crestview, FL	Mississauga, ON
Car Number	ACFX 5965	ACFX 19122	ALLX 11	GATX 50344	GATX 50347	UTLX 28727	CGTX 90003
Test Pressure	300	500	500	500	500	500	500
Cap'y. in Tons	55	55	30	90	90	90	90
Mat'l. Spec.	A-285-C	TC-128-B	ASTM 89-33	TC-128-B	TC-128-B	TC-128-B	TC-128-B
Shell Thk.	1.125"	.752"	1" Plus	.787"	.787"	.779"	.787"
Head Thk.	1.125"	.752"	1" Plus	.812"	.812"	.812"	.812"
Insulation	4" Cork	4" Cork	4" Cork	4" Urethane	4" Urethane	4" Urethane	4" Urethane
Train Speed, Cars in Train and Derailed	20 mph 67 car train 11 cars derailed	20 mph 67 car train 11 cars derailed	Unknown (Derailment at crossing)	50 mph 133 car train 7 cars derailed	40 mph 139 car train 44 cars derailed	30 mph 116 car train 28 cars derailed	35 mph 106 car train 24 cars derailed
Car Movement and Position After Derailment	Car went down 60 ft. incline with 75% of manway in snow and ground	Car went down 60 ft. incline with manway tilted 45°	Car rolled ending up on its side	Car overturned with several holes in jacket	Car landed on its side adjacent to track	Car came to rest up-right, across and normal to track	Car came to rest up-right across and approx. normal to track
Magnitude and Location of Tank or Fittings Damage	Bonnet cover torn off, valve stems bent and handles off	Packing gland nut loose	Dome cover stove-in cocking vapor valve	Liquid and vapor valves loose	3/4" sq. ft. irregular shaped puncture near bottom/ center of tank shell	Size of puncture on "BL" side of shell is unknown	2-1/2 ft. hole on top of shell near head
Possible Cause of Damage	Mechanical Impact	Mechanical Impact	Mechanical Impact	Mechanical Impact	Mechanical Impact	Type "F" Coupler	Mechanical and/or heat-ferric chloride re-action
Amount of Lading Loss and Corrective Action	Slight leaks - stopped by tightening nuts and applying safety caps	Slight leak - stopped by tightening packing gland nut	1000 Gal. - leak stopped by tightening nuts on valve	Slight leaks-stopped by tightening liquid valve plugs and nuts on vapor valve	90 Tons - foam used to neutralize gas	45 Tons - remainder neutralized and burned	leaked at rate of 15kg/hr. for 4 days before tear plugged
People Evacuated	Evacuated homes within 1/2 mile radius	Evacuated homes within 1/2 mile radius	Several families	None	2,500 people evacuated	4,500 people evacuated	240,000 people evacuated
Injuries and Deaths	15 injured - no deaths	15 injured - no deaths	None	None	138 injured - 8 deaths	1 injured - no deaths	None

