7. CORRIDOR RISK ANALYSIS FOR ONTARIO

7.1 Traffic Pattern of Dangerous Goods by Truck and Rail in Ontario

The traffic patterns of dangerous goods in Ontario have been studied to determine the most heavily used rail and road corridors for the transportation of LPG. The different sources of data were compared, and any shortcomings in the data were noted.

The sources of information for rail flows are: CN Rail shipment records; CP Rail Ontario flow graphs; 1985 DC (dangerous commodity) flows around Toronto, tabulated by Philip E. Wade Associates (1986); and producer capacities supplied by Corpus Information Service (1983). The main source of data for truck flows is the Ontario Ministry of Transportation and Communications' 1983 Commercial Vehicle Survey (Ontario Ministry of Transportation and Communications, 1984). The study by Cawdery and Swoveland (1984) was used to estimate LPG flows.

7.1.1 Production of LPG

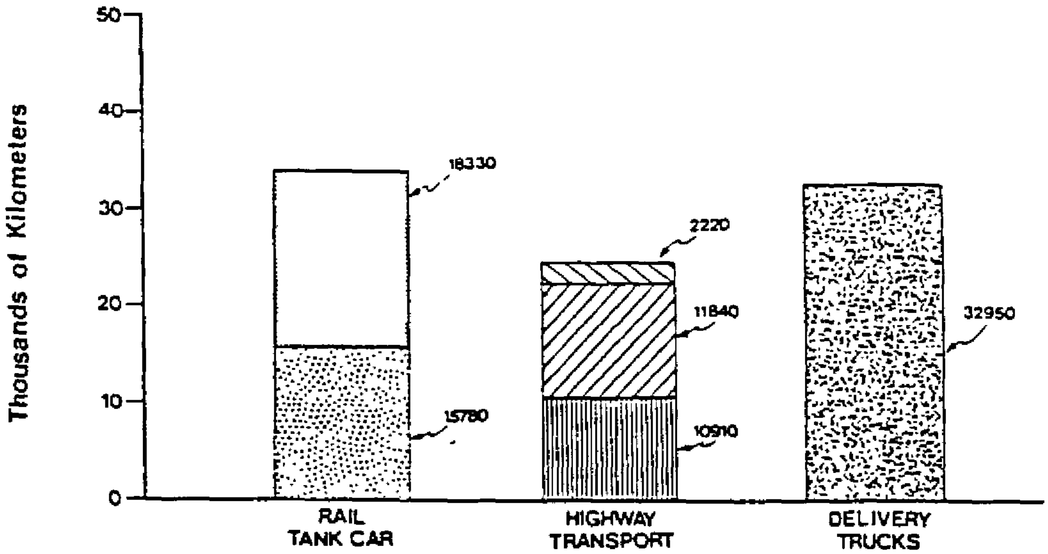
In 1983 approximately 5,200 kilotonnes of propanes and butanes were produced in Canada (excluding tonnage used in on-site miscible floods of oil reservoirs) and approximately 2770 kilotonnes were exported. About 80% of total production took place at gas plants and the remainder was produced at petroleum refineries. Ontario refineries produced 363 kilotonnes. Ontario demand was estimated at approximately 610 kilotonnes in 1984 (Cawdery and Swoveland, 1984). Statistics Canada (1982) reported that in 1982, 3019 kilotonnes were shipped by Canadian manufacturers.

Ontario production is mainly at the Dome plant in Sarnia; some production takes place at the Esso plant in Sarnia and at the Texaco plant in Nanticoke (Cawdery and Swoveland, 1984). Dome in Sarnia serves eastern Canada (to the Atlantic provinces) by truck and rail. Depending on demand and availability of rail capacity, truck movement takes place as far east as Quebec, although rail shipments predominate over 250 miles according to Cawdery and Swoveland (1984).

Approximately 100 kilotonnes of propanes and butanes were exported from the Dome plant in Sarnia (130 barrel/day plant - 10,500 tonnes/day) in 1983, of which 70% were exported by rail (Cawdery and Swoveland, 1984). The product was shipped by rail from Sarnia, or first pipelined to Windsor or St. Clair, Michigan, then shipped by rail to American destinations. Pipeline and truck movements accounted for 300 kilotonnes exported from Sarnia.

Nearly all deliveries to northwestern Ontario are by rail and truck shipments from Winnipeg (some shipments originate in Alberta). These shipments are divided almost equally between rail and truck (Cawdery and Swoveland, 1984).

In Canada the mileage from local deliveries of LPG almost equals the rail mileage, and the total truck mileage exceeds rail mileage as shown in Figure 7.1. Tonne-kilometers are also shown



b.Annual Tonne-Kilometers

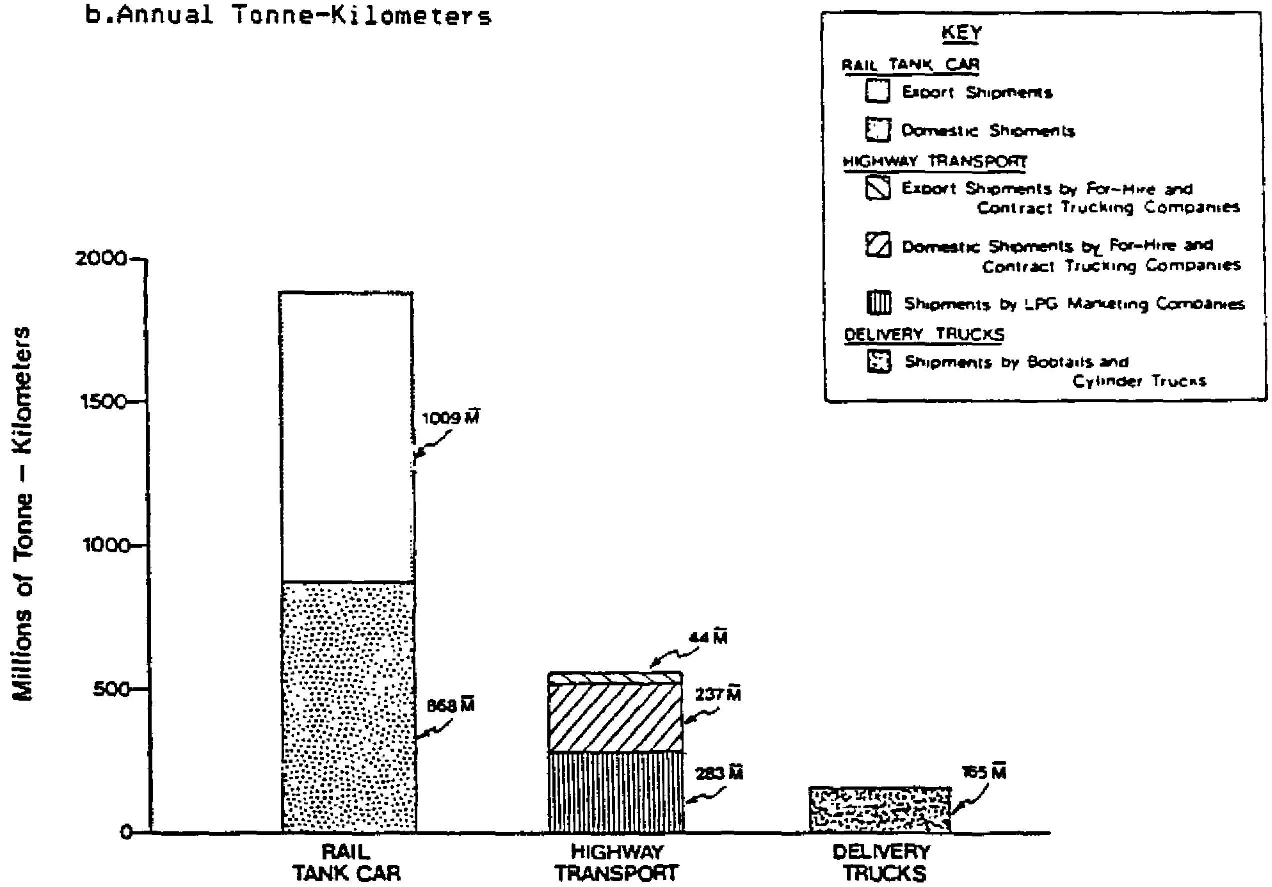


Figure 7.1 Annual Kilometers (Cawdery and Swoveland, 1984).

in Figure 7.1 where the rail mode is almost double highway transport and local deliveries combined. In Figure 7.2, the number of shipments and volumes shipped on each mode are shown for all Canada.

