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Contents

Transportation of Hazardous Wastes in Arizona: Development of a Data Base Management System for Basic Analysis

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ABSTRACT

A data base management system for hazardous waste movements in Arizona was developed for the years 1983 and 1984. The data were taken from the full manifest system provided by the Arizona Department of Health Services. A total of 5,053 manifests were reviewed for the 2 years, and a microcomputer software (DBASE III) was used for data storage, retrieval, and analysis. The computer system provided statistical reports by month of year, day of week, chemical number, and other attributes selected by the user for the year 1984. An origin-destination analysis of the data was conducted to trace the flow of waste shipments on all highway routes and links. Results of this analysis provided some insight on the distribution of origins and destinations of shipments within and outside urban areas. Data generated from the origin-destination analysis together with other accident, traffic volume, and population information were used to conduct a risk analysis.

The transportation of hazardous materials and the risk involved with such activity has been identified as a serious problem in the United States. It has been estimated that at least 250,000 shipments of hazardous materials are made each day, totaling at least 4 billion tons per year, and this volume is expected to double every 10 years (1). The U.S. Department of Transportation estimates that between 5 and 15 percent of all trucks on the road at any time carry hazardous materials (2).

When considering the transportation of hazardous materials, it is important to differentiate between hazardous materials and hazardous wastes. All hazardous wastes are hazardous materials, but only a small fraction of hazardous materials shipped are hazardous wastes.

It is currently estimated that somewhat less than 4 percent of the total of all hazardous materials shipped are in the hazardous waste category. In the United States, 160 million metric tons of hazardous wastes are generated each year as part of the industrial process. These wastes include organic chemicals, pesticides, acids, caustics, flammables, and explosives (3).

Statistics have shown that in 1980, all modes of transportation contributed to a total of 16,115 hazardous material incidents--resulting in 619 injuries, 19 fatalities, and $10.7 billion in property damages. Of those incidents, 90 percent were in the highway mode (4). More than 8,000 incidents of hazardous material spills involving truck travel were reported in 1981, of which 84 incidents involved hazardous wastes. Although the number of hazardous waste incidents is small, the hazardous waste shipment share of the total hazardous materials shipped is also small (4 percent). The incident rate, number of incidents per million shipment miles, would be an appropriate measure by which to judge the magnitude of the problem.

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BACKGROUND INFORMATION

In response to a growing concern about the management of hazardous wastes and their impact on the population and environment, the Resource Conservation and Recovery Act (RCRA) was enacted in 1976. RCRA authorized the Environmental Protection Agency (EPA) to establish a hazardous waste control program for the nation, which includes the identification and classification of hazardous wastes, requirements for owners and operators of hazardous waste facilities, and guidelines for state programs developed under the act.

As the transportation of hazardous materials is emerging as a national concern, attempts are ongoing to assess the risks of potential accidents. An early study conducted by Russell et al. (5) provided a comprehensive review and an excellent summary of existing methods used to estimate the risks of hazardous materials transport. The methods reviewed are (a) enumerative indices, (b) regression models, (c) network and distribution models, and (d) probabilistic risk assessment models. The basic concept of all methods is to develop a risk index per transportation route using the probability of hazardous material incidence.

In a recent study conducted for the Office of Solid Waste of the EPA, attempts were made to assess the releases and costs associated with truck transport of hazardous waste (6). Three streams of data were found necessary to conduct the risk analysis:

1. Truck accident and volume data,
2. Hazardous waste shipment information, and
3. Hazardous waste incident data.

Accident and volume data over 5-mile sections were obtained from Texas, California, and New Jersey. Some states have implemented a manifest system for recording hazardous waste shipments. Waste shipment data were obtained from California, Texas, Massachusetts, and New York. The hazardous waste incident data were obtained from the HAZMAT file prepared by the U.S. Department of Transportation's Materials Transportation Bureau (MTB).

The data collected were used, in association with the RCRA risk/cost analysis model, to calculate the risks and costs involved with all possible combinations of a list of wastes, technologies, and environmental (WET) settings. The most important result of this study as reported by the investigators was that the release rates associated with transporting hazardous wastes by truck appear to be as large as the potential releases at treatment and disposal sites. For some WET combinations, transport may be a more dangerous activity.

A critical review of the literature resulted in the following observations:

1. Most statistics related to hazardous waste shipments cited by different agencies are based on estimates derived from surveys.

2. Those states that have implemented a manifest system for recording hazardous waste shipments have not, to the best of the authors' knowledge, reported on the shipments transported through their state by different category such as

   a. Time period (month of year, day of week);
   b. Hazard class (corrosive, explosive, etc.);
   c. Transportation route;
   d. Urban versus nonurban areas; and
   e. Chemical number, as defined by United Nations Classification System.

RESEARCH SCOPE

The Center for Environmental Studies and the Center for Advanced Research in Transportation at Arizona State University were awarded a research grant, sponsored by the Arizona Department of Transportation (ADOT), to develop a data base management system (DBMS) for hazardous material transport within and through the state of Arizona. One of the objectives of this research was to computerize the hazardous waste manifests for the years 1983 and 1984. To successfully meet this objective, the following tasks were outlined:

1. To use a microcomputer DBMS software to generate a hazardous waste information system for Arizona.

2. To utilize the DBMS for generating statistics related to hazardous waste shipments by transportation routes, time period, origin cities, destination cities, chemical number, chemical class, or any combination of these categories.

3. To identify the most hazardous routes in the state by means of conducting a risk analysis.

Described in this paper are the data collection process, design of the DBMS, the statistical results for 1984, and the risk analysis approach.

Data Collection Process

The Arizona Department of Health Services made available to the research team the original manifests as filed by the generators and the transporters of hazardous waste. Data were collected for the years 1983 and 1984. The manifest allows up to four chemicals to be listed. If more than four chemicals are transported per shipment, a continuation form is attached to the main form.

A total of 2,539 manifests were recorded for 1984, of which 18 shipments contained empty drums. Initial processing of 1983 data revealed that the numbers of shipments during both years are almost equal.

Design of the DBMS

During the early stage of the research, microcomputers were chosen as the data processing tool instead of mainframe computers for two reasons: (a) they are available and accessible by most state agencies, and (b) the transferability of the data base on mircrocomputers is easier and more convenient than on mainframe computers. An IBM-PC/XT with 640 K Random Access Memory was utilized for data processing and an external peripheral (Bernoulli Box) was used to back up the data on a cartridge disk. DBASE III was used to generate the data base. A sample record of the file developed is shown in Figure 1 (note: the computer record shown in Figure 1 has been retyped). A set of programs was developed to permit the user to add more manifests to an existing file, check the EPA identification number for generators and transporters, and search for all possible routes between each origin city and all possible destination cities. They are considered as utility programs to assure accurate data development.

The statistics report option allows the user to query statistics according to the following criteria:

1. By time period:
   - Year (1984, 1983, etc.),
   - Month (January, February, etc.),
   - Date (4/13/1984, etc.),
   - Day of week (Sunday, Monday, etc.);
2. By origin (city) of the chemical;
3. By destination (city) of the chemical;
4. By chemical number (9189, 1760, etc.);
5. By company (EPA identification number);
6. By chemical class (explosive, corrosive, etc.); and
7. By transportation route (any route of the 82 routes identified).

****MANIFEST OF WASTE MATERIAL****

MANIFEST No. 84055
SHIP DATE 06/18/84

GENERATOR EPA id	AZD054408794			
TRANSPORTOR EPA id	CAD008302903	OTHER TRANSPORTOR		
T/S/D EPA id	CAD008302903			
	NAME	LB	GAL	CLASS
CHEMICAL	1593	0	676	ORM-A
	2831	0	1140	ORM-A
	9189	0	1300	ORM-E

TAG

FIGURE 1 Sample of DBMS computer record.

The user may use the AND and OR options with the criteria just listed. The AND option provides a cross tabulation of two or more criteria. For example, a report can be created for the month of May and by chemical number 1760. This report will contain information related to shipments containing only number 1760 and shipped during the month of May. The OR option sums up the data of two criteria. For example, a report can be created for Saturday OR Sunday. Such a report will contain the total weekend shipments.

The statistics report contains the total weight (in pounds), the total volume (in gallons), the number of manifests being processed, and the number of shipments, totaled for the selected criteria. No conversion factors were made to convert volumes to weights. Figure 2 shows a display of a sample run of the data base (note: the sample run shown in Figure 2 has been retyped).

Statistical Results for 1984

Fifty links and 82 routes were identified for hazardous waste shipments. The annual truckloads of hazardous wastes by route were derived and are shown in Figure 3. As the plot indicates, Interstate 10 west of Phoenix, between Ehrenberg and Phoenix, carries the highest number of truck loads. This is as expected because almost all hazardous waste shipments travel on this highway en route to California, where most of the disposal facilities used by Arizona firms are located. The link that connects Tucson and Phoenix is second in ranking because waste generated from Tucson's industries has to go through Phoenix either for reprocessing or en route to California.

The program was used to generate statistical reports by time period and chemical numbers for the year 1984. The total number of loaded shipments was found to be 2,521 shipments--totaling approximately 9,457 tons and 2,464,767 gal. Figure 4 shows a display of the total number of shipments by month of year. It was observed that July and August had the highest number of shipments; their shares were 9.9 percent and 11.3 percent of the total year shipments, respectively.

The distribution of the number of shipments by day of week was derived, and the plots (shown in Figure 5) showed that Tuesday had the highest number of shipments (25.1 percent of the total number of shipments) and the weekend had the lowest. Statistics of this type could be of assistance to the Department of Public Safety in scheduling enforcement programs on the state highway system.

The distribution of shipments by chemical number was developed, and it was concluded from the results that chemical number 9169 and chemical number 1993 collectively constituted almost two-thirds of all the shipments (Figure 6). According to the 1984 Emergency Response Guidebook, chemical number 9169 is defined as hazardous waste in general, whereas chemical number 1993 included 11 different types of chemicals such as combustible liquid, weed killer, cosmetics, creosote, ethyl nitrate, flammable liquid, fuel oil, insecticide, solvent, tar, and wax (7). The guidebook provides instructions on how to handle a hazardous spill and lists emergency action that should be implemented by the HAZMAT team regarding fires, evacuation of the public, and other necessary activities. Statistics provided by the DBMS related to the most frequent chemical being transported on the highways can aid in planning a successful emergency response program.

An origin-destination analysis was conducted to trace shipment flows within and out of Arizona. It was found that shipments originating and terminating within the metropolitan areas of Phoenix and Tucson amounted to 1,082 and 116 shipments for 1984, respectively, which represented approximately 48 percent of all shipments. These intraurban movements represent shipments generated from a company and transported to a processing storage facility before they are sent out to be disposed.

The origin-destination analysis showed that 754 shipments originated from Arizona and were sent outside the state (internal-external), 40 shipments represented external-internal movements, 10 shipments were external-external movements, and 1,623 shipments represented internal-internal movements. As mentioned earlier, intraurban shipments (Phoenix and Tucson) were responsible for 1,198 out of the 1,623 shipments in the internal-internal categories (74 percent of the total).

Closer examination of shipments originating or terminating in Phoenix indicated the following:

- A total of 539 shipments left Phoenix for out-of-state destinations.
- A total of 385 shipments left Phoenix for in-state destinations.

A total of 924 shipments left Phoenix in 1984. On the other hand, 54 shipments destined for Phoenix from other localities plus the 1,082 intraurban shipments totaled 1,136 shipments. The difference between the 924 figure and the 1,136 figure represents the reduction in number of shipments due to intermediate waste processing or assembly that took place in some of the Phoenix facilities. Furthermore, the 539 shipments that left Phoenix for out-of-state destinations were heading to disposal sites. This figure represents the latent demand for the Mobile disposal facility expected to be opened in Arizona.

The same approach was applied to Tucson; the results were as follows:

- A total of 301 shipments were destined for Tucson from all other cities.
- A total of 116 shipments represented intraurban movement.
- A total of 160 shipments left Tucson for out-of-state destinations.
- A total of 11 shipments left Tucson for in-state destinations.

A total of 417 shipments were destined for Tucson and a total of 171 shipments originated from Tucson, resulting in a reduction of 246 shipments due to processing and storage. The latent demand for the new Mobile site from Tucson is approximately 160 shipments annually.

A final observation resulting from the origin-destination analysis is that the 10 shipments that crossed Arizona without stopping (external-external movement) originated from New Mexico and were destined for disposal sites in southern California.

Risk Analysis Approach

Risk assessment involves the measurement of the probability and severity of harm inherent in exposure to a hazardous object or event. Risk assessment is a scientific activity and should be distinguished from judging safety. By providing objective measures or rankings of risk, it is the purpose of a risk assessment to provide empirical, scientific data so that the subjective process of judging the relative safety of various options can be performed on an informed basis.

```
                                                            MAIN DATABASE : mal
******** Main Menu ********

   1> Statistic Report
   2> Database Diagnosis
   3> Switch Database
   4> Re-index Database
   5> Exit

Is route-links related query involved?
(Say no for fast execution)         N

              1> By Time Period
              2> By Chemical Original City
              3> By Destination City
              4> By Chemical Number
              5> By Company
              6> By Chemical Class
              7> By Shipment Route

Select criteria to be used ->       1

                                                            MAIN DATABASE : mal
                                                                    Select time unit
                                                                     1> By year
                                                                     2> By month
                                                                     3> By day
                                                                     4> By week day
                                                                 => 4
              1> By Time Period      *
              2> By Chemical Original City
              3> By Destination City
              4> By Chemical Number
              5> By Company
              6> By Chemical Class
              7> By Shipment Route

                                                            MAIN DATABASE : mal
Specify Week Day ( 1(Sun),2(Mon),.. 7 )
=>     1

              1> By Time Period      *
              2> By Chemical Original City
              3> By Destination City
              4> By Chemical Number
              5> By Company
              6> By Chemical Class
              7> By Shipment Route

                                                            MAIN DATABASE : mal
-- Current Criteria --
dow(SHIP_DATE) = 1    (Sunday)

              1> By Time Period      *
              2> By Chemical Original City
              3> By Destination City
              4> By Chemical Number
              5> By Company
              6> By Chemical Class
              7> By Shipment Route

Any other criteria to be used ( Y/N ) ?
( Statistic criteria can be multichoosed )
=>     N

                                                            MAIN DATABASE : mal
-- Selected Criteria --
dow(SHIP_DATE) = 1    (Sunday)

Total weight                           235240 lbs
Total volume                           128010 gals
Number of records processed                60
Number of shipments                        60

< Type any key to return to the main menu >
```

FIGURE 2 Sample run of the DBMS.

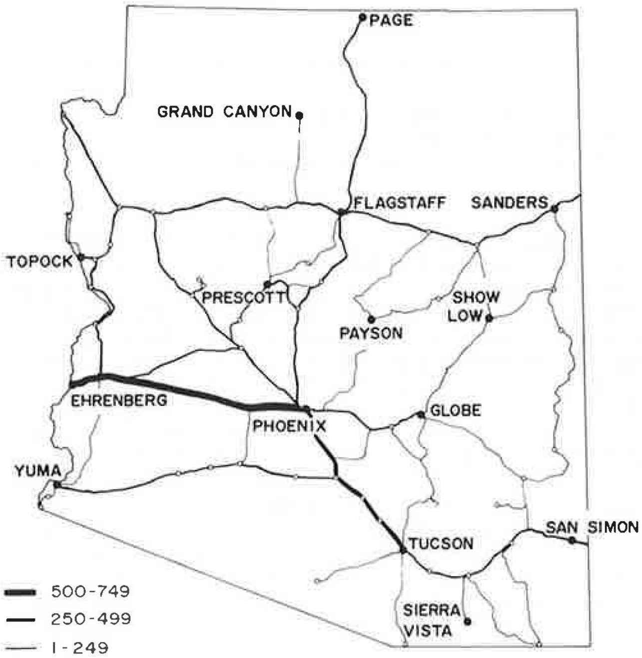

FIGURE 3 Total annual truckloads of hazardous wastes for 1984.

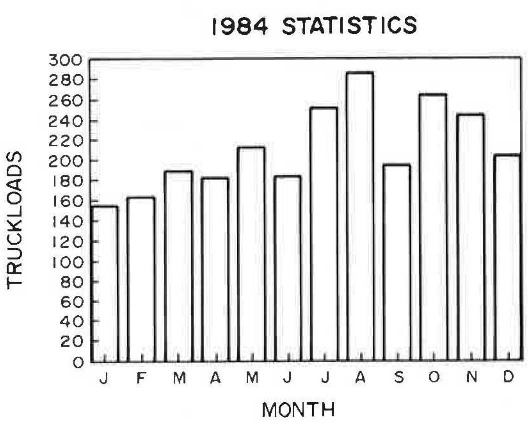

FIGURE 4 1984 shipment classification by month of year.