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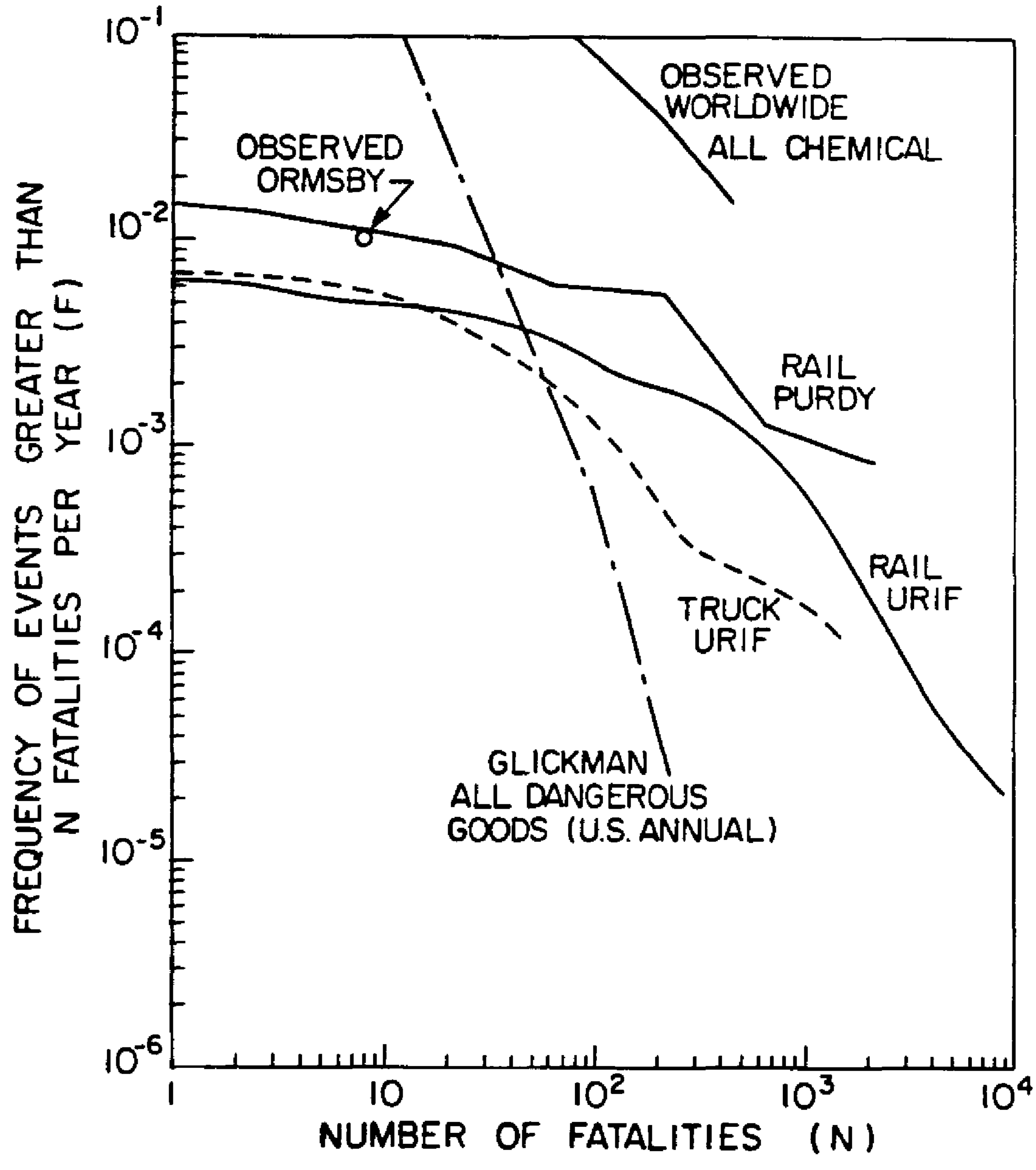
Figure A.1 Predicted and Observed Risks of Transporting 180 Million Tonne-km of Chlorine in a Typical Corridor (average density, 660 persons per square kilometer).



It should be noted that the FN curve can generally be shifted vertically to reflect changes in the volume of product shipped or expanded horizontally to reflect the population density and the possible magnitude of damages in an accident. The data in Figure A.1 were developed from the study results for per car kilometer estimates and are compatible with the results given in the study and the Transportation Research Board (TRB) paper noting that the average population density in Figure A.1 is 660 persons per square kilometer which is the actual average density along the route for the rail mode. In this appendix the FN curves have, where possible, been shifted or expanded to a common basis for both the volume moved and the overall population density before comparisons are made.