7.1.2 Sources of Flow Information

a. CN Rail

The CN shipments of LPG that would likely have traversed Ontario (from CN rail shipment data for 1983) were extracted and entered into origin-destination matrices. These data were routed on CN track maps, using the shortest distance except for the Toronto area where all shipments were routed along the north branch through MacMillan yard. Table 7.1 shows the changing levels of dangerous commodity volumes in the Toronto area.

TABLE 7.1

CHANGING LEVELS OF DC VOLUMES IN TORONTO AREA

Rail Corridors	1982	1985	Change
	(DC Carloads - six months)		(Number of Carloads)
CP North Toronto	6,489	5,205	-1,284
Mactier/CN Weston *	5,122	4,794	- 328
CP Galt (west of West Toronto Yard)	9,286	8,614	- 672
CP Galt / CN Weston / CN Newmarket *	1,281	1,516	+ 235
CP Belleville / CN Bala *	79	608	+ 529
CN Kingston	25	425	+ 400
CN Oakville	2,103	461	-1,642
CN Newmarket	609	546	- 63

* Data combined for parallel subdivision corridors.

The DC tonnage shipped through and around the Toronto area is shown in Figure 7.3 (adapted from Wade, 1986). The Wade study used car counts, which were translated to tonnage for this study, using an average of 70 tons per car, a value similar to that calculated from the CN data (70 tons per car for LPG, and 80 tons per car for chlorine).

b. CP Rail

The CP Rail tonnages for 1985 were reduced in order to reflect 1983 shipping levels, since all other data were for 1983. For LPG, the data were reduced by 30%, the decrease noted between 1985 and 1983 in Statistics Canada (1985).

The CP flow maps can give good estimates of corridor flows; however, for total volumes shipped in the province and exact origin and destination points, detailed flow records are required (these were not available for this study). CP statistics indicate that on average 6.6% of all cars carry dangerous goods. Using an average of 64 tonnes (70 tons) per car this equates to

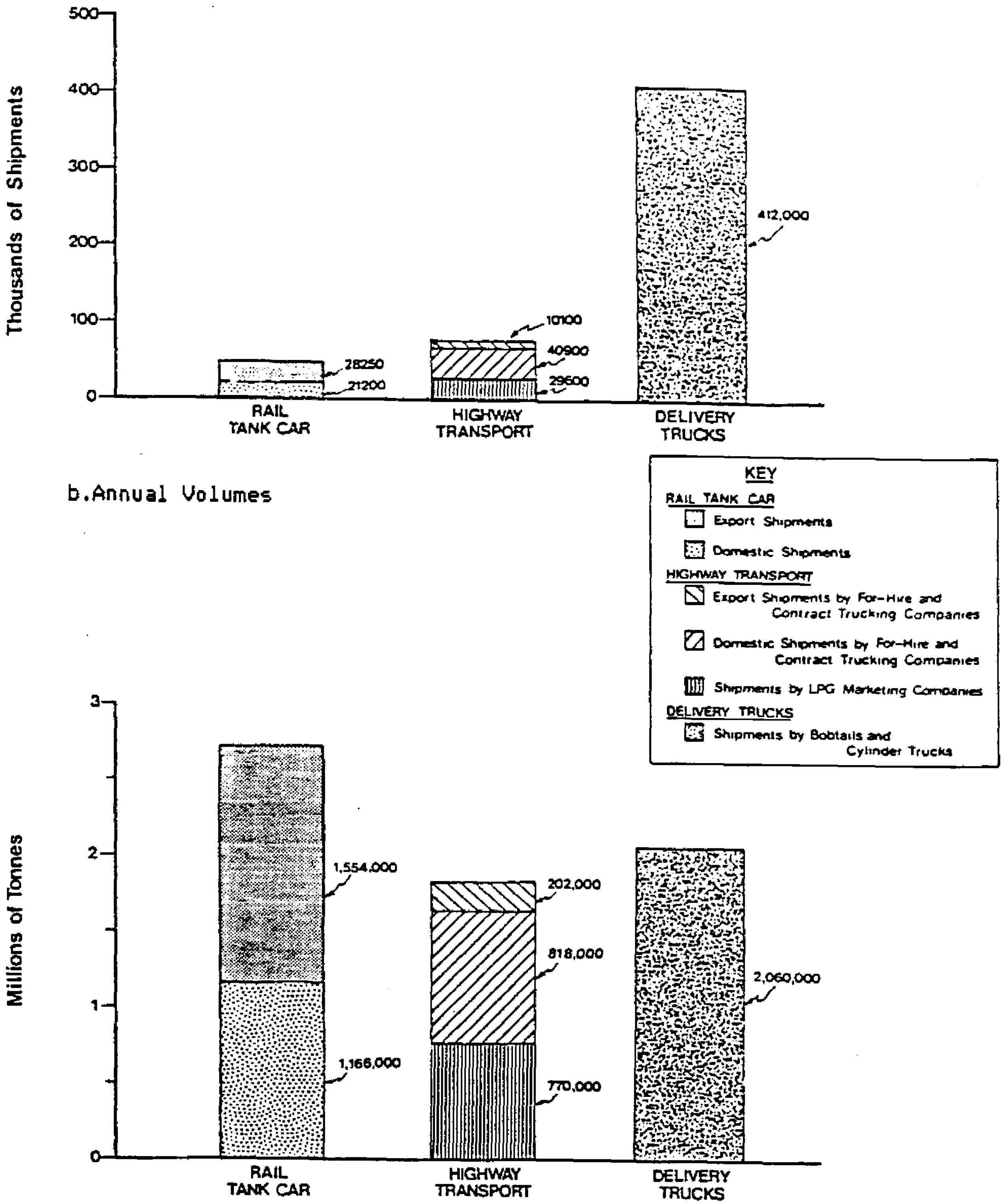


Figure 7.2 Annual Shipments (Cawdery and Swoveland, 1984).