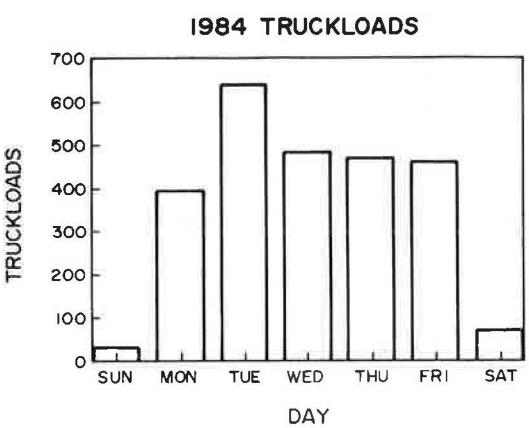

FIGURE 5 1984 shipment classification by day of week.

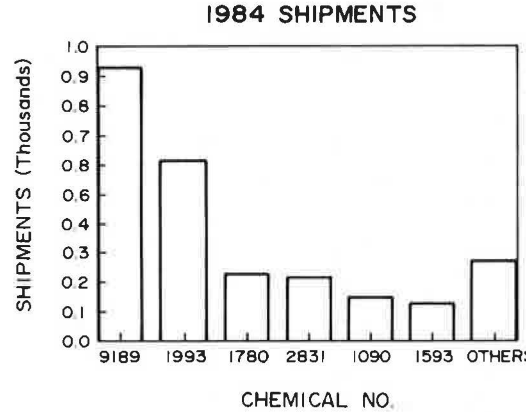

FIGURE 6 1984 shipment classification by selected chemical numbers.

In this section, an empirical risk analysis of transporting hazardous wastes on Arizona highway routes is presented. The objective is to determine risk ratings for routes under study so that transportation routes can be comparatively evaluated regarding level of risk. Such evaluation is crucial for good and sound response planning and implementation to hazardous waste incidents at the state level.

Two factors are identified and used to calculate a risk factor for each route: the first factor represents the probability of a hazardous waste accident for commercial vehicles; the second factor captures the population-at-risk due to a hazardous waste incident. In the next section, the calculations of the two factors and the definition of the final ratings will be described.

Hazardous Waste Accident Probabilities

Four pieces of information were gathered:

1. Highway section length in miles (LENGTH),
2. Daily commercial vehicle traffic volume for 1984 (TRVOL),
3. Number of annual hazardous waste shipments for 1984 (CHEM), and
4. Number of annual commercial vehicle accidents for 1984 (ACCD).

Table 1 gives the four measures for each of the 50 links being considered. The section lengths were measured from the county maps. Average daily traffic (ADT) data as well as the commercial vehicle percentage for each highway were obtained from the ADOT. It was noticed that, for some highways, more than one ADT existed. The worst scenario was assumed, and the highest ADT was used for calculating the daily commercial vehicle traffic.

Concerning the annual accident number, a computer printout showing all accidents that occurred on all Arizona highways in 1984 was provided by ADOT. Those accidents were reported by location (milepost) and severity level. Data on accidents by vehicle type were not available, and therefore it was assumed that the probability of commercial vehicle accidents is directly related to the proportion of commercial vehicle traffic. Percentages of commercial vehicles were then used in conjunction with the accident numbers to calculate the commercial vehicle accident numbers. The number of annual hazardous waste shipments was derived earlier from the computer DBMS.

TABLE 1 Risk Analysis Input Data

	Highway Section Length (mi)	Daily Commercial Vehicle Traffic Volume (TRVOL)	No. Annual Hazardous Wastes Shipments (CHEM)	No. of Annual Commercial Vehicle Accidents (ACCD)
1	33.69	11,700	2,276	60
2	36.7	4,600	734	33
3	9.71	4,410	711	5
4	27.63	4,800	664	23
5	17.88	9,000	565	29
6	12.8	13,490	774	54
7	3.99	3,150	798	2
8	11.83	2,730	792	6
9	18.72	2,730	792	10
10	74.36	2,520	793	42
11	19.09	3,060	795	2
12	86.47	1,700	50	18
13	19.47	780	50	4
14	12.91	1,275	50	4
15	32.26	1,888	50	5
16	26.65	1,706	50	6
17	14.58	4,840	28	10
18	20.71	3,520	28	17
19	38.15	2,940	28	22
20	50.21	3,395	28	27
21	33.49	480	9	26
22	45.55	2,420	92	33
23	15.39	1,692	4	3
24	18.17	464	7	1
25	39.35	624	4	5
26	35.4	200	4	1
27	23.41	136	8	1
28	46.52	330	8	5
29	31.55	198	2	2
30	70.93	720	2	10
31	61.62	3,300	83	51
32	15.75	2,860	83	12
33	24.68	2,200	64	8
34	89.58	1,820	1	2
35	61.68	1,440	1	8
36	22.96	1,870	2	10
37	51	2,850	39	30
38	62.72	2,646	39	38
39	16.35	1,000	7	2
40	39.78	1,470	7	10
41	40.37	1,710	2	27
42	44.91	750	2	4
43	24.38	33	1	1
44	54.58	378	1	9
45	9.25	1,400	23	4
46	4.02	90	6	0
47	11.7	25	6	0
48	138.91	1,540	24	20
49	80.35	1,330	17	6
50	23.82	1,692	2	15

An index PRO that combines the four measures was developed:

PRO = (ACCD X CHEM)/(LENGTH X TRVOL)

A higher number of accidents and a higher number of shipments produce higher values of PRO. Furthermore, short sections and low commercial vehicle volume produce higher values of PRO, and a higher risk factor should be associated with these conditions. The calculations of the PRO factor showed a range of between 0.000012 and 0.3460. Three arbitrary levels of risk were assumed:

High risk	PRO > 0.03
Intermediate risk	$0.03 \geq PRO \geq 0.01$
Low risk	PRO < 0.01

To assess the three levels of risk, arbitrary ratios of 1:5:10 were used to represent high, intermediate, and low risk, respectively. A PROB index was assumed to take the values of 70, 35, and 7 for the three levels of risk.

Population-at-Risk Factor

Two types of population-at-risk were identified:

1. Permanent population living near the transportation route and
2. Drivers and passengers of vehicles on the roads.

The first measure was obtained from the 1980 census data. The boundaries were defined by an evacuation distance of 3 miles on either side of a route and along the route, per mile length. The vehicular traffic at risk was estimated by using basic principles of traffic flow theory. Traffic flow (vehicles per hour) is equal to traffic density (vehicles per mile) times the average operating speed (miles per hour). The ADT per link being known, it was assumed that the peak-hour traffic is 8 percent of ADT. The traffic density was then calculated for each section, and a vehicular occupancy factor of 1.3 was assumed. The two population-at-risk measures, population (POPS) and number of passengers (PSGR), are given in Table 2. The sum of the two measures ranged between 101,273 persons per mile and 11 persons per

TABLE 2 Risk Analysis Results

	Population (POPS)	No. of Passengers (PSGR)	Rating (RTG)	Risk
1	101,070	203	220	1
2	2,419	35	145	2
3	867	36	145	2
4	2,175	42	145	2
5	26,328	78	220	1
6	38,400	123	220	1
7	537	26	145	2
8	675	23	85	3
9	883	23	85	3
10	1,192	21	85	3
11	1,550	31	110	3
12	9,778	17	82	3
13	235	9	50	4
14	790	9	50	4
15	976	10	22	5
16	7,527	10	82	3
17	359	0	22	5
18	1,857	28	82	3
19	3,561	24	82	3
20	2,525	17	22	5
21	2,675	21	110	3
22	509	38	50	4
23	311	10	22	5
24	789	10	22	5
25	1,043	14	22	5
26	786	17	22	5
27	3,535	6	82	3
28	209	6	22	5
29	51	6	22	5
30	688	16	22	5
31	4,816	26	110	3
32	535	24	50	4
33	3,490	19	82	3
34	1,212	23	22	5
35	8,040	28	82	3
36	214	19	22	5
37	6,728	26	82	3
38	4,054	19	22	5
39	5,589	43	82	3
40	5,078	36	82	3
41	2,369	33	22	5
42	2,625	26	22	5
43	62	1	22	5
44	147	3	22	5
45	789	10	22	5
46	233	2	22	5
47	11	0	22	5
48	3,671	24	22	5
49	241	33	22	5
50	591	10	22	5

mile. The same ratio (1:5:10) was applied and a PORSK index was assumed to make the following values:

(POPS + PSGR)	PORSK
< 100	15
100-500	75
> 500	150

Ratings and Risk Factors

The two factors PROB and PORSK were summed to produce RTG, and its value ranged between 22 and 220. Five levels of risk were assumed:

Risk = 1 (high)	$RTG \leq 40$
Risk = 2	$40 < RTG \leq 80$
Risk = 3	$80 < RTG \leq 120$
Risk = 4	$120 < RTG < 160$
Risk = 5 (low)	$RTG \geq 160$

The results of the risk levels are given in Table 2. As expected, links 1, 5, and 6 had the highest risk because they are located within the Phoenix and Tucson metropolitan areas. Links 2, 3, 4, and 7 are second highest. Links 2, 3, and 4 represent the route between Phoenix and Tucson on Interstate 10, and link 7 connects Phoenix with California on Interstate 10. Figure 7 shows a display of the risk levels of the 50 links; a comparison of Figure 3 and Figure 7 would show the direct correlation between the number of shipments and the risk level.

SUMMARY AND CONCLUSIONS

Data on hazardous waste shipments in Arizona were collected for the years 1983 and 1984. These data were extracted from official manifests made available by the Arizona Department of Health Services. DBASE III was utilized on an IBM-PC/XT to develop a DBMS for the 1984 hazardous waste data.

The DBMS was utilized to generate statistical reports on month of year, day of week, and selected chemical numbers. An origin-destination analysis was conducted to trace hazardous waste shipments within Arizona.

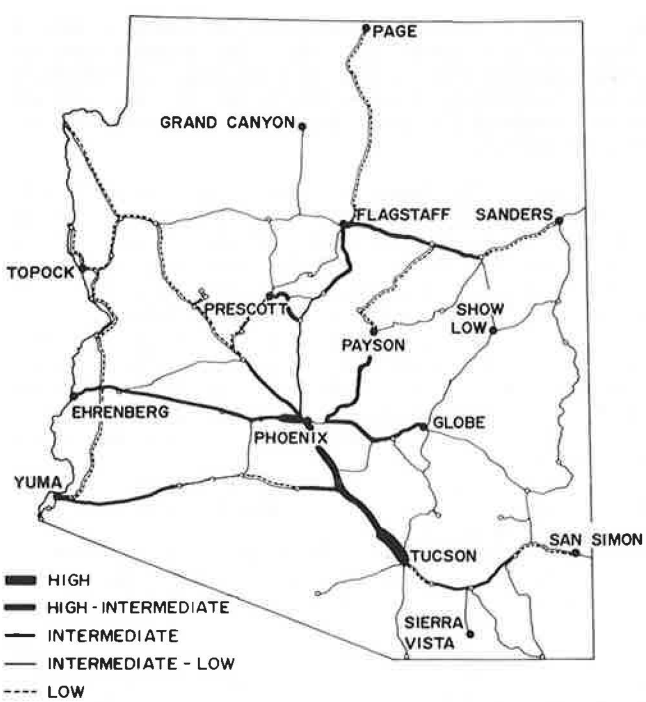

FIGURE 7 Map showing risk levels of the 50 lines.

A risk analysis was conducted to assess the risk levels of selected links on the transportation routes. Data on link lengths, commercial vehicle traffic volume, commercial vehicle accidents, number of hazardous waste shipments, population-at-risk factor, and passenger-at-risk factor were collected for all 50 links to conduct the risk analysis.

Several conclusions were reached:

1. The use of DBMS computer software provided a powerful and easy approach for data storage, retrieval, and analysis.
2. In 1984, 2,521 shipments occurred, totaling 9,457 tons plus 2,464,767 gal of wastes in Arizona for 1984.
3. August and October had the highest number of shipments, with shares of 9.9 percent and 11.3 percent of the 1984 total shipments, respectively.
4. Tuesday had the highest number of shipments, representing 25.1 percent of the total shipments, and the weekend had the lowest share.
5. Chemicals identified as numbers 9189 and 1993 collectively represented almost two-thirds of all 1984 shipments.
6. Intraurban shipments with Phoenix and Tucson metropolitan areas collectively constituted 48 percent of all shipments.
7. The origin-destination analysis of the 1984 data provided valuable information on waste movements within and across Arizona.
8. It was concluded based on the risk analysis that the highway links located within the Phoenix and Tucson metropolitan areas had the highest risk factors. The lines with the second highest risk factors were found to be located on the route between Phoenix and Tucson, and the links that connect Phoenix with California on Interstate 10.

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Incidence, Regulation, and Movement of Hazardous Materials in New Jersey

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ABSTRACT

The New Jersey Department of Transportation adopted regulations governing the transportation of hazardous materials by truck and rail, as mandated by the state legislature; these regulations took effect on March 18, 1985. Concomitantly, the state initiated steps to find out as much as possible about the movement of hazardous materials in New Jersey, in addition to the frequency and severity of hazardous material incidents in the state. Described are the incidence and means of hazardous materials transportation in New Jersey. Tonnage estimates of hazardous materials transported by rail, truck, air, and water were developed from 1982 TRANSEARCH data. Intrastate tonnage of hazardous materials was estimated at 31.9 million tons; interstate inbound tonnage of hazardous materials was estimated at 21.5 million; and interstate outbound hazardous material tonnage approximated 32.1 million tons. Hazardous material tonnage represented approximately 45 percent of all freight tonnage. Between 1971 and 1984 (the period during which these data were recorded), 3,417 hazardous material incidents were recorded to have taken place in New Jersey. Six deaths, 335 injuries, and $3.3 million in damages were reported during this time period. Most of the incidents (91 percent) were related to the highway mode of travel; 7 percent were related to rail transport. New Jersey also originated 10,746 shipments involved in incidents occurring elsewhere across the nation. The majority of these incidents were due to human error (44 percent) or package failure (22 percent). Only 2 percent were the result of vehicular accidents or derailments.

The New Jersey State Legislature, pursuant to N.J.S.A. 39:5B-25 et seq., provided for the adoption of regulations governing the transportation of hazardous materials. The legislation required the New Jersey Department of Transportation (NJDOT) to promulgate rules and regulations in substantial conformance with the federal requirements contained in Title 49 of the Code of Federal Regulations (C.F.R.), Parts 100 to 199. NJDOT was further directed to consult with all appropriate state departments and agencies during this process.

As a result of the developmental process incurred in promulgating the regulations, several additions and modifications to the original legislation were identified by NJDOT and the New Jersey State Police. The statutory needs were brought to the attention of the state legislature, which passed the necessary legislation, effective January 1986.

New Jersey's Hazardous Material Regulations were developed using a three-phase strategy. First, because hazardous materials transportation involved a new area of expertise within NJDOT, advanced technical training was undertaken to develop a working knowledge of the federal regulations. Second, a broad frame of reference was defined in order to set priorities and identify the problems that most likely would need to be addressed by a hazardous materials safety program. Finally, a forum was established within the state; this forum included agencies involved with, or affected by, the proposed action. All three phases occurred concurrently, and are still active and available for response to specific needs.

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REGULATIONS

New Jersey's Hazardous Materials Regulations became effective on February 11, 1985. The state's regulations embrace the federal regulations, specifically 49 C.F.R.--Transportation, Parts 100 to 199, revised as of November 1, 1983. In summary, those sections adopted include

1. Part 171, General Information, Regulations, and Definitions. (Note: Sections 171.15 and 171.16 were modified, and Sections 171.1, 171.4, 171.5, 171.10, and 171.20 were excluded from adoption.)
2. Part 172, Hazardous Materials Table and Hazardous Materials Communications Regulations.
3. Part 173, Shippers--General Requirements for Shipments and Packagings. (Note: Section 173.118a and applicability to Section 173.24 were modified; Section 173.32 was excluded from adoption.)
4. Part 174, Carriage by Rail. (Section 174.8 was omitted.)
5. Part 177, Carriage by Public Highway. [Appendix A and Section 177.825(a),(b),(c), and (e) were excluded from adoption.]
6. Part 178, Shipping Container Specifications.
7. Part 179, Specifications for Tank Cars. (Sections 179.3, 179.4, and 179.5 were omitted.)

The regulations define the commodities that constitute a hazard to the general public and prescribe conditions under which they may be transported. When a commodity is defined within a particular hazard class, such as a Poison B or an Explosive A, shippers originating the material and carriers transporting the material must comply with specific requirements pertaining to shipping papers, packaging, labeling, marking, placarding, signed certifications, loading and storage specifications, blocking and bracing requirements, and so forth. The regulations define standards that ensure that the materials remain safely contained while in transit. Hazardous materials demand that strict packaging and containerization requirements be met so that the public is adequately safeguarded.

New Jersey's Hazardous Material Regulations will be used in conjunction with the federal regulations. The intent is to create state requirements that are in substantial conformance with federal rules. States authorities are preempted by the federal government in regulating the transportation of hazardous materials. Uniformity is a key objective in national efforts aimed at cooperative enforcement and reciprocity. Uniformity is also desirable to achieve compliance from the motor carrier industry. Without endorsing national accepted standards, New Jersey or any other state would experience difficulty in achieving high levels of compliance. By adopting uniform standards, New Jersey can anticipate support for enforcement efforts from both the public and private sectors.