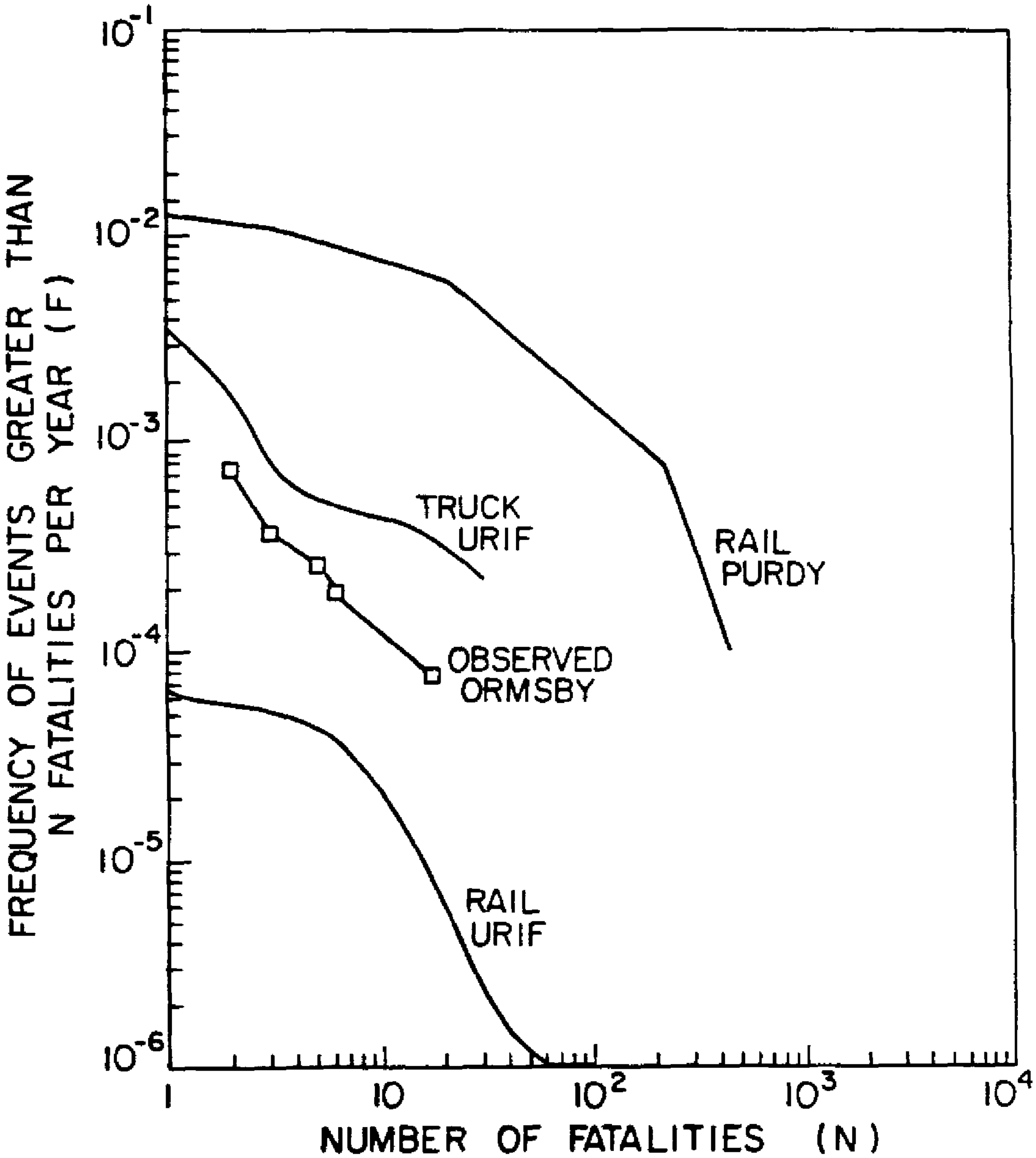
The FN curve was constructed by keeping track of each predicted accident, for each type of accident, each quantity of release, each type of damage area within the risk model and for each level of population density within the damage area along the route. The data are representative of the journey from Sarnia to Toronto.

The number of fatalities in an accident would depend on where a potential accident occurred. If the accident occurred in a rural area with a low population density then even in the worst case there would be few fatalities predicted. On the other hand, if the potential accident were in an urban area then even a small release could have high consequences. Variation in population densities along the route is one of the main causes of variation in the number of fatalities in an accident.

The chlorine curve in Figure A.1 is downward sloping to the right due to the N or greater nature of the x axis. The intercept for an accident involving one or more fatalities is 0.07 or about an accident every 15 years on average, given that the volume is approximately representative of the volume of chlorine shipped (e.g., 10,000 carloads each travelling about 250 kilometers or 180 million tonne-kilometers).

Figure A.2 shows the results of the movement of 180 million tonne-kilometers of LPG by truck or rail on the Sarnia-Toronto corridor (for comparison with the chlorine results). This volume, which is only a fraction of the annual movement of LPG, is approximately equivalent to the movement of LPG in Ontario on an annual basis. The probability of an accident involving one or more fatalities is .001, for the rail mode. The smaller expected risk value for LPG reflects the much lower "maximum possible event" on the route of 95 fatalities for LPG as compared to 8,000 fatalities for chlorine. The FN curve for LPG also has a steeper slope than for chlorine, again reflecting the lower level of events with potentially higher fatalities.

Figure A.2 Predicted and Observed Risks of Transporting 180 Million Tonne-km of LPG in a Typical Corridor (average density, 660 persons per square kilometer).