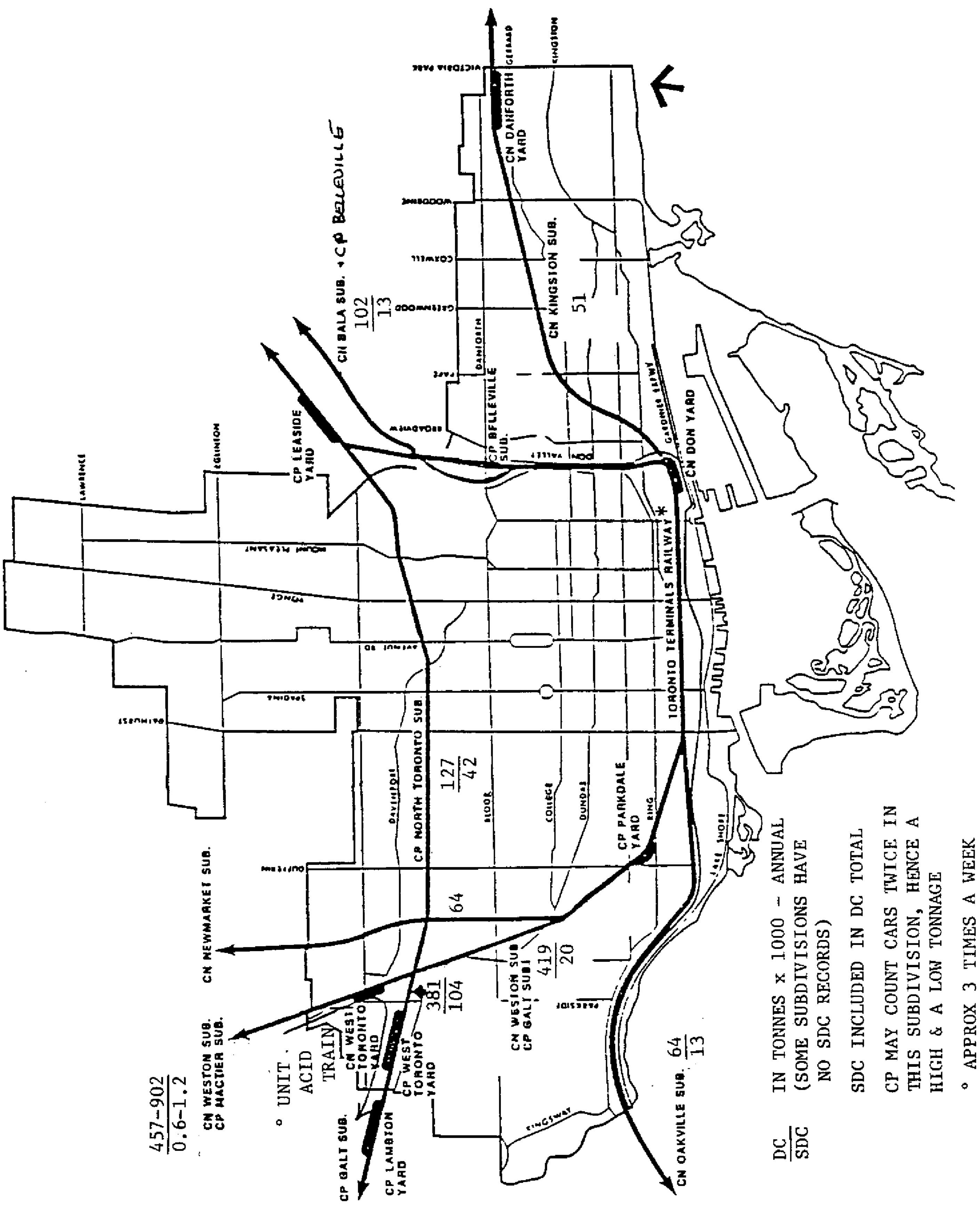


Figure 7.3 DC Shipments in Toronto
(adapted from Wade, 1986)

an average of approximately 6,353,472 tonnes of dangerous commodities hauled per year (see Table 7.2).

TABLE 7.2

CP RAIL DANGEROUS COMMODITIES HANDLED (CP Rail, 1985)

Year	DC Cars Handled	Tonnes of DC*	% DC Cars of Total
1980	91,871	5,879,744	5.9
1981	98,324	6,292,736	6.3
1982	101,491	6,495,424	7.3
1983	103,259	6,608,576	7.18
1984	101,420	6,490,880	6.48
Average	99,273	6,353,472	6.6

* 64 tonnes/car

c. Commercial Vehicle Survey

The Commercial Vehicle Survey (CVS) was carried out by the Ontario Ministry of Transportation and Communications between April and August, 1983. A 24 hour sample population was achieved, and an equivalent Average Annual Daily Traffic (AADT) and the percentage of trucks per link were derived. The type of good carried was noted, hence flow patterns for dangerous goods were derived.

Dangerous goods comprised 8.1% of all truck movements and 12.3% of all tonnage hauled. Data were extracted for Class 2 goods as defined by the Transport of Dangerous Goods Regulations. Class 2 goods includes LPG (Class 2.1). The data were sorted by origin, and each observation of this reduced data set was examined in detail to determine if it was a shipment of the desired commodity. If the origin or destination matched with known producers, distributors or consumers of LPG, the observation was labelled as a shipment of LPG. Out of 98 Class 2 observations, 24 shipments were labelled as LPG. Empty, returning trucks were included in the routing of goods by assigning the average loaded weight for that commodity to the shipment. Information on shipper and consignee was provided so that the direction of flow was easily identifiable. Yearly shipments were extrapolated from the daily shipments by multiplying the number of trucks on one day by an extrapolation factor K, where:

$$K = \frac{\text{\# of shipping days per year}}{\text{survey sample percentage}} * \text{seasonal correction}$$

The overall sample rate was 20.1% (13,213 drivers interviewed out of 65,803 trucks observed passing by). Using the survey sample percentage of 20%, a seasonal correction of 1 (see below), and the number of shipping days as 250 days (50 weeks * 5 days per week), K is 1250.

After examining yearly flow data for LPG, seasonal corrections were not applied to the amounts calculated from the survey. The annual data for LPG (McBean, 1984) indicated that 7% more LPG was carried during April to August, 1978 than would be expected for an evenly distributed monthly flow, but 3% less was carried for the same period in 1979. A lack of definite trends in LPG shipments was also noted by Cawdery and Swoveland (1984).

Chapter 5 gives a summary of the flow of LPG for the province of Ontario.

7.2 Corridor Risks for LPG Shipments

In order to determine corridor risks, the risk analysis model was run using the generic tables already determined (see Chapter 6). These tables were applied to each link in the corridor for rail and road; the resultant probability was multiplied by the accident rate for each link. This gives the risk on the link. Summing over all links in the corridor gives a measure of the total risk of routing a shipment of a dangerous good (LPG) along the corridor. The risks between rail and road transportation can then be compared.

The corridor considered for the comparison is from Sarnia to Toronto. The corridor characteristics required for the analysis for each link are: link type, length and speed; population density; property density; and lake and river density. The population densities for each link were determined using topographic maps (Energy, Mines and Resources Canada, 1975), and census information (Statistics Canada, 1981). The census gives population densities for cities, towns, villages and townships; these densities were adjusted by the population densities estimated from the topographic maps. These maps give building locations for non-built up areas, so that the number of people living in the area immediately surrounding the link can be estimated. Corridor characteristics were determined for both road routes (Route A - minimum time, and Route B - minimum distance) discussed in Chapter 5.

Table 7.3 gives the rail link file, and Tables 7.4 and 7.5 give the road link files for the Sarnia to Toronto corridor, including population density information. The population densities are critical in the estimation of risk.

Running the risk analysis model gives the risks in terms of fatalities for the Sarnia to Toronto corridor. Fatalities per car (or truck), and fatalities per tonne of LPG shipped are given for rail (Table 7.6), road route A (Tables 7.7 and 7.8), and road route B (Tables 7.9 and 7.10).