REGULATORY DATA: HOW NEW JERSEY COMPARES

The federal Hazardous Materials Transportation Act of 1974 was intended "to regulate commerce by improving the protections afforded the public against risks connected with the transportation of hazardous materials. Operating under the premise that a knowledgeable regulated public will comply with the hazardous materials safety regulations. . ." (1). The U.S. Department of Transportation has sought to promote public safety while concomitantly saving industry the burden of complying with unnecessarily stringent or duplicative regulations.

In 1981, the State Hazardous Materials Enforcement Development (SHMED) Program was established to encourage states to assume a larger share of the responsibility for enforcement of regulations governing hazardous materials transportation. This program has provided financial and technical incentives to encourage states to adopt and enforce federal regulations. The prime objective of this effort has been to achieve "the uniform application of a single national set of regulatory standards for both interstate and intrastate movement of hazardous materials" (1). Approximately 25 states have received funding through the SHMED Program. New Jersey did not qualify for this program and therefore has not been a program participant. The phasing out of SHMED's financial program began during fiscal year 1984 and will end during fiscal year 1987.

To date, most states have adopted the federal hazardous material regulations, particularly 49 C.F.R., Parts 171, 172, 173, 177, and 178. According to the Bureau of Motor Carrier Safety, another five states have similar rules and only seven states have no regulations on this subject (as of August 6, 1984).

The federal Motor Carrier Safety Assistance Program (MCSAP), although broader in scope, is a logical extension of the SHMED Program. Established by Congress in the Surface Transportation Assistance Act of 1982, MCSAP is designed to encourage states to adopt not only uniform federal hazardous material regulations, but also requires states to adopt the Federal Motor Carrier Safety Regulations, 49 C.F.R., Parts 386 and 388 through 399, or alternatively to provide an official legal opinion from the State's Attorney General that the state embraces similar rules and regulations.

State participation in the adoption of Federal Motor Carrier Safety regulations is less comprehensive than for hazardous material regulations. State endorsement varies with each part of the federal regulations, although a majority of states have adopted Parts 391 through 397 (as of August 6, 1984, according to the Bureau of Motor Carrier Safety).

In October 1984, the U.S. Congress passed the Motor Carrier Safety Act of 1984. This Act includes additional initiatives directed toward requiring uniform commercial motor vehicle safety standards nationwide and strengthening of enforcement efforts. The Act requires that "no state may have in effect or enforce with respect to commercial motor vehicles any State law or regulation pertaining to commercial motor vehicle safety which the Secretary finds under this section, may not be in effect and enforced." This provision will take effect within 5 years. In the meantime, the U.S. Department of Transportation is directed to review all state statutes, rules, regulations, and standards. The U.S. Secretary of Transportation will then rule on the consistency of these provisions.

COMMODITY FLOWS OF HAZARDOUS MATERIALS IN NEW JERSEY

Hazardous material movements were estimated from the 1982 TRANSEARCH data base developed by Reebie Associates of Greenwich, Connecticut. Tonnage estimates were available for the rail, truck, and water transport modes. The data presented included only movements that had either an origin or destination in New Jersey. It did not include commodity movements passing through the state or international shipments originating or terminating in the state.

Commodity movements considered hazardous totaled 85.4 million tons during 1982. Approximately 32.1 million tons of hazardous materials moved outbound from New Jersey by truck, rail, or water; approximately 21.4 million tons of hazardous materials entered the state; and 31.9 million tons had both an origin and destination within the state (see Table 1).

Hazardous material tonnage represented 45 percent of all freight tonnage. Water transport was dominated by hazardous materials (commonly referred to as hazmats), comprising 71 percent of total water-

TABLE 1 1982 Hazardous Material Tonnage and Total Freight Tonnage in New Jersey

	Rail	Truck	Water	Total
Hazardous Material Tonnage (millions)				
Interstate inbound	2.9	3.2	15.3	21.4
Interstate outbound	1.4	3.1	27.6	32.1
Intrastate	0.4	1.7	29.8	31.9
Total Hazardous Materials (tons)	4.7	8.0	72.7	85.4
Total Freight Tonnage (millions)				
Interstate inbound	12.6	32.9	18.1	63.6
Interstate outbound	4.3	24.1	31.2	59.6
Intrastate	0.7	11.8	53.7	66.2
Total Hazardous Materials	17.6	68.8	103.0	189.4
Hazardous Material Tonnage as Percentage of Total New Jersey Freight Tonnage				
	27	12	71	45

Source: Reebie Associates, Greenwich, Connecticut, 1982 TRANSEARCH data.

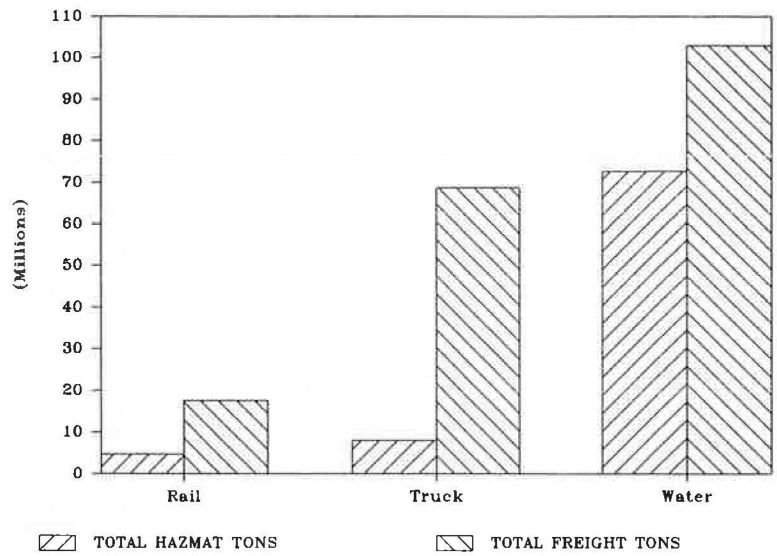

FIGURE 1 Hazardous material tonnage by mode compared with total freight tonnage.

borne traffic in New Jersey. Proportionally more hazardous materials were transported by rail (27 percent of total rail tonnage) than by truck (12 percent of total truck tonnage). Actual hazmat tonnage by truck, however, was close to twice that of rail (8 million tons compared with 4.7 million). Figure 1 shows a comparison of hazardous material tonnage and total freight by model.

Of the total interstate tonnage inbound to New Jersey (hazardous and nonhazardous), 34 percent was designated as hazardous. The majority of this freight moved by water (71 percent); 14 percent moved by rail; and 15 percent was shipped by truck. Over one-half (54 percent) of the interstate outbound traffic was classified as hazardous. This traffic also moved predominantly by water (86 percent) as opposed to truck (10 percent) or rail (4 percent). Close to one-half (48 percent) of the interstate tonnage transported (by all modes) involved hazardous materials.

Table 2 gives hazardous material tonnage by commodity type (Standard Transportation Commodity Code). Petroleum and coal products predominate, making up 81 percent of hazmat tonnage movements by all modes. Chemicals comprise the second largest category, representing 10 percent of hazardous material tonnage; crude petroleum, natural gas, and gasoline make up 5 percent of the shipments.

TABLE 2 1982 Hazardous Material Tonnage in New Jersey by Standard Transportation Commodity Code

		Total Tonnage	
STCC No.	STCC Classification	No.	Percent
		(In Millions)	
29	Petroleum or coal products	69.7	81
28	Chemicals or allied products	8.8	10
13	Crude petroleum, natural gas, or gasoline	4.1	5
49	Hazardous material (specially classified)	2.3	3
	All other	0.5	1
Total		85.4	100

Note: Includes rail, truck, and water modes.

Source: Reebie Associates, Greenwich, Connecticut, 1982 TRANSEARCH data.

The majority of hazardous material tonnage inbound to New Jersey originates from two regions: the Middle Atlantic section, comprised of New York and Pennsylvania; and the West-South-Central portion of the United States, which includes Arkansas, Louisiana, Oklahoma, and Texas. Substantial hazmat tonnage also originates from the South Atlantic region.

The majority of hazardous material tonnage outbound from New Jersey is destined for New England; the second major destination is New York or Pennsylvania. Substantial hazmat tonnage is also shipped to the south Atlantic region. Figure 2 shows the distribution of both origins and destinations for all hazmat tonnage movements.

HAZARDOUS MATERIAL INCIDENTS

The U.S. Department of Transportation, pursuant to 49 C.F.R. Part 171, requires interstate carriers and shippers to report in writing any unintentional release of hazardous materials from a package or container (including a tank). A report is also required for any quantity of hazardous waste that has been discharged during transportation as a result of accidents, leaks, spills, and so forth. Transportation is broadly defined to include loading and unloading, as well as temporary storage. Reports are also required if, as a direct result of an accident involving hazardous materials, any one of the following circumstances occur:

- A person is killed.
- A person receives injuries requiring hospitalization.
- Estimated carrier or other property damage exceeds $50,000.
- Fire, breakage, spillage, or suspected contamination occurs involving shipments of radioactive material or etiologic agents.
- A situation exists of such a nature that, in the judgment of the carrier, it should be reported even though it does not meet the preceding criteria.

All reports are submitted on form DOT F 5800.1 and are entered into the hazardous materials data base, formally referred to as the Hazardous Mate-

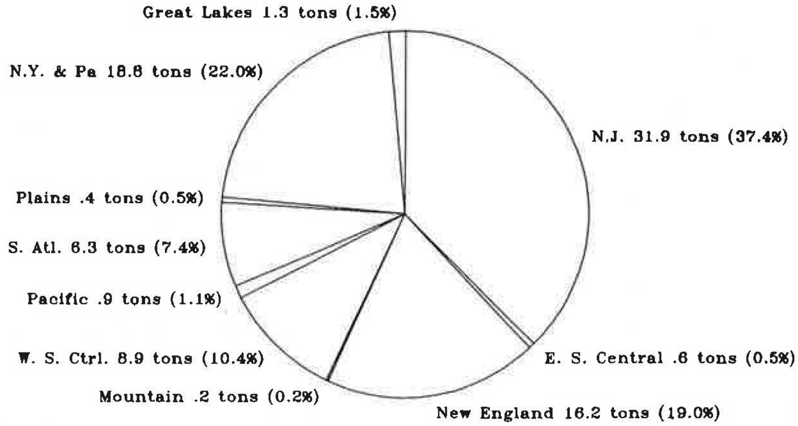

FIGURE 2 1982 origins and destinations of New Jersey hazardous material tonnage.

rials Incident Reporting System (HMIRS). This data base is maintained by the Materials Transportation Bureau at the U.S. Department of Transportation. States may access the information directly by modem to obtain information. Records date back to 1971, although the records are less complete for the first several years. Annual comparisons are further complicated by a change in the reporting requirements effective January 1, 1981. Fewer incidents were reported after this date, due at least in part to less stringent reporting requirements.

The ensuing analysis is based on data on hazardous material incidents retrieved from the HMIRS. Descriptive indicators are available for all states. The focus of this analysis is New Jersey, in relation to other states and the nation as a whole. Some of the more important indicators are

- Mode of travel,
- Consequence of incident,
- Cause of incident,
- Incident location,
- Origin and destination of incident shipment,
- Commodity types involved, and
- Reasons for the release of hazardous materials.

New Jersey Compared with the Nation

Between 1971 and the end of 1984, 3,417 incidents were recorded to have taken place in New Jersey. This statewide total can be compared with a nationwide total of 142,348 incidents occurring during the same time period. These incidents represent 2.4 percent of all incidents occurring nationally. Table 3 gives a list of the 20 states with the highest number of reported incidents occurring between 1971 and 1984; New Jersey ranks 16th. The five states with the highest reported incident levels are Pennsylvania, Ohio, Illinois, Texas, and California.

Of those incidents occurring in New Jersey, 38 percent involved shipments originating within the state (Table 4). Other states' originating shipments involved in New Jersey hazardous material incidents included 9 percent from New York, 8 percent from Pennsylvania, 6 percent each from Illinois and Ohio, and 4 percent from Texas.

New Jersey originated substantially more shipments involved in hazardous material incidents that occurred elsewhere across the country. As the data in Table 5 indicate, New Jersey ranks third in originating shipments that are later involved in hazardous material incidents. Out of 142,348 incidents oc-

TABLE 3 States with Highest Number of Hazardous Material Incidents Reported (1971-1984)

Rank	State	Total No. of Incidents	Percent Highway Related	Percent Rail Related
1	Pennsylvania	13,944	96	3
2	Ohio	9,865	95	4
3	Illinois	7,590	84	15
4	Texas	7,309	77	21
5	California	6,622	77	20
6	New York	6,290	93	4
7	Tennessee	5,895	84	5
8	North Carolina	5,594	93	6
9	Georgia	5,506	91	9
10	Missouri	5,091	96	4
11	Michigan	5,079	93	6
12	Indiana	4,413	93	6
13	Wisconsin	3,991	98	2
14	Florida	3,799	82	17
15	Virginia	3,596	94	5
16	New Jersey	3,417	91	7
17	Alabama	3,144	83	16
18	Louisiana	2,893	78	18
19	South Carolina	2,526	93	7
20	Minnesota	2,462	93	5
	All Other	33,322	–	–
Total		142,348	89	9

Source: Hazardous Materials Incident Reporting System, Materials Transportation Bureau, U.S. Department of Transportation.

TABLE 4 States Originating the Most Hazardous Material Incidents Occurring in New Jersey (1971-1984)

Originating State	No. of Incidents	Percent of Incidents Occurring in New Jersey
New Jersey (intrastate)	1,309	38
New York	315	9
Pennsylvania	272	8
Illinois	219	6
Ohio	205	6
Texas	139	4
Michigan	94	3
Connecticut	87	3
Massachusetts	73	2
Maryland	69	2
Missouri	67	2
West Virginia	51	2
All Other	517	15
Total incidents in New Jersey	3,417	100

Source: Hazardous Materials Incident Reporting System, Materials Transportation Bureau, U.S. Department of Transportation.

TABLE 5 Originating State for Nationwide Hazardous Material Incidents (1971-1984)

Originating State	No. of Incidents
1 Illinois	12,623
2 Ohio	12,073
3 New Jersey	10,746
4 Texas	10,387
5 Pennsylvania	8,244
6 California	7,478
7 New York	6,908
8 Michigan	6,741
9 Georgia	6,304
10 Missouri	6,143
11 Tennessee	3,762
12 Indiana	3,743
13 Louisiana	3,117
14 North Carolina	3,089
15 Wisconsin	2,917
16 Minnesota	2,895
17 Florida	2,701
18 Kentucky	2,665
19 Massachusetts	2,651
20 Kansas	2,420
All Other	24,741
Total	142,348

Source: Hazardous Materials Incident Reporting System, Materials Transportation Bureau, U.S. Department of Transportation.

curring nationwide between 1971 and 1984, 10,746 or 7.5 percent were shipments that originated in New Jersey. Only Illinois and Ohio generated more incident-related shipments.

Profile of New Jersey Incidents

The HMIRS data base recorded 3,417 hazardous material incidents occurring in New Jersey between 1971 and 1984. A high percentage of the incidents occurred while in transit by motor carrier (91 percent), and 7 percent occurred while being transported by rail. Less than 1 percent were related to either air or waterborne transportation. New Jersey's modal split was similar to that of the nation (Table 6).

Almost one-half of the incidents occurring in New Jersey were caused by human error; 25 percent were due to package failure; and 3 percent were a result of vehicular accidents or derailments. Cause of incidents was similarly distributed at the national level (Table 7). At both the state and national levels, the majority of incidents resulted in spillage (Table 8).

TABLE 6 New Jersey and National Incidents by Mode (1971-1984)

	New Jersey Incidents		National Incidents	
Travel Mode	No.	Percent	No.	Percent
Air	19	<1	1,822	1
Highway (for hire)	2,924	86	120,576	85
Highway (private)	179	5	6,723	5
Rail	241	7	12,427	9
Water	23	<1	292	<1
Freight forwarder	20	<1	203	<1
Other	11	<1	305	<1
Total	3,417	100	142,348	100

Source: Hazardous Materials Incident Reporting System, Materials Transportation Bureau, U.S. Department of Transportation.

TABLE 7 Cause of Hazardous Material Incidents in New Jersey (1971-1984)

	New Jersey		National Comparison
Cause	No.	Percent	Percent
Human error	1,630	48	46
Package failure	856	25	20
Vehicular accident or derailment	105	3	4
Other	147	4	4
Unknown	679	20	26
Total	3,417	100	100

Source: Hazardous Materials Incident Reporting System, Materials Transportation Bureau, U.S. Department of Transportation.