Data were available from the Health and Safety Executive in the United Kingdom (U.K.) for a complete risk analysis of a similar corridor which included a mix of rural and urban population densities (Purdy, 1988). These data were modified to reflect Canadian versus U.K. conditions. For example, for the rail chlorine shipment: higher tank car capacity, 90 tonnes versus 29 tonnes; the different length of the corridor, 274 kilometers versus 101; and the average population density, 660 persons per kilometer square versus 300. Figure A.1 presents the comparison between the U.K. predictions and those made by the IRR risk model. It should be noted that complete information was not available on the U.K. predictions.

The comparisons in Figure A.1 do not reflect differences between types of accidents, characteristics of rail cars and other major differences between the two countries. However, the comparisons do indicate a very close correspondence in the shapes of the estimated FN curves. The vertical position of the curves for chlorine is close, with the U.K. estimates of risk being higher. " Close" in risk estimation terms is used to describe a difference of a half an order of magnitude. In non-risk analysis this would not be considered close; however, risk analysis estimates are based on many levels of models, very small data samples and high levels of uncertainty.

Figure A.1 also shows the predicted results for the truck mode, again for an equal number of tonne-kilometers and for comparable average densities. It is observed that, relative to rail, the truck has a higher predicted frequency of events up to about 20 fatalities and then a lower frequency of larger events.

The FN curve, predicted by Glickman and Rosenfield (1984), for all fatalities due to all movements of dangerous goods on an annual basis for the U.S. is also included in Figure A.1. Glickman and Rosenfield used observed data to calibrate the model and, as seen in Figure A.1, the lack of observations of low frequency/high consequence events creates a difference between the two curves, with the risk analysis models predicting the events that have not yet been observed. This point is discussed in depth below.

Figure A.2 shows the predicted results for both truck and rail movement of LPG as well as the predictions for rail made by the Health and Safety Executive in the U.K. For LPG, the IRR model results for rail are considerably below those of the U.K. model and this may indicate possible difficulties with some components of the IRR model. On the other hand, comparisons with observed data for North America indicate that the model predictions are realistic.

Figure A.2 indicates that the truck results for LPG have a much higher frequency of fatal events. This large difference may reflect difficulties with components of the risk model or they may be real. This particular study concentrated on the accident part of the model and uncertainties still exist in the fault and release parts of the model as well as the damage propagation.

The model results can be compared to predictions made by the Toronto Area Rail Transportation of Dangerous Goods Task Force for rail movements (Transport Canada, 1988). The Task Force estimated that, for the Toronto area, there would be 4.1 statistical deaths per year. If these fatalities were all assigned to the 18,000 carloads of special dangerous commodities, and it was assumed that the average car travelled 70 kilometers, then the expected number of fatalities per 180 million tonne-kilometers is 8.4. This can be compared to predictions of the IRR model of 10.3 for chlorine and .004 for LPG. This comparison is very crude but does indicate that the IRR model predictions are clearly lower than those made in the Toronto study. The likelihood that those estimates were high was discussed in that study; however, the predicted values were used in presenting the study results.

COMPARISONS TO OBSERVED DATA

It is desirable to compare the model predictions to observed data for accidents and fatalities. The FN curve is ideal for this since the historical record will mainly reflect the higher frequency, smaller sized events. These observed results can generally be extrapolated to compare them to the predicted FN curves. For example, Figure A.3 illustrates that when the database is expanded to include more countries, more years, and more situations, an FN curve for chemical accidents extends to events of considerable size (Fernandes-Russell, 1987). Thus, there is a basis for extrapolating the observed data in order to make comparisons with the model predictions.

Ormsby and Lee (1987) have compiled data on the transportation of LPG and chlorine in the United States, by all modes of transport, for the period 1976-1986. The data were modified to reflect equivalent tonne-kilometers of shipments for comparison with the model results. The density could not be controlled for in the comparison. The results are presented in Figures A.1 and A.2.

The observed data for chlorine in Figure A.1 are, fortunately, only one point. There is good agreement between this point and the predicted model FN curve. It should be noted that with the passage of time, assuming that there have been no further fatalities observed, the frequency of the point would be reduced. In fact, it currently would be almost on the predicted model line.