The risk predictions are modified as given in Tables 7.6 through 7.10. The original predictions were reviewed by comparison to actual risks recorded by CANUTEC and predictions by other researchers (Swoveland and Cawdery, 1986; Purdy et al., 1988). It is expected that predicted risks will be higher than observed risks since the observed risks will not reflect the possible occurrence of low probability-high consequence events.

The original predictions of the risk analysis model were found to overestimate the risks, due mainly to two factors. Firstly, the risk analysis model damage areas were higher than those predicted by other researchers. Secondly, the risk

TABLE 7.3

RAIL LINK FILE - SARNIA-TORONTO CORRIDOR

Link #	From		To		Length (km)	Speed (km/hr)	Population Density (/km^2)
1	11	50	11	51	2.7	25	1554.0
2	11	51	11	52	10.3	115	22.0
3	11	52	13	41	9.7	115	66.0
4	13	41	13	42	6.3	115	93.0
5	13	42	13	43	13.8	115	33.0
6	13	43	17	44	22.0	115	91.0
7	17	44	18	42	13.8	115	96.0
8	18	41	18	42	3.2	115	31.0
9	18	41	18	43	6.7	115	49.0
10	18	43	18	46	2.8	115	36.0
11	18	46	18	47	6.8	115	1567.0
12	18	47	18	48	2.5	115	1567.0
13	18	48	21	41	29.5	115	378.0
14	21	41	22	41	15.7	115	320.0
15	22	41	22	44	2.0	115	1089.0
16	22	42	22	44	18.0	115	157.0
17	22	42	44	42	8.3	115	24.0
18	44	42	44	43	2.8	115	699.0
19	44	43	44	44	13.7	70	582.0
20	44	44	55	59	14.5	115	243.0
21	55	59	55	61	2.7	70	72.0
22	55	61	55	54	9.2	115	806.0
23	55	54	55	52	5.3	115	2495.0
24	55	52	56	41	8.4	115	2495.0
25	56	41	57	41	8.5	115	647.0
26	57	41	57	42	6.5	115	549.0
27	57	42	77	41	21.7	115	549.0
28	77	41	79	46	6.4	115	6168.0

TABLE 7.4

ROAD LINK FILE - SARNIA-TORONTO CORRIDOR
ROUTE A

Link #	From	To	Length (km)	Speed (km/hr)	Population Density (/km^2)
1	11 7	11 6 1	5.5	80	30.0
2	11 6	11 5 1	1.3	80	115.0
3	11 5	13 2 1	18.6	100	17.0
4	13 2	13 3 1	9.3	100	10.0
5	13 3	13 4 1	3.7	100	10.0
6	13 4	13 6 1	6.5	100	10.0
7	13 6	17 5 1	20.3	100	10.0
8	17 5	17 4 1	20.5	100	47.0
9	17 4	18 2 1	12.3	100	23.0
10	18 2	18 4 1	5.9	100	13.0
11	18 4	18 5 1	2.6	100	784.0
12	18 5	18 7 1	3.3	100	1567.0
13	18 7	18 8 1	6.3	100	16.0
14	18 8	18 10 1	7.5	100	25.0
15	18 10	18 11 1	5.5	100	11.0
16	18 11	21 1 1	10.1	100	6.0
17	21 1	20 5 1	13.2	100	20.0
18	20 5	20 6 1	4.4	100	20.0
19	20 6	22 3 1	1.1	100	20.0
20	22 3	43 1 2	40.4	100	19.0
21	43 1	43 3 2	4.5	100	65.0
22	41 8	43 3 2	12.9	100	50.0
23	41 8	58 2 2	24.6	100	37.0
24	58 2	58 3 2	12.7	100	42.0
25	58 3	60 2 2	9.1	100	17.0
26	60 2	60 10 2	8.2	100	10.0
27	60 10	77 5 2	7.8	100	4.0
28	77 5	77 7 2	3.6	100	2410.0
29	77 7	77 8 2	1.9	100	2410.0
30	77 8	77 9 2	1.8	100	2410.0
31	77 9	77 15 2	3.2	100	2410.0
32	77 15	77 17 2	3.4	100	2410.0

TABLE 7.5

ROAD LINK FILE - SARNIA-TORONTO CORRIDOR
ROUTE B

Link #	From	To	Length (km)	Speed (km/hr)	Population Density (/km^2)
1	11 7	11 6	5.5	80	30.0
2	11 6	13 1	18.6	80	51.0
3	13 1	13 4	13.3	80	4.0
4	13 4	13 5	2.0	80	75.0
5	13 5	13 7	5.4	80	2.0
6	13 7	13 8	3.7	80	13.0
7	13 8	17 6	16.5	80	13.0
8	17 6	18 14	29.6	80	85.0
9	18 14	18 15	5.0	60	510.0
10	18 12	18 15	5.6	60	737.0
11	18 12	21 2	18.1	60	154.0
12	21 2	22 1	19.4	60	56.0
13	22 1	22 3	8.0	60	488.0
14	22 3	43 1	40.4	100	19.0
15	43 1	43 3	4.5	100	65.0
16	41 8	43 3	12.9	100	50.0
17	41 8	58 2	24.6	100	37.0
18	58 2	58 3	12.7	100	42.0
19	58 3	60 2	9.1	100	17.0
20	60 2	60 10	8.2	100	10.0
21	60 10	77 5	7.8	100	4.0
22	77 5	77 7	3.6	100	2410.0
23	77 7	77 8	1.9	100	2410.0
24	77 8	77 9	1.8	100	2410.0
25	77 9	77 15	3.2	100	2410.0
26	77 15	77 17	3.4	100	2410.0

TABLE 7.6

RAIL CORRIDOR RISKS FOR LPG

Link #	Link Length (km)	Fatality (given accident)	Accident Rate/car-km	Fatalities/ car	Accident Rate/tonne-km	Fatalities/ tonne
1	2.7	5.70E-02	2.91E-07	4.48E-08	3.64E-09	5.60E-10
2	10.3	1.29E-03	2.91E-07	3.85E-09	3.64E-09	4.82E-11
3	9.7	3.86E-03	2.91E-07	1.09E-08	3.64E-09	1.36E-10
4	6.3	5.44E-03	2.91E-07	9.96E-09	3.64E-09	1.25E-10
5	13.8	1.93E-03	2.91E-07	7.74E-09	3.64E-09	9.68E-11
6	22.0	5.32E-03	2.91E-07	3.40E-08	3.64E-09	4.26E-10
7	13.8	5.61E-03	2.91E-07	2.25E-08	3.64E-09	2.82E-10
8	3.2	1.81E-03	2.91E-07	1.69E-09	3.64E-09	2.11E-11
9	6.7	2.86E-03	2.91E-07	5.58E-09	3.64E-09	6.98E-11
10	2.8	2.10E-03	2.91E-07	1.71E-09	3.64E-09	2.14E-11
11	6.8	9.16E-02	2.91E-07	1.81E-07	3.64E-09	2.27E-09
12	2.5	9.16E-02	5.75E-07	1.32E-07	7.19E-09	1.65E-09
13	29.5	2.21E-02	5.75E-07	3.75E-07	7.19E-09	4.68E-09
14	15.7	1.87E-02	5.75E-07	1.69E-07	7.19E-09	2.11E-09
15	2.0	6.37E-02	5.75E-07	7.32E-08	7.19E-09	9.15E-10
16	18.0	9.18E-03	5.75E-07	9.50E-08	7.19E-09	1.19E-09
17	8.3	1.40E-03	5.75E-07	6.69E-09	7.19E-09	8.37E-11
18	2.8	4.08E-02	5.75E-07	6.58E-08	7.19E-09	8.22E-10
19	13.7	2.77E-02	5.75E-07	2.18E-07	7.19E-09	2.73E-09
20	14.5	1.42E-02	5.75E-07	1.18E-07	7.19E-09	1.48E-09
21	2.7	3.43E-03	5.75E-07	5.32E-09	7.19E-09	6.66E-11
22	9.2	4.71E-02	5.50E-07	2.38E-07	6.87E-09	2.98E-09
23	5.3	1.46E-01	5.50E-07	4.25E-07	6.87E-09	5.31E-09
24	8.4	1.46E-01	5.50E-07	6.74E-07	6.87E-09	8.41E-09
25	8.5	3.78E-02	5.50E-07	1.77E-07	6.87E-09	2.21E-09
26	6.5	3.21E-02	5.50E-07	1.15E-07	6.87E-09	1.43E-09
27	21.7	3.21E-02	5.50E-07	3.83E-07	6.87E-09	4.78E-09
28	6.4	3.60E-01	5.50E-07	1.27E-06	6.87E-09	1.58E-08
Totals	273.8			4.86E-06		6.07E-08