TABLE 8 Consequence of Hazardous Material Incidents in New Jersey (1971-1984)

	New Jersey		National Comparison
Result	No.	Percent	Percent
None	34	1	2
Fire	7	<1	<1
Explosion	3	<1	<1
Fire and explosion	1	<1	<1
Spillage	2,799	82	75
Spill and fire	18	1	1
Spill and explosion	1	<1	<1
Spill-fire-explosion	1	<1	<1
Undefined	553	16	22
Total	3,417	100	100

Source: Hazardous Materials Incident Reporting System, Materials Transportation Bureau, U.S. Department of Transportation.

Specific reasons for container failure are given in Table 9. Primary reasons for the unintentional release of hazardous materials were external punctures; loose fittings, valves, or closures; droppage while handling; defective fittings, valves, or closures; damage by other freight; and spills occurring during loading and unloading.

Table 10 gives the hazard classes involved in New Jersey's reported incidents. Almost one-half of the incidents involved hazard classes defined as flammable liquids; 31 percent were related to corrosive materials; combustible liquids comprised 5 percent

TABLE 9 Primary Reason for Release of Hazardous Materials, New Jersey Incidents (1971-1984)

	Primary Reason	
Failure Description	No.	Percent
External puncture of container	549	16
Loose fittings, valves, or closures	404	12
Other conditions, unspecified	322	10
Droppage while handling	294	9
Defective fittings, valves, or closures	252	7
Damage by other freight	248	7
Spills during loading or unloading (tank trucks and trailers)	182	5
Bottom failure	167	5
Body or side failure	82	2
Improper blocking or bracing	70	2
Vehicular accident or derailment	67	2
Internal pressure	64	2
All other conditions	716	21
Total	3,417	100

Source: Hazardous Materials Incident Reporting System, Materials Transportation Bureau, U.S. Department of Transportation.

TABLE 10 Hazard Class Involved in New Jersey Incidents (1971-1984)

Hazard Class	Incidents No.	Incidents Percent
Flammable liquid	1,687	49
Corrosive material	1,063	31
Combustible liquid	177	5
Class B poison	167	5
Oxidizer	82	2
Nonflammable compressed gas	67	2
Flammable compressed gas	57	2
Organic peroxide	31	1
All other	86	3
Total	3,417	100

Source: Hazardous Materials Incident Reporting System, Materials Transportation Bureau, U.S. Department of Transportation.

of the state's incidents; and Class B poisons also made up 5 percent.

Table 11 gives data on New Jersey's hazardous material incidents on an annual basis. The number of incidents varies from 65 in 1971, when incident reporting requirements were initiated, to a high of 380 in 1977. Reporting requirements were made less stringent in 1981, which in part resulted in fewer incidents being reported. The trend in New Jersey's incidents parallels that of the nation as shown in Figure 3.

TABLE 11 Annual Depiction of New Jersey Incidents

Year	No. of Incidents	No. of Deaths	No. of Injuries	Damages ($000s)
1971	65	0	10	1,337
1972	114	1	3	177
1973	208	0	10	40
1974	288	1	11	235
1975	331	1	17	185
1976	352	0	43	123
1977	380	0	94	138
1978	336	0	19	271
1979	331	2	35	252
1980	306	0	56	98
1981[a]	212	1	20	235
1982	178	0	7	60
1983	158	0	4	70
1984	158	0	6	122
Total	3,417	6	335	3,343

Source: Hazardous Materials Incident Reporting System, Materials Transportation Bureau, U.S. Department of Transportation.

[a]Reporting requirement was made less stringent, effective January 1, 1981.

The data in Table 11 indicate that six deaths resulted from incidents involving hazardous materials in New Jersey between 1971 and 1984. This compares with 305 deaths occurring nationwide during the same time period. The number of persons sustaining injury within the state ranges from a low of 3 in 1972 to a

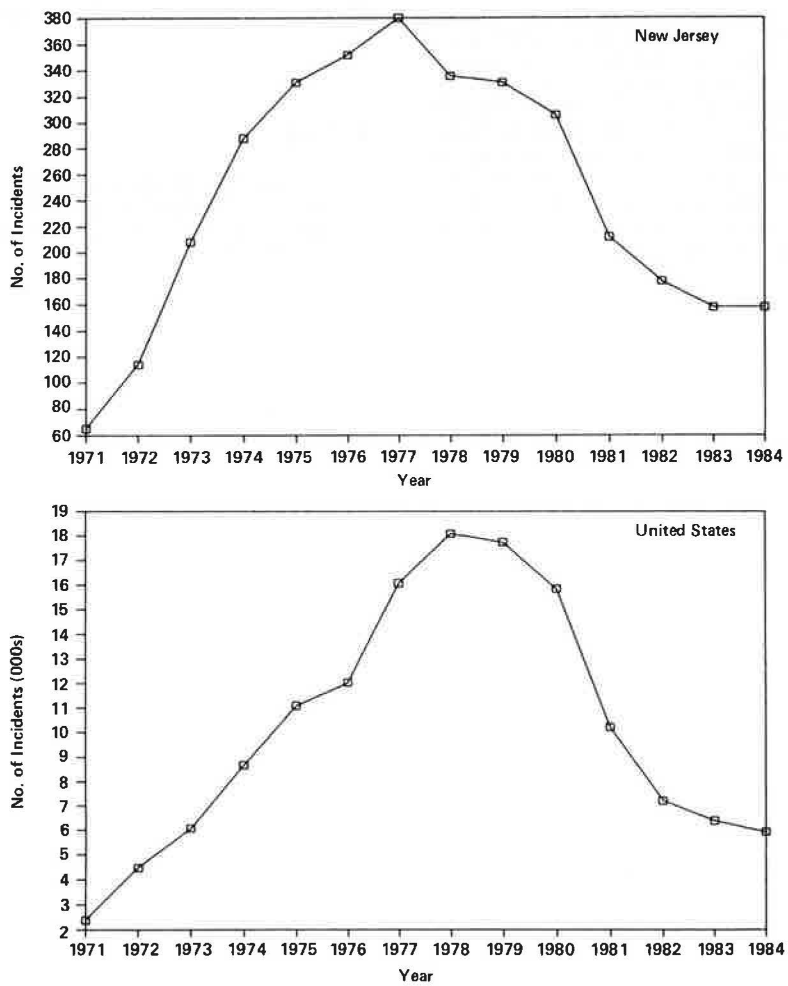

FIGURE 3 Hazardous material incidents in New Jersey and the United States (1971-1984).

high of 94 in 1977. Injuries to date in New Jersey total 335, compared with 8,016 reported nationally. Monetary damages incurred as a result of hazmat incidents in New Jersey range from $40,000 in 1973 to $1.3 million in 1971.

New Jersey has not been the site for any catastrophic hazardous material incident resulting in multiple deaths or major injuries. The public welfare related to hazardous materials transportation is not related to a high rate of incidents as much as it is related to the potential for a catastrophic incident to occur. New Jersey has been able to avoid any such incident. The primary goal of New Jersey's hazardous material regulations is to maintain this record and improve on the existing safety record by further reducing the number of all types of hazardous material incidents.

ENFORCEMENT

Enforcement of New Jersey's Hazardous Materials Regulations is now in progress and is being conducted by the Office of Hazardous Materials Transportation Compliance and Enforcement of the New Jersey State Police. The state's current legislation further authorizes the Port Authority of New York and New Jersey to enforce New Jersey's Hazardous Materials Regulations, as well as authorizing NJDOT to inspect rail equipment used in the transportation of hazardous materials.

NJDOT is also involved with the creation of a data base to monitor hazardous materials enforcement activities. The data base will include violations records and will communicate with other information systems such as the HMIRS, provided by the Materials Transportation Bureau. Communication will also be established with the SAFETYNET system being created by the federal Bureau of Motor Carrier Safety. Ultimately, the data base will be used for impact assessment. Enforcement efforts will be focused as a result of data analyses and targeted to problem locations such as high incident sites and terminals with frequent or flagrant violations.

SUMMARY AND CONCLUSIONS

The transportation of hazardous materials requires constant monitoring in New Jersey and across the nation. Significant quantities of various hazardous materials, substances, and wastes are transported daily throughout New Jersey. Although New Jersey accounted for only 2.4 percent of all hazardous material incidents occurring nationwide, it originated 7.5 percent of all trips resulting in hazardous material incidents nationwide. This statistic is indicative of the large volume of hazardous material tonnage that originates in New Jersey. A comparison of state and national data has not identified any unusual differences unique to New Jersey's hazardous material shipments.

A majority of New Jersey's hazardous material incidents are related to the highway mode of travel; most incidents are caused by human error or package failure. Few incidents are caused by vehicular accidents or derailments. A majority of the state's incidents involve commodity types known as flammable liquids, corrosive materials, combustible liquids, and Class B poisons. Trends depicted in more recent data on New Jersey's hazardous material incidents do not deviate significantly from the state's historical data.

Greater national attention and priority needs to be focused on hazardous material transportation. Of greatest importance is the need for education of those who handle or transport hazardous materials, and those emergency response personnel who must react to incidents involving these materials.

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Information Sources for Flow Analyses of Hazardous Materials

GEORGE LIST, MARK ABKOWITZ, and EDITH PAGE

ABSTRACT

As increasing amounts of hazardous materials are transported in the United States, a significant concern has been the associated risk to public safety and the environment. Although a national reporting system for hazardous materials transport incidents exists, a companion data base on hazardous materials movements does not. Thus, it is difficult to monitor the activity level of hazardous materials movements and to assess the safety of the industry. Identified are potential sources of information to perform flow analyses of hazardous materials; the quality and usefulness of these data bases for diagnostic, policy planning, and evaluative needs are assessed. The study scope includes flow, fleet, and network utilization across the major modes of hazardous materials transport. Several important conclusions are reached about the applicability of existing information, in terms of both the way the information is collected and what it represents. Based on these conclusions, recommendations are made on how information reporting policies and practices can be improved to enhance the capability of analyzing hazardous materials transport.

As increasing amounts of hazardous materials cargo are transported in the United States, the associated risk to public safety and the environment has become a significant and growing concern. In 1971, the Office of Hazardous Materials Transport (OHMT) began collecting data on hazardous materials incidents in the United States. Although the data are often criticized as being unrepresentative, a more glaring problem is the lack of comprehensive information on hazardous materials movements. Little information exists about where these moves occur, what vehicles are employed, and what network elements are used. Because of this deficiency, it has been difficult to monitor the activity level of hazardous materials movements and to assess the safety (i.e., accident and incident rates) of this industry as a whole or the relative safety of different modes and containers.

The purpose of this paper is to identify potential sources of information for performing flow analyses of hazardous materials, and to assess the quality and usefulness of these data bases for diagnostic, policy planning, and evaluative needs. The paper concludes with an assessment of the current analysis environment, and suggests reporting modifications that could enhance the capability of performing flow analyses of hazardous materials.

A COMPLEX ARRAY OF SOURCES

Identifying the array of data bases is a complex task. Not only are there three types of data to consider (i.e., flow, fleet, and network) but there are four major vehicular modes involved in transporting hazardous materials: truck, rail, water, and air. Furthermore, many organizations maintain information--including federal agencies, state and local governments, trade organizations, carriers, shippers, and consulting firms.

It would be nearly impossible to describe all of the data bases, especially when carriers and shippers are included; however, it is possible to describe the major ones, particularly those that are publicly available. For the most part, these data bases are kept by federal agencies, state and local governments, and trade organizations.

For many data bases, it is possible to give a synopsis of their characteristics, such as name, sponsoring organization, contents, sources, cross-checks, strengths, and weaknesses. In this paper, the discussion is segmented into flow data bases, fleet data bases, and network data bases.

FLOW DATA BASES

In general, flow data bases contain information on the movement of commodities from one place to another. They can be classified into two tiers, the first indicating whether they include all commodities or a subset only, and the second indicating whether they are multimodal or mode-specific.

Data Bases for All Commodities

Multimodal

Since 1963, the Bureau of the Census has been collecting transportation data every 5 years at varying levels of detail. Most recently, surveys were conducted in 1977 and 1983. The 1977 survey contains four parts: the Commodity Transportation Survey (CTS), the Truck Inventory and Use Survey (TIUS), the National Travel Survey, and the Nonregulated Motor carriers and Public Warehousing Survey (1).

The 1977 CTS contains flow data for commodities shipped by manufacturing establishments selected from each of 456 industries. Each record lists the

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total number of tons shipped from a given origin (state, production area, or Bureau of Economic Analysis region) to a given destination (same basis) for a specific commodity [up to five-digit Standard Transportation Commodity Code (STCC)], the principal mode of transport, weight block, and value block. The data are based on voluntary responses from approximately 16,000 of the 19,500 establishments to which survey forms were sent. The data are checked against the Census of Manufacturers Survey by using the value of shipment information to ensure that the expanded value of shipments made corresponds closely to the value of commodities produced (1).

Although the main strength of the census is its multimodal nature, inasmuch as it provides ways to estimate market shares and trends in a wide variety of situations, it does have limitations. The most important of these are as follows. It does not contain data on waste shipments, or agricultural or raw material shipments such as crude petroleum and natural fertilizers. The shipments that are present are only from point of manufacture to first destination, often a warehouse; they do not reflect movements in the entire distribution chain. Data submission is voluntary, creating unknown biases due to nonreporting. In addition, the data are collected only every 5 years, the scope of the survey is heavily dependent on federal budget priorities, and the questions asked are not consistent, making trend analyses difficult. Finally, the Census Bureau typically takes at least 2 years to release the data; as of the publication date of this paper, the 1983 data have yet to be released. Moreover, the data are released at the state-to-state or production area-to-production area level and are carefully screened to release data only on those respondents whose confidentiality can be maintained. Consequently, some flows are omitted at the higher levels of detail. Finally, there is no specific focus on hazardous materials. Therefore, one is limited to the data contained in the commodity flows, and if the detail is weak or suppressed, it is impossible to determine--especially at the two-, three-, and four-digit levels of detail--what percent of the shipments are hazardous.

To demonstrate these problems, only the differences between the CTS data collected in 1983 and those collected in 1977 need be considered. Although the 1977 CTS provides true commodity flow data, the 1983 CTS does not. In 1983, the respondents were asked to identify their line of business by four-digit Standard Industrial Classification (SIC) code and then report the number of tons they shipped to each state and the modal shares, giving no direct indication of commodity. Thus, it is impossible to determine exactly what commodities were shipped and what percent of the tonnage constituted hazardous materials.

Despite these problems, the CTS is the only multimodal data base available. Other organizations, such as state and local governments, do not collect similar information. They rely either on the CTS directly or its interpretation and enhancement by consulting firms for their multimodal flow information. Consulting firms using the CTS supplement it heavily with other modal sources, described later, to improve the quality of the data (2).

Truck

Virtually no truck (highway) flow data exist. There is no evidence that a federal agency maintains this information explicitly; the Interstate Commerce Commission (ICC) does not keep it, nor does the FHWA, U.S. Department of Transportation. The only source of information is the CTS described earlier.

However, three tangentially related data bases are worthy of discussion. The first is the TIUS collected by the Bureau of the Census. The 1977 TIUS contains data on the character and use of approximately 117,000 trucks, drawn from an estimated universe of 28 million. The sampling rate is skewed toward large trucks to enhance that portion of the data, but the sample size is still small. More than one-half of the states have samples of about 1,600 large trucks; for the largest states of Texas and California, the sample size reaches 3,000 (3).

The TIUS contains information on each vehicle's registration (vehicle identification number), physical characteristics (size, type of body, engine size, transmission type, braking system, etc.), operator class (ICC-certified common carrier, contract carrier, etc.), range of operation (e.g., short range), annual mileage, percent of mileage in home state, principal and secondary commodity carried, and the percent of time hazardous materials were carried. It is based on voluntary responses from the owners of the vehicles selected. It has no cross-checks except the state registration files from which the survey vehicles were selected.

The significance of the TIUS from a hazardous materials standpoint stems from it showing what percent of the time (1977) or miles (1982) a vehicle was used to haul hazardous materials. Through the answer to this question and several others, such as the annual mileage statistics, it is possible to estimate various measures of transport activity, such as annual truck-miles by commodity group and carrier category. In addition, through the range of operation and state base of operation, it is possible to develop rudimentary spatial information.

The second source is the Motor Carrier Census (MCCS) maintained by the Bureau of Motor Carrier Safety. It contains a profile on approximately 250,000 motor carriers. Although the data base is used primarily to monitor carrier safety, it can be used to develop activity measures and simple spatial flow indicators. The data base contains each carrier's base-of-operations state, the states served, the type of commodities carried, and--for hazardous materials--the kind of container and tank or package used to carry commodities in each of the hazard classes designated by the U.S. Department of Transportation. Also, it contains information on the carrier's classification (e.g., ICC common, ICC exempt, private), number of miles operated, number of drivers, and numbers of trucks, truck tractors, and trailers, segmented by type of ownership (owned, leased, or trip leased).

The third source is the ICC Waybill Sample (see the description under the section on Rail that follows). It contains data on the rail portion of truck shipments that use rail for one segment of the move, usually referred to as container-on-flatcar or trailer-on-flatcar shipments.

At the state level, several data bases are being developed. New York, for example, is computerizing the data collected by its state police during their roving truck inspections. The data base is both clean and complete. Other states with similar information include Virginia (4), New Mexico (5), Washington (6), and Colorado (6).