In Figure A.2 the predicted truck FN curve lies above the observed points while the rail curve lies below the observed points. Since the observed data are for both truck and rail there is a correspondence between the observations and the estimated curves. The U.K. predictions appear to be high and may reflect differences in equipment, types of accidents, etc. Ormsby and Lee (1987), also include an FN plot for worldwide data for LPG and that curve is very close to the U.S. curve except that it includes some larger events. This curve is reproduced in Figure A.4 in the original form, which is not comparable with the frequencies in Figure A.2.

Figure A.3 Examples of FN Curves Based on Worldwide Events (Fernandes-Russell, 1987).

FREQUENCY OF ACCIDENTS FOR SELECTED CATEGORIES CAUSING FATALITIES WORLDWIDE

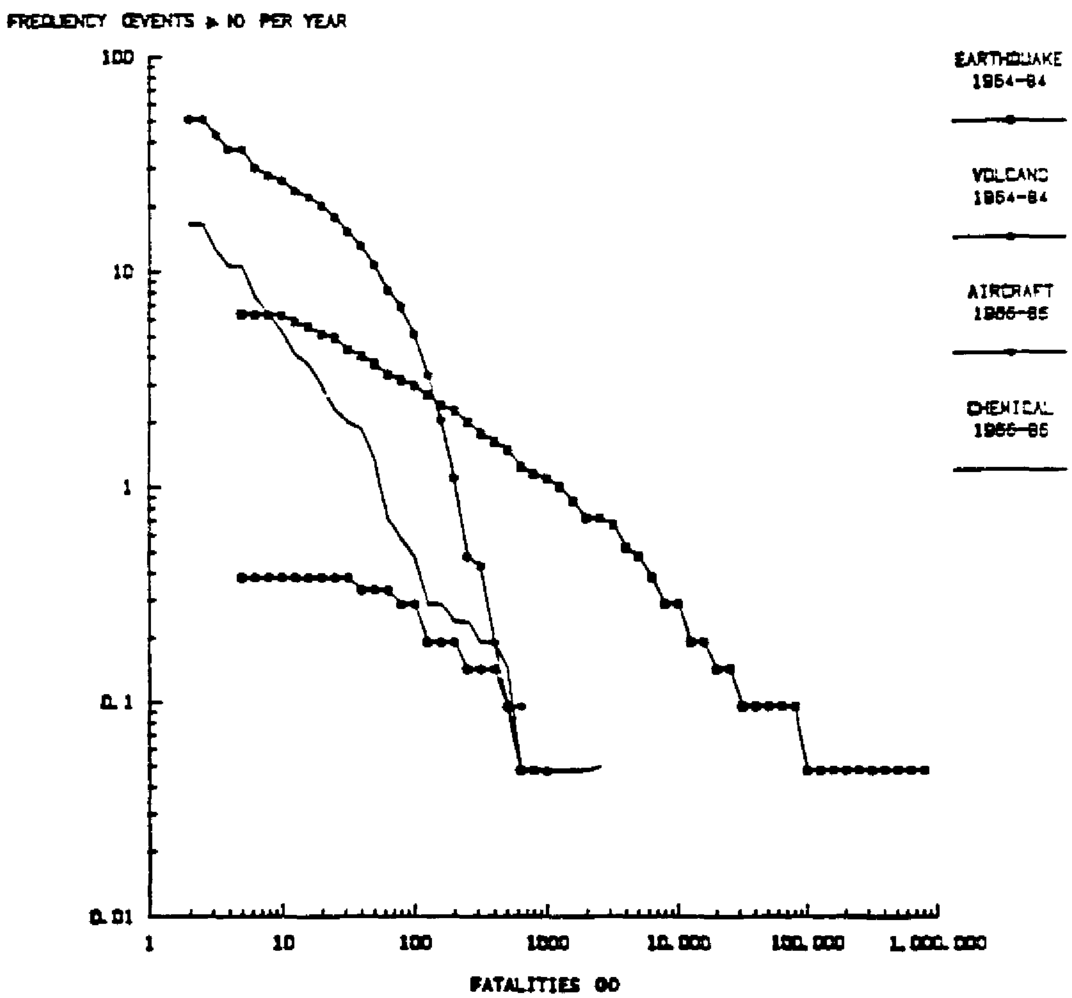
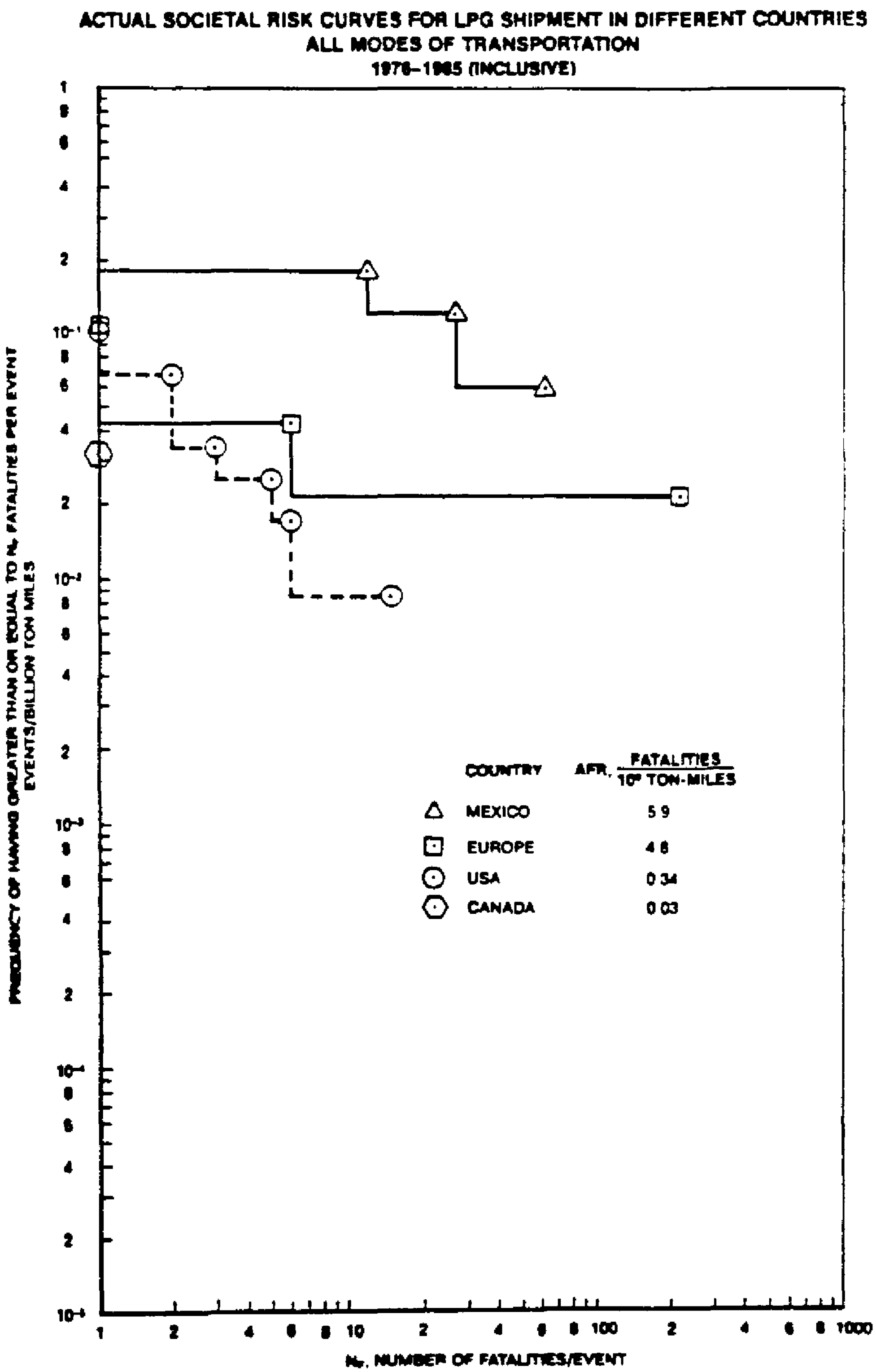