TABLE 7.7

ROAD CORRIDOR RISKS FOR LPG - ROUTE A (PER TRUCK)

Link #	Link Length (km)	Fatality (given accident) singles	Accident Rate/trk-km singles	Fatal/ trk singles	Fatality (given accident) doubles	Accident Rate/trk-km doubles	Fatal/ trk doubles
1	5.5	3.06E-04	4.66E-07	7.83E-10	3.67E-04	9.64E-07	1.94E-09
2	1.3	1.17E-03	4.66E-07	7.09E-10	1.40E-03	9.64E-07	1.76E-09
3	18.6	1.73E-04	5.04E-07	1.62E-09	2.08E-04	5.93E-07	2.29E-09
4	9.3	1.02E-04	5.04E-07	4.77E-10	1.22E-04	5.93E-07	6.74E-10
5	3.7	1.02E-04	5.04E-07	1.90E-10	1.22E-04	5.93E-07	2.68E-10
6	6.5	1.02E-04	5.04E-07	3.34E-10	1.22E-04	5.93E-07	4.71E-10
7	20.3	1.02E-04	5.04E-07	1.04E-09	1.22E-04	5.93E-07	1.47E-09
8	20.5	4.24E-04	4.66E-07	4.05E-09	5.08E-04	9.64E-07	1.00E-08
9	12.3	2.07E-04	5.04E-07	1.29E-09	2.49E-04	5.93E-07	1.81E-09
10	5.9	1.17E-04	5.04E-07	3.48E-10	1.41E-04	5.93E-07	4.92E-10
11	2.6	7.07E-03	1.06E-06	1.95E-08	8.48E-03	1.25E-06	2.75E-08
12	3.3	1.41E-02	1.06E-06	4.95E-08	1.69E-02	1.25E-06	6.98E-08
13	6.3	1.63E-04	1.06E-06	1.09E-09	1.96E-04	1.25E-06	1.54E-09
14	7.5	2.25E-04	1.06E-06	1.79E-09	2.70E-04	1.25E-06	2.53E-09
15	5.5	9.92E-05	1.06E-06	5.79E-10	1.19E-04	1.25E-06	8.16E-10
16	10.1	5.41E-05	1.06E-06	5.80E-10	6.49E-05	1.25E-06	8.18E-10
17	13.2	1.80E-04	1.06E-06	2.52E-09	2.16E-04	1.25E-06	3.56E-09
18	4.4	1.81E-04	1.06E-06	8.43E-10	2.17E-04	1.25E-06	1.19E-09
19	1.1	1.81E-04	1.06E-06	2.11E-10	2.17E-04	1.25E-06	2.97E-10
20	40.4	2.16E-04	1.06E-06	9.25E-09	2.59E-04	1.25E-06	1.30E-08
21	4.5	7.38E-04	1.06E-06	3.52E-09	8.86E-04	1.25E-06	4.97E-09
22	12.9	5.68E-04	1.06E-06	7.77E-09	6.81E-04	1.25E-06	1.10E-08
23	24.6	4.20E-04	1.06E-06	1.10E-08	5.04E-04	1.25E-06	1.55E-08
24	12.7	4.77E-04	1.06E-06	6.42E-09	5.72E-04	1.25E-06	9.06E-09
25	9.1	1.93E-04	1.06E-06	1.86E-09	2.32E-04	1.25E-06	2.63E-09
26	8.2	1.14E-04	1.06E-06	9.88E-10	1.36E-04	1.25E-06	1.39E-09
27	7.8	4.54E-05	1.06E-06	3.76E-10	5.45E-05	1.25E-06	5.30E-10
28	3.6	2.74E-02	1.06E-06	1.05E-07	3.28E-02	1.25E-06	1.47E-07
29	1.9	2.74E-02	1.06E-06	5.52E-08	3.28E-02	1.25E-06	7.78E-08
30	1.8	2.74E-02	1.06E-06	5.23E-08	3.28E-02	1.25E-06	7.37E-08
31	3.2	2.74E-02	1.06E-06	9.29E-08	3.28E-02	1.25E-06	1.31E-07
32	3.4	2.74E-02	1.06E-06	9.87E-08	3.28E-02	1.25E-06	1.39E-07
Total	292			5.32E-07			7.56E-07

TABLE 7.8

ROAD CORRIDOR RISKS FOR LPG - ROUTE A (PER TONNE)