A few metropolitan areas such as Indianapolis (7), Portland (8), and San Francisco (9) have collected hazardous materials flow data for information and planning purposes. Moreover, the number is growing, partly as a result of pilot projects funded by federal agencies (6). However, the data are focused on local movements and are of little value for national flow analyses.

Trade organizations generally do not keep flow data. The American Trucking Associations (ATA), for example, keeps only aggregate statistics on tons and ton-miles. Moreover, the firms that submit the data are principally less than truckload carriers, so the data lack information about bulk shipments. Occasionally, the ATA's Safety Department collects site-specific data, but only in response to field studies being conducted at specific locations. Shipper organizations, such as the American Petroleum Institute, the Chemical Manufacturers Association, the Petroleum Marketers Association, and the National Association of Chemical Distributors, are in much the same position as the ATA.

Individual firms, however, do keep data on their own movements. Trucking firms generally keep computerized traffic data bases that include origin, destination, commodity (by a variety of codes), shipment weight, and shipment date. Major shippers, such as the large chemical and petroleum companies, also keep computerized data on their truck shipments. They record origin, destination, commodity (often on the basis of some marketing-based coding scheme), shipment weight, and shipment date.

Other types of data are kept by consulting firms, such as Transportation Research and Marketing, which has developed a National Motor Truck Data Base (NMTDB) (10). Started by the Association of American Railroads in 1977, the NMTDB contains information on approximately 36,000 movements per year, some 4,000 of which involve hazardous materials. The data are collected at 18 selected truck stops, typically in the West and Midwest, in an attempt to sample selectively long-haul moves. For the shipments it covers, the data base includes origin city and state, destination city and state, commodity (up to seven-digit STCC), vehicle characteristics, operator characteristics, and an operator profile. It is cross-checked to a limited extent against fuel sales at the truck stops and volume counts on selected Interstates.

Rail

The federal rail data base is the Waybill Sample collected by the ICC (11). Every year, the ICC requires railroads to submit waybills on a certain percentage of the traffic they terminated. The waybill data base for 1984 contains flow data for approximately 6 percent of all rail movements, approximately 315,000 records. It shows origin (city and state), destination (city and state), commodity (seven-digit STCC), number of cars, shipment weight, shipment cost (rail revenue), and the railroad junctions traversed. It is based on carloads terminated by all the Class I carriers and some of the Class IIs and Class IIIs. Since the AAR took responsibility for collecting the waybills and preparing the samples, numerous editing checks and cross-checks have been introduced. Moreover, by working with the roads involved, the AAR has been able to improve the quality of the sample.

The sample size has risen to 6 percent because of a recent ICC proceeding. Historically, the sample was created by collecting waybills ending in 01, which resulted in about a 0.8 percent sample of all car movements because of underreporting for multiple-car shipments. In Ex parte 385 (12), it was decided to alter the sampling method to correct for this problem. For example, for railroads submitting hard copy waybills, three criteria are now involved. For waybills covering 1- to 5-car movements, the 01 rule still applies; for waybills covering 6 to 25 cars, those ending in 1 must be submitted; and for waybills covering more than 25 cars, those ending in 1 and 7 must be submitted.

The data base does, however, have its limitations. For past years, it reflects only movements terminated by Class I carriers, which means that movements terminated by Class II carriers and Class III carriers are missing (reportedly about 6 percent of all movements). Little edit checking was done before 1983. Occasionally, cars with extremely large loads or cars without any shipment weight appear. Sometimes the same car shows up repeatedly, indicating faulty records. In addition, because many multiple-car shipments are missing in the samples before 1983, some commodities, such as coal and grain, are significantly underreported. For determining spatial flow patterns, the sample is generally considered adequate for region-to-region flows, but for state-to-state flows or anything finer, its credibility is hotly debated.

State and local governments do not appear to collect rail data. Two states with strong rail divisions, New York and New Jersey, do have data bases, but these are derived from the ICC data. In a few instances, localized data have been collected, for example, in the state of Washington (6) and in Indianapolis, Indiana (7).

The major trade organization, the AAR, maintains a comprehensive data base on railcar movements (13). TRAIN II contains status information on the movement of about 80 percent of all railcars. Its purpose is to allow railroads and shippers to trace their cars regardless of where they are located. Each railroad participating in TRAIN II submits location and status information on all the cars on its lines, both owned and foreign, so that shippers and other roads can determine where their cars are and their respective status. For each car, the data base includes current location (at an origin, destination, or some intermediate point), empty or loaded status, and the commodity being carried (seven-digit STCC).

The AAR currently uses TRAIN II to develop summaries of hazardous material flows. Occasionally, it has prepared tables of carload originations and terminations by STCC code for each state, and tables showing U.S. flows for all hazardous commodities, ranked by total carloadings.

Regarding carriers, most railroads--and certainly the major ones--maintain traffic flow data bases. A few keep times and locations for all events in the car-movement cycle (14). Most keep data that can be captured from the waybill: shipper, consignee, on-line and off-line origins and destinations, cars, tons, revenue, and so forth.

Water

At the federal level, the U.S. Army Corps of Engineers maintains a complete data base on all trade movement of U.S. and foreign vessels in U.S. waters (15) including domestic as well as international shipments. Only data on military cargo moved in U.S. Department of Defense vessels are missing. The following information is provided on each movement: origin district, port, dock, and date; destination district, port, dock, and date; commodity (four-digit code); shipment weight (short tons); operator; vessel description; and the waterways traversed, including entry and exit mileposts. It is based on data submitted by carriers, shippers, and vessel owners. The reporting requirements are comprehensive, and thus it effectively represents a 100 percent sample.

The main weakness of this data base is its commodity classifications. These are based on a four-digit code, but total only 163; as a result, the classifications are broad. Hazardous materials could conceivably fall into 30 of these classifications, but it cannot be determined which ones or to what extent. The level of detail at which one can analyze flows is consequently limited.

Air

No data base on air shipments, hazardous or otherwise, is kept other than the CTS already described. Federal Aviation Administration (FAA) inspectors sometimes perform 90-day record checks, but the only information they keep is the number of hazardous class shipments, not the overall percentage or the total volume.

The situation appears to be much the same for state and local governments. Only Virginia has collected any primary data (4) consisting of information on hazardous materials passing through many of its major airports.

Carriers and shippers maintain traffic flow data bases, including information on hazardous material flows. Generally, they keep track of origin, destination, commodity (again on the basis of a marketing-based code), shipment weight, and shipment date.

Specialized Data Bases

Hazardous Wastes

Environmental Protection Agency (EPA) regulations require every hazardous waste shipment to have a manifest (16). Thus, in theory, a complete flow data base exists detailing hazardous waste movements. In practice, however, the extent of computerization varies from one EPA region to another. An outgrowth of the requirement for manifests is that states generally have good information on waste movements and the carriers involved. In some cases, they are collecting and computerizing the data for EPA. Carriers also appear to have fairly complete data even though they are not technically responsible for preparing the manifests.

Radioactive Materials

The U.S. Department of Energy (DOE) maintains a list of all high-level radioactive shipments, and it conducts surveys of the low-level radioactive shipments. One such survey was conducted in 1975 (17), and a second was recently conducted by SRI International (18).

A Potpourri of Codes

It is surprising, because federal data collection is not new, that numerous hazardous materials commodity codes are used by the different federal agencies. At least 10 exist, not counting those used internally by carriers and shippers. These include the codes used in the U.S. Department of Transportation's OHMT Hazardous Materials Incident Reporting system data base; the EPA codes (16); the United Nations/North American (UN/NA) codes (19); the STCC (20), of which two versions exist; the standard codes (01 through 48) and the 49 series of codes specifically established for hazardous materials; the National Motor Freight Classifications (NMFC) (21); the U.S. Army Corps of Engineers codes (15); several Bureau of the Census codes; the Transportation Commodity Codes for domestic shipments (1977 Census) (22); the SIC codes for the 1983 census (technically speaking, the SIC codes are developed and maintained by the Bureau of Economic Analysis, U.S. Department of Commerce) (23); the Schedule A codes for imports and the Schedule E codes for exports.

These codes are all used simultaneously, yet few cross-reference tables have been developed for them, either for hazardous materials or any other type of commodity. The tables include the conversion file from series 49 STCCs to regular STCC codes and UN/NA codes maintained by the AAR (24); the STCC-to-SIC code conversion table at the four-digit SIC level maintained by the AAR, which is in hard copy only (24); the NMFC-to-STCC conversion table maintained by the ATA (25); the U.S. Army Corps of Engineers conversion file between their commodity codes for water to Bureau of the Census Standard International Trade Classification (SITC) codes (it appears that these SITC codes are used only for translation purposes); and the SITC, SIC, Schedule A, and Schedule E translation files maintained by the Bureau of the Census. It is interesting to note that UN/NA numbers appear only once and OHMT or EPA numbers do not appear at all.

FLEET DATA BASES

Highway

For the highway mode, no useful fleet data base exists. There are data bases for trucks, meaning single-unit trucks and truck tractors, but no similar data base for trailers. Yet trailers are clearly the main highway vehicle for hazardous materials.

At the federal level, the only potential sources of information are the TIUS and the MCCS data bases described previously in the section on Flow Data Bases, but neither of these is adequate. The former is only a small sample, and its focus is on single-unit trucks and truck tractors, not trailers. The latter contains counts of trailers for each carrier, but no information on trailer characteristics, and a dry van is indistinguishable from a stainless steel tank.

The situation is much the same at the state level. Although the states have some information about the trailers they register and inspect, the level of detail is low. The data bases indicate only such details as whether the trailer is a tank or a dry van, and so forth; they do not differentiate between an MC301, MC302, MC306, or MC331, not do they show whether the trailer is being used to carry hazardous materials.

The trade organizations do not maintain fleet data bases. Trailer manufacturers are required to report their production statistics to the Bureau of the Census (26), but the level of detail is aggregate. For example, only 4 categories of tank trailers are indicated, while 10 or more are listed in the OHMT's incident data base. Furthermore, these categories vary from year to year.

Rail, Water, and Air

Relatively comprehensive fleet data are kept for these three modes. The AAR maintains a master file called the Universal Machine Language Equipment Register (UMLER file) on all cars and locomotives in use in the United States (27); the U.S. Army Corps of Engineers keeps a master file on all vessels involved in commercial shipping in the United States; and the FAA keeps records on all aircraft in use in the United States.

However, none of these data bases has flags indicating whether the vehicle is used to carry hazardous materials. One can only infer such information by analyzing the commodity flow and accident and/or incident data bases, and determining the types of vehicles that are typically used for hazardous materials for each mode. It is then possible to extrapolate fleet sizes by reflecting these findings back into the fleet data bases.

TABLE 1 Data Base Summary

Data	Highway	Rail	Water	Air
Flows	CTS[a]	CTS[a]	CTS[a]	CTS[a]
	CFIRM-1	CFIRM-1	CFIRM-1	CFIRM-1
	NMTDB[b]			
	TI&U[c]			
	MCS[c]			
	ICC[d]	ICC[e]		
		TRAIN II		
			WCS[f]	
	EPA-1	EPA-1	EPA-1	EPA-1
	DOE	DOE	DOE	DOE
Fleets	TIUS[g]			
	MCCS[h]			
	DMV[i]			
	UMLER[d]	UMLER		
			VMF	
				ARF
	EPA-2	EPA-2		
Networks	DOE/ORNL			
		FRA		
			WMF	
	CFIRM-2	CFIRM-2	CFIRM-2	CFIRM-2

[a]Limited sample; only from point of manufacture to first destination; no wastes or agricultural products.
[b]Only long-haul shipments outside the Northeast.
[c]Level of activity data only, such as truck-miles.
[d]Only for trailers and containers that move via railroads.
[e]No more than a 6 percent sample of all movements.
[f]Limited commodity detail—only 30 classes of hazardous materials.
[g]No specific data on trailers.
[h]Only counts of trailers, truck tractors, and trucks.
[i]No physical characteristics or use indicators for trailers.

NETWORK DATA BASES

Network data bases for highway, rail, and water are each maintained by a federal agency. None is kept for air; the air traffic control system provides national network control. The DOE, through Oak Ridge National Laboratory, maintains an inventory of the principal segments of the U.S. highway network. The Federal Railroad Administration maintains a complete inventory of the line segments in the U.S. network, although it is important to note that the railroads are not directly involved in updating this data base. The U.S. Army Corps of Engineers maintains a complete inventory of the waterway segments in the U.S. waterway network. Moreover, states and some consulting firms keep network data bases that have been derived from these and other data.

Two points are important here. First, the data bases do not contain flags showing which network elements carry heavy volumes of hazardous materials. Second, developing such flags is problematic. In the case of the highway network, the federal standards direct carriers to use the Interstate system, so one can infer general routing patterns with reasonable validity. In the case of the rail network, making inferences is not as easy. Some railroads have more than one way in which they can route a car from point A to point B, and some have special rules for routing hazardous material shipments. In addition, historical movement data are difficult to obtain, and some railroads do not computerize it. Finally TRAIN II does not show a high level of routing detail--just passing times for selected locations within each carrier's network. In the case of water, the vessel movement files show routings in considerable detail, but the commodity data are too weak to draw significant conclusions.

The second problem is that the data bases do not contain the information required to perform risk analyses. In general, their link and node information does not include population statistics, or link condition data such as level of maintenance, accident rates, or historic flow volumes, all of which are key to any method of risk analysis. Fortunately, some private consulting firms have added some of this information to their data bases, but it is not publicly available.

SUMMARY AND CONCLUSIONS

The foremost conclusion is that no single, publicly available data base exists describing the hazardous materials transportation system. An array of data bases is required to develop even crude flow, fleet, and network information, as shown in Tables 1 and 2. The CTS is the only multimodal data base showing flows; however, it is weak from the standpoint of hazardous material flow definition and is 7 years out of date. In addition, when the 1983 CTS is released, it will be of limited value because the survey was small and the flow data do not consist of individual shipments.

Moreover, such a data base cannot be assembled because two of the major components are missing. No comprehensive data base for highway flows is kept, nor is there one for trailers despite the apparent depth in Table 1. Because the highway mode has the most widespread public impact, these are noteworthy gaps. The CTS is helpful for highway flows, but its data are thin. The TIUS and MCCS data bases are helpful, but they provide only the trucks and truck-miles involved in hazardous materials movements, not true flow data. The only other source is the NMTDB, but it has limitations because of its intentional bias toward long-haul shipments and restricted geographic coverage.

TABLE 2 Data Bases

Acronym	Data	Organization
ARF	Aircraft registration files	Federal Aviation Administration
CFIRM-1	Flow data bases	Consulting firm
CFIRM-2	Network data bases	Consulting firm
CTS	Commodity Transportation Survey	Bureau of the Census
DOE	Radioactive shipment data bases, high and low level	U.S. Department of Energy
DOE/ORNL	Highway network file	Maintained by the U.S. Department of Energy at Oak Ridge National Laboratory
DMV	Motor vehicle records	State departmens of motor vehicles
EPA-1	Waste shipment manifests	Environmental Protection Agency
EPA-2	Waste carrier permits	Environmental Protection Agency
FRA	Rail network data base	Federal Railroad Administration
ICC	ICC Waybill Sample	Interstate Commerce Commission
MCCS	Motor Carrier Census	Bureau of Motor Carrier Safety, Federal Highway Administration
NMTDB	National Motor Truck Data Base	Transportation Research and Marketing (consulting firm)
TIUS	Truck Inventory and Use Survey	Bureau of the Census
TRAIN II	Rail locator data base	Association of American Railroads
UMLER	Uniform machine language equipment register	Association of American Railroads
VMF	Vessel master file	U.S. Army Corps of Engineers
WCS	Waterborne commerce flow statistics	U.S. Army Corps of Engineers
WMF	Waterway master file	U.S. Army Corps of Engineers

Although the ICC data are adequate for rail flows, they could be enhanced or replaced by the TRAIN II data kept by the AAR, if the latter could be obtained. TRAIN II provides much better information because it represents 100 percent data on at least 80 percent of the rail-based shipments.

The data for water are essentially complete, especially insofar as vessel movements are concerned. The main shortcoming is that the commodity classifications are too broad. This problem could be resolved by expanding the commodity list or by adding a flag that shows whether a given shipment was a hazardous commodity.

The absence of interchangeable commodity codes is an additional and major problem. The OHMT has one set of codes, the EPA another, and there are UN/NA codes, modal codes, and codes used internally by carriers and shippers. The level of detail varies widely between one set of codes and another, and no standard officially recognized or maintained cross-reference tables have been developed.

The current status of reporting hazardous materials movement information suggests that major modifications to existing reporting practices are necessary to enable national hazardous commodity flows to be quantified. These modifications must occur at several levels, beginning with designing adequate procedures for cross-referencing, defining uniform categories of measurement, and implementing enforcement programs regarding reporting requirements and standards. This process is likely to be resource-intensive and require a considerable degree of institutional cooperation.