Figure A.4 Worldwide Data on Risks from the Transportation of LPG (Ormsby and Lee, 1987).



FAULT AND RELEASE PROBABILITIES

The probabilities in the fatalities were reviewed and the general conclusion was that much more work was required before any degree of confidence could be placed in these components of the model. This is in spite of the reasonableness of the comparison of the final risk model predictions and the observed data.

The fault tree probabilities were reviewed with respect to the data available on the effects of head shields, double shelf couplers and insulation of tank cars. The predictions of the model before and after modifications were examined to see if they were reasonable in terms of the observed results. Discrepancies were noted.

The original probabilities for the fault trees were reviewed and some difficulties identified (Andrews et al., 1980; Geffen, et al., 1980). For example, for chlorine shipments by rail there was a probability of 0.16 of a release due to crushing of the tank wall given a crush load, while for LPG the probability assigned was 0.0.

The conclusion reached was that a complete study of the fault and release components of the model using the latest available information is needed. In this respect it is expected that detailed data on the distribution of damages to all tank cars damaged would be very useful. There was not time in the preparation of this appendix to undertake this work.

LOW FREQUENCY HIGH CONSEQUENCE EVENTS

Given the model results in the form of an FN curve it was possible to address the question of the probability of observing no fatalities, 10 fatalities, ..., etc., in a given time period. In order to study this situation, a small simulation program was developed to use the FN curve as input and then to simulate on a year-by-year basis the frequency and type of incidents. This information could be summarized by periods of 16 years and repeated samples of 16 year periods could then be drawn from the simulation.

The simulation results are expected, over a very long period of time, to be equal to the expected values. The expected value of the risk model is that value used to predict risks and is equal to the sum of the probability of each event times the size of that event. The expected value, then, has much of its value contributed to high consequence but very low probability events. In a short period the likelihood that these high consequence events will not occur is high; thus, the expected value will not be realized.

This is a problem in the interpretation of the model results. There is a high probability that in the next 10,000 years or so the risk levels predicted by the model will not occur. There is of course a likelihood that they will happen or even be exceeded since that is the meaning of the expected value.

It should be noted that in a time span of 10,000 years there may be greenhouse effects, ice ages, wars, etc., that make the predicted risks insignificant. This raises a quandry for the decision maker and appears to reinforce the value of FN curves for displaying the risk estimates since they make explicit the low frequency/high consequence situation.

This consideration can only be raised as no solution can be suggested at this time. However, there is the possibility that in many situations a decision maker may wish to "discount" the expected value of the risk estimate to reflect the possiblity that this level of risk would not be realized within a reasonable period of time.

The simulation program was run for an FN curve of the same shape as in Figure A.1 for two cases. In the first case the curve had an intercept of 0.05 per year and in the second case an intercept of 0.02 was used. These values represented curves that were both considerably higher than the model or the U.S. observations in Figure A.1. The results of one simulation are given in Table A.2.

The simulations represented FN curves which, for a 16 year period, would result in an expectation of 78 and 31 (for the 0.02 and 0.05 intercepts, respectively) deaths for the entire 16 year period. Approximately 1,600 years are represented in the simulation results. As indicated, there is a 45% and 72% probability, respectively, for observing no fatalities in a 16 year period. There is a 56% and 79% probability that 8 or fewer fatalities would be observed in a 16 year period. The average fatalities per 16 year period were only about 60% of the "expected values" of 78 and 31 fatalities, over the 1600 year period.

These results clearly illustrate the difficulties of trying to validate the risk analysis predictions by the use of observed data. The results also illustrate the difficulty in using expected value results as a measure of the risks. It is clear that this is an important area for further research and discussion.

TABLE A.2

SIMULATION RESULTS FOR OCCURRENCE OF FATALITIES FOR 16 YEAR TIME PERIODS (GIVEN THE FN CURVE FOR CHLORINE).

	Intercept (at 1 fatality) for FN Curve	
	.05	.02
Average expected number of fatalities for a 16 year period	78	31
Frequency of 0 fatalities in a 16 year period	45%	72%
Frequency of 8 or less fatalities in a 16 year period	56%	79%
Fatalities per 16 year period, average results for 1,600 years of simulation	44	24

CONCLUSIONS

As a result of some very interesting questions on the interpretation of the results of the study of risks due to rail and truck transport, some subsequent analysis and research was done to determine the distributional aspects of the risk estimates, the reasonableness of the risk model predictions and the interpretation of the results.

It can be concluded that:

1. The model results are comparable both to the results of other researchers and to observed data. It appears that the use of FN curves is an effective way to represent the distributional aspects of the risk model predictions.

2. More work needs to be done on the fault tree and release components of the risk model.

3. The difficulty in interpreting low probability high consequence events has been identified. In particular, the use of the "expected" value requires further research to determine if it should be discounted in consideration of the expected time period for civilization.

4. There is a very high probability that in a period of 16 years only a few fatalities will be observed for chlorine shipments even though the underlying risks are orders of magnitude greater than the observed risks.

Work is ongoing in this area. Further details are available upon request.

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