Link #	Link Length (km)	Fatality (given accident) singles	Accident Rate/tonne-km singles	Fatal/ tonne singles	Fatality (given accident) doubles	Accident Rate/tonne-km doubles	Fatal/ tonne doubles
1	5.5	3.06E-04	1.60E-08	2.69E-11	3.67E-04	2.70E-08	5.44E-11
2	1.3	1.17E-03	1.60E-08	2.44E-11	1.41E-03	2.70E-08	4.93E-11
3	18.6	1.73E-04	1.70E-08	5.47E-11	2.08E-04	1.60E-08	6.18E-11
4	9.3	1.02E-04	1.70E-08	1.61E-11	1.22E-04	1.60E-08	1.82E-11
5	3.7	1.02E-04	1.70E-08	6.41E-12	1.22E-04	1.60E-08	7.24E-12
6	6.5	1.02E-04	1.70E-08	1.13E-11	1.22E-04	1.60E-08	1.27E-11
7	20.3	1.02E-04	1.70E-08	3.51E-11	1.22E-04	1.60E-08	3.97E-11
8	20.5	4.24E-04	1.60E-08	1.39E-10	5.08E-04	2.70E-08	2.81E-10
9	12.3	2.07E-04	1.70E-08	4.33E-11	2.49E-04	1.60E-08	4.90E-11
10	5.9	1.17E-04	1.70E-08	1.18E-11	1.41E-04	1.60E-08	1.33E-11
11	2.6	7.07E-03	3.50E-08	6.43E-10	8.48E-03	3.50E-08	7.71E-10
12	3.3	1.41E-02	3.50E-08	1.63E-09	1.69E-02	3.50E-08	1.96E-09
13	6.3	1.63E-04	3.50E-08	3.59E-11	1.96E-04	3.50E-08	4.31E-11
14	7.5	2.25E-04	3.50E-08	5.91E-11	2.70E-04	3.50E-08	7.10E-11
15	5.5	9.92E-05	3.50E-08	1.91E-11	1.19E-04	3.50E-08	2.29E-11
16	10.1	5.41E-05	3.50E-08	1.91E-11	6.49E-05	3.50E-08	2.29E-11
17	13.2	1.80E-04	3.50E-08	8.33E-11	2.16E-04	3.50E-08	9.99E-11
18	4.4	1.80E-04	3.50E-08	2.78E-11	2.16E-04	3.50E-08	3.33E-11
19	1.1	1.80E-04	3.50E-08	6.94E-12	2.16E-04	3.50E-08	8.33E-12
20	40.4	2.16E-04	3.50E-08	3.05E-10	2.59E-04	3.50E-08	3.66E-10
21	4.5	7.38E-04	3.50E-08	1.16E-10	8.86E-04	3.50E-08	1.39E-10
22	12.9	5.68E-04	3.50E-08	2.56E-10	6.81E-04	3.50E-08	3.07E-10
23	24.6	4.20E-04	3.50E-08	3.62E-10	5.04E-04	3.50E-08	4.34E-10
24	12.7	4.77E-04	3.50E-08	2.12E-10	5.72E-04	3.50E-08	2.54E-10
25	9.1	1.93E-04	3.50E-08	6.15E-11	2.32E-04	3.50E-08	7.38E-11
26	8.2	1.14E-04	3.50E-08	3.26E-11	1.36E-04	3.50E-08	3.91E-11
27	7.8	4.54E-05	3.50E-08	1.24E-11	5.45E-05	3.50E-08	1.49E-11
28	3.6	2.74E-02	3.50E-08	3.45E-09	3.28E-02	3.50E-08	4.14E-09
29	1.9	2.74E-02	3.50E-08	1.82E-09	3.28E-02	3.50E-08	2.18E-09
30	1.8	2.74E-02	3.50E-08	1.72E-09	3.28E-02	3.50E-08	2.07E-09
31	3.2	2.74E-02	3.50E-08	3.06E-09	3.28E-02	3.50E-08	3.68E-09
32	3.4	2.74E-02	3.50E-08	3.26E-09	3.28E-02	3.50E-08	3.91E-09
Total	292			1.76E-08			2.12E-08

TABLE 7.9

ROAD CORRIDOR RISKS FOR LPG - ROUTE B (PER TRUCK)

Link #	Link Length (km)	Fatality (given accident) singles	Accident Rate/trk-km singles	Fatal/ trk singles	Fatality (given accident) doubles	Accident Rate/trk-km doubles	Fatal/ trk doubles
1	5.5	3.06E-04	4.66E-07	7.83E-10	3.67E-04	9.64E-07	1.94E-09
2	18.6	5.20E-04	4.66E-07	4.50E-09	6.23E-04	9.64E-07	1.12E-08
3	13.3	4.07E-05	4.66E-07	2.52E-10	4.89E-05	9.64E-07	6.27E-10
4	2.0	7.64E-04	4.66E-07	7.12E-10	9.16E-04	9.64E-07	1.77E-09
5	5.4	2.04E-05	4.66E-07	5.12E-11	2.44E-05	9.64E-07	1.27E-10
6	3.7	1.32E-04	4.66E-07	2.28E-10	1.59E-04	9.64E-07	5.67E-10
7	16.5	1.32E-04	4.66E-07	1.02E-09	1.59E-04	9.64E-07	2.53E-09
8	29.6	8.66E-04	4.66E-07	1.19E-08	1.04E-03	9.64E-07	2.96E-08
9	5.0	4.60E-03	4.66E-07	1.07E-08	5.52E-03	9.64E-07	2.66E-08
10	5.6	6.64E-03	4.66E-07	1.73E-08	7.97E-03	9.64E-07	4.30E-08
11	18.1	1.39E-03	4.66E-07	1.17E-08	1.67E-03	9.64E-07	2.91E-08
12	19.4	5.05E-04	4.66E-07	4.56E-09	6.05E-04	9.64E-07	1.13E-08
13	8.0	4.40E-03	4.66E-07	1.64E-08	5.28E-03	9.64E-07	4.07E-08
14	40.4	2.16E-04	1.06E-06	9.24E-09	2.59E-04	1.25E-06	1.31E-08
15	4.5	7.38E-04	1.06E-06	3.52E-09	8.86E-04	1.25E-06	4.98E-09
16	12.9	5.68E-04	1.06E-06	7.76E-09	6.81E-04	1.25E-06	1.10E-08
17	24.6	4.20E-04	1.06E-06	1.10E-08	5.04E-04	1.25E-06	1.55E-08
18	12.7	4.77E-04	1.06E-06	6.42E-09	5.72E-04	1.25E-06	9.08E-09
19	9.1	1.93E-04	1.06E-06	1.86E-09	2.32E-04	1.25E-06	2.63E-09
20	8.2	1.14E-04	1.06E-06	9.87E-10	1.36E-04	1.25E-06	1.40E-09
21	7.8	4.54E-05	1.06E-06	3.75E-10	5.45E-05	1.25E-06	5.31E-10
22	3.6	2.74E-02	1.06E-06	1.04E-07	3.28E-02	1.25E-06	1.48E-07
23	1.9	2.74E-02	1.06E-06	5.51E-08	3.28E-02	1.25E-06	7.80E-08
24	1.8	2.74E-02	1.06E-06	5.22E-08	3.28E-02	1.25E-06	7.39E-08
25	3.2	2.74E-02	1.06E-06	9.28E-08	3.28E-02	1.25E-06	1.31E-07
26	3.4	2.74E-02	1.06E-06	9.86E-08	3.28E-02	1.25E-06	1.40E-07
Total	284.8			5.24E-07			8.28E-07

TABLE 7.10

ROAD CORRIDOR RISKS FOR LPG - ROUTE B (PER TONNE)