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The views presented in the paper represent those of the authors and do not necessarily reflect those of the Office of Technology Assessment or the Technology Assessment Board.

Scheduling Truck Shipments of Hazardous Materials in the Presence of Curfews

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ABSTRACT

Locally imposed curfews have been considered as a mechanism for reducing risks associated with movements of hazardous materials through heavily populated areas. However, the imposition of such curfews creates scheduling problems for carriers and the need for consideration of overall policy at the state and federal levels. Simple algorithms for addressing these scheduling issues are presented; their use in doing sensitivity analysis of a hypothetical problem involving shipment of spent nuclear fuel by truck is demonstrated.

Transportation of hazardous materials is an issue of considerable public concern. This concern is most sharply focused when the materials being transported are radioactive, but a wide variety of toxic and flammable chemicals also presents varying degrees of risk to people and property. In the United States, most hazardous materials are moved by truck or rail, and these movements frequently pass through heavily populated urban areas.

The mechanisms used to reduce the risks associated with hazardous materials movements include attempts to reduce both the probability of accidents involving these shipments and the number of people potentially exposed to the consequences of an accident, should one occur. In practice, this has led to consideration of restricting hazardous materials to certain specified routes, restricting their movement during some portions of the day (e.g., rush hour), or both.

Regulation of hazardous materials transportation occurs at the local, state, and federal levels. These regulations are in many cases implemented independently, and in some cases they conflict with each other. This has led some observers and participants in the industry to criticize the hodgepodge of local regulations, while others defend the rights of local governments to control movements within their jurisdictions.

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The focus of this paper is on one important type of movement restriction: the imposition of time-of-day curfews by localities. The objective is to develop analytical tools that can be used for two basic purposes:

1. For a carrier of hazardous materials facing a particular set of curfews in specific cities, an important operational problem is to schedule shipments to minimize total transit time, including delay due to the curfews.
2. For policy analysis, it is important to be able to estimate the total delay imposed by curfews of various types in different numbers of cities in order to determine the aggregate effect of the pattern of local regulations.

Use of the models developed here for operational planning by carriers is important because en route delays imposed by curfews are clearly undesirable. Such delays increase the cost of shipment and, because they increase total time en route, they also increase some elements of risk associated with hazardous materials movement.

To minimize total in-transit time, the carrier may change the departure time of the shipment or the actual route the shipment takes. In the next two sections, methods are developed for optimizing departure times, given a fixed route. In the section Curfew Delay Under Fixed Routing and Deterministic Travel Time, the simplest version of the problem is discussed, that is, the version in which times are assumed to be deterministic. In the section Stochastic Intercity Travel Times, the analysis is extended to address uncertain travel times. An example application of these methods to sensitivity analysis of a hypothetical problem of moving spent nuclear fuel assemblies is presented in the third section.

Use of these tools in policy analysis is important because the Hazardous Materials Transportation Act places responsibility on the U.S. Department of Transportation to ensure that local regulations do not impose an unreasonable burden on interstate commerce. Federal officials and various carrier organizations are interested in determining the inconsistency of the curfew restrictions, that is, whether these curfews unreasonably burden commerce. To do this, it is important to determine the effects of curfews on both routing and scheduling decisions, in an aggregate sense.

In this paper, scheduling decisions are addressed. In a subsequent paper, the authors will address combined routing-scheduling analyses. Given a set of origins and destinations for shipments and a set of jurisdictions imposing curfews, combined routing-scheduling methods will estimate various measures of risk, total delay, additional miles traveled, and changes in the temporal and spatial pattern of movements.

CURFEW DELAY UNDER FIXED ROUTING AND DETERMINISTIC TRAVEL TIME

In this section, discussion is presented about how a carrier should operate to minimize its delay time, given no opportunity to reroute to avoid curfews and given no unexpected changes in its travel time along the route. The important point to note is that, given a departure time, an optimal strategy that minimizes total in-transit delay time is to delay a shipment only when it is about to violate a curfew and to delay it only until the curfew passes. This is an intuitive result, for which the formal justification is given by Cox (1).

Because this intuitive procedure yields the minimum delay solution for any specified departure time, the departure scheduling problem can be solved by a simple enumeration scheme. To demonstrate the idea, consider a hypothetical route containing five cities with curfews. For simplicity in this example, it will be assumed that all cities have identical curfews: 7:00 a.m. to 11:00 a.m. and 3:00 p.m. to 7:00 p.m.

This sort of curfew pattern is the type proposed by Rhode Island for liquid nitrogen gas (LNG) and liquid petroleum gas (LPG) tanker movements (2). However, many other patterns are possible. The method for shipment scheduling described here works under any arbitrary curfew pattern, and different cities along the route need not have the same pattern.

For this example, assume that travel times (in hours) between cities are as shown along the links in Figure 1. Suppose the shipment leaves the origin at 7:00 a.m. It will arrive at City 1 at 12:30 p.m., which is an acceptable time to pass through City 1, and proceed to City 2, arriving at 1:30 p.m. City 2 is also passed without delay, and the shipment arrives at City 3, 2 hr later, at 3:30 p.m. Because this arrival time is during City 3's curfew, the shipment must wait until 7:00 p.m. before passing through City 3, a delay of 3.5 hr. Leaving City 3 at 7:00 p.m., the shipment arrives at City 4 at 11:30 p.m. and at City 5 at 4:00 a.m. the following morning. It may then proceed to its destination. Thus, the total delay is 3.5 hr, incurred entirely at City 3.

Suppose the departure had been delayed 1 hr, to 8:00 a.m. Arrival at Cities 1, 2, and 3 would also be delayed 1 hr, but the shipment would still miss the curfews at City 1 and City 2. Because arrival at City 3 would now be at 4:30 p.m. instead of 3:30 p.m., delay would be 2.5 hr instead of 3.5 hr, with a departure at 7:00 p.m. as before. Because the shipment departs from City 3 at the same time, the subsequent portion of the trip is unaffected, and it can be concluded that total delay en route is reduced by 1 hr. This delay can be reduced further through postponement of the departure time until 8:30, at which point the shipment encounters the curfew at City 2 (arriving at 3:00 p.m.), and is delayed for 4 hr.

By repeating this analysis for various possible departure times, a graph can be developed of delay with respect to departure time; such a graph is shown in Figure 2. From Figure 2 departure time can be optimized to minimize total en route delay. Note that substantial gains can be made by judicious choice of departure time. Scheduling departures for 6:00 a.m. or 5:30 p.m. results in no delay, whereas departing at 9:30 a.m. results in 8 hr of delay time (17.5 hr of actual travel time).

The simple enumeration analysis just described can be implemented easily on a personal computer, so that the type of diagram shown in Figure 2 can be produced in a matter of seconds, given basic information about the route to be followed and the curfew restrictions in force. The diagram is therefore a potentially useful tool for guiding dispatching decisions.

However, this departure time analysis is limited because intercity travel times for hazardous materials shipments have a large random component that cannot be ignored in scheduling decisions. Notice in Figure 2 that local minima and maxima of en route delay with respect to departure times are adjacent to one another. If a shipment were to depart at 5:30 p.m., expecting to incur no curfew delay, and be unexpectedly delayed for an hour sometimes before it arrived at City 4, it would be delayed an additional 7 hr because of curfews.

A method by which this uncertainty may be addressed is presented in the next section.

STOCHASTIC INTERCITY TRAVEL TIMES

If travel times have some random component, a recursion may be derived to estimate the expected delay given the departure time of the shipment and a probability distribution for intercity travel times.

Consider a fixed route with N curfew cities along it. The expected value for curfew delay for any departure time is the expected value, taken over all curfew cities n = 1, 2, . . ., N, of the conditional

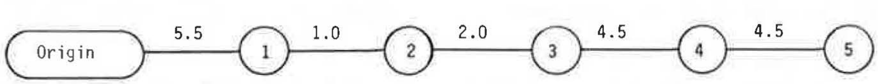

FIGURE 1 Travel times (in hours) for example problem.

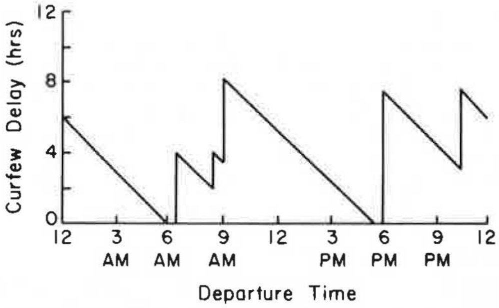

FIGURE 2 Curfew delay as a function of departure time.

expected delay, given that the shipment first encounters a curfew at City n.

Formally:

$$ED(t) = \sum_{n=1}^{N} p(n,t)[d(n,t) + s(n,t)] \quad (1)$$

where

$ED(t)$ = expected delay for departure time t;
$p(n,t)$ = probability that first curfew encountered after departure time t is at City n;
$d(n,t)$ = expected delay at City n, given that original departure is at t and that shipment arrives at n during its curfew; and
$s(n,t)$ = expected delay encountered in all cities subsequent to n, given that City n curfew is encountered after initial departure at t.

After City n's curfew is encountered, all shipments must wait until the curfew passes before continuing, independent of when during the curfew they arrive. Thus, $s(n,t)$ is only dependent on t, the original departure time, if multiple curfew periods exist during each day.

The expected delay after City n's curfew is encountered is the expected value, taken over all Cities $m > n$, of the conditional expected delay associated with encountering City m's curfew next:

$$s(n,t) = \sum_{m=n+1}^{N} P(n,m,t)[D(n,m,t) + s(m,t)] \quad (2)$$

where $P(n,m,t)$ is the probability that the next curfew encountered after n is at City m, when original departure is at time t; and $D(n,m,t)$ is the expected delay at City m, given that the original departure is at t and the last curfew encountered is at City n.

Equations 1 and 2 may be solved recursively. Beginning with the origin $(n = 0)$, one can compute $p(n,t)$, $d(n,t)$, $P(n,m,t)$, and $D(n,m,t)$ for $n < m < N$ and $n = 0, 1, 2, \ldots, N$. Then, $S(n,t)$ can be computed by using the recursive formula (Equation 2), and finally $ED(t)$ can be computed using Equation 1.

The most difficult part of this calculation is the determination of the probability distribution of arrival time at City m, given a departure time from City n. This is necessary to compute $P(n,m,t)$ and $D(n,m,t)$. Because several cities may exist between n and m, one must either specify directly the distribution of travel times between each pair of cities, or calculate a convolution of travel times across individual links. The authors have implemented the algorithm in BASIC on an IBM personal computer by using a numerical approximation to the convolution of individual link travel time distributions to calculate $P(n,m,t)$ and $D(n,m,t)$.

As an example of the random travel time model, consider the same problem solved deterministically in the section on Curfew Delay. For the stochastic analysis, the fixed travel times are replaced with probability distributions of travel times on each link. For purposes of example, the simple three-point discrete distributions shown in Figure 3 have been used. In each case, the expected travel time from the distribution is the same as the deterministic travel time assumed in the first section.

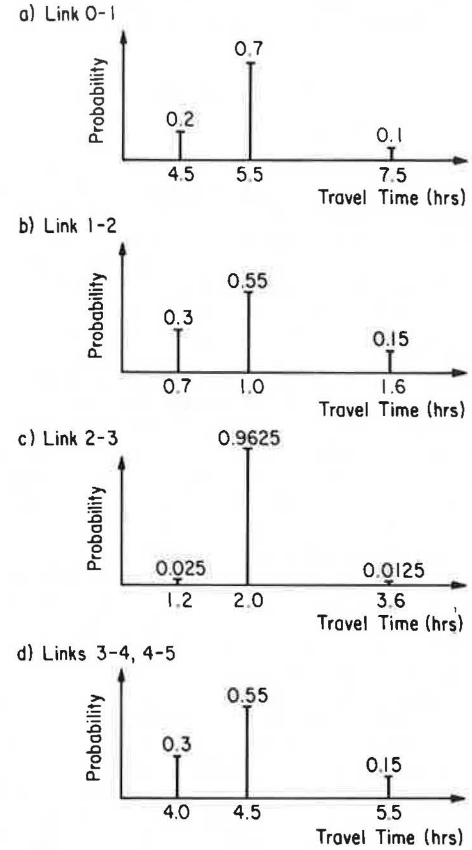

FIGURE 3 Travel time probability distributions used in example.

Figure 4 shows the results of the stochastic analysis of departure scheduling superimposed on the deterministic results from Figure 2. The random travel time analysis indicates that the best departure times are not as good as the deterministic model predicts, and that the worst times are not as bad. For example, the deterministic analysis indicates that a departure at 5:30 p.m. would result in arrival times at the cities as follows:

City	Arrival Time
1	11:00 p.m.
2	12:00 midnight
3	2:00 a.m.
4	6:30 a.m.
5	11:00 a.m.

Note that the shipment is scheduled to arrive at City 4 before the beginning of the morning curfew, and at City 5 after the end of its morning curfew. The analysis indicates a window of one-half hour during which there is no delay. This corresponds to the available time from 6:30 a.m. to 7:00 a.m. to get

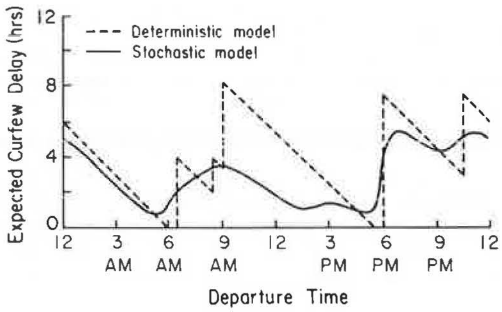

FIGURE 4 Comparison of expected curfew delay for deterministic and stochastic analyses.

through City 4 before the morning curfew. If the shipment is delayed at City 4 until the end of the morning curfew at 11:00 a.m., it will be delayed again at City 5 during the afternoon curfew.

The stochastic analysis indicates that there is some expected delay for even the best departure times because some chance of delay exists before getting to City 4. It also indicates that there is a broader window over which expected delay changes relatively little (4:00 p.m. to 5:30 p.m.), and that this window is earlier than indicated by the deterministic analysis.

The wider departure window is due to the increasing uncertainty of arrival times for points farther along the route. It is difficult to plan a departure for a precise arrival time at a city that is, on average, 13 hr away. The uncertainty inherent in predicting travel times over long distances means that precise departure scheduling is not as important as implied by the deterministic model.

That the optimal departure times in the stochastic analysis are earlier than in the deterministic analysis is a reflection of the skewness assumed in the travel time distributions. Delays cause larger deviations from average travel times than do early arrivals. Thus, the statistical analysis indicates that it is wise to build some additional slack time into the schedule to accommodate those possible delays. In this example, if travel times run according to plan, a departure at 4:30 p.m. would encounter 1 hr of delay at City 5. However, 1 hr of extra slack exists to absorb delays before City 4, without getting caught during the morning curfew there, with attendant additional delays at City 5 during the afternoon.

Comparative analysis of this one simple example is insufficient as a basis for making extensive conclusions. However, these three main differences are intuitively reasonable, and should apply broadly. The implications for scheduling shipments are that precision is not as important as might be indicated by the deterministic model, and that the optimal departure time is likely to be earlier than indicated by the deterministic model.

SENSITIVITY ANALYSIS IN AN EXAMPLE APPLICATION

The transport of nuclear materials has been a topic of recent administrative rulings, court cases challenging those rulings, and congressional action. The highway transport of spent nuclear fuel in particular has been controversial. Spent fuel elements are highly radioactive and contain long-lived radioactive isotopes and transuranics, including plutonium. These wastes are currently stored at reactor sites, but the fuel pools are being filled rapidly and were never designed for permanent waste storage. The National Waste Policy Act (42 U.S.C. sec. 10222 et seq.; see also 10 C.F.R. sec. 961) requires the U.S. Department of Energy to designate one or more permanent repositories for such wastes.

This example addresses the problems of scheduling truck shipments of commercial spent fuel on the Interstate highway system, in particular focusing on the changes in the curfew delay incurred by a spent fuel shipment as the following characteristics of the curfew pattern and the shipment change:

- Length of the curfew
- Type of curfew (all day or peak period only)
- Number of jurisdictions imposing curfews
- Whether the departure times of shipments are scheduled to minimize curfew delay
- Variance associated with travel time

The example is a hypothetical one involving shipments from a single reactor to a single permanent repository, with a set of 11 cities imposing curfews en route. The data for this example apply to a particular reactor and potential repository site in the eastern United States, but the actual identity of the sites is not important for the purposes of this paper, and this example is not intended to represent a complete analysis of this route.

Deterministic Travel Time Analysis

The graphic procedure presented in the first section to estimate delay as a function of departure time was applied to this route, assuming that each city imposes the same curfews (7:00 a.m. to 11:00 a.m. and 3:00 p.m. to 7:00 p.m.). The results are shown in Figure 5 as a graph of delay versus departure time. Note the characteristic sawtooth pattern resulting in delay estimates ranging from 14.5 hr when departing at 5:30 a.m. to 1.5 hr when departing at 10:30 p.m.

By varying the length of the peak-period curfew, the sensitivity of average and minimum delays to changes in this value can be explored. The results are given in Table 1. By repeating the analysis with a single-period curfew, the delay time estimates presented in Table 2 are obtained. Note that under both types of curfew, the average and minimum delays increase approximately quadratically as the length of the curfew increases. Also note that the delay under peak-period curfews is substantially less than that under single-period curfews of the same total length. This is because the peak-period curfews allow a window of travel during midday.

By randomly assigning a subset of the cities to impose a 7:00 a.m. to 11:00 a.m. and 3:00 p.m. to 7:00 p.m. curfew, with the remaining cities imposing

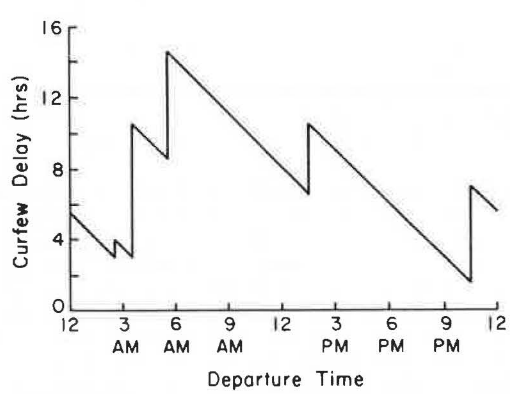

FIGURE 5 Curfew delay as a function of departure time—fixed route.

TABLE 1 Length of Peak-Period Curfew Versus Average and Minimum Delays

Curfew Period	Average Delay over All Departure Times (hr)	Minimum Delay over All Departure Times (hr)
6:00 a.m.–11:00 a.m. 3:00 p.m.–8:00 p.m.	12	4.5
7:00 a.m.–11:00 a.m. 3:00 p.m.–7:00 p.m.	7.7	1.5
7:00 a.m.–10:00 a.m. 3:30 p.m.–6:30 p.m.	4.0	1.0
7:00 a.m.–9:00 a.m. 4:00 p.m.–6:00 p.m.	2.0	0
7:30 a.m.–8:30 a.m. 4:30 p.m.–5:30 p.m.	0.4	0

TABLE 2 Single-Period Curfew Analysis

Curfew Period	Average Delay over All Departure Times (hr)	Minimum Delay over All Departure Times (hr)
6:00 a.m.-8:00 p.m.	28.3	16.5
7:00 a.m.-7:00 p.m.	22.6	14.5
8:00 a.m.-6:00 p.m.	13	5.0
9:00 a.m.-5:00 p.m.	10.8	3.0
10:00 a.m.-4:00 p.m.	5.9	1.0
3:00 p.m.-7:00 p.m.	2.9	0
4:00 p.m.-6:00 p.m.	1.1	0

no curfew, one can estimate how delay varies with the number of cities imposing curfews on the route. The results are shown in Figure 6. On this scatterplot, each point represents the average curfew delay with a random subset of cities imposing curfews on the route, where the number of cities in the subset is plotted on the x-axis. Note that the relationship between delay and the number of cities with curfews is approximately linear. However, for any given number of cities imposing a curfew, the variance in total shipment delay is large, indicating that the total delay is sensitive to which cities impose curfews.

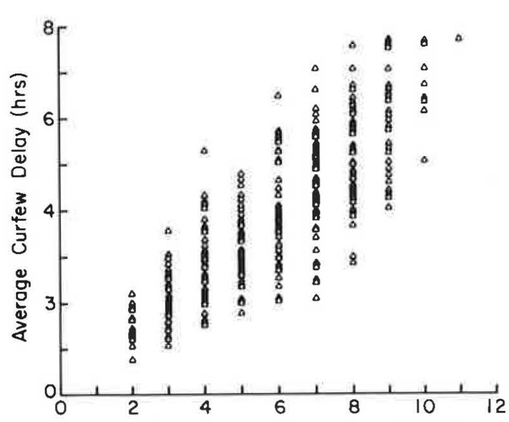

FIGURE 6 Delay versus number of cities imposing curfews.

Results for Stochastic Travel Times

To compute the delay under stochastic travel times, the recursion formulas discussed in the section on Stochastic Intercity Travel Times were used. Assuming a curfew of 7:00 a.m. to 11:00 a.m. and 3:00 p.m. to 7:00 p.m. for all cities, Figure 7 shows delay as a function of departure time for three different values of intercity travel time variance. The first point

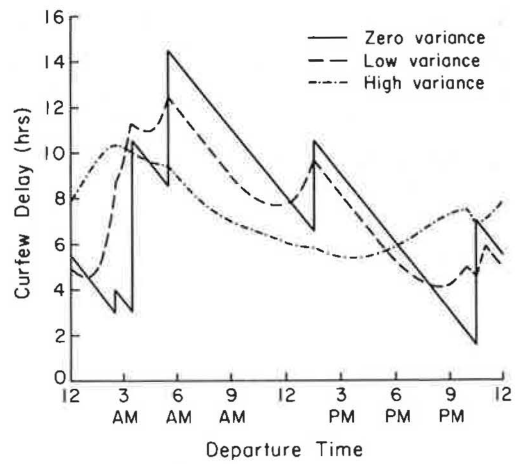

FIGURE 7 Curfew delay profile as variance of travel time changes.

to note is that for the zero-variance case, the delay function is the same as the one shown in Figure 5, as expected. Second, note that as the variance increases, the difference between minimum and maximum delay is reduced, and the profile becomes smoother. This is to be expected; as travel times grow more uncertain, it becomes less likely that either the best possible outcome (minimum delay) or worst possible outcome (maximum delay) will be observed. Thus, the expected delay becomes less sensitive to the actual departure time of the shipment. Last, note that the local minima of the delay profile move to the left as variance increases. As variance increases, it is more likely that a shipment will be delayed unexpectedly. If a shipment departed during the zero-variance delay minimum, such as at 10:30 p.m., a good chance exists that the actual delay would be as though it left at 11:00 p.m., which is a local maxima, because it is more likely that travel time will be longer than expected rather than less than expected. It is wiser, in the case of uncertain travel times, to depart earlier to account for the expected values of delays. Thus, the minima for scheduling departure times should move to the left.

SUMMARY

In the first section on Curfew Delay, it was argued that the natural approach to delaying a shipment along a route in the face of curfews was the optimal strategy to minimize total curfew delay. As a result, given a departure time and intercity travel times, the delay time may be estimated using a simple enumeration. In the section on Stochastic Intercity Travel Times, a recursive procedure was presented for estimating expected delay, given a departure time, for random travel times.

The major implications of uncertain travel times in the analysis are as follows:

1. It is unreasonable to expect delays as small as those indicated by optimal deterministic solutions;

2. As uncertainty in travel times increases, the relative advantages of precise dispatching decrease;

3. The optimal departure time when travel times are uncertain is earlier than when they are assumed to be known with certainty.

The important benefits from the models described in this paper are that they are relatively simple; require modest amounts of data; can be operated easily on a personal computer; and can provide estimates of how much delay can be expected, how important precise departure scheduling is, and what are the best departure times in a given situation.

In the third section, a hypothetical example was presented of spent nuclear fuel shipments between one specific reactor and a single potential permanent spent fuel repository. The purpose of this example is to demonstrate how the models developed in this paper can be used to do sensitivity analysis on various elements of hazardous materials routing-scheduling problems. It should not be construed as a complete analysis of the effects of curfews on hazardous materials movement. The authors believe, however, that it does demonstrate the usefulness of these analytic tools in addressing several important issues in hazardous materials transportation.

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2. National Tank Truck Carriers v. Burke, 608 F2d 819 (1979), 535 F.Supp. 509 (1982).

Assessing the Risk of Hazardous Materials Flows: Implications for Incidence Response and Enforcement Training

ROGER R. STOUGH and JEFFREY HOFFMAN

ABSTRACT

Several factors affect the risk created by hazardous material (hazmat) in transit, including at least the probability of an accident involving a hazmat load, the probability of a spill given that an accident has occurred, and exposure level. In this paper, the focus is on estimating the exposure factor on highways in the heavily industrialized northwest corridor of Indiana. Exposure is defined as the frequency of hazmat loads per time period. Analysis indicates that exposure is highest between 6:00 a.m. and 6:00 p.m. and that it is highly correlated with volume of total truck traffic. Flammable liquids (58.4 percent) and corrosives (26.3 percent) are the most frequent types of loads. Most loads passing through the study area originate outside Indiana, in Illinois and Michigan. Analysis of safety indicators reveals that driver qualification was the least satisfactory and that appropriate placarding was lacking in 20 percent of the hazmat loads. The results suggest that officers should be deployed most intensively during the daytime to enhance enforcement efforts and that officer training efforts should focus on placard recognition and incident response training--especially regarding flammable liquids and corrosives. A significant effort should be made to develop cooperation and coordination among enforcement officials in Indiana, Michigan, and Illinois. Driver training should be designed to improve qualifications and particularly to increase knowledge about the nature of loads. The results and recommendations generalize most directly to heavily industrialized areas located close to or overlapping multiple state boundaries.

Technology has become the "major source of hazard for modern society" (1). Strong agreement exists on this regardless of whether one's ideological perspective is econocentric (2) or technocentric (3,4). Technological hazards may be viewed as threats to human life and property created by modern production and consumption processes (5). For the most part, hazards arise from materials that are created to satisfy modern consumption demands and their residuals. As a consequence, management of hazard from technological sources has become the focus of public policy initiatives at all levels of government (6). In particular, policy development has focused on the management of hazards from these materials at their origin, during their transport, and at their disposal. In this paper, attention is focused on the management of risk arising from the transportation of hazardous materials on Interstate and state highways. Risk as differentiated from hazard may be viewed as the probability that a particular material in a given context will lead to a specific life- or property-threatening consequence during a given period of time (1). Analyses reported in this paper are based on field data collected in the northwest corridor of Indiana.

Although public policy developments such as the revision of the Code of Federal Regulations (C.F.R.) in 1981 regarding the transportation of hazardous materials (sec 49 C.F.R., Parts 100-177, October 1981) and adoption of the manifest tracing system mandated by the Resource Conservation and Recovery Act have occurred in an effort to manage transportation-related risks, numerous problems still exist. In several recent analyses (7-12), the following have been identified as continuing major problems: (a) unclear terminology, (b) regulatory fragmentation at each level of government as well as across different levels, (c) confusing regulations, (d) inadequate training of emergency response forces, (e) inadequate risk assessment methods for judging the value of regulations, and (f) unreliability of federal and state inspections. Each of these problems stems in part from a lack of reliable and complete information about what is being shipped, where it is being shipped, and by whom.

The purposes of this paper are to

1. Develop, analyze, and test a procedure (using data collected in the northwest corridor of Indiana) for determining the nature and level of hazardous materials in transit on the nation's Interstate and state highways;
2. Determine how the nature and level of hazardous materials on Interstate and state highways vary with time of day and with state of origin;
3. Determine the level of safety of loads; and
4. Draw implications for the training of enforcement personnel and incident response forces from the analysis.

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RISK, EXPOSURE, AND MATERIALS HAZARDS

Ultimately, concern is with the social costs and benefits associated with hazardous materials and their transport. Although society has viewed the benefits as outweighing the costs, recent policy developments (discussed in the preceding section) suggest that a desire exists to increase the benefit-to-cost (b/c) ratio through more careful management of hazardous materials. However, such interpretations are based largely on qualitative observation. Ideally, it would be desirable to be able to at least quantify the social costs of hazardous materials and their transport, that is, the cost in terms of damage to life and property. The key to improving cost estimates lies in the ability to accurately estimate risk from hazardous materials. A discussion of risk is undertaken next to demonstrate that the nature and quantity of hazardous materials in transit are critically important components of risk and, therefore, of cost.

A general model for estimating the risk of transport-related hazardous materials incidents was developed in Indianapolis in 1983. In this model risk is defined as

$$R = A/Ep(S/A) \quad (1)$$

where

- R = risk of hazmat incident in transportation;
- A = expected number of transportation accidents involving hazardous materials within a definable period of time;
- E = exposure to risk, or some measure of the total amount of hazardous materials being transported (e.g., number of hazmat-laden trucks); and
- p(S/A) = probability of a hazardous materials spill, given that a transportation accident has occurred.

One problem with this model is that it appears to suggest that risk is inversely proportional to exposure. This apparent problem disappears when it is noted that A is probably an increasing function of exposure above some threshold.

Several problems exist in the implementation of this and similar models, not the least of which is data availability. As noted, the primary focus in this study is the determination of the nature of hazardous materials in transit. In the context of the model, this purpose is to estimate the exposure variable E.

Two attempts to measure exposure have been identified. The first, by Price et al. (13), involved systematic sampling of truck traffic in 1977 at numerous locations throughout Virginia. The sample data indicated that almost 13 percent of all loads involved hazardous materials and about 10 percent carried amounts sufficient to require placarding. A later study by the city of Indianapolis (14) involved the estimation of exposure by systematically recording placard numbers (United Nations/North American Classification Number, or UN/NA number) on vehicles observed at selected points of high truck traffic flows in the region. The data were used to estimate that 7.1 percent of all loads sampled were carrying hazardous materials and that the majority of these loads were flammable liquids. The study also forecast that the majority of hazardous incidents in the region would occur on city and county streets and roads.

Some problems exist with each of these approaches. In the Price et al. study, those conducting the field sampling received no or limited instruction on the identification of hazardous materials. Furthermore, after the 1981 revisions in the C.F.R. regarding the transport of hazardous materials, a clearer defintion of what constituted hazardous material in transit existed. In short, these qualifications may explain in part why the percent of hazardous loads in the Virginia study was noticeably higher than the more recent Indianapolis study.

The city of Indianapolis study is also subject to a number of qualifications. First, the sampling locations in this study appeared to have overrepresented local streets and roads, thereby calling into question the forecast that the majority of hazmat incidents would occur on city and county streets and roads. The authors of this study readily acknowledge additional problems with the methodology, including the following: (a) sampling procedures employed systematic yet less than full scientific sampling protocol; (b) the use of placards to identify hazardous loads--some types of loads need not be placarded because of the quantity of the load or its packaging and some loads are not placarded that should be; (c) the observer may not have observed some placards; and (d) some placarded trucks did not have UN/NA numbers, which made it difficult or impossible in those cases to determine the nature of the material being transported.

The Indianapolis study is the only recent (since the 1981 revision of the C.F.R.) attempt to empirically estimate exposure to hazardous materials while in transit. Given that several problems exist with earlier methodologies, there is a need to improve the measurement methodology if hazardous materials risk on highways is to be more accurately estimated.

DATA COLLECTION METHODOLOGY

A plan to collect information on hazardous materials transported on highways was developed by the Indiana State Police during fall 1983. This plan tried to address the shortcomings of the earlier studies. A key feature of the plan involved the utilization of state police officers who had recently completed a 40-hr U.S. Department of Transportation hazmat highway transportation regulation course to collect hazardous materials data as part of truck weigh scale operations. As the plan evolved, the northwest part of Indiana was selected for initial implementation. The primary reason that this region was selected stemmed from the availability of trained personnel there.

The northwest part of Indiana is heavily industrialized and is adjacent to the Chicago-Cook County metropolitan complex. Major U.S. and Interstate routes traverse this region: US 20, US 30, US 41, I-65, I-94, and I-90 (Indiana Toll Road). Data collection sites were identified and used on all routes except the Indiana Toll Road (see Figure 1). Two of the routes (US 20 and I-65) have permanent weigh scale stations. Inspection sites were set up on the other routes at places where trucks could be safely pulled off the traveled portion of the highway and inspected. These sites were operated in much the same manner as portable weigh scale stations. Each of the five routes had one location where inspections were made.

Hazmat data were collected during 1-hr periods at each site for traffic in both directions. At the beginning of the study period (October 1-30, 1983), a systematic sample of 1-hr periods on weekdays between 4:00 a.m. and 10:00 p.m. was selected for each route. Sample days varied from a minimum of 3 (which resulted as a consequence of personnel shortages) to

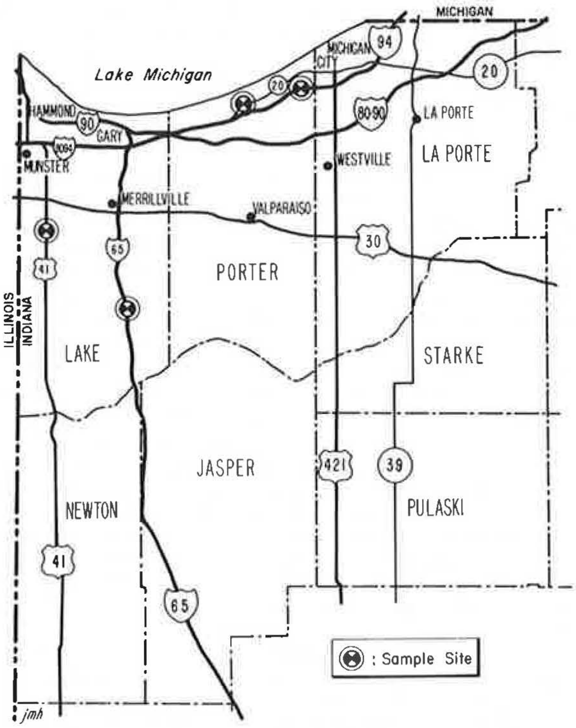


FIGURE 1 Map of Indiana's northwest corridor: sample locations of hazardous materials.