Link #	Link Length (km)	Fatality (given accident) singles	Accident Rate/tonne-km singles	Fatal/ tonne singles	Fatality (given accident) doubles	Accident Rate/tonne-km doubles	Fatal/ tonne doubles
1	5.5	3.06E-04	1.60E-08	2.69E-11	3.67E-04	2.70E-08	5.44E-11
2	18.6	5.20E-04	1.60E-08	1.55E-10	6.23E-04	2.70E-08	3.13E-10
3	13.3	4.07E-05	1.60E-08	8.67E-12	4.89E-05	2.70E-08	1.76E-11
4	2.0	7.64E-04	1.60E-08	2.44E-11	9.16E-04	2.70E-08	4.95E-11
5	5.4	2.04E-05	1.60E-08	1.76E-12	2.44E-05	2.70E-08	3.56E-12
6	3.7	1.32E-04	1.60E-08	7.84E-12	1.59E-04	2.70E-08	1.59E-11
7	16.5	1.32E-04	1.60E-08	3.50E-11	1.59E-04	2.70E-08	7.08E-11
8	29.6	8.66E-04	1.60E-08	4.10E-10	1.04E-03	2.70E-08	8.30E-10
9	5.0	4.60E-03	1.60E-08	3.68E-10	5.52E-03	2.70E-08	7.45E-10
10	5.6	6.64E-03	1.60E-08	5.95E-10	7.97E-03	2.70E-08	1.20E-09
11	18.1	1.39E-03	1.60E-08	4.02E-10	1.67E-03	2.70E-08	8.14E-10
12	19.4	5.05E-04	1.60E-08	1.57E-10	6.05E-04	2.70E-08	3.17E-10
13	8.0	4.40E-03	1.60E-08	5.63E-10	5.28E-03	2.70E-08	1.14E-09
14	40.4	2.16E-04	3.50E-08	3.05E-10	2.59E-04	3.50E-08	3.66E-10
15	4.5	7.38E-04	3.50E-08	1.16E-10	8.86E-04	3.50E-08	1.39E-10
16	12.9	5.68E-04	3.50E-08	2.56E-10	6.81E-04	3.50E-08	3.07E-10
17	24.6	4.20E-04	3.50E-08	3.62E-10	5.04E-04	3.50E-08	4.34E-10
18	12.7	4.77E-04	3.50E-08	2.12E-10	5.72E-04	3.50E-08	2.54E-10
19	9.1	1.93E-04	3.50E-08	6.15E-11	2.32E-04	3.50E-08	7.38E-11
20	8.2	1.14E-04	3.50E-08	3.26E-11	1.36E-04	3.50E-08	3.91E-11
21	7.8	4.54E-05	3.50E-08	1.24E-11	5.45E-05	3.50E-08	1.49E-11
22	3.6	2.74E-02	3.50E-08	3.45E-09	3.28E-02	3.50E-08	4.14E-09
23	1.9	2.74E-02	3.50E-08	1.82E-09	3.28E-02	3.50E-08	2.18E-09
24	1.8	2.74E-02	3.50E-08	1.72E-09	3.28E-02	3.50E-08	2.07E-09
25	3.2	2.74E-02	3.50E-08	3.06E-09	3.28E-02	3.50E-08	3.68E-09
26	3.4	2.74E-02	3.50E-08	3.26E-09	3.28E-02	3.50E-08	3.91E-09
Total	284.8			1.74E-08			2.32E-08

analysis model does not currently account for either shielding of population due to the structures they are in at the time of the event, or the potential for evacuation of persons within the damage areas. Analysis done in the U.K. indicates that this is a very significant factor (Purdy et al., 1988). In consideration of these two factors an adjustment factor of 0.05 was applied to <u>all</u> the risks predicted in Tables 7.6 through 7.10. This reflects a factor of 0.1 for shielding and evacuation, and a factor of 0.5 for predicted damage areas. The predicted risks still appear to be on the high side in comparison to observed data.

The risk analysis model is currently in the process of review and upgrading, and will be modified to incorporate these factors, as well as provide for calibration against available Canadian data.

The predictions given in Tables 7.6 to 7.10 confirm the high risks associated with larger double trailer trucks as compared to single trailer trucks. This comparison is thought to be valid since the two vehicles are subject to similar road and traffic conditions for each route. The comparison of Route A and B can be carried out in relation to the risks of transporting LPG's by various truck types. Although from an accident rate point of view route B is generally safer than route A, when the risks of transporting LPG's are considered both routes reflect a similar level of safety. The variation in route length accident rates and population densities on the routes leads to a similar estimate for either route for the risks due to the dangerous goods carried.

The comparison of truck and rail risks due to LPG indicates that the rail mode has higher risks. There are some unanswered questions concerning the risk model that suggest that these differences are not significant. The problems with the estimated damage areas, poor comparison of model estimates and observed data, and uncertainties about the fault trees are all areas requiring further review and model improvement. It should be noted that the main thrust of this study was to improve the accident analysis, and that the next step is to improve the risk model. There are many other issues such as the safety of dangerous goods vehicles relative to other vehicles which will have to be addressed in the next phase.

Comparison of fatalities in an accident for rail and road links with comparable population densities indicates that rail accidents result in higher fatalities per accident, as expected. However, when the tonnage carried and the accident rates per vehicle kilometer are considered, rail fatality rates for LPG are similar to those for road. For example, comparing road Link 25 (Route B - singles) with rail Link 24, which have 2410 and 2495 population per square kilometer respectively, Table 7.6 gives a rail risk of 1.0×10^{-9} per tonne-km while Table 7.10 gives a road risk of 9.6×10^{-10} per tonne-km. For comparable population densities the two modes are similar.

The greatest difference between modes for the Sarnia to Toronto corridor is the population density impacted by the different modes. Tables 7.3, 7.4 and 7.5 show that based on the measures used the rail mode has a higher average population density and that this leads to a higher estimate of risk in spite of the inherent safety advantage. The estimate of population density and exposed population along the route then becomes critical.

A methodology for estimating exposed population was developed, and is discussed in the next section. This methodology will be applied to the Sarnia-Toronto example to refine the estimates of risk.

The total exposure of trucks in Ontario in 1983 was 4662.3 x 10^{-6} kilometers, and the number of truck accidents in this year was 4354. Of these accidents, 138 involved at least one fatality. Using these numbers, the general accident rate was 0.9339 x 10^{-6} per truck-km, and the fatal accident rate was 0.0296 x 10^{-6} per truck-km. Truck accidents comprised 3.2% of all accidents. For all accidents in Ontario in 1985 (Ontario Ministry of Transportation and Communications, 1985), there were 1.15 fatalities per fatal accident. Therefore the fatality rate for trucks is estimated as 0.036 per truck accident. This is a general rate, and currently cannot be differentiated by truck type.

The estimated fatality rate per truck accident of 0.036 deaths per accident was applied to the estimated truck accidents from Figure 5.2, to estimate fatalities due to the accident for a million truck movements from Sarnia to Toronto. For example, for singles on Route A there are an estimated 283 truck accidents per million truck movements. This gives 10.2 deaths per million truck movements. This compares to the fatalities associated with LPG movement of 0.53 deaths (from Table 7.7), or 19.2 times as many deaths due to the accident as due to the dangerous good. For doubles on Route A, this ratio is 16.6. Route B has similar ratios.

Similarly, for rail movements the average fatality rate for 1985 for freight movements was estimated as 0.012 x 10^{-6} deaths per car-kilometer. For the Sarnia to Toronto corridor, this indicates 3.2 deaths per million cars. This compares to an estimated 4.9 deaths per million car movements associated with LPG movement (from Table 7.6), or a ratio of 0.65.

Table 7.11 compares the total fatalities for the movement of a million tonnes of LPG from Sarnia to Toronto by truck and rail using the above ratios of deaths due to the accident and deaths estimated for the movement of LPG. On a total fatality comparison, the truck movement is about 3.5 times more risky than the rail movement, even though the rail movement is more dangerous with respect to LG transport. Table 7.11 also shows a comparison for equal population densities.

It should be noted that in Table 7.11 the fatalities due to the accidents are comparable, since the majority of them involve the travelling public. Most rail accident deaths are associated with road-rail crossing accidents and most truck accidents involve fatalities to automobile occupants in the collision.

7.3 Example of Detailed Link Analysis

The previous discussion gives a demonstration of the risk analysis model, and the estimated fatalities. When an accident

TABLE 7.11

COMPARISON OF TOTAL FATALITIES FOR LPG SHIPMENT
FROM SARNIA TO TORONTO BY ROAD AND RAIL

	Estimated Fatalities per Million Tonnes from Sarnia to Toronto		
	Due to LPG	Due to Accident	Total
ROAD Singles Route A	0.02	0.34	0.36
Doubles Route A	0.02	0.35	0.37
RAIL	0.06	0.04	0.10

	Estimated Fatalities per Million Tonnes from Sarnia to Toronto (Assuming equal population densities)		
	Due to LPG	Due to Accident	Total
ROAD Singles Route A	0.02	0.34	0.36
RAIL	0.02	0.04	0.06

occurs involving a dangerous good, the population at risk is usually those who are immediately adjacent to the transportation corridor where the spill occurred. Census information to determine population densities (as in the previous section) is generally for a large area. In order to determine the population actually at risk, it is necessary to examine the area immediately adjacent to the transportation corridor.