TABLE 1 Sample Hours by Time of Day

Hour	No. of Sample Hours
4 a.m.	4
7 a.m.	14
9 a.m.	8
10 a.m.	2
11 a.m.	2
12 noon	14
2 p.m.	4
3 p.m.	2
4 p.m.	2
5 p.m.	4
10 p.m.	4
All times	60

a maximum of 11 at the different sites. In total, there were 60 sample hours at all 5 sites. The data in Table 1 indicate that the majority of sample hours occurred between 6:00 a.m. and 6:00 p.m.

During each sample hour, all truck vehicles passing the sample point (regardless of direction) were inspected. Sample periods were set at 1 hr to reduce site-avoidance behavior arising from truckers talking on citizens band radios or coffee house conversations. Each inspection included identification of type of commodity, total weigh and/or quantity, container type, number of containers, and origin and destination (state). For loads identified as hazardous (from their shipping papers), the hazard class, UN/NA number, was determined. In addition, through a physical inspection of the truck, its contents and shipping papers, a credentials check, and a short questioning period with the driver, a determination was made of apparent violations of existing laws and those that were soon to be enacted in areas that were considered to be integral to effective enforcement of the laws. These included:

- Driver training and qualifications,
- Placarding,
- Shipping papers, and
- Vehicle and equipment condition.

In general, the criteria used to determine apparent violations were based on existing laws in Indiana used to enforce motor carrier safety (I.C. 8-2-7 and 49 C.F.R., Parts 390, 391, 392, 395, 396, and 397) as well as those that were not Indiana law at the time but were contained in 49 C.F.R., Parts 171, 172, 173, 177, and 178, pertaining to transportation of hazardous materials.

For each of the four enforcement areas just listed, a rating of either satisfactory or unsatisfactory was made of apparent violations or deficiencies. Table 2 gives a description of the criteria used to determine an unsatisfactory rating in each of the four areas. Assessment of drivers' qualifications included licensing and limits on driving time as well as the evaluation of their knowledge, emergency procedures, and awareness of the CHEMTREC hotline and how to use it. Some drivers expressed no

TABLE 2 Load Safety: Criteria for Unsatisfactory Rating

Enforcement Area	Criteria	Rating
Driver training	Proper license Knowledge of CHEMTREC hotline Any training on HAZMAT received Driving hours within limits Knowledge of load substance	3 of 5 unsatisfactory = unsatisfactory driver training
Placarding	Placard present Empty load--proper placard present Proper placard for load	2 of 3 unsatisfactory = unsatisfactory placarding
Shipping papers	Present with load Entire load manifested Adequate load description	2 of 3 unsatisfactory = unsatisfactory shipping papers
Vehicle condition	Brakes Tires Proper registration Lights Load security Proper weight	1 of 5 unsatisfactory = unsatisfactory vehicle condition

knowledge or concern of their load's nature: they were hauling cargoes based solely on a numerical assignment of a trailer at the dispatch location.

Placarding was checked to determine if the load indicated was the load specified in the shipping papers or if the load should have been placarded and was not. Some trucks although empty are required to be placarded. These loads were noted when detected.

Determining if a load is adequately placarded is complicated because of the complexity of federal laws. Not all loads may be required to be placarded even though they are carrying hazardous cargo because of quantity or packaging of the cargo or both. In addition, when more than one hazardous material is present in a single load, complex and at times apparently contradictory regulations must be interpreted to determine the correct placarding.

Shipping papers were inspected for presence or absence of hazardous materials and, as noted previously, compared with the C.F.R. to determine appropriate placarding. The origin and destination of the load were also determined by these documents.

Vehicle condition was evaluated in the same manner as that used for any vehicle required to stop at roadside inspection or permanent weigh scale locations. This was probably the easiest of the four inspection activities to accurately evaluate.

ANALYSIS AND RESULTS

During the study month (October 1983), 12,321 loads were inspected at the five sample locations. Of these, 687 or 5.6 percent were hazardous loads. This figure is somewhat less than the 7.1 percent observed in the city of Indianapolis study (14) and considerably less than that observed in the Price et al. study (13). Some variation was observed in the percentage of hazardous loads at different times: the high was 6.0 percent between 7:00 a.m. and 11:00 a.m.; the low was observed during late evening (10:00 p.m.--4.3 percent) and during the early morning (4:00 a.m.--4.8 percent).

The overall pattern of hazardous and nonhazardous loads is similar, as shown in Figure 2. Beginning early in the morning (probably about 6:00 a.m. to 7:00 a.m.), traffic density increases and peaks at about 10 a.m. Density drops off significantly during the next hour but subsequently increases at noon and reaches a second high at 3:00 p.m. (hazardous loads are at a plateau from noon through 3:00 p.m.). A second low-density period occurs at 4:00 p.m. Density increases, however, at 5:00 p.m. and appears to gradually decline from that time until early the following day (6:00 a.m. to 7:00 a.m.). These findings suggest that the apparent high truck density perceived by automobile travelers during the night does not hold for the authors' sample locations.

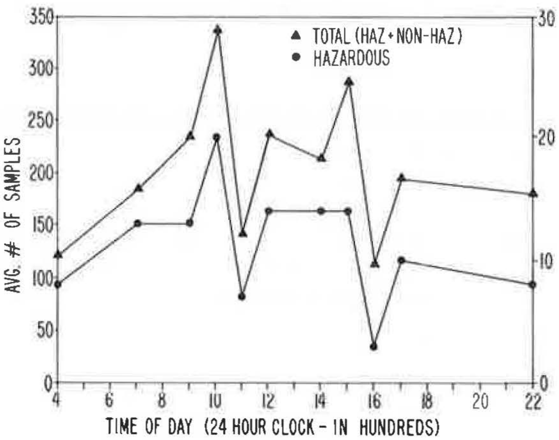


FIGURE 2 Average number of loads per sample hour.

Data presented in Table 3 indicate that 58.4 percent of all loads are flammable liquids. The next largest class is corrosives at 26.3 percent. Other types of hazardous loads comprise a small percentage of all loads. This pattern is characteristic of all sample times. However, during the 4:00 a.m. sample period, the percent of loads for oxidizing and poisonous substances was found to be slightly higher during the early morning.

TABLE 3 Percentage of Hazardous Loads by Hazardous Class and by Time

	Time				
Class	4:00 a.m.	7:00-11:00 a.m.	12:00-3:00 p.m.	10:00 p.m.	All times
Explosives	0.0	0.6	0.3	0.0	0.4
Gases	0.0	3.1	9.4	3.2	5.8
Flammable liquids	39.1	62.5	54.5	67.7	58.4
Flammable solids	0.0	1.2	0.7	0.0	0.9
Oxidizing substances	4.3	2.2	1.6	3.2	1.9
Poisonous substances	4.3	0.6	2.9	0.0	1.7
Radioactive substances	0.0	0.9	1.3	0.0	1.0
Corrosives	47.8	24.8	26.8	22.6	26.3
Other	4.3	4.0	2.9	3.2	5.5
All classes (n)	23	323	310	31	687

Data given in Table 4 show relationships between the origin and destination of hazardous loads. Most loads originated in Illinois, Indiana, and Michigan. Illinois was the largest source (39.9 percent), which reflects the mass of the Chicago-Cook County metropolitan industrial complex. Kentucky, Ohio, and Wisconsin are sources of relatively small percentages of loads. Almost 40 percent (266) of all loads (667) are destined for Indiana: 43.6 percent of these loads come from Indiana but almost 30 percent come from Illinois and 30.3 percent originate in Michigan. In summary, both origin and destination of hazardous materials at the sample sites are dominated by three states: Illinois, Indiana, and Michigan. Perhaps the most surprising aspect of these findings is the relatively minor role Ohio plays as an origin or destination. However, this may be due to no sampling taking place along the Indiana Toll Road (I-90), which serves as the most direct link with Ohio.

Data on driver qualification, vehicle condition, shipping papers, and placarding are summarized in Figure 3. Overall, driver qualification is observed as the least satisfactory of the four indicators of safety. This is particularly disturbing in the case of the high-danger explosives and classes of radioactive substances. Although the number of cases for these classes was small (three in the case of explosives), it would be hoped that driver qualifications for these types of cargo would be impeccable.

Appropriate placarding was lacking for about 20 percent of all loads. Clearly, a need exists for greater enforcement in this area. There is probably also a need for more education as well as regulation recodification to reduce the complexity involved in determining the appropriate placarding.

Generally, vehicle condition is the strongest of the four safety indicators. More than 95 percent of all inspected vehicles were judged to be in satisfactory condition. It is important to note that no unsatisfactory vehicles were found for loads such as explosives and radioactive substances.

The overall or average safety conditions found for all loads are almost identical to those observed for the categories of high-density hazardous flammable liquids and corrosives. Almost 85 percent of all hazardous loads are of these two types. The results suggest that any plan to improve safety for these hazardous categories should focus on placarding, driver qualifications (training and education), and vehicle condition.

TRAINING AND ENFORCEMENT GUIDELINES

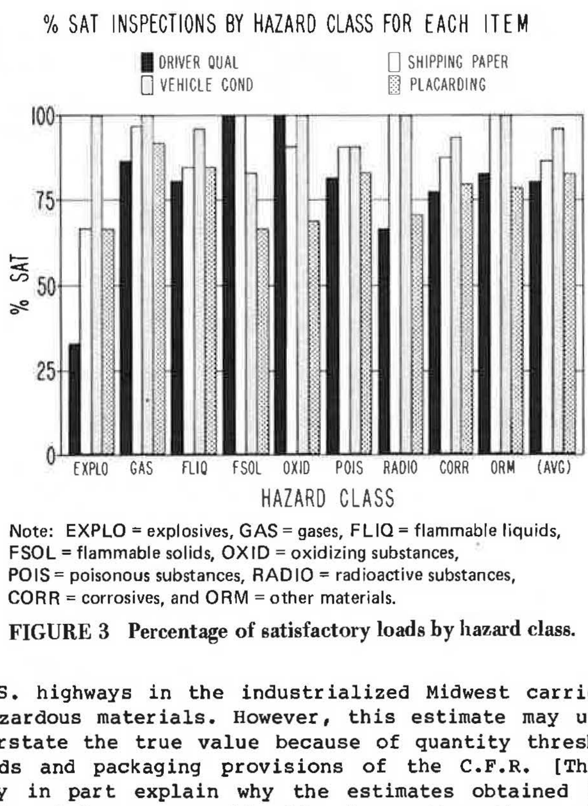
In the initial part of this paper, exposure to a hazmat spill was identified as one of the key factors contributing to risk and therefore to the social cost of hazardous material transport. Exposure was defined in terms of a surrogate variable--amount of hazardous material being transported. The analysis identified a number of empirical regularities regarding this variable, including regularities in the way the number of hazardous loads vary with time of day, type of hazardous material, origin and destination, and safeness of the load. The implications of these findings for enforcement and incident response are discussed in the following paragraphs.

The northwest Indiana study suggests that about 1 in every 17 trucks operating on Interstate and other

TABLE 4 Origin and Destination of Hazardous Materials Loads

	Destination							
Origin	Illinois	Indiana	Kentucky	Michigan	Ohio	Wisconsin	Other	Total
Illinois								
Number	8	79	14	80	37	1	47	266
Percent	3.0	29.7	5.3	30.1	13.9	0.4	17.7	100.1[a]
Indiana								
Number	27	116	0	10	2	1	10	166
Percent	16.3	69.9	0.0	6.0	1.2	0.6	6.0	100.0
Kentucky								
Number	7	4	0	0	0	2	2	15
Percent	46.7	26.7	0.0	0.0	0.0	13.3	13.3	100.0
Michigan								
Number	56	54	9	1	8	0	8	136
Percent	41.1	39.7	6.6	0.7	5.9	0.0	5.9	99.9[a]
Ohio								
Number	7	2	0	1	0	2	6	18
Percent	38.9	11.1	0.0	5.6	0.0	11.1	33.3	100.0
Wisconsin								
Number	1	2	2	3	1	0	8	17
Percent	5.9	11.8	11.8	17.6	5.9	0.0	47.1	100.1[a]
Other								
Number	21	9	1	5	4	5	4	49
Percent	42.8	18.3	2.0	10.2	8.2	10.2	8.2	99.9[a]
Total								
Number	127	266	26	100	52	11	845	667
Percent	19.0	39.9	3.9	15.0	7.8	1.7	12.7	100.0

[a]Totals may not sum to 100.0 percent because of rounding.



Note: EXPLO = explosives, GAS = gases, FLIQ = flammable liquids, FSOL = flammable solids, OXID = oxidizing substances, POIS = poisonous substances, RADIO = radioactive substances, CORR = corrosives, and ORM = other materials.

FIGURE 3 Percentage of satisfactory loads by hazard class.

U.S. highways in the industrialized Midwest carries hazardous materials. However, this estimate may understate the true value because of quantity thresholds and packaging provisions of the C.F.R. [This may in part explain why the estimates obtained in this study are considerably lower than those obtained by Price et al. (13) in 1982.] Nevertheless, it is reasonable to conclude that hazardous loads as defined by the C.F.R. comprise a relatively small proportion of all loads--probably not more than 7 to 8 percent. Enforcement and incident response training and management must begin with an awareness of this statistic. Moreover, the results of this study strongly suggest that the proportion of hazardous loads does not vary much with time of day, which implies that the need for enforcement and incident management will vary directly with traffic volume.

The northwest Indiana study shows that (a) traffic density is highest during the period 6:00 a.m. to 6:00 p.m. and (b) during this period, peak-volume periods are observed between 7:00 a.m. and 10:00 a.m. and between 12:00 and 3:00 p.m. Consequently, training efforts should make enforcement and incidence response planners and personnel aware that demands are likely to be greater during these daytime periods. Forces should be deployed more intensively during the daytime; this is consistent with current general deployment practice.

Two of the hazardous materials classes (flammable liquids and corrosives) were found to represent almost 85 percent of all loads. Consequently, hazardous loads may be viewed as falling into two broad groups: frequent hazmat loads and rare hazmat loads. To demonstrate this, it need only be noted that 1 in 36 trucks on the highway transports flammable liquids, whereas 1 in about 4,000 trucks carries explosives.

If it is assumed that the probability of an accident involving a hazardous cargo spill is invariant with the type of material, then the majority of enforcement and incident training effort should address the transportation of flammable liquids and corrosives. This conclusion is further supported when it is considered that regulations for the transport of many of the other categories (e.g., explosives and radioactive substances) are more stringent, thereby making their transit presumably even safer. The reason that regulations for the transit of these types of materials are more stringent is because the social costs of incidents involving explosives or radioactive substances are likely to be much higher.

The origin and destination analysis showed that northwest Indiana is a net receiver of hazardous materials from other states. Most of the externally generated hazardous materials received by Indiana from other states come from Illinois and Michigan. Consequently, training should make enforcement and incident response planners and personnel aware of this. Moreover, training efforts should include familiarization with hazmat enforcement and incident response procedures and training in these adjacent states.

It was interesting to find that the condition of vehicles is the strongest overall safety feature. This is not unexpected because many problems with vehicles are readily observable; furthermore, these are areas of routine enforcement for the state police.

In contrast to vehicle condition, problems with appropriate placarding are widespread. Transporters fail to correctly placard vehicles about 20 percent of the time. A need therefore exists for better education of appropriate placarding for shippers. A need also apparently exists to rewrite some of the placarding guidelines and regulations because their complexity probably contributes to inappropriate placarding or the failure to use placards to identify loads that require them. Significant effort should focus not only on developing a more significant placard education program for shippers but also on a placard enforcement program. Emergency response efforts begin with identification.

The overall safety findings in the northwest study showed that driver qualification is the weakest safety category. Attempts to reduce driver qualification problems should begin with an education program designed to make drivers and shippers more aware of the nature of the load they are carrying, the appropriate response if a leak or spill is detected, and knowledge of the CHEMTREC hotline telephone number. Licensing guidelines that include these points should be developed and implemented.

Finally, it is important to note how this study and its findings might be generalized. First, the data collection methodology is an improvement over earlier ones used to measure exposure. The study was designed to preserve most aspects of scientific sampling protocol and used highly trained state police officers to collect field data. One problem with the procedure occurred when absences or higher priority work necessitated foregoing data collection, which resulted in an unevenness in sample sizes at the five sample locations. In the future, this problem could be overcome simply by oversampling at different locations and times.

The data collected and analyzed in this study were obtained in one of the most heavily industrialized and heavily populated areas of the United States. Such areas are known to be both large-scale producers and consumers of hazardous materials and, as a consequence, are characterized by high levels of hazardous materials in transit. The findings of this study are, therefore, most directly generalizable to areas with similar characteristics.

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