The area chosen to give an example of a more detailed analysis of population density is Guelph, Ontario. This area was chosen for a number of reasons. These include: the presence of rail and road corridors; the mix of freeway and nonfreeway on the road route chosen; and the presence of a large population at risk.

Information on land use in Guelph was determined from Pathfinder maps (Pathfinder, 1985). These maps are based on aerial photographs, and show all buildings. Based on the buildings observed adjacent to the rail and road lines chosen to carry dangerous goods, the population at risk from a spill can be determined. A sample of the road and rail routes through Guelph is shown in Figure 7.4.

A number of assumptions were made for determining the population at risk. These assumptions are based on population and employment characteristics. The population assumptions are: 3 persons per single family dwelling; 2 persons per unit in apartments and townhouses; apartments are 5 stories high in suburban areas, 10 stories high in urban areas. The assumptions made about employment imformation are: industrial and office buildings contain 1 person per 250 square feet; commercial buildings contain 1 person per 100 square feet; all of these buildings are 1 storey high in suburban areas, 3 stories high in urban areas; schools contain 750 people. Note that population is assumed to be constantly exposed to risk, while employment is assumed to be mainly daytime exposure.

There is also exposure based on the population on the facility being used. On rail, this is limited to the train crew (assumed to be 5 persons). The exposure on the road is calculated from the Average Annual Daily Traffic (AADT). Assuming an AADT for road of 16,000 vehicles per day, and a 16 hour day, this gives a rate of 1000 vehicles per hour. The average speed on the road is 30 kilometers per hour. Assuming two persons per vehicle, and given a radius of event of 100 meters, the population at risk from a road accident would be 1000 vehicles/hour x 0.1 kilometer x 2 x 2 / 30 kilometer/hour = 13 persons. For an event radius of 300 meters, the number of persons at risk is 40.

Based on the above analysis, the typical exposure of population in Guelph is given in Table 7.12 for east-west movement through the city on either the rail line, or highway No. 7.

It can be seen from this example that the population at risk on the road network is slightly higher at 100 meters, demonstrating that the rail right-of-way is generally larger than for road. Since the majority of fatalities involved in dangerous goods accidents are from the accidents themselves, road demonstrates a higher risk due to higher use of the facility.

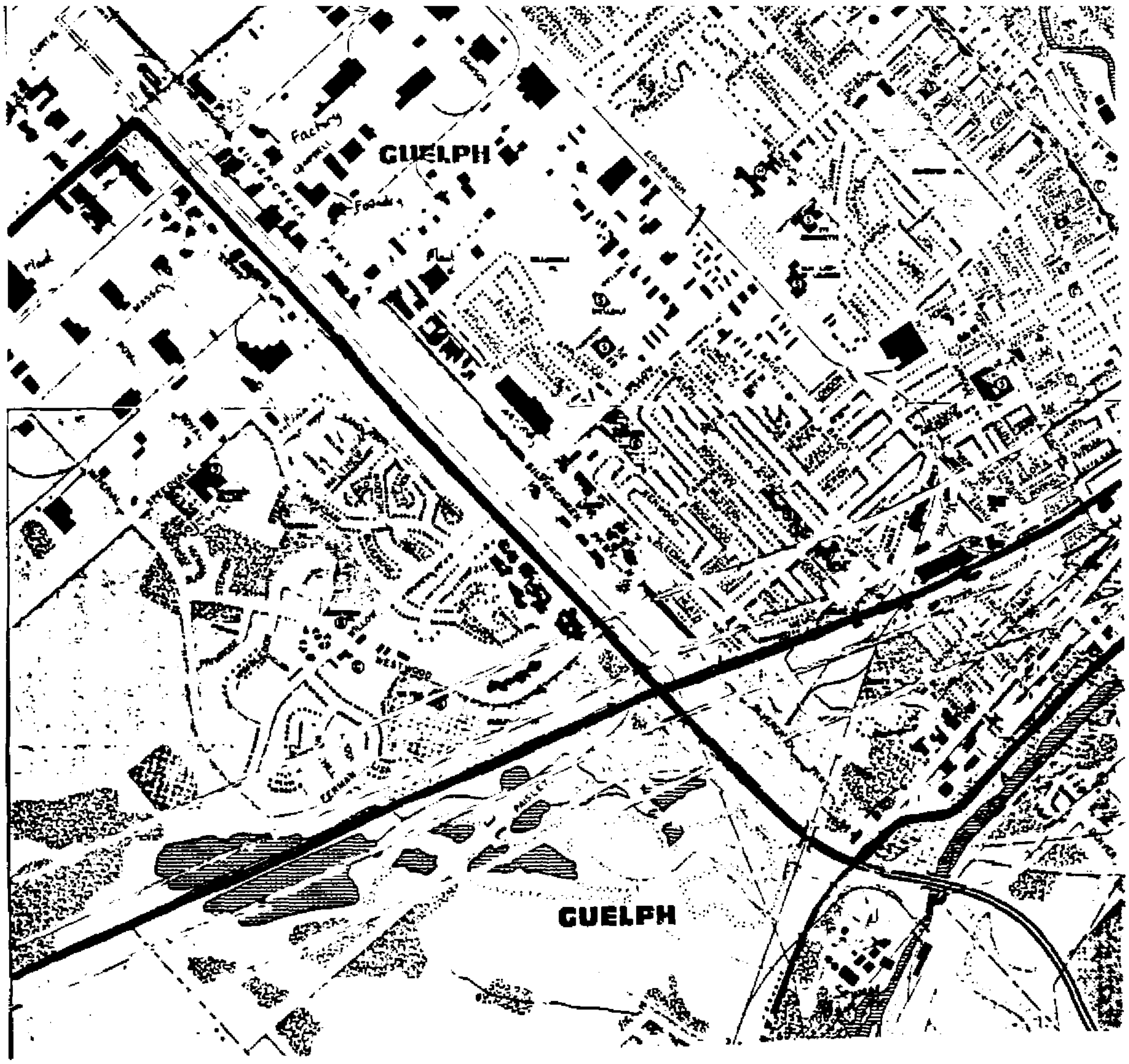


Figure 7.4 Sample of Guelph Road and Rail Routes

TABLE 7.12

TYPICAL EXPOSURE OF POPULATION AND EMPLOYMENT
East - West Rail and Road Routes Through Guelph

	Radius of Event		Remarks
	100 m	300 m	
Rail			
Exposed Population/km	346	1032	
Exposed Employment/km	366	1678	
On Facility	3	3	Train Crew
Road			
Exposed Population/km	457	1232	
Exposed Employment/km	385	1327	
On Facility	13	40	AADT

Notes:
1) Employment includes school population @ 750 persons per school
2) Route lengths for East - West movement through Guelph
   a) Rail - 8.9 km
   b) Road - 10.5 km
3) AADT is assumed to be 16,000 vehicles per day

Although the risk analysis model contains a number of approximations, it remains a useful tool for the estimation and comparison of risks involved in transportation of dangerous goods. With further refinements (to be performed under the University Research Incentive Fund extension to this study) it will become even more useful.